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Daily Intake of Metals and Health Risk Index of Pb, Cd, and Zn in Leafy Vegetables Consumed by Children and Adults in Mining-Impacted Communities of Ebonyi State, Nigeria

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ABSTRACT
Consumption of vegetables grown on metal-contaminated soils is a major pathway of human exposure to toxic heavy metals. This study quantifies the transfer of Pb, Cd, and Zn from soil to three commonly consumed food crops (cassava leaf – Manihot esculenta; pumpkin leaf – Cucurbitas spp.; rice – Oryza sativa) in mining-impacted communities of Ebonyi State, Nigeria. Soil and corresponding plant tissue samples were analyzed by AAS. Transfer Factor (TF), Daily Intake of Metals (DIM), and Health Risk Index (HRI) were calculated for children (32.7 kg body weight) and adults (55.9 kg body weight). Results indicate that pumpkin leaf accumulates the highest Zn concentration (1.15 mg/kg), while cassava leaf accumulates the highest Pb concentration (1.17 mg/kg). TF for Cd in rice reached 2.474, indicating hyperaccumulation. DIM values for children consuming pumpkin leaf were: Zn = 6.9×10^{-4}, Pb = 6.24×10^{-4}, Cd = 9.4×10^{-6} mg/kg/day, all below oral reference doses (RfD). HRI values for all metals were < 1, indicating no immediate non-carcinogenic risk. However, the cumulative exposure from multiple vegetables and pathways warrants continuous monitoring. This study provides the first comprehensive DIM-HRI dataset for this region and establishes baseline for future epidemiological studies.

Keywords: Daily Intake of Metals; Health Risk Index; Transfer Factor; Food chain contamination; Pb-Zn mines; Abakaliki

I. INTRODUCTION

Soil-to-plant transfer of heavy metals is the primary entry point of toxic elements into the terrestrial food chain as reported by (Alloway, 1995). In developing countries, where subsistence agriculture is practiced on marginal lands, including abandoned mine sites and contaminated floodplains, this pathway assumes critical public health significance as reported by (McLaughlin et al., 1999; Sharma & Dubey, 2005).

The Abakaliki area of Ebonyi State has a century-long history of Pb-Zn mining. Despite cessation of large-scale operations, artisanal miners continue to exploit residual ores, and communities cultivate vegetables on soils enriched with Pb, Cd, and Zn as reported by (Oti&Nwabue, 2012; Nweke et al., 2013). Telfairiaoccidentalis (fluted pumpkin), Manihot esculenta (cassava), and Oryza sativa (rice) are staple food crops in the region, with leaves consumed as vegetables.

While(Ezeh& Chukwu, 2011; Onyedika& Nwosu, 2008)had reported total metal concentrations in these crops, none have quantified the site-specific Transfer Factor or conducted probabilistic health risk assessment using locally relevant consumption rates and body weights. This study addresses this gap by:

1. Determining Pb, Cd, and Zn concentrations in soil and edible plant tissues;
2. Computing soil-to-plant Transfer Factors;
3. Estimating Daily Intake of Metals (DIM) for children and adults;
4. Calculating Health Risk Index (HRI) using USEPA reference doses.

II. Materials and Methods

Study area
The study area lies within latitudes 6°09'–6°13'N and longitudes 8°04'–8°09'E, covering Abakaliki, Ikwo, Izzi, Ezza South, Ezza North, and Ivo Local Government Areas.

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Figure 1 Ebonyi State map

2.1 Sampling Strategy

Paired soil and plant samples were collected from three locations: Ezza North (cassava leaf), Abakaliki (pumpkin leaf), and Ezza South (rice husk/stem). Sampling points were within 500 m of active quarry or abandoned mine pits. Soil samples (0–15 cm) were collected from the rhizosphere of each plant. Plant tissues were harvested at maturity.

2.2 Sample Preparation and Analysis

Plant samples were washed with deionized water to remove adhered soil particles, oven-dried at 70°C for 72 hours, and ground in a stainless-steel mill. One gram of dried plant material was digested with 5 mL of 4:1 HNO_3:$HClO_4$ at 105°C until clear (APHA, 2000). Soil digestion followed the aqua regia method described in Article 1. Metal analysis was performed by AAS.

2.3 Transfer Factor (TF)

Transfer Factor was calculated as (OLĂNESCU et al., 2007):

$$TF=\frac{C_{plant}}{C_{soil}} \quad (1)$$

Where:
TF–transferfactor,
-1
C_{plant}–heavymetal concentration inplantasextracted(mgkg),
-1
C_{soil}–heavymetalconcentration in thesoil(mgkg).

2.4 Daily Intake of Metals (DIM)

DIM was estimated using the model of Chary et al. (2008):

$$DIM=\frac{C_{metal}\times C_{factor}\times D_{foodintake}}{BW_{averageweight}} \quad (2)$$

Where C_{metal} is heavy metal concentration in plants or crops, C_{factor} stands for conversionfactor (0.085) (Rattan *et.al*., 2005), D_{food} intake stands for daily intake of vegetables and BWaverageweight stands for averagebodyweight.

The average daily intake of food crops and vegetables for adult and children areconsidered to be 0.345 and 0.232kg/person/day respectively. While the average adult andchild body weight are taken to be 55.9kg and 32.7kg respectively
Consumption and body weight data were obtained from (Ge 1992, Wang *et.al*.,2005).

2.5 Health Risk Index (HRI)

HRI was calculated as (Cui et al., 2004):

$$HRI=\frac{DIM}{RfD} \quad (3)$$

WhereDIM represents the dailyintakeof metaland R_fD referenceoral dose.
$R_fD$valueofCr,Ni,Cu,Pb,Cd,Mn,As,andZnis1.5,0.02, 0.04,0.004,0.001,0.033,

0.003,0.003
(mg/kgbw/day)respectively(USEPAIRIS, 2006).HRI < 1 indicates no significant health risk.

III. Results

3.1 Metal Concentrations in Soil and Plants
Soil Pb concentrations ranged from 28.30–99.60 mg/kg; Cd from 0.0156–23.76 mg/kg; Zn from 58.05–109.79 mg/kg. The highest soil Pb and Cd occurred at Abakaliki and Ezza South, respectively.

Plant tissue concentrations followed distinct patterns:

· Cassava leaf: Pb (1.167 mg/kg) > Zn (0.368 mg/kg) > Cd (0.027 mg/kg)
· Pumpkin leaf: Zn (1.146 mg/kg) > Pb (1.035 mg/kg) > Cd (0.016 mg/kg)
· Rice husk/stem: Cd (0.039 mg/kg) > Zn (0.314 mg/kg) > Pb (0.206 mg/kg)

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Table 1. Heavy Metal Concentrations in Paired Soil and Plant Samples

Sample Type	Lead (Pb) mg/kg	Cadmium (Cd) mg/kg	Zinc (Zn) mg/kg
Soil (Range)	28.30 – 99.60*	0.0156 – 23.76**	58.05 – 109.79
Cassava Leaf	1.167	0.027	0.368
Pumpkin Leaf	1.035	0.016	1.146
Rice Husk/Stem	0.206	0.039	0.314

*Highest concentration recorded at Abakaliki
**Highest concentration recorded at Ezza South

3.2 Transfer Factor

Transfer Factor for Cd in rice was exceptionally high (TF = 2.474), indicating hyperaccumulation. Pumpkin leaf showed the highest Zn transfer (TF = 0.0197), while cassava leaf showed the highest Pb transfer (TF = 0.0412). Cd transfer in cassava and pumpkin was low (TF = 0.00065–0.00203)

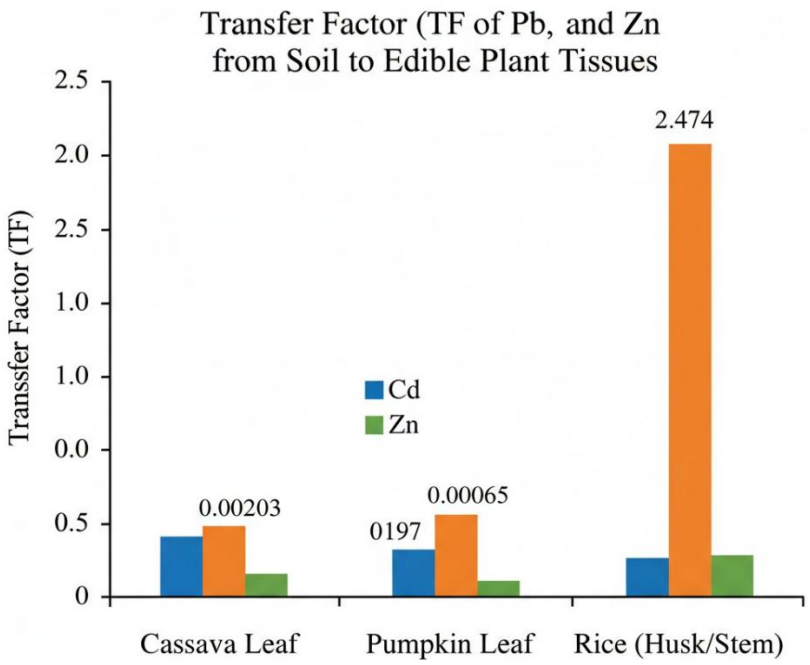

Figure 2. Transfer Factor (TF) of Pb, Cd, and Zn from soil to edible plant tissues

3.3 Daily Intake of Metals

DIM values for children consuming pumpkin leaf were: Zn = 6.90×10^{-4}, Pb = 6.24×10^{-4}, Cd = 9.40×10^{-6} mg/kg/day. Adult DIM values were approximately 40% lower due to higher body weight. All DIM values were below the respective RfD thresholds.

Table 2. Daily Intake of Metals (DIM) for Children and Adults

Experimentplot	*ConcentrationsofHeavySoil(mg/kg)*			*Plant Sample Identity*	*Concentrations of HeavyPlant(mg/kg)*			*Daily Intake of Metals(DIM)*		
	Cf	*Dfi(kg/person/day)*	Bw(kg)		*Zinc(Zn)ppm*	*Cadmium(Cd)ppm*	*Lead(Pb)ppm*	*Zinc(Zn)*	*Cadmium(Cd)*	*Lead(Pb)*
EzzaNorth4	0.085	0.232	32.7	*Cassava Leaf*	0.3684	0.0269	1.167	2.22×10^{-4}	1.6×10^{-5}	7.03×10^{-4}

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Abakaliki1	0.085	0.232	32.7	***Pumpkin Leaf***	1.1456	0.0156	1.0348	$6.9x10^{-4}$	$9.4x10^{-6}$	$6.24x10^{-4}$
Ezza South3	0.085	0.232	32.7	***Rice Husk/Stem***	0.3139	0.0386	0.2064	$1.89x10^{-4}$	$2.32x10^{-5}$	$1.24x10^{-4}$

3.4 Health Risk Index

HRI values for all metal-crop combinations were < 1, ranging from:

· Zn: 0.023–0.074
· Pb: 0.031–0.176
· Cd: 0.009–0.023

The highest HRI was for Pb from cassava leaf consumption (HRI = 0.176).

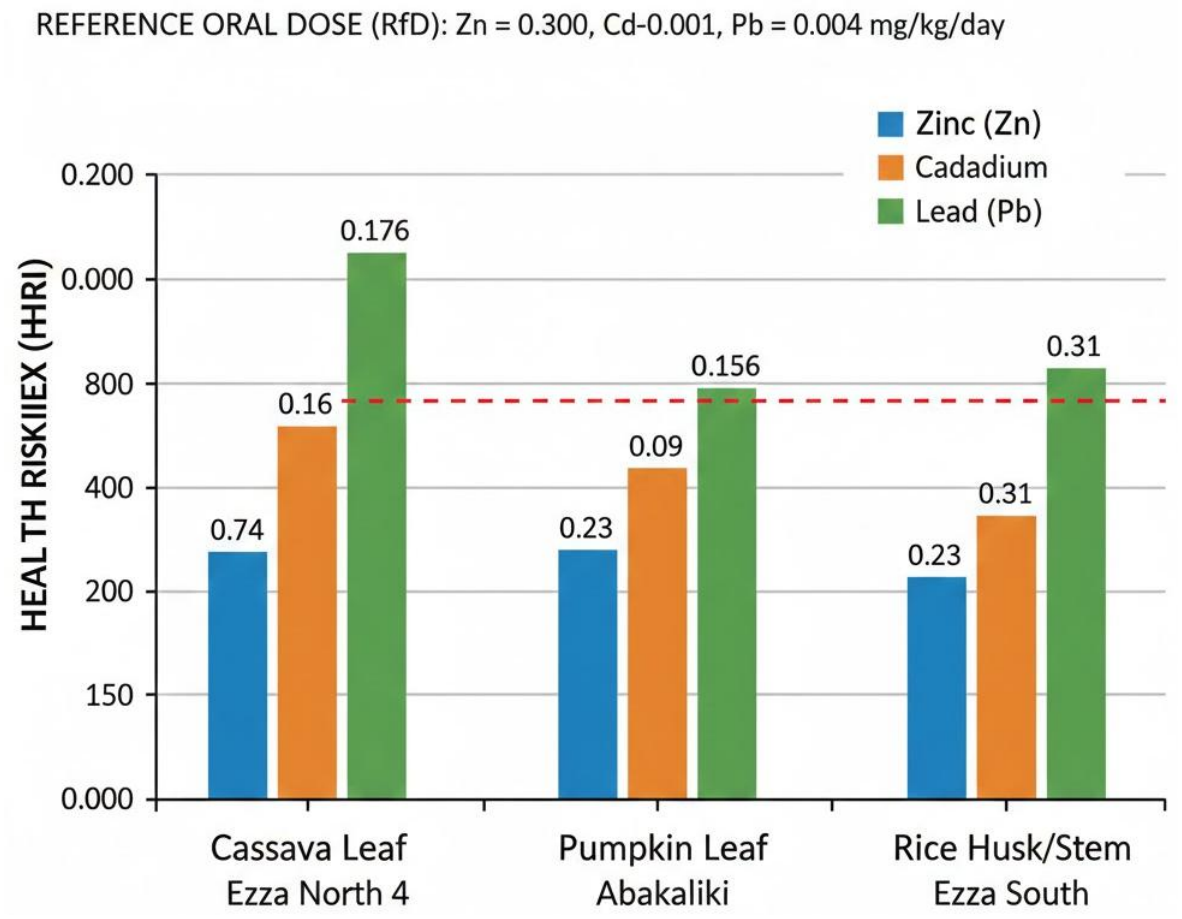

Figure 3. Health Risk Index (HRI) for children consuming vegetables from mining-impacted soils

IV. Discussion

4.1 Differential Metal Accumulation

The high Transfer Factor for Cd in rice is particularly noteworthy. TF > 1 indicates that rice actively bioaccumulates Cd, consistent with its classification as a Cd-accumulating cereal as reported by (Grant et al., 2008). This finding has serious implications because rice is a staple food, and chronic Cd exposure causes itai-itai disease (osteomalacia, renal tubular dysfunction) as reported by (Kabata-Pendias&Pendias, 2001).

Pumpkin leaf accumulated Zn preferentially over Pb and Cd. This is physiologically expected because Zn is an essential micronutrient with dedicated membrane transporters (ZIP family), whereas Pb and Cd are non-essential and subject to exclusion mechanisms as reported by (Sanità di Toppi &Gabbrielli, 1999). Nevertheless, the Pb concentration in pumpkin leaf (1.035 mg/kg) exceeded the FAO/WHO permissible limit of 0.3 mg/kg for leafy vegetables as reported by (Codex Alimentarius, 2001).

4.2 Risk Characterization

Although all HRI values were < 1, indicating no significant non-carcinogenic risk from individual vegetables, three important caveats apply. First, the cumulative HRI from consuming multiple contaminated vegetables simultaneously may exceed unity. Second, this study did not account for other exposure pathways (inadvertent soil ingestion, dermal contact, inhalation of dust). Third, Pb has no known safe threshold; the USEPA RfD for Pb (0.004 mg/kg/day) is under revision and may be lowered (EFSA, 2010).

The DIM for Pb in children consuming cassava leaf (7.03×10^{-4} mg/kg/day) corresponds to a blood lead level (BLL) increase of approximately 1–2 µg/dL using the IEUBK model as established by (USEPA, 2007). Given that background BLL in Nigerian children is already elevated as reported by (Nriagu et al., 1997), this additional dietary burden is concerning.

4.3 Comparison with Other Studies

The DIM values obtained in this study are lower than those reported for Pb-Zn mining areas in China as reported by (Cui et al., 2004; Wang et al., 2005) but comparable to values from similar artisanal mining communities in Nigeriaas reported by (Oti&Nwabue, 2012). The lower DIM reflects the relatively low consumption rates of leafy vegetables in this region compared to Asian populations.

V. Conclusion

This study demonstrates that while Pb, Cd, and Zn are transferred from contaminated soils to food crops, the current daily intake levels do not exceed oral reference doses. However, the hyperaccumulation of Cd by rice and the elevated Pb levels in pumpkin and cassava leaves are warning signals. Regular monitoring is recommended, particularly for Cd in rice grains (not just husk/stem). Community-level interventions should include:

· Promotion of low-accumulating crop varieties
· Soil amendment with lime and phosphate
· Dietary diversification to reduce reliance on contaminated vegetables

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