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Occurrence of Heavy Metals in Soil and Selected Edible Plants in the Vicinity of Major Lead-Zinc Mining Sites in Ebonyi State, Nigeria

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ABSTRACT

The occurrence of heavy metals in soil and selected edible plants (*Manihot esculenta, Dioscorea rotundata, Ipomoea batatas, Telfairia occidentalis,* and *Chromolaena odorata*) in the vicinity of major Lead-Zinc mining sites in Ebonyi State, Nigeria was investigated. The concentrations of the detected heavy metals in soil from the study sites ranged from 0.38-77830.99 (mg.kg^{-1}). The limit values for all detected metals in soil from the mining sites were exceeded in most instances. The results showed that the plant species accumulated heavy metals near the mining sites to varying levels in their shoots and roots. The limit values for all detected heavy metals in the edible plants were not exceeded except in a few instances. The plant species demonstrated varying effectiveness for phytoextraction, indicating their appropriateness in the phytoremediation of heavy metal-contaminated soil. Therefore, examining the environmental consequences of uncontrolled mining activity in the vicinity of the mining sites with a scientific approach has helped to increase our knowledge of the pollution problem in the mining sites, reveal the ferocity of the situation, and contribute to the techniques presently in use for monitoring chemical pollution in a mining-impacted ecosystem.

INTRODUCTION

Mining is an important economic activity that plays an indispensable role in the evolution and growth of a nation (Mohsin et al. 2021). Uncontrolled mining methods are often employed in most developing nations, such as Nigeria (Elom et al. 2018). When not adequately controlled, mining activities could lead to environmental pollution and social problems (Rajasekaran 2007, Štofejová et al. 2021). Environmental pollution by heavy metals from mining activities could negatively affect the health of the local residents and biota (Rajasekaran 2007, Roba et al. 2016, Nawab et al. 2016, Wang et al. 2017, Nuapia et al. 2018). The occurrence of toxic metals such as lead (Pb), cadmium (Cd), arsenic (As), and chromium (VI) (Cr^{+6}), among others, in the vicinity of mining sites could constitute serious health risks to the ecosystem (Sharma & Dubey, 2005, Lamare & Singh 2017). Heavy metals are toxic chemicals that could create scores of upset in a plant due to their bioaccumulation in plant tissues and concomitant interference with several metabolic processes (Mahdavian & Somashekar 2009, Gomes et al. 2014). As most heavy metals are not essential elements, most plants lack mechanisms for their uptake. Therefore, these metals bind to specific functional groups (carboxylic groups) of plant secretion (mucilage uronic acids) on root surfaces (Sharma & Dubey 2005). However, it is still unknown how these metals, especially Pb, are absorbed into the root tissue.

Although some plants tolerate toxic metals through specific chemical interactions, other species could experience toxicity, as toxic metals could hamper several plant metabolic pathways (Wierzbicka 1999). In a few plant species, higher levels of toxic metals such as Pb inhibit the germination of seeds, growth of plants, and synthesis of chlorophyll, among other effects (Peralta-Videa et al. 2009). Generally, heavy metals reduce the uptake and transport of vital nutrients in plants by obstructing the attachment of ions to ion carriers, making them inaccessible from plant roots (Xiong 1997). Heavy metals could form strong bonds in interaction with active chemical groups and adversely affect metabolism in plants (Taub 2004). Under normal circumstances, these bonds should produce vital linkages that maintain molecules in their true configuration.

Mining and industrial processing of natural resources remain a primary source of the increased toxic metals in the environment (Davis 1995, Rajasekaran 2007, Sherene 2009). Lead-Zinc (Pb-Zn) mining in Ebonyi State dates back to 1925 (Chrysanthus 1995) and has progressed enormously in an unregulated manner (Elom et al. 2018). In Nigeria, Lead-zinc mining is not strictly monitored (Elom et al. 2018) and hence could serve as a great source of metal contamination in the vicinity of the mining sites (Abrahams 2002). Toxic metals are usually released into the surrounding environment during mining activities (Roba et al. 2016, Nawab et al. 2016, Wang et al. 2017, Nuapia et al. 2018, Štofejová et al. 2021), and this could pose a serious threat to various life forms in the mining zones (Soucek et al. 2000). The occurrence of toxic metals in the environment portends significant health risks to the ecosystem and public health (Elom et al. 2018, Eze et al. 2019, 2020). In developing nations, little attention is often paid to the environmental consequences of unregulated mining (Mohsin et al. 2021). Reports of heavy metal levels in soil from the vicinity of major Pb-Zn mining sites in Ebonyi State exceed soil guideline values (SGVs) (Elom et al. 2018, Okeke & Ifemeje 2021). Since farming is a major source of income in the area, the quality of farm produce, such as edible plants near the mining sites, is likely to be affected. Therefore, the occurrence of heavy metals in soil and selected edible plant species (*Manihot esculenta* (Cassava), *Dioscorea rotundata* (White yam), *Ipomoea batatas* (Sweet potatoes), *Telfairia occidentalis* (Fluted pumpkin) and *Chromolaena odorata* (Siam weed)) in the vicinity of major lead-zinc mining sites in Ebonyi State, Nigeria was investigated. Determining the exposure pathway to toxic chemicals is vital in health risk assessment to properly establish adequate monitoring plans and risk management strategies (Bierkens et al. 2009).

MATERIALS AND METHODS

Study Area

Ebonyi State is located on latitude 6° 15' N and 6° 20'N and longitude 8° 05' E and 8° 10'E, in the eastern part of Nigeria and shares a border with Benue State in the North, Cross River State by East, Enugu State by the West, and Abia, and Imo states by South (Odoh et al. 2012). The state has 13 Local Government Areas and occupies a surface area of about (5,923 sq.km) representing 2% of Nigeria's total surface Area (Odoh et al. 2012). It has a population of about 2,176,947 million (NPC 2010). The lead-zinc mine communities in Ebonyi State are situated in three local government areas generally referred to as the Abakaliki lead-zinc mine area (Fig. 1). The Abakaliki lead-zinc area is primarily made up of three lodes: Enyigba, Ameri, and Ameka in the lower Benue trough located in Ebonyi State (Agumanu 1989). The Enyigba, Ameri, and Ameka communities are situated in the south of Abakaliki (Okeke & Ifemeje 2021) and are notable lead-zinc mining zones in Nigeria (Eze et al. 2021) that have experienced significant mining activities (Okeke & Ifemeje 2021). The area experiences a warm, humid tropical climate. The relative humidity is high, usually over 90% in the early morning but falls between 6 and 80 % in the afternoon; it is highest between May and October and ranges between 57.6 % in the dry season to 82.1% in the wet season. The temperature range is between 23°C and 26 °C for the dry season and 26°C and 28°C for the wet season. Rainfall in the area is heaviest during July and September and relatively low between November and March. About 80% of the total rainfall occurs between June and September, while only about 12% of the annual total fall between November and February (Odoh et al. 2012). The cultivated crops in the area include rice, cassava, leafy vegetables, and yam of different species (Okeke & Ifemeje 2021). The most prevalent tree species found in the study area are the agricultural tree crops, particularly oil palm, and kolanut. Many timber species of economic importance still exist in the area. The soil parent material is primarily shale and fine-grained sandstones of the Asu River formation (Agumanu 1989). The texture varied from loamy clay on the surface (0-15 cm) to clay at the subsurface layers (below 15 cm). The soil has a good potential to support tree crops and arable crops. However, there have been reports of heavy metal pollution resulting from uncontrolled mining activity (Eze et al. 2021).

Sample Collection

Top (0-30cm) and sub (30-45 cm) soil samples were collected randomly from the vicinity of Enyigba, Ameri, and Ameka Pb-Zn mining sites. Control soil (top and sub) was also collected from a remote location with no lead-zinc mining activity (about 25km from the Abakaliki area) to serve as reference soil. The soil samples were collected during September 2021 using a soil auger, geo-referenced, homogenized accordingly to form representative soil from each site, and transported to the laboratory in a black polythene bag. Each representative soil was air dried, ground using mortar and pestle into powder, sieved using a 2mm mesh, and stored in polythene bags before analysis. A total of hundred (100) plant samples were used for this study. Five (5) of each of the plant samples (*Manihot esculenta*

(Cassava), *Dioscorea rotundata* (White yam), *Ipomoea batatas* (Sweet potatoes), *Telfairia occidentalis* (Fluted pumpkin), and *Chromolaena odorata* (Siam weed)) were randomly collected from the vicinity of the mining sites.

Furthermore, five (5) of each plant species were also collected from the control site to serve as reference plant species. The underground and aerial parts of the plant species were collected in September 2021, placed accordingly in a labeled polyethylene bag, and transported to the laboratory. The plant samples were cleaned of residual materials, dried, homogenized accordingly, and divided into parts (root and shoot) for metal analysis. All samples were collected, putting into consideration the pollution dynamics of the mining sites.

Heavy Metal and Physicochemical Analysis

The representative soil, as well as root and shoot of the selected plant species, were analyzed for the presence and varying concentrations of lead (Pb), copper (Cu), zinc (Zn), cadmium (Cd), manganese (Mn), chromium (VI), iron (II) (Fe) and nickel (Ni) using the spectrometric method as described by Štofejová et al. (2021). The physicochemical analysis of soil was done using standard methods described by American Public Health Association (APHA) (2005). The obtained values were compared with data from a reference site and limit values for toxic metals as set by USEPA (1986). The quality control and assessment measures adopted in this investigation included field blanks, field duplicates, reference sites, lab replicates, and calibration blanks and standards.

Determination of Phytoextraction Quotient

The translocation factor (T/F), defined as the ratio of heavy metals in a plant's shoot to that of the root ($[metals]_{Shoot}/[metals]_{Root}$), was used in the determination of the phytoextraction quotient as described by Cui et al. (2007).

Statistical Analysis

The data generated were presented as mean ± Standard deviation (SD) of three replicates. One-way Analysis of variance (One-way ANOVA) performed with SPSS version 9.2 (Inc. Chicago, USA) was used to analyze data while significant differences were determined at $P \leq 0.05$.

RESULTS AND DISCUSSION

The result of the soil physicochemical and heavy metal analyses is shown in Table 1 and 2 respectively, while the result of the occurrence of heavy metals in the shoot and root of the plant species (*Manihot esculenta* (Cassava), *Dioscorea rotundata* (White yam), *Ipomoea batatas* (Sweet potatoes), *Telfairia occidentalis* (Fluted pumpkin) and *Chromolaena odorata* (Siam weed)) from the vicinity of Ameka, Ameri, Enyigba and control sites are presented in Tables 3 to 6

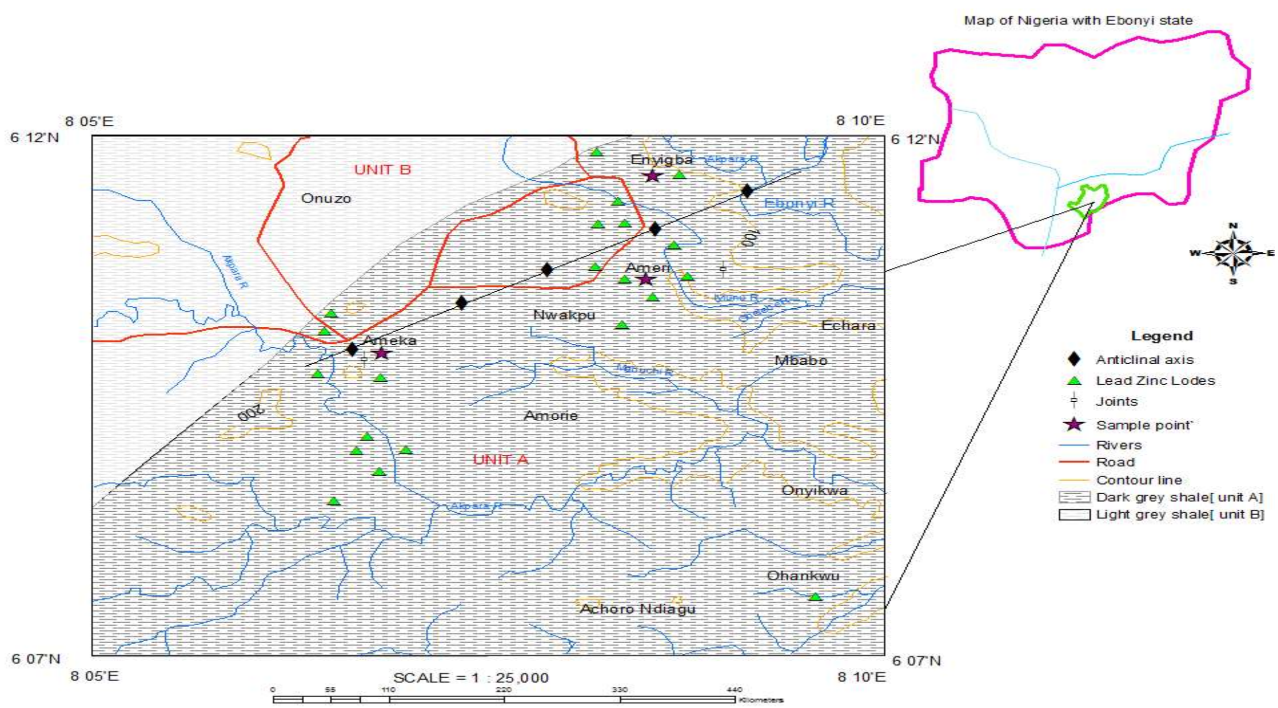

Fig. 1: Map of Abakaliki lead-zinc mining zone showing sample locations.

respectively. The limit values for all detected metals in soil from the mining sites were exceeded in most instances. The obtained soil pH value ranged from 6.36 ± 0.07 - 6.81 ± 0.05, EC ranged from 1.12 ± 1.05 - 4.87 ± 1.61 ($mS.m^{-1}$), CEC ranged from 19.37 ± 0.74 - 59.12 ± 1.31 ($Cmol.kg^{-1}$), TOC ranged from 0.90 ± 0.50 - 2.35 ± 0.21 (%), TOM ranged from 1.55 ± 0.85 - 4.05 ± 0.72 (%), Clay ranged from 0.92 ± 0.31 - 8.44 ± 0.35 (%), Silt ranged from 0.28 ± 0.40 - 4.20 ± 0.50 (%) and Sand (%) 87.36 ± 0.28 - 98.80 ± 0.53 (%) (Table 1). The topsoil from the Ameka mining site showed the highest pH value, while sub soil from the Ameri mining site showed the lowest (Table 1). The highest level of EC, CEC, TOC, TOM, Clay, Silt, and Sand was detected in topsoil from Enyigba, subsoil from Ameri, topsoil from Ameri, topsoil from Ameri, subsoil from Ameka, subsoil from Ameka and subsoil from the control site respectively (Table 1). The concentrations of the detected heavy metals in soil from the study sites ranged from 0.38 ± 0.33 - 77830.99 ± 5.12 ($mg.kg^{-1}$), with Fe showing the highest concentration in topsoil from Ameri and Cd showing the lowest concentration in subsoil from the control site (Table 2). The determined physicochemical parameters and heavy metals in soil from the mining sites differ significantly ($P \leq 0.05$) from the control site. The obtained soil pH values suggest that soil from the study sites is slightly acidic and might have influenced the distribution of heavy metals in soil in the vicinity of the study sites (Sherene 2009, Štofejová et al. 2021, Kashyap et al. 2016).

The limit values for all detected metals in the shoots and roots of plants from the Ameka mining site were not exceeded except for Cd and Fe in the shoot of *Telfairia occidentalis* (Table 3). The highest average concentration of Pb (2.56 $mg.kg^{-1}$) in plants from Ameka mining site was detected in the root of *Telfairia occidentalis,* Zn (2.76 $mg.kg^{-1}$) in the shoot of *Chromolaena odorata*, Fe (990.5 $mg.kg^{-1}$) in the shoot of *Telfairia occidentalis*, Cu (1.05 $mg.kg^{-1}$) and Cd (1.48 $mg.kg^{-1}$) in the root of *Telfairia occidentalis*, Mn (0.31$mg.kg^{-1}$) in the shoot of *Chromolaena odorata*, Ni (0.90 $mg.kg^{-1}$) in the shoot of *Dioscorea rotundata* and Cr (0.99 $mg.kg^{-1}$) in roots of *Ipomoea batatas* and *Telfairia*

Table 1: Physicochemical parameters of soil from the study sites.

Parameters	AMEKA	AMEKA	AMERI	AMERI	ENYIGBA	ENYIGBA	CONTROL	CONTROL
	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil
pH	6.81 ± 0.05	6.47 ± 0.18	6.57 ± 0.03	6.36 ± 0.07	6.55 ± 0.15	6.41 ± 0.05	6.57 ± 0.05	6.74 ± 0.13
EC [$mS.m^{-1}$]	1.17 ± 0.62	1.74 ± 0.65	3.95 ± 1.13	4.46 ± 0.33	4.87 ± 1.61	4.04 ± 1.19	1.12 ± 1.05	1.79 ± 0.73
CEC [$Cmol.kg^{-1}$]	40.55 ± 1.12	56.31 ± 0.63	53.58 ± 0.56	59.12 ± 1.31	53.92 ± 1.04	58.49 ± 0.27	20.42 ± 0.42	19.37 ± 0.74
TOC [%]	1.45 ± 0.37	1.02 ± 0.93	2.35 ± 0.21	1.54 ± 0.28	1.93 ± 0.34	0.90 ± 0.50	1.55 ± 0.25	1.47 ± 0.41
TOM [%]	2.50 ± 0.19	1.76 ± 0.11	4.05 ± 0.72	2.65 ± 0.36	3.33 ± 0.27	1.55 ± 0.85	2.67 ± 0.54	2.53 ± 0.15
Clay [%]	6.21 ± 0.27	8.44 ± 0.35	8.00 ± 0.40	7.96 ± 0.15	8.02 ± 0.26	7.57 ± 0.22	1.40 ± 0.14	0.92 ± 0.31
Silt [%]	2.26 ± 0.16	4.20 ± 0.50	2.49 ± 0.53	2.15 ± 0.15	2.67 ± 0.32	2.96 ± 0.23	0.35 ± 0.25	0.28 ± 0.40
Sand [%]	91.53 ± 0.87	87.36 ± 0.28	89.51 ± 0.45	89.89 ± 0.93	89.31 ± 0.29	89.47 ± 0.71	98.25 ± 0.47	98.80 ± 0.53

EC = Electrical conductivity, **CEC** = Cation exchange capacity, **TOC** = Total organic carbon, T**OM** = Total organic matter.

Table 2: Heavy metal contents [$mg.kg^{-1}$] of soil from the study sites.

Metals [$mg.kg^{-1}$]	USEPA [$mg.kg^{-1}$]	AMEKA	AMEKA	AMERI	AMERI	ENYIGBA	ENYIGBA	CONTROL	CONTROL
		Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil
Pb	300	1953.59 ± 1.78	1946.24 ± 0.83	154.88 ± 0.96	1154.05 ± 0.26	214.67 ± 1.12	212.33 ± 0.41	30.03 ± 0.34	29.95 ± 0.15
Zn	200	141.06 ± 2.38	1140.75 ± 0.52	1197.23 ± 0.74	1193.13 ± 1.11	1182.82 ± 1.05	1179.04 ± 0.63	8.88 ± 0.68	8.77 ± 0.45
Fe	1000	44595.70 ± 3.17	44619.28 ± 2.11	77830.99 ± 5.12	77545.80 ± 1.58	7903.73 ± 2.74	77525.58 ± 0.93	70.17 ± 0.17	70.12 ± 0.31
Cu	250	141.69 ± 0.32	139.53 ± 0.41	35.54 ± 0.18	33.99 ± 0.33	34.40 ± 0.56	29.83 ± 0.12	18.02 ± 0.35	12.65 ± 0.64
Cd	3.0	4.53 ± 0.44	3.46 ± 0.72	5.37 ± 0.55	5.04 ± 0.23	5.65 ± 22	4.67 ± 0.34	0.39 ± 0.31	0.38 ± 0.33
Mn	80	2211.0 9 ± 2.11	2283.70 ± 1.78	1238.11 ± 1.37	1238.28 ± 2.13	1219.21 ± 0.96	1224.15 ± 1.64	5.96 ± 0.52	6.91 ± 0.75
Ni	150	38.96 ± 0.33	38.75 ± 0.12	72.28 ± 0.24	72.17 ± 0.93	64.61 ± 0.19	61.76 ± 0.35	2.60 ± 0.51	2.50 ± 0.20
Co	NA	55.81 ± 0.42	47.52 ± 0.30	33.07 ± 0.38	32.44 ± 0.45	56.22 ± 0.51	56.06 ± 0.36	0.8.03 ± 0.29	1.02 ± 0.81
Cr	750	1176.05 ± 0.40	1194.63 ± 0.73	1127.57 ± 0.47	1121.80 ± 0.85	196.70 ± 0.50	144.37 ± 0.23	1.40 ± 0.26	1.58 ± 0.33

Table 3: Occurrence [mg.kg^{-1}] of heavy metals in plant species from the Ameka mining site.

Metals	USEPA [mg.kg^{-1}]	*Manihot esculenta*		*Dioscorea rotundata*		*Ipomoea batatas*		*Telfairia occidentalis*		*Chromolaena odorata*	
		Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root
Pb	5.0	1.69 ± 1.11	1.72 ± 0.08	0.98 ± 0.33	1.12 ± 0.09	0.89 ± 0.22	0.11± 0.55	1.550 ± 0.05	2.560 ± 0.05	0.90 ± 0.03	1.250 ± 0.02
Zn	100.0	1.05 ± 0.13	1.10 ± 0.03	1.07 ± 0.06	1.11 ± 0.44	1.08 ± 0.51	1.17 ± 0.33	2.200 ± 0.05	1.05 ± 0.03	2.760 ± 0.04	1.27 ± 0.05
Fe	250	230.85 ± 0.21	120.5 ± 0.23	90.45 ± 0.09	130.92 ± 1.02	100.22 ± 0.37	130.14 ± 1.07	990.50 ± 0.05	166.21 ± 0.13	60.00 ±0.03	60.05 ± 0.05
Cu	40.0	0.36 ± 0.09	0.75 ± 0.15	0.64 ± 0.03	0.94 ± 0.75	0.66 ± 0.82	0.91 ± 0.62	0.92 ± 0.04	1.05 ± 0.11	0.92 ± 0.02	0.99 ± 0.03
Cd	0.10	0.37 ± 0.23	0.95 ± 0.05	0.54 ± 0.07	0.98 ± 0.34	0.25 ± 0.09	0.53 ± 0.34	0.980 ± 0.02	1.48 ± 0.02	1.26 ± 0.02	1.035 ± 0.03
Mn	1.0	0.195 ± 0.17	0.245 ± 0.22	0.145 ± 0.11	0.210 ± 0.35	0.170 ± 0.42	0.225 ± 0.08	0.19 ± 0.01	0.11 ± 0.01	0.310 ± 0.05	0.20 ± 0.11
Ni	10-100	0.75 ± 0.04	0.170 ± 0.67	0.90 ± 0.05	0.75 ± 0.11	0.85 ± 0.50	0.70 ± 0.22	0.060 ± 0.02	0.10 ± 0.02	0.180 ± 0.02	0.186 ± 0.02
Cr	2.0	0.21 ± 0.03	0.52 ± 0.32	0.32 ± 0.05	0.55 ± 0.31	0.59 ± 0.12	0.99 ± 0.13	0.530 ± 0.05	0.991 ± 0.02	0.195 ± 0.02	0.720 ± 0.04

Data are presented as mean ± SD of three replicates. Statistical significance was determined at P ≤ 0.05.

Table 4: Occurrence [mg.kg^{-1}] of heavy metals in plant species from Ameri mining site.

Metals	USEPA [mg.kg^{-1}]	Manihot esculenta		Dioscorea rotundata		Ipomoea Batatas		Telfairia occidentalis		Chromolaena odorata	
		Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Root	Shoot
Pb	5.0	0.78 ± 0.21	0.90 ± .11	0.92 ± 0.44	0.98 ± 0.97	1.21 ± 0.12	0.84 ± 0.05	0.08 ± 0.08	1.10 ± 0.02	0.19 ± 0.04	0.19 ± 0.02
Zn	100.0	0.209 ± 0.34	0.150 ± .09	0.64 ± 0.11	0.86 ± 0.22	1.42 ± 0.02	0.86 ± 0.22	0.14 ± 0.02	1.58 ± 0.04	2.050.05	0.145 ± 0.03
Fe	250	56.390 ± 1.77	55.850 ± 1.09	23.980 ± 0.84	14.125 ± 1.50	44.76 ± 0.17	31.04 ± 0.06	6.92 ±0.12	118.75 ± 0.11	58.32 ± 0.17	48.44 ± 0.12
Cu	40.0	0.131 ± 0.41	0.088 ± 0.11	0.42 ± 0.43	0.74 ± 0.11	1.31 ± 0.11	0.88 ± 0.02	0.99 ± 0.11	1.10 ± 0.02	0.92 ± 0.05	0.76 ± 0.04
Cd	0.10	0.127 ± 0.33	0.102 ± 0.23	0.041 ± 0.52	0.132 ± 0.34	0.31 ± 0.03	0.98 ± 0.02	0.98 ± 0.02	0.99 ± 0.05	0.52 ± 0.04	0.95 ± 0.05
Mn	1.0	0.278 ± 0.07	0.295 ± 0.44	0.125 ± 0.38	0.200 ± 0.52	0.31 ± 0.01	0.24 ± 0.03	0.66 ± 0.04	0.50 ± 0.04	0.26 ± 0.07	0.28 ± 0.02
Ni	10-100	0.094 ± 0.18	0.075 ± 0.52	0.085 ± 0.21	0.078 ± 0.35	0.11 ± 0.01	0.08 ± 0.01	0.06 ± 0.01	0.09 ± 0.01	0.10 ± 0.02	0.07 ± 0.01
Cr	2.0	0.046 ± 0.22	0.099 ± 0.12	0.031 ± 0.33	0.102 ± 0.17	0.82 ± 0.02	0.57 ± 0.02	0.45 ± 0.02	0.64 ± 0.02	0.18 ± 0.03	0.34 ± 0.03

Data is presented as mean ± SD of three replicates. Statistical significance was determined at P ≤ 0.05.

Table 5: Occurrence [mg.kg^{-1}] of heavy metals in plant species from the Enyigba mining site.

Metals	USEPA [mg. kg^{-1}]	*Manihot esculenta*		*Dioscorea rotundata*		Ipomoea Batatas		Telfairia occidentalis		Chromolaena odorata	
		Shoot	Root	shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root
Pb	5.0	0.089 ± 0.12	0.201 ± 0.43	0.099 ± 0.52	0.315 ± 0.44	0.79 ± 0.05	0.42 ± 0.02	0.16 ± 0.07	0.11 ± 0.02	0.120 ± 0.11	0.21 ± 0.01
Zn	100.0	0.068 ± 034	0.199 ± 0.11	0.054 ± 0.28	0.260 ± 0.23	1.09 ± 0.13	0.87 ± 0.03	0.86±0.02	0.54 ± 0.02	0.95 ± 0.03	0.50 ±0.04
Fe	250	24.150 ± .17	56.010 ± 0.45	24.070 ± .25	78.110 ± 1.04	38.11 ± 1.13	25.54 ± 1.15	18.12± 0.15	26.02 ± 0.08	28.44 ± 0.16	76.15 ± 0.21
Cu	40.0	0.110 ± 0.22	0.275 ± 0.51	0.048 ± 0.33	0.099 ± 0.24	0.75 ± 0.05	0.56 ± 0.05	0.55±0.04	0.82 ± 0.04	0.84 ± 0.02	0.95 ± 0.07
Cd	0.10	0.055 ± 0.31	0.102 ± 0.22	0.032 ± 0.45	0.154 ± 0.19	0.76 ± 0.02	0.26 ± 0.01	0.450.04	0.26 ± 0.01	0.18 ± 0.01	0.10 ± 0.03
Mn	1.0	0.495 ± 0.06	0.700 ± 0.37	0.505 ± 0.53	0.702 ± 0.13	0.51 ± 0.03	0.39 ± 0.02	0.20±0.02	0.11 ± 0.02	0.28 ± 0.04	0.30 ± 0.02
Ni	10-100	0.087 ± 0.81	0.090 ± 0.44	0.089 ± 0.13	0.091 ± 0.54	0.07 ± 0.03	0.04 ± 0.02	0.03±0.01	0.06 ± 0.02	0.03 ± 0.01	0.05 ± 0.01
Cr	2.0	0.025 ± 0.23	0.099 ± 0.17	0.020 ± 0.34	0.120 ± 0.35	0.48 ± 0.02	0.31 ± 0.01	0.15±0.03	0.23 ± 0.03	0.13 ± 0.02	0.24 ± 0.02

Data are presented as mean ± SD of three replicates. Statistical significance was determined at $P \leq 0.05$.

Table 6: Occurrence [mg.kg^{-1}] of heavy metals in plant species from the Reference site.

Metals	USEPA [mg.kg^{-1}]	*Manihot esculenta*		*Dioscorea rotundata*		*Ipomoea batatas*		*Telfairia occidentalis*		*Chromolaena odoranta*	
		Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root
Pb	5.0	0.03 ± 0.01	0.02 ± 0.01	0.01 ± 0.03	0.03 ± 0.02	0.03 ± 0.02	0.09 ± 0.03	0.10 ± 0.01	0.09 ± 0.01	0.02 ± 0.01	0.01 ± 0.01
Zn	100.0	0.45 ± 0.03	0.10 ± 0.05	0.44 ± 0.02	0.92 ± 0.05	0.80 ± 0.05	0.89 ± 0.09	0.18 ± 0.09	0.13 ± 0.01	0.32 ± 0.01	0.42 ± 0.02
Fe	250	2.85 ± 0.05	2.40 ± 0.02	3.51 ± 0.03	3.66 ± 0.05	2.18 ± 0.03	2.99 ± 0.09	12.18 ±0.03	13.17 ± 0.04	12.08 ± 0.06	10.20 ± 0.10
Cu	40.0	0.21 ± 0.04	0.03 ± 0.05	0.03 ± 0.05	0.06 ± 0.02	0.26 ± 0.02	0.02 ± 0.01	0.09 ± 0.05	0.05 ± 0.02	0.13 ± 0.03	0.12 ± 0.03
Cd	0.10	0.42 ± 0.02	0.13 ± 0.01	0.28 ± 0.02	0.62 ± 0.02	0.15 ± 0.01	0.26 ±0 .02	0.70 ± 0.02	0.97 ± 0.07	0.99 ± 0.03	0.81 ± 0.03
Mn	1.0	0.13 ± 0.01	0.11 ± 0.03	0.21 ± 0.05	0.45 ± 0.03	0.23 ± 0.03	0.44 ± 0.02	0.42 ± 0.02	0.27 ± 0.02	0.47 ± 0.05	0.41 ± 0.05
Ni	10-100	0.09 ± 0.01	0.02 ± 0.01	0.05 ± 0.03	0.07 ± 0.02	0.04 ± 0.02	0.05 ± 0.01	0.01 ± .0.01	0.02 ± 0.01	0.06 ± 0.01	0.08 ± 0.02
Cr	2.0	0.11 ± 0.02	0.09 ± 0.01	0.08 ± 0.02	0.09 ± 0.01	0.01 ± 0.01	0.05 ± 0.01	0.06 ± 0.01	0.11 ± 0.01	0.04 ±0.01	0.07 ± 0.01

Data are presented as mean ± SD of three replicates. Statistical significance was determined at $P \leq 0.05$.

occidentalis (Table 3). The limit values for all detected metals in the shoots and roots of plants from the Ameri mining site were not exceeded except for Cd in the shoot of *Manihot esculenta,* the root of *Dioscorea rotundata,* and shoots and roots of *Ipomoea batatas, Telfairia occidentalis, and Chromolaena odorata* (Table 4). The highest average concentration of Pb (1.21 $mg.kg^{-1}$) in plants from the Ameri mining site was detected in the shoot of *Ipomoea batatas,* Zn (2.05 $mg.kg^{-1}$) in the root of *Chromolaena odorata*, Fe (118.75 $mg.kg^{-1}$) in the root of *Telfairia occidentalis*, Cu (1.31 $mg.kg^{-1}$) in the shoot of *Ipomoea batatas*, Cd (0.99 $mg.kg^{-1}$) and Mn (0.66 $mg.kg^{-1}$) in the root and shoot of *Telfairia occidentalis respectively* and Ni (0.11 $mg.kg^{-1}$) as well as Cr (0.82 $mg.kg^{-1}$) in the shoot of *Ipomoea batatas* (Table 4). The limit values for all detected metals in the shoots and roots of plants from the Enyigba mining site were not exceeded except for Fe in the shoot of *Telfairia occidentalis* and Cd in the root of *Dioscorea rotundata,* shoots, and roots of *Ipomoea batatas* and *Telfairia occidentalis* as well as the shoot of *Chromolaena odorata* (Table 5). The highest average concentration of Pb (0.79 $mg.kg^{-1}$) and Zn (1.09 $mg.kg^{-1}$) in plants from Enyigba mining site was detected in the shoot of *Ipomoea batatas,* Fe (78.1 $mg.kg^{-1}$) in the root of *Dioscorea rotundata*, Cu (0.95 $mg.kg^{-1}$) in the root of *Chromolaena odorata*, Cd (0.45 $mg.kg^{-1}$) in the shoot of *Telfairia occidentalis*, Mn (0.7 $mg.kg^{-1}$) and Ni (0.09 $mg.kg^{-1}$) in the roots of *Manihot esculenta* and *Dioscorea rotundata* and Cr (0.48 $mg.kg^{-1}$) in the shoot of *Ipomoea batatas* (Table 5). The limit values for all detected metals in the shoots and roots of plants from the reference site were not exceeded except for Cd (Table 6). The highest average concentration of Pb (0.1 $mg.kg^{-1}$) in plants from the reference site was detected in the shoot of *Telfairia occidentalis*, Zn (0.92 $mg.kg^{-1}$) in the root of *Dioscorea rotundata*, Fe (13.17 $mg.kg^{-1}$) in the root of *Telfairia occidentalis*, Cu (0.26 $mg.kg^{-1}$) in the shoot of *Ipomoea batatas*, Cd (0.99 $mg.kg^{-1}$) and Mn (0.47 $mg.kg^{-1}$) in the shoot of *Chromolaena odorata,* Ni (0.09 $mg.kg^{-1}$) in the shoot of *Manihot esculenta* and Cr (0.11 $mg.kg^{-1}$) in the shoot and root of *Manihot esculenta* and *Telfairia occidentalis* respectively (Table 6). The plant species accumulated heavy metals to varying levels in their shoots and roots. However, higher average concentrations of the detected metals occurred in the shoot compared to the root (Tables 3 - 6). Although the limit values for all detected metals in shoots and roots of the plants from the mining sites were not exceeded except in a few instances, accumulation of these metals over time could result in accumulation and have deleterious consequences on biota in the impacted area. In general, the average concentration of Fe was highest in both soil and plants compared to other detected metals detected in this study (Tables 3 - 6). This aligns with the study report by Okeke and Ifemeje (2021). The highest average concentration of Pb (2.56 $mg.kg^{-1}$), Zn (2.76 $mg.kg^{-1}$), Fe (990.5 $mg.kg^{-1}$), Cd (1.48 $mg.kg^{-1}$), Ni (0.90 $mg.kg^{-1}$) and Cr (0.99 $mg.kg^{-1}$) recorded in this study occurred in plants from Ameka mining site. In comparison, the highest average concentration of Cu (1.31 $mg.kg^{-1}$) and Mn (0.7 $mg.kg^{-1}$) occurred in plants from Ameri and Enyigba mining sites, respectively (Tables 3 - 6). Significantly ($P \leq 0.05$), higher concentrations of the detected metals were determined in the mining sites than in plants from the reference site. The obtained results suggest that the degree of heavy metal pollution of the mining sites could range in the following order: Ameka > Ameri > Enyigba.

Plants' accumulation of toxic metals and uptake of essential elements varies greatly among plant species due to variations in plant metabolic activities (Nasim & Dhir 2010, Cai et al. 2020). According to Obasi et al. (2012), accumulation of Pb could inhibit the activity of enzymes, give rise to water imbalance, trigger hormonal changes and alter membrane structure in plants. These series of changes disrupt metabolic activities in a plant and, at high concentrations, may lead to the death of plant cells (Seregin et al. 2004, Soucek et al. 2000). The phytotoxic characteristics of Pb may include blackening of the roots, chlorosis, and stunted growth (Sharma & Dubey 2005). The plant species used for this study exhibited observable characteristics such as stunted growth and chlorosis, which may have resulted from the accumulation of toxic metals near the mining sites. In non-tolerant plants, higher levels of Zn could cause chlorosis and inhibit root elongation (Sharma & Dubey 2005). The elevated levels of the detected Fe call for serious concern since the plants are edible. Accumulation of Fe over time could result in severe health conditions for consumers (Khan et al. 2009). Cu is a vital element necessary for plant growth; however, it could be potentially toxic at higher levels (Yruela 2005, Prasad & Strzalka 1999). At concentrations above 40mg.kg-^{1}, Cu could be phytotoxic (Prasad & Strzalka 1999). In some plants, accumulated Ni protects against fungi and bacteria pathogens (Prasad et al. 2005) and, as such, may confer such an advantage to plants in the study sites. Cr could disrupt metabolic activities and inhibit plant growth (Shanker et al. 2005).

The results of the translocation factor (Phytoextraction quotient) of heavy metals in the selected plants are shown in Fig. 2 (a-e). The results showed that the translocation factor of *Manihot esculenta* was greater than one (TF > 1) for Zn at Ameka site, greater than one (TF > 1) for all the detected metals with the exception of Cu, Mn, Zn and Cd at Ameri site and less than one (TF < 1) for all the detected metals at Enyigba (Fig. 2a). The *Dioscorea rotundata* had translocation

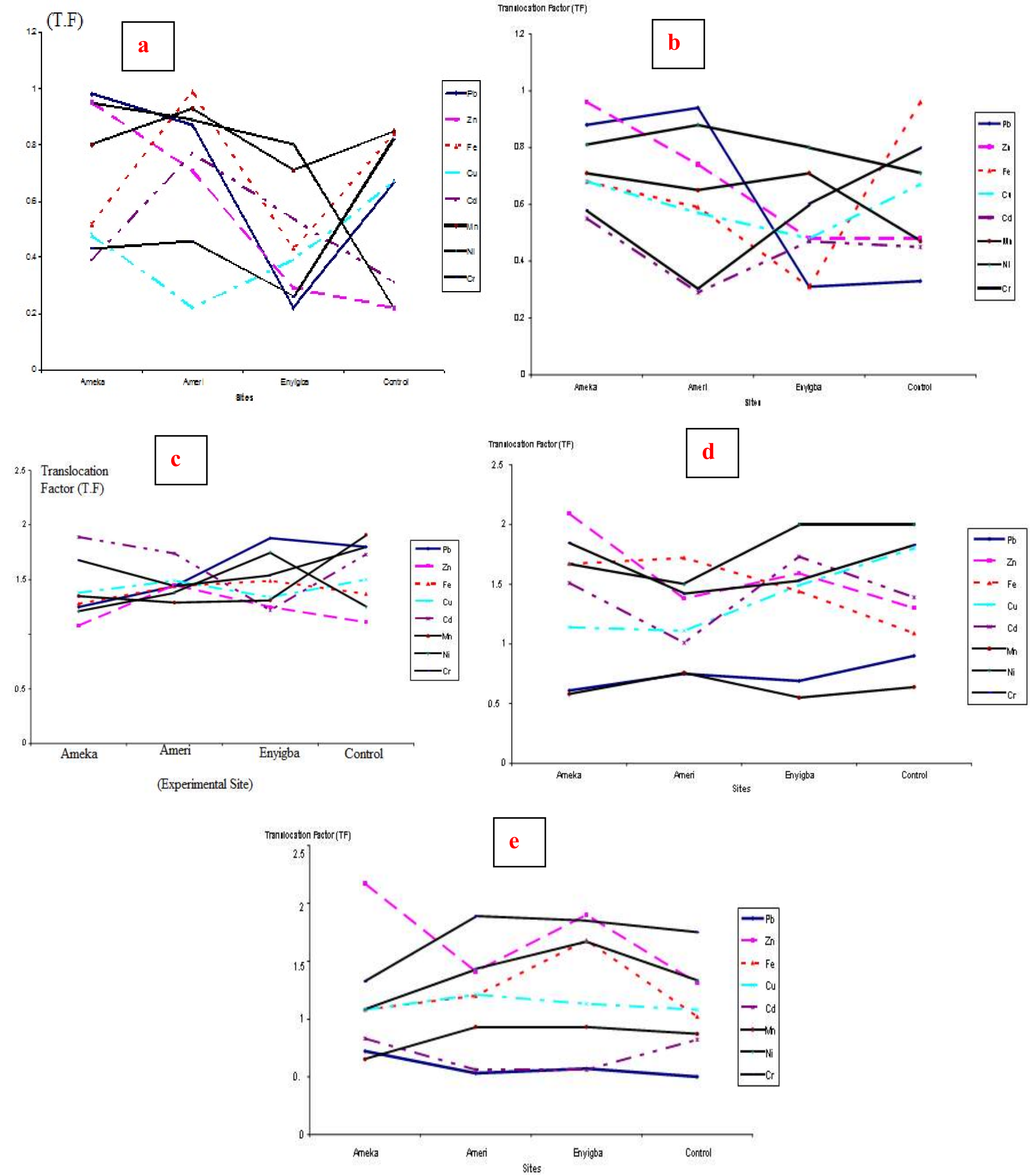

Fig. 2: Translocation Factor (TF) of (a) *Manihot esculenta*, (b) *Dioscorea rotundata*, (c) *Ipomoea batatas*, (d) *Telfairia occidentalis* and (e) *Chromolaena odorata* for all the detected Metals.

factor less than one (TF < 1) for all the detected metals at the study sites with the exception of Ni which had translocation factor greater than one (TF > 1) at Ameka and Ameri sites and Zn which had translocation factor greater than one (TF > 1) at Ameri site (Fig. 2b). The translocation factor for *Ipomoea batatas* was greater than one (TF > 1) for all tested heavy metals at the study sites (Fig. 2c). The same observation was noted for *Telfairia occidentalis*, except for Ni and Cr that has TF < 1 in all the sites (Fig. 2d). The *Chromolaena odorata* exhibited TF greater than one (TF > 1) for all tested heavy metals in all the sites, except for Cd and Cr.

CONCLUSION

The study revealed the occurrence of heavy metals in some selected plant species (*Manihot esculenta* (Cassava), *Dioscorea rotundata* (White yam), *Ipomoea batatas* (Sweet potatoes), *Telfairia occidentalis* (Fluted pumpkin) and *Chromolaena odorata* (Siam weed)) from the vicinity of major Lead-Zinc mining sites in Ebonyi State, Nigeria. The results showed that plant species in the mining sites accumulated varying metals in their shoots and roots. The plant species have demonstrated varying effectiveness for phytoextraction, indicating their appositeness in the phytoremediation of heavy metal-contaminated soil. However, the limit values for all detected metals in the shoots and roots of the plant species were not exceeded except in a few instances. The results obtained in our study suggest that the Ameka mining site could be more polluted than Ameri and Enyigba mining sites. Therefore, examining the environmental consequences of uncontrolled Pb-Zn mining activity in the vicinity of the mining sites with a scientific approach has helped to increase our knowledge of the pollution problem in the mining sites, reveal the ferocity of the situation, and contributed to the techniques presently in use for monitoring of chemical pollution in a mining-impacted ecosystem.

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