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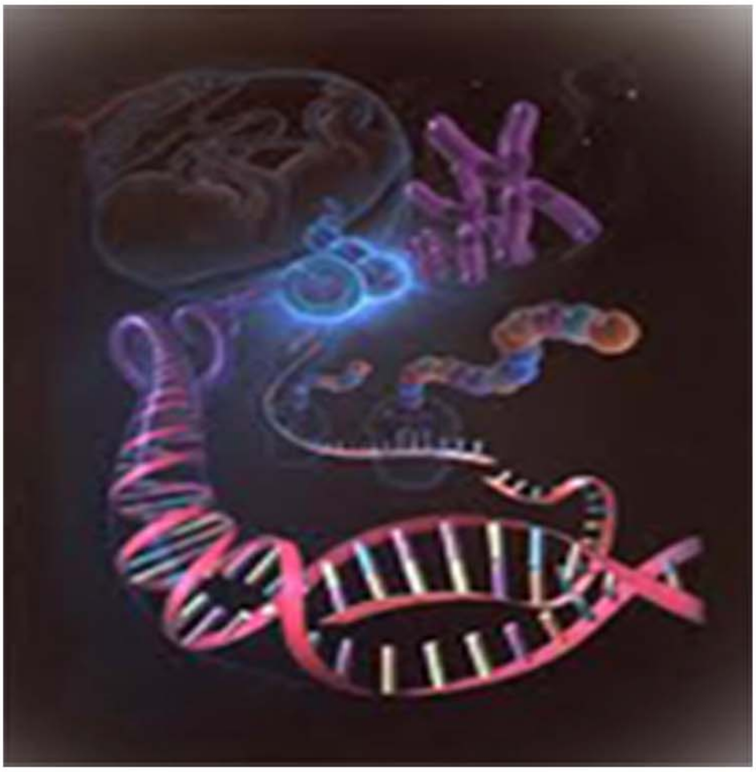

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Research Paper

SOIL ENVIRONMENTAL METALS SPECIATION AND ASSOCIATED HEALTH RISKS IN SELECTED EDIBLE LEAFY PLANTS ON AMAÉCHI AND FOUR-CORNER DUMPSITES IN ENUGU OF ENUGU STATE, NIGERIA

N A Obasi[1]*, S O Elom[1], C O Edeogu[1], C O Alisa[2] and S E Obasi[3]

Corresponding Author: **N A Obasi ✉ naobasi@yahoo.com*

This work evaluated environmental metals speciation and the associated health risks using five selected edible leafy plants in Amaéchi and Four-Corner dumpsites in Enugu, Enugu State, Nigeria. The soil and plants samples were obtained from Amaéchi and Four-Corner dumpsites in Enugu and a nearby farm land (control site) and were subjected to standard methods of chemical analysis. Results obtained showed that mean soil physicochemical parameters and total extractable metals were significantly higher ($P < 0.05$) in the dumpsites compared to control site. Carbon:Nitrogen (C:N) ratio was significantly higher ($P < 0.05$) in the control site compared to that in Amaéchi dumpsite. Sequential extraction showed higher percentages (%) of the non-residual fraction for all the metals studied except Cu and Cr. The mean order of mobility and bioavailability of the metals were: Pb > Fe > Cd > Zn > Mn > Cr > Ni > Cu. Total mean concentration of metals in roots, stems and leaves of *Amaranthus hybridus*, *Talinum triangulare*, *Carica papaya*, *Ipomea batatas* and *Luffa aegyptica* were significantly higher ($P < 0.05$) in the dumpsites compared to control site. The translocation factor, biological concentration factor and biological accumulation coefficient values of the plant species varied for all the metals. The health risks implications of the study were discussed.

Keywords: Bioavailability, Phytoaccumulation, Dumpsites, Amaéchi, Four-Corner, Enugu

INTRODUCTION

Environmental metals are non-biodegradable and they are toxic to flora and fauna in the ecosystem when they exceed their threshold limit (Benjamin and Mwashote, 2003; Ikem *et al*., 2003; Krissanakriangkrai *et al*., 2009; Ozturk *et al*., 2009). Reports have shown that solid wastes dumps are sources of environmental pollution that introduce intolerable doses of heavy metals into surrounding soil and ground water (Uba *et al.,*

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[1] Department of Medical Biochemistry, Federal University Ndufu-Alike, Ikwo-Nigeria.

[2] Department of Chemistry, Federal University of Technology, Owerri-Nigeria.

[3] Department of Science Laboratory Technology, Akanu Ibiam Federal Polytechnic Unwana-Nigeria.

2008; Nubi *et al.,* 2008). Enugu is the state capital of Enugu State south-east, Nigeria with high population density, increased commercial and industrial activities and these have been associated with high refuse disposal rate (Ogwueleka, 2009; Abul, 2010).

Chemical fractionation of soil environmental metals shows that they are associated with organic matter, adsorbed onto Fe/Mn oxides or complexed with hydroxides, sulphides and carbonates (Tessier *et al.*, 1979; Kabata-Pendias, 2004). This speciation determines the relative mobility and bioavailability of the metals in the ecosystem and when the exchangeable, acid soluble and easily reducible fraction are high, the metal pollution is said to be of anthropogenic origin (Ewa-Szarek *et al.*, 2006; Obasi *et al.*, 2012). It is the chemical form or species of these heavy metals that is important in assessing their impacts on the environment because their chemical forms control their bioavailability or mobility which ultimately control heavy metal soil-plant transfer (Gupta and Sinha, 2006).

Dumpsites depending on age support flora and fauna due to the high organic manure contents which makes the soil fertile. Poor dumping of domestic, commercial and industrial refuse by most State Environmental Protection Agency in Nigeria on farmlands has led to the use of such dumpsites for cultivating varieties of edible vegetables and plant based foodstuff since in most cases, the soils are fertile and support plant growth. This practice gives serous health concern due to existing data on heavy metals phyto-accumulation potentials of plants in metal contaminated and polluted soils (Benson and Ebong, 2005). Reports have shown varying degree of phytotoxicity effects of these metals in food chain and food web within the ecosystem (Ellis and Salt, 2003; Jarup, 2003).

Amaéchi and Four-Corner areas are suburb in Enugu metropolis where Enugu State Environmental Protection Agency dumps most of their evacuated refuse in their farmland. The preoccupation of the residents in these areas is farming and they extensively use these dumpsites as arable lands for cultivating varieties of edible vegetables and plant-based foodstuff. Since there is no proper routine assessment of the associated health risks, there may be danger along the food chain and food web at the future. This research therefore aims at providing baseline data that could be used to assess the futuristic health risks associated with such practice.

MATERIALS AND METHODS

Refuse Waste Soil Collection

Refuse waste soils were collected from two dumpsites, Amaéchi (Latitude 06 23' 08.32", Longitude 007 13' 38.50") and Four-Corner (Latitude 06 22' 09.68", Longitude 007 11' 18.45") and from the control site (Latitude 06 21' 58.55", Longitude 007 09' 36.25"), which is a farm land situated within the region. Triplicate sample from each dumpsite and control site were collected 7 m within the vicinity of the sites and composite samples were made in the laboratory. The samples were air dried, ground using manual soil grinder (DGSI Geotechnical instrumentation Model S-178), sieved (using 2 mm sieve), put in polythene bags and kept in glass desiccators (Baroda Scientific Glass Works) until analysis. During soil sample collection, care was taken to ensure that top soil at 0-20 cm depth from the rhizosphere of the studied plants were obtained from each site from where plant samples were rooted.

Dumpsite/Control Site Plant Sample Collection

Five dominant edible plant species within each study location: *Amaranthus hybridus*, *Talinum triangulare*, *Carica papaya*, *Ipomea batatas* and *Luffa aegyptia* were obtained and used for the study. A total of 6-10 plant samples of each plant species were randomly uprooted and collected from each of the dumpsite and control site and separately mixed to form a composite sample, placed in labeled pre-cleaned polythene bags and transported within 14 h to the Chemistry Laboratory of National Research Institute for Chemical Technology, Zaria, Nigeria for further analysis. Before analysis, plant roots and a mixture of the stems and leaves (shoots) were carefully removed and washed (for 2-3 min approximately) with tap water and deionized water to remove any soil and surface dust. Plant samples were dried at room temperature for a day, oven dried at 80°C to constant weight and pulverized to fine powder using milling grinder (Thomas Wiley Model 4). Ground plant samples collected in labeled pre-cleaned polythene bags were stored in glass desiccators (Baroda Scientific Glass Works).

Physicochemical Analysis of Samples

Soil pH was determined using digital pH meter (Jenway 3015) at a ratio of 1:2.5 soil/water according to the procedure described by Bates (1954). Soil electrical conductivity was determined using digital electrical conductivity meter (Jenway 615D) according to the procedure outlined by Whitney (1998) with some modifications. The soil moisture content was determined according to the procedure outlined by APHA (1998) while the cation exchange capacity of the soil samples were determined by ammonium saturation method described by Dewis and Freitas (1970). Organic carbon and organic matter were determined according to the procedure outlined by Osuji and Adesiyan (2005) while total nitrogen was determined as described by Yeomans and Bremmer (1991). SO_4^{2-} was quantified by the procedure described by Butters and Chenery (1959) and PO_4^{3-} was determined by procedure described by Olsen and Sommers (1982), respectively.

Sequential Extraction of Heavy Metals

The conventional method developed by Tessier *et al*. (1979) as outlined with modifications in Obasi (2012) was employed for the sequential extraction of heavy metals.

Determination of Heavy Metals in Plant Species

The mineral elements comprising cadmium (Cd), copper (Cu), manganese (Mn), lead (Pb), zinc (Zn), iron (Fe), nickel (Ni) and chromium (Cr) were determined according to the procedure described by Obasi (2012) using atomic absorption spectrophotometer (Bulk Scientific Model 210 VGP).

Determination of Phytoremediation Quotient

The Translocation Factor (TF) defined as the ratio of heavy metals in plant shoot to that in plant root was calculated using the procedure described by Cui *et al*. (2007).

i.e. Translocation factor (TF) $=[\text{Metals}]_{\text{shoot}} / [\text{Metals}]_{\text{root}}$

The Biological Concentration Factor (BCF) was calculated as metal concentration ratio of plant roots to soil as described by Yoon *et al*. (2006).

i.e. Biological Concentration Factor (BCF) =

$[\text{Metals}]_{\text{root}} / [\text{Metals}]_{\text{soil}}$

Biological Accumulation Coefficient (BAC) was calculated as a ratio of heavy metal in shoots to that in soil as described in the procedure by Li *et al.* (2007).

i.e. Biological Accumulation Coefficient (BAC) = $[\text{Metals}]_{\text{shoot}} / [\text{Metals}]_{\text{soil.}}$

STATISTICAL ANALYSIS

The experimental results were expressed as mean ± standard deviation (SD) of triplicate determinations. Analysis of variance for all the measured variables was performed by SPSS version 9.2 (Inc., Chicago, USA) software and significant differences were shown at $P < 0.05$ (Kerr *et al.*, 2002).

RESULTS

The results of soil physico-chemical properties are shown in Table 1. Results obtained showed that mean pH, electrical conductivity, moisture, cation exchange capacity, total organic carbon, total organic matter, total nitrogen, phosphate, and sulphate, were significantly higher ($P < 0.05$) in the dumpsites compared to control site while carbon:nitrogen ratio in Amaéchi was significantly lower ($P < 0.05$) compared to control site. The results of the sequential extractions of the heavy metals are shown in Tables 2a and 2b. The results indicated that total extractable metals were significantly ($P < 0.05$) higher in all the dumpsites compared to the control site. In all cases, the highest total extractable metals were present in Amaéchi dumpsite followed by Four-Corner dumpsite except for total extractable Cu where the reverse was the order. Higher percentages (%) of the non-residual fraction were observed for all the metals studied except Cu and Cr. The mean percentage order of mobility and bioavailability of these metals (Tables 2a and 2b) were: Pb > Fe > Cd > Zn > Mn > Cr > Ni > Cu.

Table 1: Physico-chemical Parameters of Soils in Studied Dumpsites

Sites/Parameter	A	B	AB
pH(H_2O)	7.90 ± 0.00^{c}	7.65 ± 0.01^{b}	7.10 ± 0.02^{a}
Electrical Conductivity (mScm-1)	2.78 ± 0.02^{c}	1.96 ± 0.02^{b}	0.95 ± 0.01^{a}
Moisture (%)	39.60 ± 0.04^{a}	43.00 ± 0.02^{b}	40.15 ± 0.03^{a}
Cation Exchange Capacity (Cmol/kg)	15.10 ± 0.00^{b}	18.40 ± 0.03^{c}	10.20 ± 0.02^{a}
Total Organic Carbon (%)	3.00 ± 0.00^{b}	3.18 ± 0.02^{b}	1.02 ± 0.02^{a}
Total Organic Matter (%)	5.17 ± 0.09^{b}	5.48 ± 0.02^{c}	1.78 ± 0.02^{a}
Total Nitrogen (%)	0.28 ± 0.02^{b}	0.24 ± 0.02^{a}	0.25 ± 0.01^{a}
PO_4^{3-}(%)	186.70 ± 0.02^{c}	165.50 ± 0.04^{b}	142.40 ± 0.10^{a}
SO_4^{2-}(%)	13.59 ± 0.13^{c}	12.00 ± 0.05^{a}	12.26 ± 0.02^{ab}
C:N RATIO	10.71^{a}	13.25^{c}	11.52^{b}

Note: Values are mean of three (n=3) replicates ± standard deviation; A = Amaéchi dumpsite, B = Four-Corner dumpsite, AB = Control site; Figures followed by the same alphabets along the row are not significantly different at $P < 0.05$ using Ducan Multiple Range Test (DMRT).

The results of total heavy metals concentration (mg/kg) in roots and shoots of plant species are shown in Tables 3a and 3b. Total mean concentration of metals in different parts of *Amaranthus hybridus*, *Talinum triangulare*, *Carica papaya*, *Ipomea batatas* and *Luffa aegyptica* were significantly higher ($P < 0.05$) in the dumpsites compared to control site. The results also showed that different plant species absorbed metals at varying concentrations in their various parts (Tables 3a and 3b). The results (Figure 1) indicated that Translocation Factor (TF) values vary from one plant species to another and from one heavy metal to another. The results indicated that *A. hybridus* had TF > 1 for Mn, Zn, Fe and Cr, *T. triangulare* had TF > 1 for Zn, Fe and Cr, *C. papaya* had TF > 1 for all the studied metals except Ni and Pb while *I. batatas* and *L. aegyptiaca* had TF > 1 for Cd, Cu, Mn, Pb, Zn, Fe, Ni and Cr (Figure 1).

Figure 2 shows the results of BCF of the five plant species for the different metals. The results (Figure 2) showed that only *A. hybridus* and *C. papaya* had BCF >1 for Cu and Fe respectively. The results of BAC are shown in Figure 3. The results (Figure 3) showed that *C. papaya* had BAC> 1 for Cu and Fe in all the sites while *A. hybridus, T. triangulare and L. aegyptica* had BAC > 1 for Fe in Amaéchi dumpsite only.

Table 2a: Heavy Metal Concentrations (Mg/Kg) in Each Fraction of Waste Soils in Studied Dumpsites

Sites/Fractions	Cd			Cu			Mn			Pb		
	A	B	AB	A	B	AB	A	B	AB	A	B	AB
Exchangeable	9.63 ±0.05	Nd	0.98 ±0.01	Nd	2.10 ±0.02	Nd	7.26 ±0.02	Nd	0.41± 0.03	88.30± 0.02	12.95± 0.03	1.95± 0.02
Oxidizable	9.61 ±0.08	3.02 ±0.03	0.64 ±0.02	4.02 ±0.03	Nd	0.74 ±0.02	73.58 ±0.02	11.68 ±0.02	3.15 ±0.05	187.65 ±0.05	Nd	3.92 ±0.02
Acid Soluble	6.18 ±0.04	5.82 ±0.03	Nd	Nd	Nd	Nd	13.57 ±0.03	26.13 ±0.11	0.85 ±0.05	102.74 ±0.02	13.06 ±0.02	2.00 ±0.01
Reducible	9.63 ±0.11	7.04 ±0.02	1.05 ±0.05	Nd	Nd	0.26 ±0.02	96.05 ±0.04	108.34 ±0.16	3.40 ±0.02	37.44 ±0.02	Nd	3.81 ±0.03
Residual	11.70 ±0.02	10.06 ±0.03	1.12 ±0.02	9.44 ±0.02	13.18 ±0.04	2.10 ±0.05	7.20 ±0.02	18.61 ±0.07	1.07 ±0.03	202.70 ±0.05	13.48 ±0.02	3.24 ±0.02
Total Extractable Metals	46.75^{c} ±0.05	25.94^{b} ±0.04	3.79^{a} ±0.03	13.46^{b} ±0.02	15.28^{c} ±0.02	3.10^{a} ±0.00	198.26^{c} ±0.04	164.76^{b} ±0.12	8.88^{a} ±0.05	618.83^{c} ±0.11	39.49^{b} ±0.07	15.42^{a} ±0.02
Non-residual (%)	74.97	61.22	70.45	29.87	13.74	32.26	96.37	88.70	87.95	67.24	65.86	78.99
Residual (%)	25.03	38.78	29.55	70.13	86.26	67.74	3.63	11.30	12.05	32.76	34.14	21.01
Mobile Phase (%)	33.82	22.44	25.86	0.00	13.74	0.00	10.51	15.86	14.19	30.87	65.86	25.62

Note: Values are mean of three (n=3) replicates ± standard deviation; A = Amaéchi dumpsite, B = Four-Corner dumpsite, AB = Control site; Figures followed by the same alphabets along the row are not significantly different at $P < 0.05$ using Ducan Multiple Range Test (DMRT).

Table 2b: Heavy Metal Concentrations (Mg/Kg) in Each Fraction of Waste Soils in Studied Dumpsites Continued

Sites/Fractions	Cd			Cu			Mn			Pb		
	A	B	AB	A	B	AB	A	B	AB	A	B	AB
Exchangeable	37.15 ±0.03	Nd	1.46 ±0.02	35.88 ±0.02	Nd	11.2 ±0.02	Nd	Nd	0.2 ±0.01	2.9 ±0.02	Nd	0.22 ±0.02
Oxidizable	48.5 ±0.02	34.4 ±0.00	2.96 ±0.03	23.11 ±0.07	19.2 ±0.02	22.05 ±0.03	8 ±0.00	8.4 ±0.02	0.95 ±0.01	Nd	3.14 ±0.03	0.4 ±0.02
Acid Soluble	13.14 ±0.02	26.31 ±0.05	1 ±0.05	31.45 ±0.03	21.43 ±0.05	10.22 ±0.06	13.95 ±0.03	Nd	Nd	2.85 ±0.02	Nd	Nd
Reducible	42.36 ±0.03	25.38 ±0.07	2.64 ±0.02	26.18 ±0.02	27 ±0.01	21.11 ±0.03	Nd	5.4 ±0.02	0.8 ±0.02	Nd	2.22 ±0.05	0.34 ±0.02
Residual	79.8 ±0.02	100.29 ±0.03	3.08 ±0.02	37.7 ±0.02	37.28 ±0.12	24.82 ±0.16	26.66 ±0.08	7.85 ±0.03	1.35 ±0.02	16.05 ±0.04	13 ±0.02	0.81 ±0.03
Total Extractable Metals	220.95^{c} ±0.05	186.38^{b} ±0.02	11.14^{a} ±0.02	154.32^{c} ±0.11	104.91^{b} ±0.09	89.40^{a} ±0.02	48.61^{c} ±0.17	21.65^{b} ±0.08	3.30^{a} ±0.02	21.80^{c} ±0.02	18.36^{b} ±0.04	1.87^{a} ±0.03
Non-residual (%)	63.88	46.19	72.35	75.57	64.46	72.24	45.16	63.74	50.09	26.38	29.19	56.68
Residual (%)	36.12	53.81	27.65	24.43	35.54	27.76	54.84	36.26	40.91	73.62	70.81	43.32
Mobile Phase (%)	22.76	14.12	22.08	43.63	20.43	23.96	28.7	0	6.06	26.38	0	11.76

Note: Values are mean of three (n=3) replicates ± standard deviation; A = Amaéchi dumpsite, B = Four-Corner dumpsite, AB = Control site; Figures followed by the same alphabets along the row are not significantly different at $P < 0.05$ using Ducan Multiple Range Test (DMRT).

DISCUSSION

The observed mean pH shows that the dumpsites soils are alkaline which is in line with earlier reports on dumpsites (Uba *et al*., 2008; Obasi, 2012; Obasi *et al*., 2012). The observed high conductivity value of the waste soil is an indication that there are high soluble salts in the soil and this may be due to the presence of metal scraps in the refuse dumpsite (Karaca, 2004; Arias *et al*., 2005; Obasi 2012). The moisture content was observed to be generally high and it is expected considering the overall climatic condition of the area under study. Cation exchange capacity observed in the studied sites fall within permissible range for agricultural lands and may have impacted positively to the fertility of the soil (Yoo and James, 2002). The observed mean percentages of Total Organic Carbon (TOC) and Total Organic Matter (TOM) values were high (Enwezor *et al*., 1988) and thus may serve as an important indicator of the soil as a rooting environment (Okalebo *et al*., 1993). The high concentration of the total nitrogen, PO_4^{3-} and SO_4^{2-} in the refuse waste soils and the high ratio of carbon to nitrogen (C:N) may have contributed to overall fertility of the soils which is an indication that the soils would support plant species diversity and growth (Okalebo, 1993; Obute *et al*., 2010).

The observed high values of total extractable metals may be attributed to dumping of numerous metal containing wastes such as cadmium and lead acid batteries, metal scraps among others in the dumpsites. These observed values were however below the permissible limits allowable for agricultural lands except for Cd (CCME, 1991; MAFF, 1992; CEC, 1986; USEPA, 1986). The high percentage of Cd in the mobile fractions suggests that Cd in these soils was potentially more bioavailable for plants uptake (Kuo *et al*., 1983; Gupta and Sinha, 2006). Cu was mostly found in the residual phase (i.e., bound to silicates and detrital materials) which implicates association with the oxidizable fraction (bound to organic matter) as in organic copper complexes (Stumm and Morgan, 1981). The high percentage of Mn in the reducible phase in all the waste soils may be due to the precipitation of amorphous hydrous oxides of manganese as the dumpsites ages (Staelens *et al*., 2000). High percentage of Pb, Zn and Fe in the mobile phase (exchangeable and acid soluble phases) indicates high bioavailability and higher risks to the ecosystem (Kuo *et al*., 1983). Most of the Ni and Cr were found in the residual and oxidizable fractions and this may be attributed to the alkaline stabilization process of the soils leading to organic complexation that impair their mobility (Tokalioglu *et al*., 2000; Alvarez *et al*., 2002).

The observed variation in the amount of metals accumulated by the different plant species in their various parts in the various sites is an indication that uptake of an element by a plant is primarily dependent on the plant species, its inherent controls, soil quality and metal concentrations in their habitual soil environment (Chunilall *et al*., 2005). Thus, plant species significantly influence

Table 3a: Total Heavy Metals Concentration (Mg/Kg) In Roots and Shoots of Plant Species in the Studied Sites

Plant Species		*Amarathushybridus*		*Talinumtriangulare*		*Caricapapaya*		*Ipomeabatatas*		*Luffaaegyptiaca*	
Sites		**Roots**	**Shoots**	**Roots**	**Shoots**	**Roots**	**Shoots**	**Roots**	**Shoots**	**Roots**	**Shoots**
Cd	A	23.25±0.08	12.87±0.26	28.58±0.15	10.02±0.06	27.05±0.01	33.28±0.04	3.53±0.13	6.23±0.02	4.15±0.02	10.84±0.20
	B	19.44±0.02	7.95±0.02	19.45±0.01	16.80±0.01	16.93±0.02	17.24±0.03	2.08±0.01	3.04±0.02	2.46±0.02	6.55±0.03
	AB	2.44±0.55	1.26±0.02	2.31±0.31	0.86±0.01	1.78±0.02	2.62±0.06	0.27±0.03	0.43±0.01	0.34±0.01	0.83±0.11
Cu	A	13.65±0.02	9.14±0.02	7.25±0.04	4.16±0.01	6.60±0.10	15.08±0.13	3.42±0.02	5.40±0.10	2.87±0.05	4.62±0.02
	B	16.51±0.06	10.33±0.01	8.90±0.02	6.03±0.11	9.05±0.02	17.50±0.02	3.95±0.04	6.86±0.02	3.56±0.02	5.91±0.17
	AB	3.57±0.01	2.01±0.07	3.34±0.02	2.04±0.01	2.52±0.02	4.88±0.13	0.86±0.02	1.55±0.04	0.75±0.02	1.23±0.01
Mn	A	3.96±0.02	8.54±0.05	11.26±0.02	8.35±0.03	7.05±0.01	11.60±0.02	1.36±0.05	4.87±0.06	4.12±0.03	13.57±0.02
	B	3.39±0.03	7.48±0.02	8.50±0.01	4.77±0.07	8.67±0.03	14.59±0.01	1.30±0.02	4.19±0.01	3.85±0.04	8.96±0.02
	AB	0.53±0.05	0.66±0.02	1.21±0.03	0.73±0.01	4.16±0.02	7.75±0.02	0.32±0.01	1.18±0.01	2.46±0.02	6.15±0.04
Pb	A	10.80±0.02	6.95±0.04	7.75±0.04	4.96±0.02	15.14±0.03	11.68±0.02	4.37±0.03	6.60±0.01	5.14±0.02	7.65±0.04
	B	16.35±0.04	12.33±0.01	13.61±0.03	10.09±0.04	20.44±0.02	13.75±0.04	5.26±0.02	7.40±0.02	5.50±0.00	8.10±0.12
	AB	1.61±0.03	0.91±0.01	1.15±0.04	0.88±0.02	1.94±0.02	1.08±0.05	0.93±0.02	1.45±0.04	1.03±0.01	1.88±0.02

Note: Values are mean of three (n=3) replicates ± standard deviation; A = Amaéchi dumpsite, B = Four-Corner dumpsite, AB = Control site

Table 3b: Total Heavy Metals Concentration (Mg/Kg) In Roots and Shoots of Plant Species in the Studied Sites Continued

Plant Species		*Amarathushybridus*		*Talinumtriangulare*		*Caricapapaya*		*Ipomeabatatas*		*Luffaaegyptiaca*	
Sites		Roots	Shoots	Roots	Shoots	Roots	Shoots	Roots	Shoots	Roots	Shoots
Zn	A	24.95±0.04	27.92±0.02	22.36±0.04	25.05±0.03	26.72±0.02	33.52±0.02	14.97±0.03	18.35±0.04	17.85±0.03	20.17±0.09
	B	10.63±0.05	14.40±0.02	9.70±0.05	11.92±0.02	13.80±0.01	16.75±0.03	8.76±0.02	11.24±0.05	9.30±0.15	13.85±0.03
	AB	0.89±0.03	1.20±0.04	1.04±0.01	1.24±0.02	1.33±0.01	1.85±0.04	1.13±0.01	1.52±0.02	1.48±0.02	1.22±0.004
Fe	A	154.90±0.10	166.15±0.33	158.75±0.04	165.99±0.18	195.16±0.14	209.10±0.00	131.65±0.17	149.14±0.16	147.86±0.22	169.65±0.13
	B	88.61±0.13	92.33±0.21	86.41±0.16	89.48±0.07	107.82±0.14	123.66±0.18	87.16±0.05	88.06±0.02	83.08±0.23	94.84±0.15
	AB	59.33±0.15	63.96±0.04	60.67±0.23	64.09±0.16	87.11±0.09	90.27±0.29	58.36±0.23	61.93±0.15	59.93±0.17	62.98±0.14
Ni	A	3.46±0.02	3.12±0.02	2.98±0.05	2.66±0.02	4.57±0.03	4.35±0.04	2.20±0.02	2.35±0.04	2.32±0.02	2.46±0.02
	B	2.75±0.03	2.53±0.05	2.20±0.20	1.97±0.01	3.07±0.03	2.95±0.04	2.15±0.02	2.28±0.02	2.22±0.01	2.48±0.02
	AB	0.97±0.03	0.85±0.04	0.83±0.01	0.71±0.03	1.03±0.01	0.92±0.02	0.73±0.01	0.77±0.05	0.75±0.03	0.82±0.02
Cr	A	7.85±0.04	19.12±0.15	13.75±0.07	16.33±0.08	14.92±0.02	18.74±0.12	8.72±0.06	12.81±0.09	10.95±0.04	15.10±0.02
	B	5.62±0.02	7.19±0.14	4.96±0.06	6.88±0.02	6.86±0.04	9.39±0.13	3.11±0.03	5.99±0.07	6.33±0.05	7.40±0.02
	AB	0.65±0.01	0.93±0.05	0.89±0.01	1.08±0.02	1.01±0.03	1.26±0.02	0.84±0.02	0.98±0.04	0.76±0.02	0.87±0.03

Note: Values are mean of three (n=3) replicates ± standard deviation; A = Amaéchi dumpsite, B = Four-Corner dumpsite, AB = Control site

Figure 1: Translocation Factor (Tf) of Plants For All The Metals in the Studied Sites

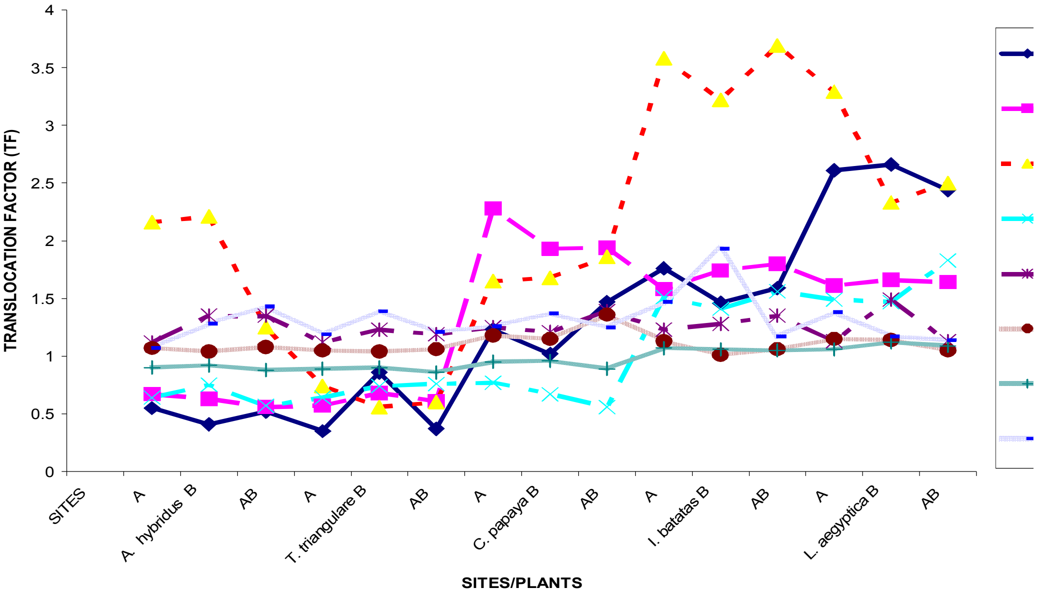


Figure 2: Biological Concentration Factor (Bcf) Of Plants For All The Metals In The Studied Sites

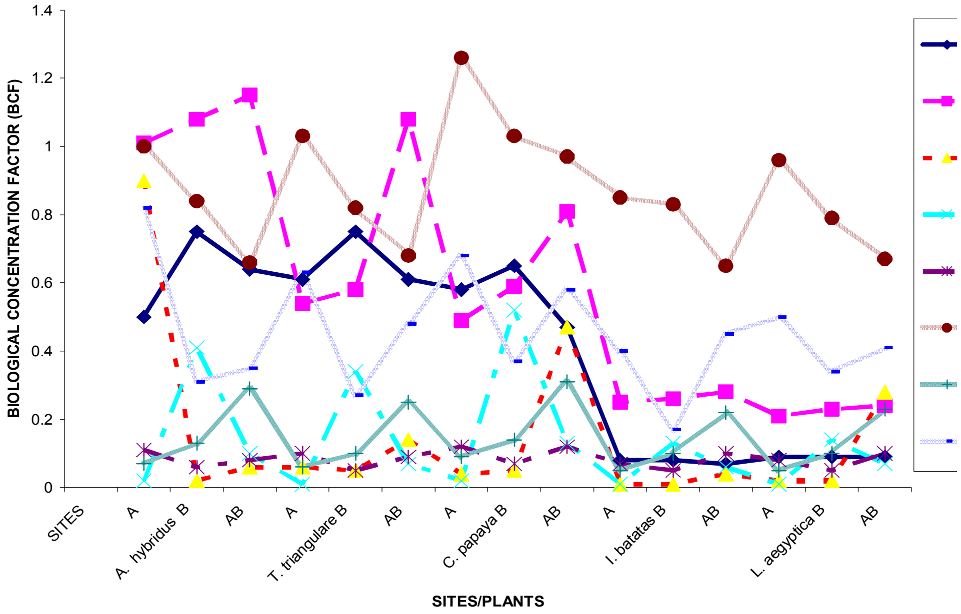
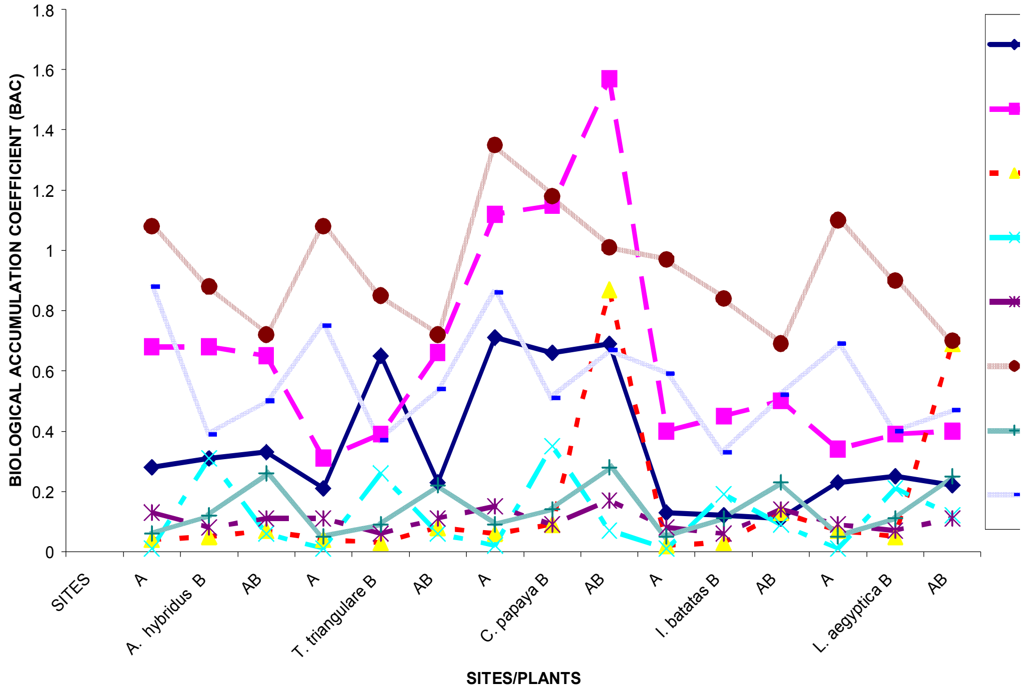


Figure 3: Biological Accumulation Coefficient (Bac) Of Plants For All The Metals In The Studied Sites



their rate of metal uptake, storage and distribution to various parts and this may be due to their genetic variability (Shauibu and Ayodele, 2002; Ebong *et al*., 2008). Since the rate of metal uptake is greatly influenced by plant species, the transfer factors of the metals by each plant species are desirable for classification of the plants' phytoaccumulation, photostabilization and phytoextarction potentials (Ayari *et al*., 2010; Malik *et al*., 2010).

The observed high level of metals in the different plant species grown on the dumpsites relative to those on the control sites is an indication that the level of metal in the soil-plants habitual environment influences its uptake (Zhu *et al*., 1990; Ghosh and Singh, 2005). The ability of these plant species to accumulate the observed high level of metals may be due to the ability of the plants to evolve mechanisms that could enhance its phyto-accumulation potentials and metal detoxification. Most of the plant species accumulated these metals in relatively high amount that could be hazardous along food chain and food web of their dependent species (Vecera *et al*., 1999; Assuncao *et al*., 2003). However, this could only arise on continual dependence on plants grown on such contaminated environment for a long period of time since in some cases the level in the dumpsites does not considerably exceed those in the control site which compare favorably with established critical permissible limits in plants (Shanker *et al*., 2005; Alloway, 1996).

A critical value greater than one (>1) for plants' Translocation Factors (TF), BCF and BAC is used to evaluate the potentials of plant species for phytoextraction, phytostabilization and phyto-remediation respectively (Yoon *et al*., 2006; Cui *et al*., 2007; Li *et al*., 2007). High root to shoot translocation (TF > 1) as observed for some of the metals in some of the studied plants is an indication that some of these plants have vital characteristics to be used in phyto-extraction (Ghosh and Singh, 2005; Malik *et al*., 2010). The observed high metal translocation quotient may be attributed to well-developed metal detoxification mechanism based on sequestration in the tolerant plant species (Ghosh and Singh, 2005; Cui *et al*., 2007). The suitability of plant species with high TF values for phyto-extraction is due to their ability to translocate heavy metals to easily harvestable parts (shoots) (Yoon *et al*., 2006; Cui *et al*., 2007; Li *et al*., 2007). Elevated concentration of heavy metals in roots of plants species and low translocation into above ground parts (BCF) indicate their suitability for phyto-stabilization (Ghosh and Singh, 2005). The observed plant species with BCF>1 and TF<1 may be useful for phyto-stabilization of one, two or more of the metal contaminants of the study area. Plants with well-developed cellular mechanisms for heavy metal detoxification and tolerance (BAC>1) is used as an indicator of high heavy metals accumulator plant species (Ghosh and Singh, 2005) and when the plant is able to accumulate up to 1000 mg/kg of metal and above, the plant is classified as a hyper-accumulator (Baker and Brooks, 1989). The observed BAC values showed that the plants exhibited varying levels of phyto-accumulation potentials. However, none of the edible plants studied is a hyper-accumulator of any of the metals based on the critical set limit (Baker and Brooks, 1989).

CONCLUSION

The metal pollution index and health risks associated with Amaéchi and Four-Corner dumpsites in Enugu, Enugu State, South-East, Nigeria have been highlighted. The dumpsites were observed to fertile with higher percentage of non-residual fraction for all the metals studied except for Cu and Cr that had more abundant pool of residual fractions. Generally, the order of mobility and bioavailability of the metals were: Pb > Fe > Cd > Zn > Mn > Cr > Ni > Cu. Mean total extractable metals in the dumpsites relative to that in the control site showed pollution from anthropogenic sources. The edible plants dominant in the area (*A. hybridus*, *T. triangulare*, *C. papaya*, *I. batatas* and *L. aegyptiaca*) accumulated metals in varying degrees in their various parts and exhibited phyto-extraction, phyto-stabilization and phyto-accumulation potentials which are indicators of health risks along food chain and food web. The nutritional quality and long term effects of dependence on edible dumpsite plants as sources of vegetables need further investigation.

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