Research Article

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Health risk assessment of heavy metals (Zn, Cu, Pb) in the leaves of *Amaranthus hybridus* grown on dumpsite soils in Anyigba Nigeria

Abstract

In Nigerian urban and suburban areas, the practice of using dumpsites as agricultural land is widespread, due to the fact that decomposed and composted wastes improve soil fertility. The presence of heavy metals in these dumpsites poses serious health risks to humans. The purpose of this study is to compare the concentrations of heavy metals (Pb, Cu, and Zn) in *Amaranthus hybridus* leaves grown on soil obtained from three distinct dumpsites in Anyigba, Kogi State, Nigeria. It also looks at the possible health risks associated with eating *Amaranthus hybridus*. After a period of four (4) weeks after planting, plant samples were selected at random, prepared, and examined using an Atomic Adsorption Spectrophotometer (AAS) Buck Scientific VG990 Model to detect the heavy metal. The following is a breakdown of the different heavy metal content found in the leaves of *Amaranthus hybridus* cultivated on the different landfill soils, Zn: *Anyigba Market* (0.4540 mg/kg) > *Redeem* (0.4286 mg/kg) > *Anokwu1* (0.3520 mg/kg) > Control (0.281 mg/kg); Cu: *Redeem* (0.1640 mg/kg) > *Anokwo1* (0.1287 mg/kg) > *Anyigba Market* (0.0947 mg/kg), and Control (0.0467 mg/kg); Pb: *Anokwu1* (0.1820 mg/kg) > *Anyigba Market* (0.0960 mg/kg) > *Redeem* (0.0580 mg/kg) > Control (0.0267 mg/kg). Every element that was examined for samples taken from dumpsites had levels that were greater than those of the control. There are potential health hazards associated with the ingestion of *Amaranthus hybridus* grown on soil obtained from these dumpsites, and this is due to the fact that its hazard quotient for Zn, Cu, and Pb, as well as its hazard indices, exceed unity (1). Strict regulations prohibiting the cultivation of food crops on dump site soils, should be enforced by the government and local authorities, to prevent the accumulation of toxic heavy metals in edible plants.

Keywords: heavy metals, dumpsite, *Amaranthus Hybridus*, kogi state, zinc, copper, lead

Volume 10 Issue 2 - 2025

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Received: March 18, 2025 | **Published:** April 28, 2025

Introduction

Inorganic compounds known as heavy metals are found all over the planet in their natural state. Heavy metals don't have a standard definition, however elements having a high atomic weight and a density at least five times that of water are commonly used to characterize them.[1] Notwithstanding their global distribution, these elements are considered trace due to their minute concentration in different environmental matrices.[2] Many physiological and metabolic processes in the body depend on several of these heavy metals, including cobalt (Co), copper (Cu), chromium (Cr), iron (Fe), magnesium (Mg), manganese (Mn), molybdenum (Mo), and zinc (Zn). Deficits in these micronutrients may lead to negative health complications or syndromes. They are also essential components of several important enzymes and play important roles in various oxidation-reduction reactions.[3]

The trace metals are necessary for the body in very small amounts, but excessive exposure or exceeding certain thresholds can make them toxic. Due to the extremely increased use of these metals in numerous industrial, household, and agricultural applications over the past few decades, human exposure to these metals has increased dramatically.[4] Consequently, a growing ecological and worldwide public health issue is linked to environmental contamination caused by these metals. According to earlier studies, the sources of heavy metals in the environment include geogenic, mining, chemical, household waste, and agricultural sources.[5] Because heavy metals are so toxic, environmental scientists have focused a great deal of attention on them out of all the pollutants. Heavy metals can build up in biological tissues.[6] Lead (Pb) exposure is linked to a number of health problems in humans. Lead poisoning manifests as symptoms in the bloodstream, including anemia, impaired reproductive function, renal failure, and neurodegenerative damage.[7] According to.[8], additional heavy metals like manganese, zinc, and copper may be the cause of severe cases, which include hypophosphatemia, heart disease, liver damage, and sensory abnormalities. According to.[9], excessive copper consumption in humans can cause severe mucosal irritation and corrosion, extensive capillary damage, hepatic and renal damage, and central nervous system irritation that is followed by depression.

In developing nations like Nigeria, where the majority of communities lack a functional waste disposal system, the situation is even more appalling.[10] Waste from homes, businesses, and agriculture is frequently dumped carelessly in landfills or dumpsites. A dumpsite is a location where solid waste is disposed of without regard to environmental regulations.[11] Several health risks may arise from waste originating from manufacturing and agriculture. Other than this, people may be exposed to chemical and radioactive risks if industrial hazardous waste is disposed of alongside urban waste.[12,13] Wastes that are dumped nearby also contaminate bodies of water and groundwater supplies. Humans are exposed to organic pollutants and hazardous metals through the food chain when untreated waste is dumped directly into rivers, lakes, and oceans.[14] This demonstrates quite well how improper waste disposal has a negative influence on the health of those who live close to dumpsites. Summertime at the dumpsites is even worse for odours and unsightly conditions because of the high temperatures. Without proper planning and management, disposing of solid waste on land can endanger both human health and the environment.[15,16] Despite the health risks associated with dumpsites, their soils are still used for crop cultivation in developing countries.[17]

Amarathus hybridus [L.] is a popular food plant in Africa that may help with sustainable land care, increase food security, and improve nutrition.[18] Known by various names, including *Efotete* or *Arowojeja* in Yoruba, *Aleifo* (Hausa), and *Inine* (Igbo), it is a popular vegetable choice in Nigerian homes. Human exposure to heavy metal toxicity primarily occurs through ingestion of *Amaranthus hybridus*.[19] In this study, *Amaranthus hybridus* leaves grown on soil collected from three dumpsites in Anyigba, Kogi State, Nigeria, were examined for levels of heavy metals (lead, copper, and zinc) and their potential health risks.

Materials and method

Study area

The study was conducted in Anyigba, Dekina L.G.A, Kogi state which is located in north central region of Nigeria. Anyigba the study area, has a latitude of 7.49ºN and longitude 7.17ºE (Figure 1).

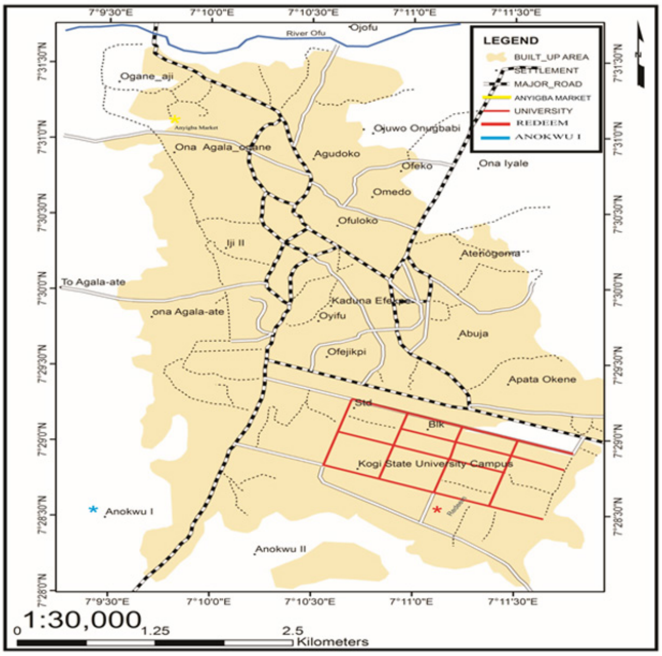

Figure 1 Map of Anyigba showing the study areas

Source: Department of Geography and Environmental Studies, Kogi State University, Anyigba.

Field Experiments

Anokwu 1 (S2) latitude 7.29ºN and longitude 7.10ºE, Redeem Street (S1) latitude 7.31ºN and longitude 7.10ºE, and Anyigba Market Area (S3) latitude 7.30ºN and longitude 7.10ºE are the three dumpsites from which the soil samples used in this study were obtained on October 12, 2020, in Anyigba, Dekina, Local Government, Kogi State. The dumpsites were chosen with consideration for the type and quantity of waste, proximity to agricultural communities, and age. Additionally, control samples were collected 500 meters from each dumpsite. A randomized complete block design with twelve (12) replicates for each soil was used in the experiment. For each treatment, twelve (12) replicates of each of the three (3) distinct soils that were obtained from the various dump sites were put in polythene bags. Throughout the study period, *Amaranthus hybridus* seeds were sown in different types of soil and received watering every two (2) days. Following a four-week planting period, twelve (12) complete Amaranthus plants were arbitrarily selected from each bed in each treatment. Their leaves were mechanically picked, washed with running distilled water to remove dirt, and allowed to air dry for three weeks at room temperature. Dried leaves were pulverized using a ceramic mortar and pestle, sieved through a 2 mm screen, and stored in airtight labelled plastic containers at room temperature for laboratory analysis.

Digestion and Analysis of Plant Sample

Each prepared sample (1.0g) was weighed into 100 cm^3 conical flasks, then HNO_3 and HCl acids were added in a ratio 3:1, the mixture was heated at 100ºC for 30 minutes using a water bath. After letting the digest cool, 5 cm3 more of HNO3 was added, and the heating was kept at 100ºC for an additional hour. Boiling the digest in the water bath reduced its volume, allowing for cooling. Another half hour of heating was spent with the addition of distilled water. After cooling, the final digest was filtered. After adding distilled water to the final digest volume of 100 cm^3, the Buck Scientific VG990 Model Atomic Adsorption Spectrophotometer (AAS) was used to determine whether the necessary heavy metal was present.

Estimated daily intake: Equation (1) below illustrates how the risk that humans are exposed to after consuming African spinach grown in the selected areas was calculated using the target hazard quotient (THQ) and estimated dietary intake (EDI), expressed in mg/kg-per person per day, as described by Zheng et al.[20] & USEPA.[21]

$$EDI = \frac{C_{plant}\left(mg/kg\right) \times \ intake\left(kg/person/day\right) \times EFr \times ED}{BM \times AT}$$

……………………………… Equation (1)

The above equation gives the following values: C_{plant} is the mean concentration of heavy metal in spinach; intake is the rate of ingestion; EFr is the frequency of exposure, estimated at 350 days per year.[22]; ED is the exposure duration, estimated at 60 years per year for carcinogenic effect.[23]; and AT is the average time for non-carcinogens, estimated at 365 days per year. According to previous research in the literature,[24] an adult's average daily intake of 0.345 kg of *Amaranthus hybridus* per person per day and body mass of 70 kg were used.

Target Hazard Quotient (THQ): It is a percentage of the likely exposure to a substance or element at a level where no adverse effects are anticipated. If the quotient is larger than 1, it indicates that there may be health hazards associated with exposure, whereas a quotient of less than one indicates that no possible health impacts are anticipated from exposure.[25] THQ was calculated using the oral reference dose (ORD) ratio (o) derived from the Department of Environment, Food and Rural Affairs.[26] and Integrated Risk Information Systems.[27]The following equation (2) was applied.

$$THQ = \frac{EDI}{\left(RfD_o\left(mg/kg \text{ per person per day}\right)\right.}$$

……………………………………….Equation 2

Where *EDI*, is the average vegetables intake per day (mg/kg/day) and RFD_o is the oral reference dose of the metal (mg/kg/day). RFD_o is an approximation of daily tolerable exposure to which a person is expected to have without any significant risk of harmful effects during a lifespan. RFD_o for, Zn, Cu and Pb is 0.3, 0.04 and 0.004 mg/kg/day respectively.[28]

Hazard Index (HI): Additive impacts arise from several pollution exposures. The hazard index (HI) is a crucial metric that evaluates the total likelihood of potential consequences resulting from exposure to several contaminants. According to sahu.,[29] when the HI is more than 1, it indicates that eating a food that contains pollutants may have a substantial negative impact on one's health. As seen by equation (3), the HI is computed as the arithmetic sum of the hazard quotients for each pollutant.

$$H = \sum_{I=O}^{n} \text{HQ} \quad \text{Equation}(3)$$

Where HQ is hazard quotient of a heavy metal.

Data Analysis

One-Way Analysis of Variance (ANOVA) was used to compare the concentrations of various heavy metals (Zn, Cu and Pb) in the leaves of plants grown on the different dumpsites (S1, S2, S3 and control). Duncan Multiple Range Test (DMRT) was used to separate means where significant. $P < 0.05$ was considered statistically. Statistical Package for Social Science (SPSS; version 20.0) of the International Business Machines (IBM) was used to analyze the data.

Results

Table 1 reveals the result of heavy metals (Zn, Cu and Pb) concentration in the leaves of *Amaranthus hybridus* grown on soils obtained from different dumpsites in Anyigba. It was observed that the concentration of heavy metals (Zn, Cu and Pb) in the leaves of *Amaranthus. hybridus* grown on dumpsite soil (*Redeem* (S1), *Anokwu1* (S2) and *Anyigba Market Dumpsite* (S3) was significantly higher compared to the control. The concentration of Zinc (Zn) in the leaves of the plant grown on dumpsite soil were in the following order *Anyigba Market* (0.4540mg/kg) >*Redeem* (0.4286mg/kg) >*Anokwu1* (0.3520mg/kg) > Control (0.281mg/kg). The concentration of Copper (Cu) in the leaves of the plant grown on dumpsite soil were in the following order: *Redeem* (0.1640 mg/kg) > *Anokwu1* (0.1287 mg/kg) > *Anyigba Market* (0.0947 mg/kg), and Control (0.0467 mg/kg). The concentration of Lead (Pb) in the leaves of the plant grown on dumpsite soil were in the following order: *Anokwu1* (0.1820 mg/kg) > *Anyigba Market* (0.0960 mg/kg) > *Redeem* (0.0580 mg/kg) > Control (0.0267 mg/kg)

Table 1 Concentration of Zn, Cu and Pb in the leaves of *Amaranthus hybridus* found on Dumpsites

	Zn (mg/kg)	Cu (mg/kg)	Pb (mg/kg)
Control	0.2810 ± 0.0006a	0.0467 ± 0.0009a	0.0267 ± 0.0009a
S1(mg/kg)	0.4286 ± 0.0009c	0.1640 ± 0.0006d	0.0580 ± 0.0006b
S2(mg/kg)	0.3520 ± 0.0006b	0.1287 ± 0.0009c	0.1820 ± 0.0006d
S3(mg/kg)	0.4540 ± 0.0006d	0.0947 ± 0.0009b	0.0960 ± 0.0006c
PL (WHO/ FAO, 2013)	0.6	10	2

Values are means ± standard error of triplicate determinations. Means with different superscripts within the same group are significantly different (p<0.05).

Key:

PL = Permissible Limit

S1 = *Redeem Dumpsite*

S2 = *Anokwu1 Dumpsite*

S3 = *Anyigba market Dumpsite*

Estimated daily intake of heavy metals for zn, cu and pb

Table 2 reveals the Estimated Daily Intake (EDI) for heavy metals (Zn, Cu and Pb) concentration in the leaves of *Amaranthus hybridus* grown on soils obtained from different dumpsites in Anyigba. That of Zn is in the following order: *Anyigba Market* (0.13 mg/kg) > *Redeem* (0.12 mg/kg) >*Anokwu 1* (0.10 mg/kg). That of Cu is in the following order: *Redeem* (0.05 mg/kg) > *Anokwu1* (0.04 mg/kg) > *Anyigba Market* (0.03 mg/kg). That of Pb is in the following order: *Redeem* (0.34 mg/kg) > *Anokwu1* (0.05 mg/kg) > *Anyigba Market* (0.03 mg/kg). The total EDI for Zn, Cu and Pb for *Redeem*, *Anokwu1* and *Anyigba Market* were 0.34, 0.19 and 0.19 mg/kg respectively.

Table 2 Estimated daily intake, *EDI* in mg/kg BM/d for adults through consumption of *Amaranthus hybridus* from the three dumpsite and the control.

	S1(mg/kg)	S2(mg/kg)	S3(mg/kg)	PMTDI(mg/kg)
Zn (mg/kg)	0.12	0.1	0.13	3.16 mg/kg
Cu (mg/kg)	0.05	0.04	0.03	0.880mg/kg
Pb (mg/kg)	0.17	0.05	0.03	0.200mg/kg
Total	0.34	0.19	0.19	

Key:

PMTDI = Permitted Maximum Tolerable Daily Intake[28]

S1 = *Redeem Dumpsite*

S2 = *Anokwu Dumpsite*

S3 = *Anyigba market Dumpsite*

Target hazard quotient for zn, cu and pb

Table 3 reveals Target Hazard Quotient (THQ) for heavy metals (Zn, Cu and Pb) concentration in the leaves of *Amaranthus hybridus* grown on soils obtained from different dumpsites in Anyigba. That of Zinc (Zn) were in the following order: *Anyigba Market* (0.43 mg/kg) >*Redeem* (0.4 mg/kg) >*Anokwu 1* (0.3 mg/kg).

Table 3 Heavy metal Target Hazard Quotient (THQ) in adult through consumption of *Amaranthus hybridus* from the three dumpsite and the control sites.

	S1(mg/kg)	S2(mg/kg)	S3(mg/kg)	RFD_o
Zn (mg/kg)	0.4	0.3	0.43	0.3mg/kg/day
Cu (mg/kg)	1.25	1	0.7	0.04mg/kg/day
Pb (mg/kg)	42.5	12.5	7.5	0.004mg/kg/day

Key:

RFD_o = Reference Dose[28]

S1 = *Redeem Dumpsite*

S2 = *Anukwu Dumpsite*

S3 = *Anyigba market Dumpsite*

That of Cu was in the following order: *Redeem* (1.25 mg/kg) >*Anokwu 1* (1.0 mg/kg) >*Anyigba Market* (0.7 mg/kg). That of Pb was in the following order: *Redeem* (42.5 mg/kg) >*Anokwu1* (12.5 mg/kg) >*Anyigba Market* (7.5 mg/kg)

Hazard index for zn cu and pb

Figure 2 reveals the Hazard Index (HI) for heavy metals (Zn, Cu and Pb) concentration in the leaves of *Amaranthus hybridus* grown on soils obtained from different dumpsites in Anyigba. The Target Hazard Index (HI) concentration of Zn, Cu and Pb in the leaves of the plant grown on the dumpsite soil were in this order *Redeem Dumpsite* (44.15 mg/kg) >*Anokwu 1 Dumpsite* (13.8 mg/kg) >*Anyigba Market Dumpsite* (8.6 mg/kg).

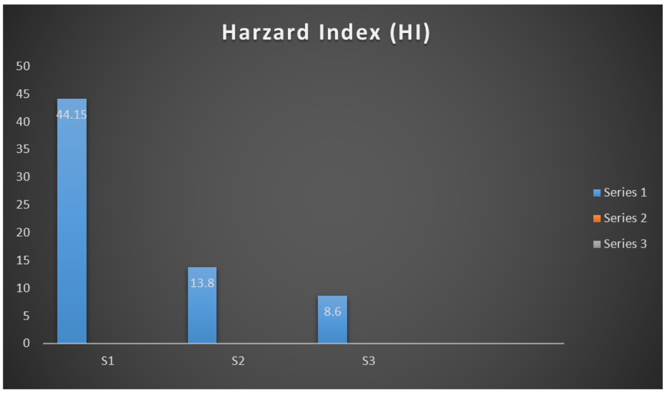

Figure 2 Hazard index (HI) for studied *Amaranthus hybridus*.

Discussion, Conclusion and Recommendation

The results revealed that plant grown on soils from the dumpsites recorded higher metal concentrations than their corresponding levels on the control soil. This is in agreement with the results obtained from similar studies by Amusan AA, et al.,[30] and it could be attributed to the availability of metal containing wastes at dumpsites which are eventually absorbed by the plants and stored in different organs. Zn in *Amaranthus hybridus* leaves grown on the three dumpsites ranged between 0.281 - 0.4540mg/kg with the control having the lowest and *Anyigba market Dumpsite* the highest; all of which were within World Health Organization (WHO) permissible limit for Zinc (0.6mg/kg). The findings of the current study are consistent with those of Opaluwa et al.,[31] for the leaves of *Amaranthus dubius* (0.01 - 0.03 mg/kg) planted on dumpsite.[32] reported the presence of Zinc in leaves of for *Talinium triangulae* (0.01 – 0.04 mg/kg) grown in *Awotan* and *Ajakanga* dumpsite, Ibadan. Zinc is an essential micro element for plants, animals and humans found in virtually all food and potable water in the form of salts or organic complexes.[33] However, an excess of this metal (zinc toxicity) in the human body can cause health complications such as heart disease, liver damage and sensory disturbances.[34] The concentration of Cu in the leaves of *Amaranthus hybridus* grown on soil from different dumpsites in Anyigba ranged between 0.0467 and 0.164mg/kg; all of which were within the permissible limit (10mg/kg) for Copper in plants. This current finding, is consistent with the report by Benson.,[35] in *Manihot utilissima* (0.052 and 0.251mg/kg) obtained from a municipal dumpsite, in Nigeria. This may be attributed to the low level of the metal in the earth's crust and as a non-essential element for plants.[36] Copper is a vital element in the human body as it is responsible for upholding central nervous system health, proper working of the metabolic processes, pigmentation, and prevention of anaemia.[37] However, continuing low Cu levels have damaging effects to humans due to the nature of the role copper plays.[38] For Pb, its concentration ranged between 0.0267 - 0.1820 mg/kg, all of which did not exceed the WHO permissible limit (2mg/kg). The result for the current finding is in agreement with those of Opaluwa OD, et al.,[39] in the leaves of Spinach (0.07mg/kg) obtained from dumpsite in Lafia Metropolis, Nasarawa State. This low uptake of Pb by *Amaranthus hybridus* may be due to the low concentration of the metal in the growth medium.[40] Although the levels of this metal are within normal range for the plant, continual consumption could lead to accumulation and adverse health implication.[39]

Health risk estimation based on the estimated daily intake (EDI) of the heavy metal contaminant is one of the vital health risk assessment tools. It takes into account the frequency and duration of exposure and the bodyweight of the exposed persons. In general, health risk due to metal contamination depends on the average daily dietary intake .[41] The EDI results recorded were compared with the permitted maximum tolerable daily intake of metals endorsed by (WHO/FAO).[3] The EDI of Zn (mg/kg) which ranged from 0.10 to 0.13 in *Amaranthus hybridus* from the three dumpsites were within permitted maximum tolerable daily intake (PMTDI) endorsed by WHO/FAO of 3.16 mg/person/day. These low concentrations of EDI were consistent with the report of.[29] in *Amaranthus hybridus* (1.87 mg/kg) grown on dumpsite. This could be as a result of weak adsorption properties from the soil to the leaf. The EDI of Cu ranged from 0.037 to 0.05 mg/kg in the *Amaranthus hybridus* from the three dumpsite were below permitted maximum tolerable daily intake (PMTDI) endorsed by WHO/FAO of 0.88 mg/kg body weight/day. The result observed in this current study are consistent with the presence of Copper recorded by Meseret et al.[42] where *Aloe Percrassa* (0.00323 mg/kg) was planted on dumpsites. This could also be as a result a result of weak adsorption properties from the soil to the leaf. The EDI of Pb mg/kg ranged from 0.03 to 0.17 in the *Amaranthus hybridus* from the three dumpsite were below permitted maximum tolerable daily intake (PMTDI) endorsed by WHO/FAO of 0.21 mg/kg bogy weight/day. The findings of this current study were consistent with presence of Pb reported by Meseret.,[42] in *Chenopodium murale* (0.00050 mg/kg). From the EDI findings, consumption of *Amaranthus hybridus* grown on the three studied area, is not a threat to the health of the consumer. From the result of THQ, the concentrations of Zn which ranged between 0.3 to 0.4mg/kg were all less than 1, this indicate that Zn do not pose any health threat in the studied area. However, THQ of Cu which ranged between 0.7 to 1.25mg/kg was greater than 1 at all locations, except for *Anyigba Market Dumpsite* (0.7mg/kg). The high THQ for Cu recorded on *Redeem Dumpsite* (1.25mg/kg) and site *Anokwu 1 Dumpsite* (1.0mg/kg) poses significant carcinogenic health threat to consumers. The result from this current study is in agreement with the presence of Cu reported by Mosiamisi and Sello.[43] in *Spinacia oleracea* (2.44mg/kg) grown on dumpsites. The THQ of Pb which ranged between (7.5 to 42.5mg/kg) were greater than 1, suggesting that the long-term exposure to *Amaranthus hybridus* grown on the selected dumpsite poses a health risk to its consumer due to over exposure to Pb. High THQ for Pb from the study align with findings reported by Kacholi and Sahu.[29] in *Amaranthus hybridus* (2.46mg/kg). High THQ for Pb was also reported in China and India.[44,45]

There is increasing evidence worldwide that pollution due to heavy metal contamination causes death, for example, in Zambia alone, tens of thousands of the residents of kwabe suffered from lead poising by the lead-zinc mining and smelting.[46] The potential risk could be multiplied when considering all the heavy metals together.[19,20]

Hence, estimation of hazard index (HI), which takes care of the chemical mixtures, is very important in assessing multiple effects of the heavy metals. From the results for HI, the highest value was found in *Amaranthus hybridus* obtained from *Redeem Dumpsite* (44.15mg/kg) followed by *Anokwu1 Dumpsite* (13.8mg/kg) and Anyigba *Market Dumpsite*(8.6mg/kg).When the HI surpasses unity, this tells us that eating of the food can cause health effects.[47-49] Consumption of *Amaranthus hybridus* grown on soil obtained from the dumpsite poses high risks to their health as their HI was greater than one.

Conclusion

I. Heavy metals (Zn, Cu and Pb) were detected in the leaves of African spinach (*Amaranthus hybridus*) planted on the three different dumpsites (*Redeem, Anokwu 1 and Anyigba Market Dumpsites*)

II. For *Redeem dumpsite* (S1), the content of Copper (Cu) was found to be the highest while that of Lead (Pb) was the lowest. For *Anokwu 1 dumpsite* (S2), Lead (Pb) had the highest concentration while Zinc (Zn) had the lowest concentration. For *Anyigba Market dumpsites* (S3), Zinc (Zn) had the highest concentration while Copper (Cu) had the lowest concentration. This study has established that the levels of heavy metals in the leaves of *Amaranthus hybridus* grown on dumpsite are within the permissible limit.

III. Health risk assessment for all the sites (Redeem, Anokwu1 and Anyigba Market Dumpsite) in *Amaranthus hybridus* indicated that there is no particularly dangerous single heavy metal, but their cumulative effect, indicated by the hazard index (HI), calls for concern. Hazard Index (HI) for the stations highly exceeded threshold value one (1).

Recommendations

A. Government and local authorities, should enforce strict regulations prohibiting the cultivation of food crops on dump site soils to prevent the accumulation of toxic heavy metals in edible plants. Routine inspections and penalties should be implemented to ensure compliance.

B. Environmental and health agencies should launch continuous public awareness campaigns to educate farmers and the general public on the dangers of using untreated dump site soils for farming. Emphasis should be placed on the health risk associated with consuming vegetables grown on contaminated environment

C. Local governments should upgrade open dump site into sanitary landfills that meet environmental safety standards. The modern waste management system should include proper lining, leachate control and gas collection to minimize soil and water contamination

D. Contaminated dump site soils should undergo remediation through government sponsored environmental rehabilitation programs. Techniques such as phytoremediations, soil washing or the application of soil amendments should be employed to detoxify these site before any reuse.

Acknowledgments

None

Conflicts of interest

The authors declare that there was no conflict of interest.

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