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RESEARCH ARTICLE

HEAVY METAL CONCENTRATIONS IN SOILS AND ACCUMULATION IN *AMARANTHUS HYBRIDUS* GROWN NEAR SOLID WASTE DUMPSITES IN GOMBE, NIGERIA

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ABSTRACT

A study of the concentrations and accumulation of heavy metals (Pb, Cd, Ni, Fe and Zn) in *Amaranthus hybridus* (green spinach) plant around four solid waste dumpsites in Gombe metropolis, Nigeria was carried out using Atomic Absorption Spectrophotometer (A Analyst 400 Perkin Elmer USA). The result indicated the following trend in heavy metals' concentrations in both dumpsite soil and plant samples: Fe>Zn>Pb>Ni>Cd. Roots showed highest metal concentration followed by leaves and then stems. The Accumulation Factor (AF) was calculated for assessment of the plant's bio-accumulation potential. The Accumulation Factor (Transfer Ratio) indicated the following trend: Cd>Pb>Ni>Fe>Zn. Although the metals concentrations in *Amaranthus hybridus* were less than 1000mgKg^{-1}, their average accumulation factors (AF) being greater than 1.00 for the five heavy metals studied is an indication of the plant's potential as hyper accumulator. Thus, it may be risky to consume *Amaranthus hybridus* grown at close proximity to dumpsites since they can greatly accumulate much of these toxic metals.

INTRODUCTION

Increasing industrialization essential for sustaining economic and financial health of countries has accentuated the generation of solid waste. Studies have shown that soils at refuse dumpsites contain different kinds and concentration of heavy metals (Odukoya *et al*., 2000). In recent times, it has been reported that these elements accumulate and persist in soils at an environmentally hazardous levels (Alloway, 1996). Moreover, soluble components of solid waste in contact with water will change the groundwater quality either directly or indirectly by infiltration of contaminated surface water. These heavy metals contaminants in water become absorbed by plants (Alma *et al*., 2010). Green sprouts have been part of the human diet for much of recorded history. It has been observed that some common vegetables are capable of absorbing and retaining heavy metals from contaminated and polluted soils (Cobb *et al*., 2000). This poses serious health and environmental danger because of the phytotoxicity of these metals to the plants as well as humans and animals consuming such vegetables (Ellis and Salt, 2003; Pillay *et al*., 2003). Nevertheless, most solid waste dumpsites in Gombe have been used extensively as cultivation ground for vegetables, the most common vegetable plant being *Amaranthus hybridus* (green spinach).

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This vegetable plant has always formed part of the human diet for centuries due to its nutritional value. The objective of this study is to determine the levels of heavy metals namely, Cadmium (Cd), Lead (Pb), Nickel (Ni), Iron (Fe) and Zinc (Zn) in *Amaranthus hybridus* and soil samples collected from four dumpsites within Gombe. The accumulation factors and mobility indices were also determined to understand the vegetables' bio-accumulation potential. This is of great interest since the vegetable in question constitute a major part of human diet in the metropolis. Thus, the result will enhance the quality of life of end-users.

MATERIALS AND METHODS

Study Area

This study was carried out in four solid waste dumpsites (PZ, Army Barrack, Yalengruza and Buhari Estate) and one control site within the capital city of Gombe as shown in Figure 1. Gombe is a centre of commercial and industrial activities in Gombe State. The State located at Latitude $9^0 30'$ and $12^0 30'$N and Longitude $8^0 45'$ and $11^0 45'$E, is surrounded by hills, thereby creating natural depressions within the State. Gombe, with an estimated population of about two million, generates large volume of wastes which are deposited at designated dumpsites. Vegetable plants are also grown by local farmers at close proximity to such dumpsites.

Figure 1. Map of Gombe showing the study sites (1: PZ; 2: Army Barrack; 3: Yalengruza; 4: Buhari Estate).

Sample Collection and Digestion

Amaranthus hybridus plants were randomly collected at different points near four waste dumpsites in Gombe. For each vegetable plant sampled, surrounding soil of depth 0-20cm was collected. All the samples were collected during the dry season between January and March 2013. The vegetable plants were washed with tap water several times, then separated into parts (roots, stems and leaves) and air-dried. The dried samples were ground to fine powder, sieved through a 1.5mm sieve and transferred to polyethylene bags for storage until later analysis. 5g of vegetable samples were weighed into a 100cm^3 beaker and aqua regia (3:1 HCl/HNO_3) was added. The beaker was covered with a watch glass and placed on a hotplate in a fume cupboard. The mixture was boiled and allowed to simmer for 1 hour. The beaker was removed and allowed to cool. When no fumes were given off, the watch glass was removed allowing the liquid attached to it to drain into the beaker. The content of the beaker was filtered through a Whatman no. 540 filter paper into the volumetric flask using distilled water. The flask was inverted several times to achieve homogeneity of the solution.

1g of the sieved soil was weighed out and transferred into a 100 cm^3 tall-form beaker. About 20 cm^3 of (1:1) HNO_3/HCl acid mixture was added and boiled gently on a hotplate until the volume of nitric acid mixture was reduced to about 5 cm^3. Then 20 cm^3 of deionized water was added and boiled gently again until the volume is approximately 10 cm^3. The resulting suspension was cooled and filtered through a Whatman no. 540 filter paper, washing the beaker and the filter paper with small portions of deionized water until a volume of about 25 cm^3 was obtained. The filtrate was then transferred to a 50 cm^3 graduated flask and made up to the mark using deionized water (Vogel, 2000; Ogundiran and Osibanjo, 2008).

Determination of Heavy Metal Concentrations in Soils and Plant Parts

Atomic Absorption Spectrophotometer (Perkin Elmer; Model: AANALYST 400) was used for the quantitative determination of heavy metals of interest in both the vegetable and soil samples. The concentrations of the various metals (Cd, Pb, Ni, Fe and Zn) to be determined were obtained directly from the instrument by aspirating the samples into the instrument.

Enrichment Factor (Singh *et al*., 2010; Kisku *et al*., 2000)

The enrichment factor (EF) has been calculated to derive the degree of soil contamination and heavy metal accumulation in soil and in plants growing near contaminated sites with respect to soil and plants growing on uncontaminated soil.

$$EF = \frac{\text{Concentration (mgKg}^{-1}\text{) of metals in soil or plant parts at contaminated site}}{\text{Concentration (mgKg}^{-1}\text{) of metals in soil or plant parts at uncontaminated site}}$$

Accumulation Factor (Kumar *et al*., 2009)

As total heavy metal concentration of soils is a poor indicator of metal availability for plant uptake, Accumulation Factor (AF) was calculated based on metal availability and its uptake by the vegetable plant as follows:

$$\text{Accumulation Factor (AF)} = \frac{\text{Weighted Mean Plant Concentration (mgKg}^{-1}\text{)}}{\text{Mean Soil Concentration (mgKg}^{-1}\text{)}}$$

The Accumulation Factor gives an idea of the ability of a plant to accumulate metals absorbed from the soil. In addition, AF quantifies the relative differences in the bioavailability of metals to plants (Pahalawattaarachchi *et al*., 2009). These factors are based on the root uptake of metals and the surface absorption of atmospheric metal deposits (Kachanko *et al*., 2004).

RESULTS

The heavy metal enrichment factor in the contaminated and control sites are presented in Table 1. The result showed that the soils were highly contaminated with the heavy metals under investigation when compared with the control (uncontaminated) soil.

Table 1. Heavy metal enrichment (mgKg^{-1}) of soils in the contaminated and control sites

DUMPSITE	Cd	Pb	Ni	Fe	Zn
1. (PZ)	8.00^a ±1.21	11.50^a ±2.05	5.50^a ±3.01	9.25^a ±2.34	26.25^a ±6.60
2.(Army Barrack)	3.00^b ±2.53	3.00^b ±1.82	2.50^a ±0.92	6.08^b ±1.05	14.00^b ±5.02
3. (Yalengruza)	42.00^c ±5.87	141.50^c ±9.25	60.00^b ±5.42	41.83^c ±8.15	75.25^c ±13.27
4.(Buhari Estate)	11.00^a ±3.64	31.50^d ±2.29	17.00^c ±3.35	16.67^d ±4.03	41.25^d ±10.76
Control Site	0.01 ±0.01	0.02 ±0.02	0.02 ±0.01	0.12 ±0.04	0.04 ±0.01
Normal Range In Soil	0.1-2.4$^\alpha$	0.2-20$^\beta$	1.0-110$^\gamma$	1.0-200$^\beta$	1.0-400$^\beta$

($^\alpha$Alloway, (1996); $^\beta$FAO/WHO; $^\gamma$Kabata-Pendias and Henryk, (1984); Values within a column with different superscripts are significantly different at $p<0.05$).

The heavy metal contents of the respective plant tissues (parts) and their total concentrations are shown in Tables 2 and 3.

As can be seen from the result, the concentrations of heavy metals were greatest in plant roots and least in plant stems. The metal concentrations are in this order: Fe>Zn>Pb>Ni>Cd.

Table 2. Accumulation pattern of Heavy Metals (mgKg^{-1}) in *Amaranthus hybridus* at sites 1 and 2

Metal	SITE 1				SITE 2				CONTROL SITE				NORMAL RANGE IN PLANTS
	Root	Stem	Leaf	Weighted mean	Root	Stem	Leaf	Weighted mean	Root	Stem	Leaf	Weighted mean	
Cd	0.45^{a} ±0.03	0.11^{b} ±0.02	0.16^{b} ±0.02	0.24	0.16^{a} ±0.03	0.09^{b} ±0.02	0.14^{a} ±0.02	0.13	0.02 ±0.03	0.01 ±0.02	ND	0.02	0.1-2.4$^{\alpha}$
Pb	0.84^{a} ±0.03	0.63^{b} ±0.03	0.45^{c} ±0.02	0.64	0.23^{a} ±0.02	0.17^{b} ±0.02	0.21^{a} ±0.02	0.20	0.02 ±0.03	0.01 ±0.03	0.02 ±0.01	0.02	0.2-20$^{\beta}$
Ni	0.57^{a} ±0.03	0.12^{b} ±0.02	0.22^{c} ±0.02	0.30	0.17^{a} ±0.04	0.15^{a} ±0.03	0.16^{a} ±0.04	0.16	0.03 ±0.02	0.01 ±0.01	0.02 ±0.03	0.02	1.0-110$^{\gamma}$
Fe	1.88^{a} ±0.04	1.33^{b} ±0.03	1.62^{a} ±0.03	1.61	1.84^{a} ±0.04	1.35^{b} ±0.03	1.50^{c} ±0.03	1.56	0.13 ±0.01	0.11 ±0.03	0.11 ±0.02	0.12	1.0-200$^{\beta}$
Zn	1.59^{a} ±0.03	0.84^{b} ±0.03	1.27^{c} ±0.02	1.23	1.58^{a} ±0.03	1.16^{b} ±0.03	0.66^{c} ±0.03	1.13	0.03 ±0.05	0.01 ±0.03	0.02 ±0.04	0.02	1.0-400$^{\beta}$

($^{\alpha}$Alloway, (1996); $^{\beta}$FAO/WHO; $^{\gamma}$Kabata-Pendias and Henryk, (1984); ND: Not detectable; Values within a row with different superscripts are significantly different at $p<0.05$)

Table 3. Accumulation pattern of Heavy Metals (mgKg^{-1}) in *Amaranthus hybridus* at sites 3 and 4

Metal	SITE 3				SITE 4				CONTROL SITE				NORMAL RANGE IN PLANTS
	Root	Stem	Leaf	Weighted mean	Root	Stem	Leaf	Weighted mean	Root	Stem	Leaf	Weighted mean	
Cd	0.31^{a} ±0.03	0.15^{b} ±0.02	0.26^{a} ±0.03	0.24	0.22^{a} ±0.03	0.16^{b} ±0.02	0.19^{b} ±0.03	0.19	0.02 ±0.03	0.01 ±0.02	ND	0.02	0.1-2.4$^{\alpha}$
Pb	1.65^{a} ±0.04	1.22^{b} ±0.02	1.48^{c} ±0.03	1.45	1.40^{a} ±0.03	0.71^{b} ±0.03	0.88^{c} ±0.04	1.00	0.02 ±0.03	0.01 ±0.03	0.02 ±0.01	0.02	0.2-20$^{\beta}$
Ni	0.81^{a} ±0.03	0.50^{b} ±0.02	0.63^{b} ±0.04	0.65	0.57^{a} ±0.03	0.38^{b} ±0.02	0.60^{a} ±0.03	0.52	0.03 ±0.02	0.01 ±0.01	0.02 ±0.03	0.02	1.0-110$^{\gamma}$
Fe	3.40^{a} ±0.04	2.80^{b} ±0.03	2.98^{b} ±0.05	3.06	3.20^{a} ±0.03	2.70^{b} ±0.03	2.94^{b} ±0.04	2.95	0.13 ±0.01	0.11 ±0.03	0.11 ±0.02	0.12	1.0-200$^{\beta}$
Zn	2.50^{a} ±0.03	1.93^{b} ±0.02	2.60^{a} ±0.03	2.34	2.46^{a} ±0.03	1.30^{b} ±0.04	2.12^{c} ±0.03	1.96	0.03 ±0.05	0.01 ±0.03	0.02 ±0.04	0.02	1.0-400$^{\beta}$

($^{\alpha}$Alloway, (1996); $^{\beta}$FAO/WHO; $^{\gamma}$Kabata-Pendias and Henryk, (1984); ND: Not detectable; Values within a row with different superscripts are significantly different at $p<0.05$)

Table 4 shows the average accumulation factor (AF) of heavy metals in the plant.

Table 4. Accumulation Factor (AF) of heavy metals in *Amaranthus hybridus*

SITE	Cd	Pb	Ni	Fe	Zn
1	3.00	2.78	2.76	1.45	1.17
2	4.33	3.39	3.20	2.14	2.02
3	0.57	0.51	0.54	0.61	0.78
4	1.73	1.58	1.52	1.47	1.19
MEAN	2.41	2.07	2.01	1.42	1.29

Figures 2 to 5 are histograms showing the percentage accumulations of the heavy metals in the various parts of *Amaranthus hybridus* at the dumpsites.

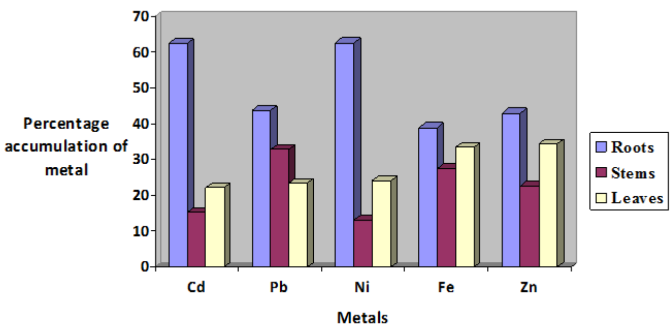

Figure 2. Percentage accumulation of metals by each plant part of *A. hybridus* at site 1

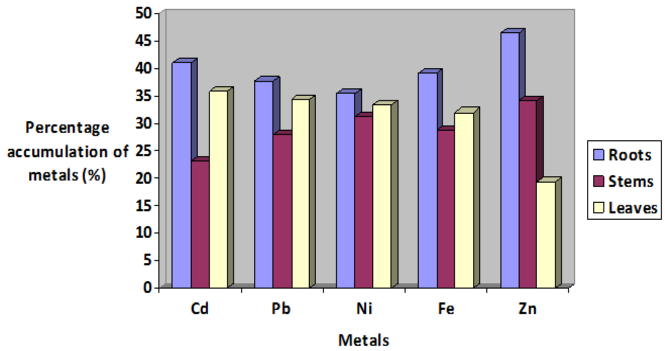

Figure 3. Percentage accumulation of metals by each plant part of *A. hybridus* at site 2

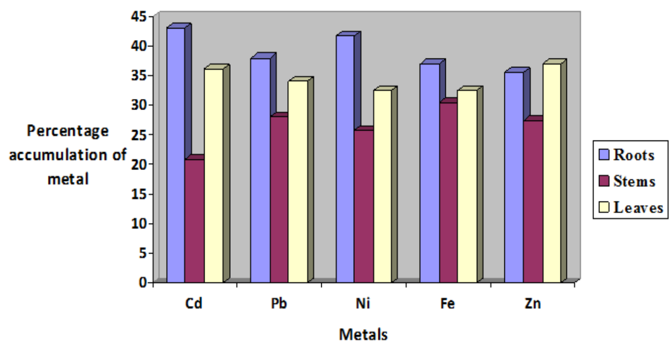

Figure 4. Percentage accumulation of metals by each plant part of *A. hybridus* at site 3

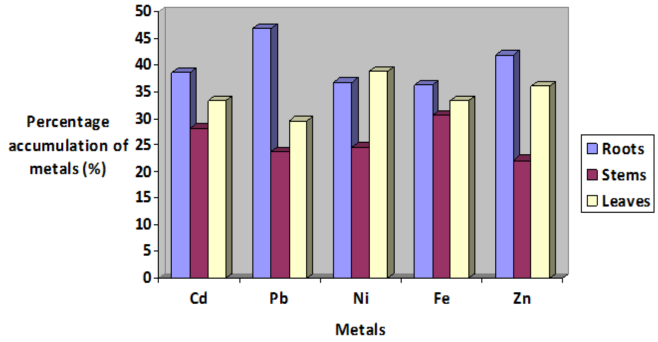

Figure 5. Percentage accumulation of metals by each plant part of *A. hybridus* at site 4

DISCUSSION

Heavy metal enrichment in the study sites

The heavy metal concentrations in the four dumpsites were well over those of the control site (Table 1). The order of abundance of the metals in the four contaminated sites were Fe>Zn>Pb>Ni>Cd while in the control site, the order was Fe>Zn>Pb=Ni>Cd.

Concentration of metals in *Amaranthus hybridus* on the contaminated sites

The results in Tables 2 and 3 show that the weighted means of the metals in the whole plant is in the order: Fe>Zn>Pb>Ni>Cd for *Amaranthus hybridus* in the four contaminated sites. The different levels of these heavy metals in study plant can be explained by their varying concentrations in dumpsite soils. In all four contaminated sites shown in Tables 2 and 3 above, it can be observed that with only very few exceptions, all metal concentrations in plant parts are in the order: $[M]_{ROOTS}>[M]_{LEAVES}>[M]_{STEMS}$. The few exceptions are Pb in site 1 ($Pb_{roots}>Pb_{stems}>Pb_{leaves}$); Zn in site 2 ($Zn_{roots}>Zn_{stems}>Zn_{leaves}$) and site 3 ($Zn_{leaves}>Zn_{roots}>Zn_{stems}$); Ni in site 4 ($Ni_{leaves}>Ni_{roots}>Ni_{stems}$). Thus in general, roots showed highest metal concentration while stem showed least. This is because the roots are the origin which comes into contact with the toxic metals present in the soil and consequently absorb and accumulate these heavy metals.

Ability of *Amaranthus hybridus* to accumulate metals on the contaminated sites

As shown in Table 4, the accumulation potential of *Amaranthus hybridus* varies from metal to metal according to the following trend: Cd>Pb>Ni>Fe>Zn. Figures 2 to 5 show the percentage accumulation of the metals in each plant part of *Amaranthus hybridus* from the four study sites. On the average, it was observed that in all four contaminated sites roots showed highest percentage accumulation. This is because the roots are the origin which comes into contact with the toxic metals present in the soil and consequently absorb and accumulate these heavy metals. The concentration of Cd is also high in the leaves of the plant especially at sites 2, 3 and 4. This may be due to atmospheric deposition of the metal from non-ferrous metal activities, fossil combustion, etc. which can be absorbed into foliage and translocated around plants. Studies have also shown that Cd is readily translocated to the plant tops after absorption (Alloway, 1996; Prasad and Hagemeyer, 1999). The high level of Fe in the plant parts can be explained by the metal's abundance in the (Nigeria) earth crust. In addition Fe is an essential for plant growth. The high concentration of zinc is explainable, since Zn is an essential trace element for humans, animals and higher plants (Alloway, 1996; Pahalawaarachchi *et al*., 2009). In all, the distribution pattern of the metals in this plant shows that more than 60% of the metals (Cd, Pb, Ni, Fe and Zn) accumulate in the roots and leaves. Furthermore, it was observed that the accumulation factors (AF) for heavy metals in *Amaranthus hybridus* are greater than 1 in most cases indicating its potential as hyper accumulator especially in soils with low pH values.

Conclusion

From the results obtained, the accumulation potential of *Amaranthus hybridus* vary from metal to metal. While concentrations of the metals in study sites is in the order of Fe>Zn>Pb>Ni>Cd, the accumulation potential of the plant for the metals follows a different trend namely: Cd>Pb>Ni>Fe>Zn, thus indicating highest mobility and accumulation for Cd and least for Zinc. Roots showed highest metal concentration while stem showed least. Although the metals concentrations in *Amaranthus hybridus* were less than $1000 mgKg^{-1}$, their average accumulation factors (AF) being greater than 1.00 is an indication of the plant's potential as hyperaccumulators when grown at contaminated sites.

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