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Assessment of Metal Pollutants Bioaccumulation in Amaranthus (*Amaranthus tricolor*) Vegetables in Maiduguri, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Author PHB designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author JAA took part in literature review. Authors MUS and MAO compute the daily intake of metal. All authors read and approved the final manuscript.

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ABSTRACT

Assessment of metal pollutants bioaccumulation in amaranthus vegetables cultivated along the bank of river Ngadda and Alau dam was carried out with the aim of establishing the health risk associated with their consumption. Samples of amaranthus vegetables were analyzed for metal pollutants namely: Aluminum (Al), Manganese (Mn), Samarium (Sm), Iron (Fe), Zinc (Zn), Cobalt (CO), Chromium (Cr), Rubidium (Rb), Barium (Ba) Scandium (Sc), Thorium (Th), Antimony (Sb) and Vanadium (V) using instrumental neutron activation analysis (INAA) techniques. Four samples from each study site were collected, analyzed for concentration values and compared with the available values of safe limit given by WHO/FAO. From the result obtained, the maximum concentrations for Al was 1508 ± 018 at sampled site A2, for Mn was 179 ± 1 at sampled site A1, for Mg was 19890 ± 537 at sampled site A3, for Fe was 655 ± 40 at sampled site A4, for Zn was 85 ± 4 at sampled site A3 for Co was 20 ± 3 at sampled site A2, for Cr was 88 ± 21 at sampled site A4, for Rb was 18 ± 1 at sampled site A4, for Sc was 15 ±1 at sampled site A4, for Th was 33 ± 5 at sampled site A4, for Sb was 18 ± 2 at sampled site A2 and for V was 2.3 ± 0.5 at sampled sites

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A2, A3. The result showed that the maximum concentration of Fe, Cr, Mn and Co exceed the values recommended by FAO/WHO of 425.5, 1.3, 25 and 0.3 ppm respectively. Therefore, the consumption of vegetables cultivated on farmland soils along the bank of river Ngadda and Alau dam may constitute health risk overtime as these metals can accumulate in the body.

Keywords: Assessment; bioaccumulation; metal pollutants; irrigation; INAA; technique.

1. INTRODUCTION

Food safety is a burning issue regarding human health in the recent decades which has stimulate researchers and scientists to work on health risk associated with consumption of heavy metals, pesticides, and toxin-contaminated food [1]. Food crops are one of the important parts of our diet, and they may contain a number of essential and toxic metals [2,3] depending on growing media characteristics.

Vegetables are edible crops and are an essential part of the human diet and generally consumed because of their nutrition value [4,5] and are also the major sources of human exposure to heavy metals which contribute about 90% of the total metal intake, while the rest of 10% intake occurs through dermal contacts and inhalation of contaminated dust [6,7,8,9].

The choice of soils on which vegetables are grown is of paramount importance as the plant can absorbed from the content of the soils used for cultivation. Study has shown that refuse dumping of solid waste generated from urban settlement in streams or along the bank of the stream that transcend urban centers are habits exhibited by urban dwellers in most developing countries and this assist in contamination of the soils with heavy metals since the metals have the capability to move from contaminated soil and water to cause the contamination of agricultural crops cultivated on such soils and bio accumulate in vegetables causing health risks [10,11,1] which therefore plants grown on contaminated soils can lead to health risk by consumers of the crops. Heavy metals have the capability to move from contaminated soil and water and bio accumulate in vegetables causing health risks [10,11,1].

Refuse dumping of solid waste generated from urban settlement in streams or along the bank of the stream that transcend urban centers are habits exhibited by urban dwellers in most developing countries and this assist in contamination of the soils with heavy metals which usually caused the contamination of agricultural crops cultivated on such soils and on the other hand use of waste water for irrigation results in the significant mixing of the heavy metal content of the agricultural land [12,13].

In most developing countries, cultivation of vegetables on farmlands near water channels or streams that passes through urban areas via irrigation during dry season are common practice due to the fact that it provides an easy access to the water used for the cultivation and cheap transportation of the matured vegetables to the market within the urban area since means of transportation is still an issue in such countries.

The accumulation of toxic heavy metals in vegetables irrigated with waste water was studied by Cheraghi et al. [14] and it was found that metal concentration was many times higher than vegetables grown in controlled area. In the study carried out by Edem et al. [15] found that concentration of Fe, Mn, Pb and Cr was highest in vegetable leaves. Copper accumulation was highest in the stem while roots had higher concentration of Zn. These heavy metals are not easily biodegradable and it leads to their accumulation in human vital organs causing varying degree of illness on acute and chronic exposure.

2. MATERIALS AND METHODS

This study carried out within an area that lies between latitude 11° 48' N to 11° 52'N and longitude 13° 06' E to 13° 14'E at an altitude of 345 m above sea level Fig. 1. The area of study is known for its long period of dryness, with Sudan type of climate, Savanna or Tropical grassland vegetation, light annual rainfall of about 864 mm (34 inches).

2.1 Sample Collection

Fresh amaranthus vegetables were collected directly from four different sites on farmlands along the bank of river Ngadda and Alau dam and labeled with the identification codes (A1, A2, A3, A4) with the alphabet representing the vegetable type and the numeral representing the site location hence combined to constitute (vegetable/sampled site) Fig. 2. These codes were assigned to the samples for easy identification during and after analysis. The vegetables collected were put in a clean black polyethylene bags and then accordingly assigned their codes. During each collection, co-ordinates were obtained from Global Positioning System (GPS) to maintain consistency and repeatability in the subsequent collection process.

2.2 Sample Preparation

The fresh vegetable samples were taken to herbarium in Biology Department of Ahmadu Bello University, Zaria for identification, after which they were taken to laboratory, thoroughly washed with running tap water and properly rinsed with double distilled water to remove possible particulate pollutants. The moisture and water droplets were removed with the help of blotting papers. The samples were air dried and oven dried at low temperature and there after grounded and sieved to required particle sizes using a sieve that were pre-cleaned. They were then put in sample bottles, labeled, capped, and taken to Centre for Energy Research Training (CERT) Ahmadu Bello University, Zaria for further preparation and analysis.

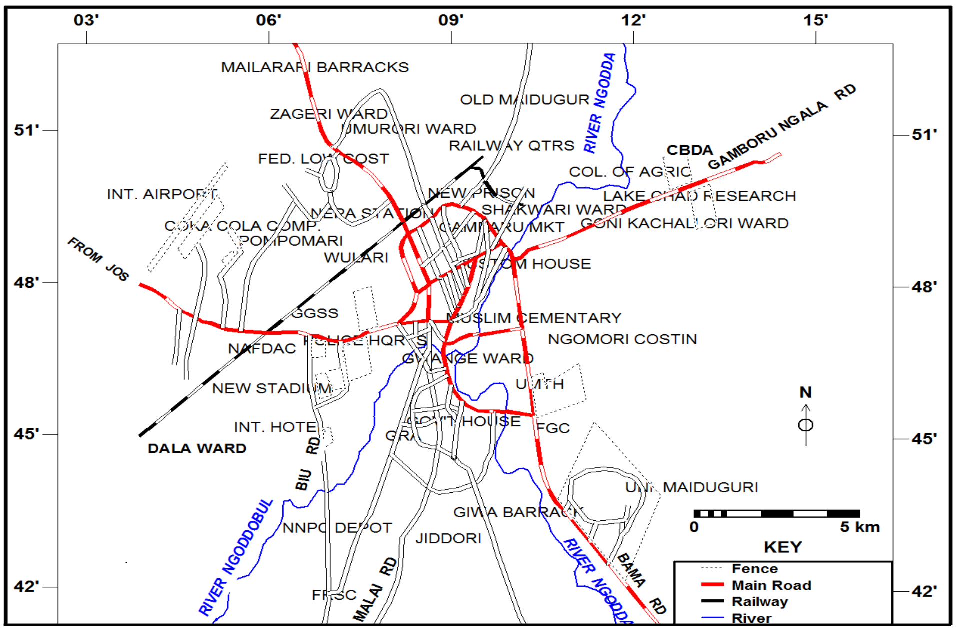

Fig. 1. Maiduguri township map
Source: Land and Survey 2012

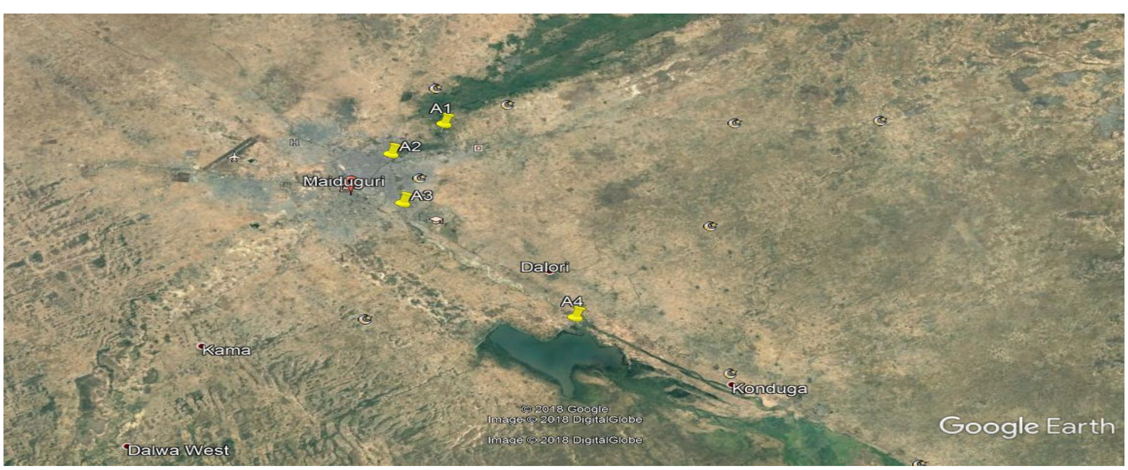

Fig. 2. Amaranthus sampled sites along the Bank of River Ngadda and Alau dam

2.3 Sample Preparation for Neutron Activation Analysis

Conventional method of sample preparation of vegetable samples for irradiation using NIRR-1 was employed provided in the work carried out by [16] after which the samples were put in an irradiation vial. The vial was capped and sealed. Standard Reference Material (SRM) NIST 1573a which is a direct representative of the vegetable sample was put in the same type of vial with that of the sample and then irradiated. The working principles and detail function of Nigeria Research Reactor-1(NIRR-1) is seen in the work of several authors [16,17].

2.4 Sample Analysis

The sample and standards of known quantities of the elements in question were irradiated simultaneously in identical positions, followed by measuring the induced intensities of both the standard and the sample in a well-known geometrical position. For data processing the gamma-ray spectrum analysis software WINSPAN, 2004 used by Liyu [18] based on the practice of using the activity induced at time after irradiation for time *t* was employed according to the equation (1)

$$A_t = \frac{\varepsilon\sigma_Q\rho W_Q\varphi}{M_Q} = N_A\left(1 - e^{-\lambda t_i}\right)ds^{-1} \quad (1)$$

where A_t is activity of element Q at the end of irradiation (d^{s-1}), σ_Q is neutron capture cross section of element (m^2), ρ is fractional abundance of particular isotope of element Q, M_Q is atomic weight of element Q to be measured, N_A is Avogadro's number (mol^{-1}), λ is decay constant of induced radionuclide (s^{-1}), t_i is irradiation time (s), φ is is the flux of neutron used in irradiation ($nm^{-2}s^{-1}$) and W_Q is weight of element Q irradiated.

The sample and standard parameters were then related by the equation (2)

$$\frac{A_{sam}}{A_{std}} = \frac{\phi\omega\epsilon I N_A\left(1-e^{-\lambda t_{irr}}\right)sam\left(e^{-\lambda t_d}\right)sam\left(1-e^{-\lambda t_c}\right)sam}{\phi\omega\epsilon I N_A\left(1-e^{-\lambda t_{irr}}\right)std\left(e^{-\lambda t_d}\right)std\left(1-e^{-\lambda t_c}\right)std} \quad (2)$$

where A_{sam} is activity of the unknown sample, A_{std} is activity of the standard. The standard is irradiated and counted under similar conditions as the sample, therefore common parameters in equation (2) cancelled out then the mass of the element in the sample relative to the standard comparator is calculated using equation

$$\frac{A_{sam}}{A_{std}} = \frac{m_{sam}}{m_{std}}\frac{\left(e^{-\lambda t_d}\right)}{\left(e^{-\lambda t_d}\right)}\frac{sam}{std} \quad (3)$$

m_{sam} = mass of element in the sample, m_{std}= mass of element in standard, λ = decay constant for the isotope.

3. RESULTS AND DISCUSSION

Table 1 present concentration values of the various elements determined in amaranthus vegetables and the values were graphically represented in Figs. 3–6 accordingly.

3.1 Daily Intake of Metals (DIM)

In order to quantify the level of exposure from consumption of the vegetable investigated, an index referred to as daily intake of metals (DIM) was calculated according to the expression:

$$DIM = \frac{M*C*I}{W} \quad (4)$$

where *M* is the metal concentration in the vegetable (mg/kg), *C* is the conversion factor, *I* was the estimated quantity of vegetable taken on daily basis, and *W* is the average weight of a human being. The conversion factor (from fresh to dry weight of vegetable) of 0.085 was adopted from [19]; the average weights of an adult and a child were approximated to be 55.9 and 32.7 kg respectively, while the average quantities of vegetable taken on daily basis by adults and children were 0.345 and 0.232 kg/person/day respectively [20,21].

The best way to estimate the risk of any pollutant is to determine the level of exposure to that pollutant and the route(s) of exposure to a particular tissue or organ. In this study, the daily intake of metals (DIM) was used as the exposure index. Evaluation of DIM based on the stated assumptions revealed a minimum of 1.20 x 10^{-3} mg and a maximum of 7.9 x 10^{-1} mg for adults, while the children had a minimum of 9.04 x 10^{-4} mg and a maximum of 6.1 x 10^{-1} mg. It is obvious from Table 1 that all the daily intakes of metal in Amaranthus by children for almost all the elements were higher than the corresponding values for adults which imply that children tend to take in more metals than adults and this could be due to tenderness of children's body tissues. Again, it can be noticed that the metals with relatively high DIM values (eg: Al = 0.837 mg, Fe = 0.464 mg for adults and Al = 0.962 mg, Fe = 0.533 mg for children) are mainly major elements with high natural abundances.

Table 1. Concentration of elements determined in amaranthus at different sites by INAA

Sampled site	Al	Ba	Co	Cr	Fe	Mn	Rb	Sb	Sc	Sm	Th	V	Zn
A1	1023±436	63±3	0.31±0.04	1.0±0.3	640±54	179±1.000	16±1.00	0.2±0.03	0.11±0.01	0.15±0.05	0.28±0.05	1.5±0.4	22±2
A2	1508±018	54±2	20±3.00	BDL	550±37	93.24±0.28	15±1.00	18±2.00	13±1.00	13.1±0.50	27±5.00	2.3±0.4	27±2
A3	1301±029	40±2	0.36±0.04	BDL	502±37	410±1.00	17.61±0.05	0.48±0.03	0.12±0.01	0.29±0.01	1.12±0.05	BDL	85±4
A4	1176±021	30±2	BDL	88±21.0	655±40	72.1±0.30	18±1.00	13±2.00	15±1.00	0.15±0.01	33±5.00	2.3±0.5	BDL

BDL: Below Detection Limit
All concentrations are in ppm

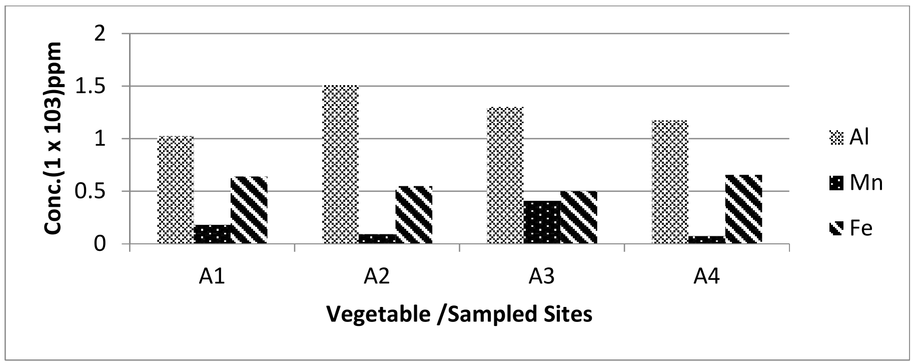

Fig. 3. Concentration of elements (Aluminium (Al), Iron (Fe) and Manganese (Mn)) determined in amaranthus vegetable

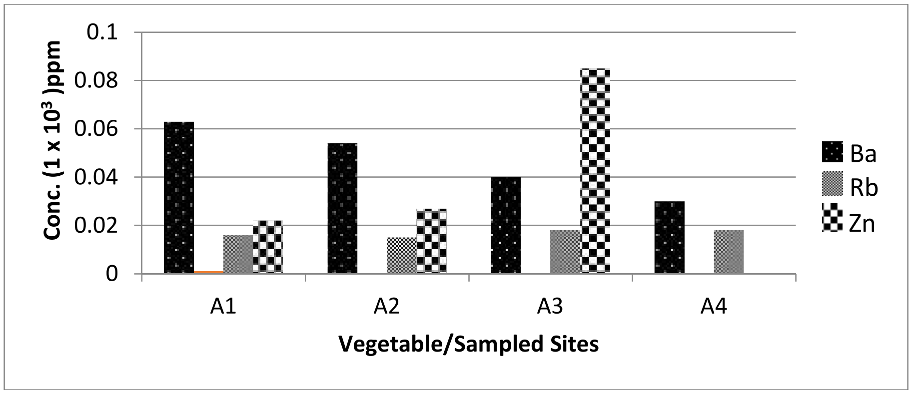

Fig. 4. Concentration of elements (Barium (Ba), Rubidium (Rb) and Zinc (Zn)) determined in amaranthus vegetable

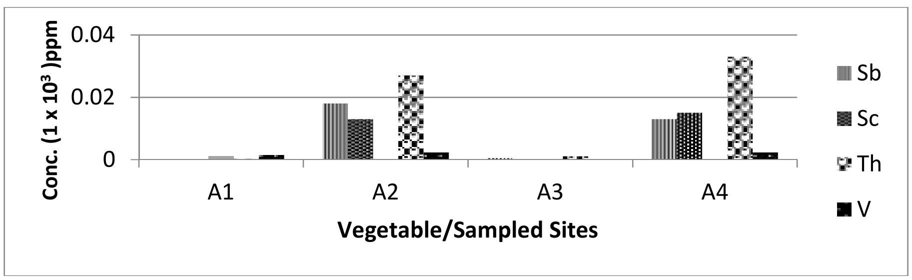

Fig. 5. Concentration of elements (Antimony, Scandium, Thorium and Vanadium) determined in amaranthus vegetable

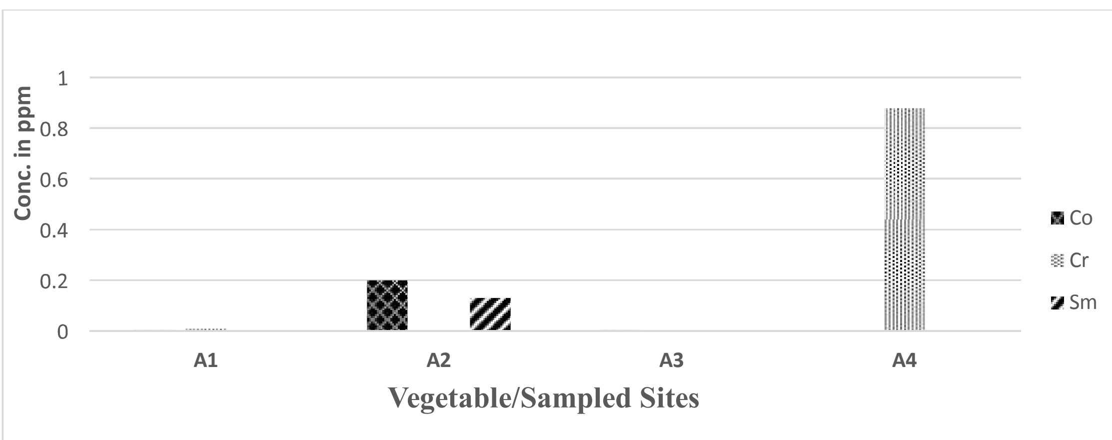

Fig. 6. Concentration of elements (Cobalt, Chromium and Samarium) determined in amaranthus vegetable

Fig. 3 shows the graph representing the concentrations of Aluminium (Al), Iron (Fe) and manganese (Mn) determined in Amaranthus samples obtained at four different sites along the bank of river Ngadda and Alau dam, it can be observed from the graph that the concentrations of Aluminium were higher in the samples obtained at the different sites followed by iron and the least is manganese. The concentrations of these elements could be due to the fact that these are elements that are naturally abundant and the concentrations of Fe in amaranthus were above MPL given by FAO/WHO [21].

Fig. 4 shows the graphical representation of the concentrations of Barium (Ba), Rubidium (Rb) and Zinc (Zn). It is obvious from the graph that Zinc had its maximum concentration at sampled site three (A3) and minimum at samples site one (A1) while Barium has its maximum concentrations at sampled site one (A1) and minimum at sampled site four (A4). Barium is on average of equal concentration values at all the sites.

Fig. 5 shows the graphical bar chart of the concentrations of Antimony, Scandium, Thorium and Vanadium determined in amaranthus vegetables obtained from the different sites of study. Sampled sites four (A4) and sampled sites two (A2) have thorium concentration highest followed by Scandium and then Vanadium respectively.

Fig. 6 shows the bar chart graph of the concentrations of cobalt, chromium and samarium determined in amaranthus vegetables obtained from the four different sites of study. Chromium value was high at sampled sites A4 while cobalt and Samarium values at sampled sites A2 were almost the same. The high concentration of Cr at sampled site A4 could be attributed to the fact the site is close to a former tannery site therefore the discharge from the tanning process might have contributed to the increase in the its content in the soil and hence absorbed the plants.

4. CONCLUSION

Amaranthus is one of the staple vegetables of the people of northern Nigeria especially during dry season. The leafy part is often used to prepare soup or mixed with other vegetables for daily consumption and because of its short time of maturity and the long dry season it can be cultivated up to three time from the beginning of a dry season to the end hence a large quantity is cultivated and consumed within a dry season period. From the result presented, it was obvious that Fe concentration value was above FAO/WHO maximum permissible limit (MPL) while the rest of the elements were within the acceptable maximum permissible limit. However, it is expedient to always investigate the metal pollutants content of the soils on which these vegetables were are cultivated and the bioaccumulation of metal pollutants in the vegetables cultivated and consumed since these metal pollutants can be transferred to human when the vegetable is consumed and can accumulate above thresh hold values thereby constituting health risk thus the need to periodically investigate the bioaccumulation of both trace and heavy metals in the vegetables being cultivated in the study sites.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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