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Assessment of heavy metals availability and its health risk on *Zea mays* and *Sorghum* grown on agricultural soil, Southern Borno, Nigeria

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Abstract

Heavy metals are deleterious due to their long biological half-lives, non-biodegradable nature, and their ability to accumulate in different body parts. Heavy metals emanating from anthropogenic sources are more dangerous because of their instability and solubility leading to high bioavailability. Heavy metals uptake by plants is generally the first step of their entry into the agricultural food chain. The present study aimed at assessing the availability of heavy metals on cereals crops (*Zea mays* and *Sorghum*) grown on agricultural soil hence their health risk index. Soil and cereals crops were digested analyzed for Cr, Cd, Cu, Pb, Ni and Zn using Atomic Absorption Spectroscopy (Buck scientific model 210GP) while transfer factor (TF), daily intake of metals (DIM) and health risk index (HRI) were evaluated. The concentration of Cd in all the three soil samples had mean values of 10.7±2.32 mg/kg while *Zea mays* and *Sorghum* had mean values of 2.12±0.09 and 2.75±0.03 mg/kg respectively. The decrease in concentrations of the metals in *Zea mays* and *Sorghum* samples across sampling locations followed this order Cd > Cu > Cr > Pb > Ni > Zn. The trend of heavy metal transfer factor from soil to *Zea mays and Sorghum* grown in Askira Uba, Southern Adamawa were in the order of Cd > Ni > Cu > Pb > Cr > Zn. The HRI values of Cd (1.00, 2.70) in both *zea mays* and *sorghum* were higher than other studied heavy metals. The finding of this study with respect to DIM and HRI showed that the consumption of *Zea mays and Sorghum* grown in Askira Uba, Southern Borno were nearly free of risks at all sites for all assessed heavy metals except Cd. Even though the values of HRI for other metals were nearly one, the long term consumption of these crops may lead to serious health risk.

Keywords: Soil; *Zea mays*; *Sorghum*; Health risk index; Heavy metals; Grains

1. Introduction

Heavy metals in soil exist in several different forms and are associated with a range of other components [1]. The accumulation of metals in soil, particularly Pb, Cd, Cu, Ni, Cr and Zn is of concern [2]. Heavy metals emanating from anthropogenic sources are more dangerous because of their instability and solubility leading to high bioavailability [3, 4]. It has been widely accepted that soil plays a key role in sustaining life in earth's ecosystems [5]. The very survival of mankind is tied on its productivity as a medium for plants to grow [6]. Soil consists of a heterogeneous media comprised of decomposed rock fragments, clay minerals, and oxides of Fe, Al and Mn, organic materials, organo-metallic complexes and soil solutions [7]. However, soil is also a transmitter of many pollutants including potentially toxic metals into the atmosphere, biosphere and water resources [8]. Plants absorb metals from soil and water, they predominantly accumulate in the roots, and then some portions are transfer to parts of plant. Plant can immobilize heavy metals through absorption and accumulation by roots, adsorption onto rots, or precipitation within rhizosphere [9]. Heavy element uptake by plants is generally the first step of their entry into the agricultural food chain [10]. Plant species and

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relative abundance and availability of necessary elements also control metal uptake rates. Heavy metals are persistent in nature, hence became accumulated in soil and plants. Exposure of plants to non- redox reactive metals results in oxidative stress as indicated by liquid peroxidation, H_2O_2 accumulation and an oxidative burst [11]. Generally, plants show signs of stress when they accumulate high percentage of heavy metals [12]. In heavy metals polluted soils, plants growth can be inhibited by metal absorption [13]. Roots crops like potatoes and carrots, leafy vegetables like spinach and lettuce and parts of plants that are grow near the soil are at greater risk for exposure to metal contamination than the higher portions of plants, like fruits or berries [12]. Plants are known to take up and accumulate heavy metals from contaminated soil and sediments with variations in metal content dependent on several factors such as soil properties, plant species, plant age, and time interval of metallic soil input, nutrient availability and interaction among the metals [14]. The study areas which are close to occupational areas such as panel beating workshops and electrical appliances repairs workshops may have high tendency of heavy metals accumulation in plant grown around the locations. The study was aimed at assessing the levels of heavy pollution in soil, its accumulation in plants, hence its health impact on food crops grown in Askira, Wamdeo and Rumirgo soils.

2. Material and methods

2.1. Description of the Study Area

Askira/uba is the one of the biggest local government area in the south of Borno state, with its headquarter located in Askira town. It has two Chiefdoms, one in Askira and the other in Uba. It has an area of 2,362km^2 and a population of 138,091 as at 2006 census. It is geographically located at longitude $12^{0}22^{1}3^{11}$ to $13^{0}19^{1}48^{11}$E and latitude $10^{0}22^{1}34^{11}$ to $10^{0}49^{1}43^{11}$N.

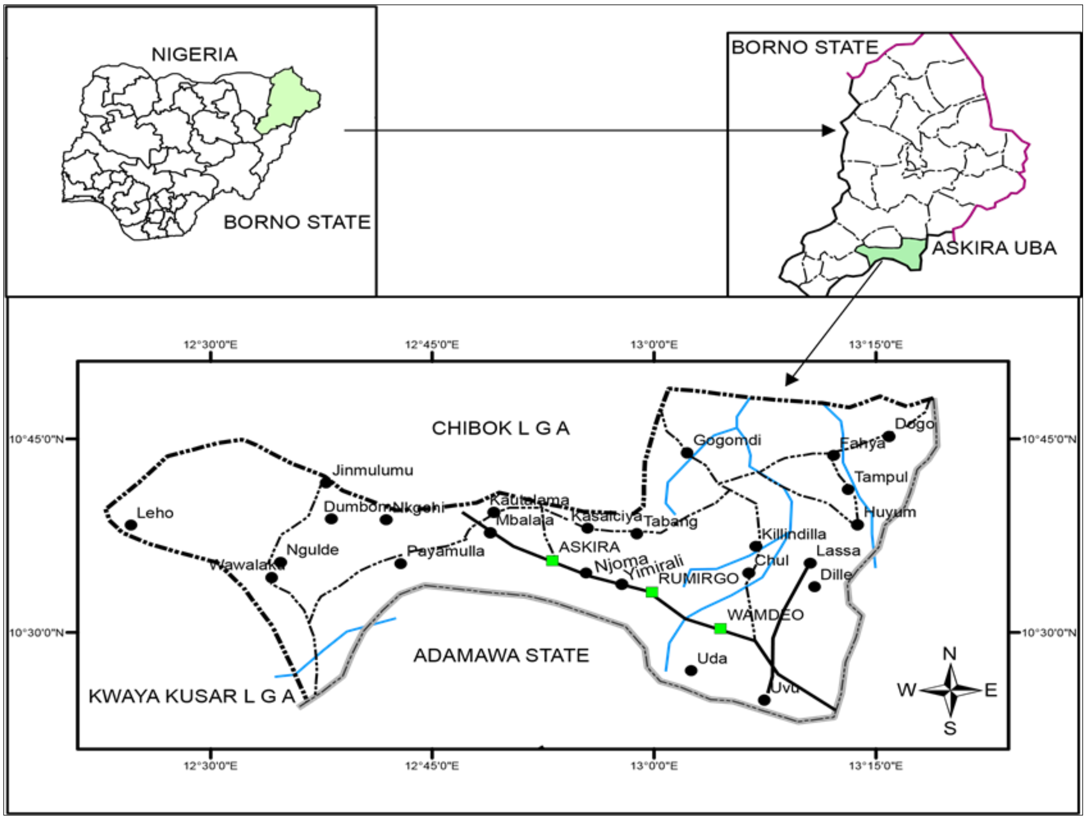

Figure 1 Map of the Study Area showing Sample Locations

The major tribes in Askira/uba local government are Margi, Chibok and Fulani. The main occupation of the people of Askira/Uba are mostly farming and cattle rearing. The people of Askira/ Uba produced lots of food and cash crops such as groundnut, *Zea mays*, Rice, Millet, Beans, Soya beans, *Sorghum*, Bambara-nut, Beni-seed and Vegetables such as Okro, Karkashi and Yakuwa (Rosel) and many others which they sold to other neighboring local government as well as other states. The raining season begins around April and last till late October.

2.2. Sample Collection, Preparation and Metal Determination

Samples were collected in the month of September, 2022. Soil samples were collected from Askira/uba local government area of Borno State and were labelled A1, B1, C1 for Askira, Rumirgo and Wamdeo respectively. In each plot, soil samples were collected at two depths (0-15 cm and 16-30 cm), using spiral auger of 2.5 cm diameter or ruler. The Soil sample was randomly selected and bulked together to form a composite sample before being placed in clean plastic bags and transported to laboratory.

A 2.0 kg of plant (*Zea mays and Sorghum*) samples grown on the farms were soil samples were randomly collected were also sampled randomly. A total of twelve (12) plants samples were collected randomly from the three study areas, four (4) from each locations; Askira (A), Rumirgo (B) and Wamdeo (C) for *Zea mays* and D, E and F for *Sorghum* from the locations respectively. The plant samples *Zea mays and Sorghum* were mixed separately to give the representative fraction of each of the plant. The harvested *zea mays and sorghum* were threshed manually to obtained the grains and oven dried at 70 °C until stable weights were obtained. It was then grounded in a mortar and sieved with 2 mm mesh size, then stored in labeled polythene container prior to analysis.

The soil samples were digested by weighing 1.0 g each into different pyrex beakers. 15 mL of HNO_3 followed by 10 mL of HCl and 5 mL HF were added to the samples. The samples were heated at 180 °C on hot plate for 1 hour until all brown fumes escaped leaving the digested sample. The samples were allowed to cooled and diluted with deionized water, samples were filtered and the filtrate were made up to 50 mL with deionized water [15]. The concentration of the metal ions present in the sample were determined by reading their absorbance using Atomic Absorption Spectroscopy (Buck scientific model 210GP). Triplicate analysis were made

A 1.0 g of the powdered (*Zea mays and Sorghum* grain samples were digested with 10 cm^3 mixture of analytical grade acids HNO_3: $HClO_4$ in the ratio 5:1. The digestion was performed at a temperature of about 90 °C for 30 minutes in a fume cupboard until clear solutions were obtained. Digested samples were allowed to cooled, filtered into a 100 cm^3 volumetric flask, and made up to the mark with deionized water [16]. The concentration of the metal ions present in the sample were determined by reading their absorbance using Atomic Absorption Spectroscopy (Buck scientific model 210GP). Triplicate analysis were made

2.3. Transfer factor (TF)

The Transfer factor (TF) is a competent technique developed to assess the level of the metal in the plant as a fraction of the soils total. Previous studies have indicated that the uptake of metals by plants differs from one metal to another, from one plant species to another and from one polluted soil to the other [16]

$$TF = \frac{\text{concentrationofmetalin plant part}}{Concnetration\ of\ metal\ in\ soil}$$

2.4. Daily intake of metal (DIM)

The daily intake of metals (DIM) was calculated to averagely estimated the daily metal loading into the body system of a specified body weight of a consumer which informs the relative phytoavailability of metal [17,18] The daily intake metals (DIM) was determined as follow:

$$DIM = \frac{Cmetal\ X\ Cfactor\ X\ Dintake}{BW}$$

where: C metal **=** heavy metal concentrations in plants (mg/kg), Cfactor = conversion factor (i.e.to convert fresh grains weight to dry weight), Dintake = daily intake of grains, BW = average body weight (65 kg) and conversion factor of 0.085 is to convert fresh grains weight to dry weight.

2.5. Health risk index (HRI)

The health risk index (HRI) was determined as described as follows [19]:

$$HRI = \frac{DIM}{Rfdose}$$

Reference oral dose (RfDo) is an estimated exposure of metal to the human body per day that has no hazardous effect during life time. Human are considered to be safe if HRI < 1[20, 21].

3. Results and discussion

3.1. Mean Concentrations of Heavy Metals in Soil, *Zea mays* and *Sorghum* (mg/kg) from Askira/Uba LGA (Askira A1, Rumirgo B1 and Wamdeo C1).

The mean concentrations of heavy metals in soil from Askira/Uba LGA (Askira, Rumirgo and Wamdeo) are presented in Table 3.1. The results also showed that all the metals do not follow the same trend of occurrence in the three farmlands; that is, each metal concentration varies independently from one another according to their sources.

3.1.1. Cadmium (Cd)

The mean concentration of Cd in *Zea mays and Sorghum* were reported to be 2.12±0.09 and 2.75±0.03 mg/kg respectively. The results showed that Cd accumulation in *Sorghum* was higher than *Zea mays.* This may be due to the tap root system of *Sorghum* and possible exposure to particulate matter since it has no complete shelf like *Zea mays.* However, the levels of heavy metals in the two grains were higher than the threshold limit (0.010 mg/kg) for grains as reported by WHO [22]. The values of metals concentration observed in this findings were higher than those reported by [16]. The concentration of Cd in all the three soil samples were A1 (10.89 mg/kg), B1 (7.78 mg/kg) and C1 (13.46 mg/kg) with mean values of 10.7±2.32 mg/kg. Cd recorded the least concentration among the studied metals in the soil samples. This is due to it geological occurrence and minimal occupational activities in the area. The values of Cd obtained were above the World Health Organization permissible limit (0.80 mg/kg) for soil [23]. Cd can accumulate and biomagnified in the soil which could leads to alteration of the food chain. Although Cd is the least of the heavy metals found on the three farmlands, its concentration is still far above the background level (0.2 - 1.0 mg/kg) according to the United States Environmental Protection Agency [24].

Cadmium is ranked as the 7th among the top 20 toxic metals [25] and is a severe threat to our environment due to its rising accumulation in agricultural soils through various components of irrigation, both indoor and outdoor [26]. In plants, Cd phytotoxicity results from Cd-induced oxidative stress. Oxidative stress impairs lipids, nucleic acids, and proteins, which in turn inhibits growth in the plant and can even cause cell death [27]. In living organisms, cadmium occupies higher toxicity and mobility as compared to other harmful heavy metal [28]. Since the Cd content of Askira, Rumirgo and Wamdeo is well above the permissible limit, it is certain that plants grown on those farmlands will suffer from the effects mentioned. Although the effects are both plant species-dependent and does-dependent, some plants show Cd tolerance through a wide range of cellular responses.

3.1.2. Chromium (Cr)

The level of Cr observed in this work ranged from 4.60 – 4.62 mg/kg with mean value of 4.61±0.01 mg/kg for *Zea mays* while *Sorghum* had mean value of 4.68±5.10 mg/kg across the sample locations. The result implied that sorghum has high tendency of metal accumulation in it grains. The high values recorded in the two grains were higher those reported by USEPA [29] which had 0.10 mg/kg. The high mean values of this metal could be detrimental to health. The concentration of chromium Cr ranged from 37.0 mg/kg at A1 to 95.80 mg/kg at C1 with a mean concentration of 75.4±27.2 mg/kg. However, the concentration of sediment in locations A2 – C2 varies from 77.28 - 94.93 mg/kg with mean of 86.4±7.22 mg/kg. The mean of concentration of Cr in the soil samples reported in this work were greater than the mean value (11.55 mg/kg) reported by [30]. The high concentration of Cr recorded at C1 could be as a result of burning of e-waste such as used computers, cables and automobile tires at the occupational areas close to the farmlands.

3.1.3. Copper (Cu)

The concentration of Cu in the studied food crops had mean values of 3.52±0.02 and 3.59±0.01 mg/kg. The high level of Cu is could impart negative effects on plant growth and productivity. Such effects are in terms of germination, growth, photosynthesis, and antioxidant response in agricultural crops. Its inhibitory influence on mineral nutrition, chlorophyll biosynthesis, and antioxidant enzyme activity has been verified. However, farmlands with Cu concentration lower than the standard background level (1.50 mg/kg) are not expected to have such effects on crops. The concentration of Cu in the soil samples ranged from 38.42 to 43.29 mg/kg across A1 to C1 respectively with the least concentration of 38.42 mg/kg in A1 while the highest concentrations were found in B1 (42.87 mg/kg) and C1 (43.29 mg/kg) with mean values of 41.5±2.20 mg/kg. The threshold level of Cu in soil according to [23] is 36.0 mg/kg. This result is similar to the findings of [31] which recorded extremely high concentrations of copper at e-waste sites, which was beyond the acceptable agricultural soils limits of 50 mg/kg in China.

Table 1 Mean concentration of heavy metals in soil, *Zea mays* and *Sorghum* samples of Askira Uba

Samples	Site		Mean of heavy metal concentration (mg/kg)				
		Cd	Cr	Cu	Pb	Ni	Zn
Maize	A	2.12	4.60	3.54	3.95	1.62	1.47
	B	2.00	4.61	3.50	3.95	1.61	1.49
	C	2.24	4.62	3.54	3.95	1.60	1.45
	Mean±SD	2.12±0.09	4.61±0.01	3.52±0.02	3.95±4.44	1.61±0.01	1.47±0.02
Soil	A1	10.9	37.0	38.4	57.3	20.7	24.2
	B1	7.79	93.4	42.9	46.2	20.7	30.1
	C1	13.5	95.8	43.3	64.6	23.9	28.4
	Mean±SD	10.7±2.32	75.4±27.2	41.5±2.20	56.0±7.54	17.4±6.97	27.6±2.51
Sorghum	D	2.79	4.68	3.59	4.10	1.66	1.56
	E	2.71	4.68	3.61	4.00	1.68	1.50
	F	2.79	4.68	3.58	4.20	1.64	1.53
	Mean±SD	2.75±0.03	4.68±5.10	3.59±0.01	4.10±0.08	1.66±0.02	1.53±0.04

3.1.4. Lead (Pb)

The level of lead concentration in *Zea mays* and *Sorghum* were reported to 3.95±4.44 and 4.10±0.08 mg/kg indication that there is a slight difference in the extent of absorption of metal between the two grains. The concentrations of the grains obtained in this work were less than the values (1.4 mg/kg) reported by [32] on mining site. The concentrations of Pb in presented in Table 4.1 were in ascending order of B1<A1<C1 corresponding to 46.23, 57.29 and 64.57 mg/kg with mean concentrations of 56.0±7.54 mg/kg. Compared mean concentrations of Pb obtained in this study to WHO/FAO standard, the amount of Pb in soil and sediment from the three farmlands (A1, B1and C1) were below the world health organization [23] permissible limit for Pb in soil (85.0 mg/kg) as reported by [33]. Hence impacts resulting from Pb cannot be felt on consumers of crops grown on any of the three locations.

3.1.5. Nickel (Ni)

The mean concentration of Ni in *Zea mays* was 1.61±0.01 mg/kg while that of *Sorghum* were observed to be 1.66±0.02 mg/kg respectively. The level of Ni in this findings was reported to have the second least concentration among the studied metals. These values were times three the permissible limit set by [22] which is 0.05 mg/kg for grains. The high level of this metals in food crops may affect the biochemical processes of the liver. The mean concentrations of nickel recorded in the soil samples were A1 (20.69 mg/kg), B1 (7.80 mg/kg) and C1 (23.95 mg/kg) with a mean value of 17.4±6.97 mg/kg. The mean concentration of Ni in soil recorded at the various locations were below the [23] permissible limit of 50 mg/kg for soils.

3.1.6. Zinc (Zn)

The concentration of Zn obtained in this work had mean value of 1.47±0.02 in *Zea mays* and 1.53±0.04 mg/kg in *Sorghum.* Zn has the least concentration among the studied metals. One of the reasons for these results is that Cd occurs with Zn in nature and are more mobile in nature [34]. However, Zn concentration in the grains were within the threshold limit (5.00 mg/kg) by [29]. The mean concentration of zinc (Zn) ranged from 24.16 mg/kg at A1 to 30.12 mg/kg at B1 with a mean value of 27.6±2.50 mg/kg. The concentrations of Zinc in the studied soils were below the WHO/FAO [23] allowable limit of 300.00 mg/kg. The presence of zinc in soil at the various locations may be as a result of the occurrence of battery dry cells from run-off water as reported by [35]. Li *et al.,* [36] reported a mean value of 3,500 mg/kg for Zn which were 100 times greater than those reported in this findings. Zinc is a vital microelement which plays a very important catalytic role in enzyme reactions [24]. The concentrations of Zn in both soil was below the recommended values by WHO [23].

3.2. Transfer Factors (TF) of Soil to *Zea mays and Sorghum,* Daily Intake of Metals (DIM) (mg/kg) and Health Risk Index (HRI) of Heavy Metals

3.2.1. Transfer Factors (TF) of Soil to Zea mays and Sorghum

Bioavailability of metals in soil is expected to be available for plants uptake. As such, heavy metals can be transfer to plant when they are in a mobile form. To evaluate the transferred of heavy metals from soil to plants, the transfer factor which a function of soil and plant properties is used [18]. [15] reported that, transfer factor does not entails the risk associated with the metals rather it helps to know the source of metal contaminants based on their quantitative values. The transfer factors from the soil to the plants (*Zea mays* and *Sorghum*) are represented in Table 2. The values of transfer factor of heavy metals in the Z*ea mays* revealed that Cd has the highest value of 0.20, followed by Ni, Cu and Pb which had 0.09, 0.08 and 0.07 while Cr and Zn had the least values as 0.06 and 0.05 respectively.

Table 2 Soil to *Zea mays and Sorghum* Transfer Factors (TF), Daily Intake of Metals (DIM) (mg/kg) and Health Risk Index (HRI) of Heavy Metals

Samples	**Parameters**	**Heavy Metals**					
		Cd	**Cr**	**Cu**	**Pb**	**Ni**	**Zn**
Zea mays	TF	0.20	0.06	0.08	0.07	0.09	0.05
	DIM	0.001	0.03	0.02	0.003	0.001	0.001
	HRI	1.00	0.02	0.50	0.75	0.01	0.003
Sorghum	TF	0.26	0.06	0.08	0.07	0.10	0.06
	DIM	0.003	0.005	0.004	0.004	0.002	0.002
	HRI	2.70	0.003	0.09	0.10	0.02	0.005

The results of transfer factor in *Sorghum* showed that Cd had the highest value as 0.26, Ni had 0.10 followed by Cu which had 0.08 while the least value were reported in Cr and Zn with 0.06 respectively.

The trend of heavy metal transfer factor from soil to *Zea mays and Sorghum* grown in Askira Uba, Southern Borno were in the order of Cd > Ni > Cu > Pb > Cr > Zn. The average transfer factor value for all studied metals are less than 0.5 which indicates the low metal contamination of *Zea mays and Sorghum* by anthropogenic activities like painting, welding, panel beating works that takes place at the town and surface run off into farmlands [33]. The *Zea mays and Sorghum* from this study areas are good bio accumulators of Cd and Ni. Therefore, the grains may be potential health hazards as the build-up of Cr and Ni in the human system has harmful consequences at the long run [34].

3.2.2. Daily intake of heavy metals (DIM)

The consumption of grains (*Zea mays and Sorghum*) were about 400 g/day which is called provisional tolerable daily intake (PTDI), this helps to evaluate the consumer based health hazard assessment [35]. The degree of toxicity of heavy metals to human being depends upon their daily intake. The daily intake of metals (DIM) in *Zea mays and Sorghum* were higher in Cr and Cu with values 0.03, 0.005 and 0.02, 0.004 while the least were found in Ni and Zn as presented in Table 2. The results of this findings suggest that the consumption of *Zea mays and Sorghum* grown in Askira Uba, Southern Adamawa have highest DIM for the heavy metals like Cd (0.03, 0.005) and Cu (0.02, 0.004) than the other studied heavy metals but the values of Cd and Cu observed in *zea mays* indicates that consumers are at risks since the dietary intake limits of Cd and Cu in adults were 0.005, 0.01 mg respectively [29]. The higher DIM values of Cr and Cu than the other heavy metals might be due to their high concentration in the *Zea mays*. Similar results were also observed in [37]. However, the DIM values of all metal reported in S*orghum* were within the dietary intake limits.

3.2.3. Health risk index (HRI)

The HRI represents the harmful effect of heavy metals in people who consume grains contaminated with them. When the value of HRI is < 1, consumers are safe to eat those kinds of grains [38, 39]. The HRI values of Cd (1.00, 2.70) in both *Zea mays* and *Sorghum* were higher than other studied heavy metals but long term consumption of these heavy metal may lead to health risk. Similar result was also reported for Cd in [37].

4. Conclusion

The present study showed that the soil and grains (Z*ea mays* and *Sorghum*) have associated risk for consumer exposure to heavy metals. All of heavy metals assessed, Cd and Cu had the highest values above the permissible limit for soil. Similar observation were made in grains grown on the soil whose tolerable daily intake were higher. From the result it was noticed that the toxicity levels of heavy metals were found to be higher in *Zea mays* than *Sorghum*. The finding of this study with respect to DIM and HRI showed that the consumption of grown consumption of *Zea mays and Sorghum* grown in Askira Uba, Southern Adamawa were nearly free of risks at all sites for all assessed heavy metals except Cd. Even though the values of HRI for other metals were nearly one, the long term consumption of these crops may lead to health risk. This need urgent attention to implement appropriate means of maintaining and regulating domestic effluent and providing appropriate support for the safety of the people.

Compliance with ethical standards

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Disclosure of conflict of interest

The Authors declared no conflict of interest.

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