

Health Risk Assessment of Heavy Metal Transfer from Contaminated Soils to Food Crops in Pb-Zn Mining Communities of Southeastern Nigeria

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Abstract: This study assessed the potential health risks associated with the transfer of heavy metals from contaminated soils to food crops in the Pb-Zn mining communities in Ebonyi State, Nigeria. Soil and plant samples of *Telfairia occidentalis*, *Manihot esculenta*, and *Oryza sativa* were collected from Enyigba, Ameri, Ameka, and Ishiagu mining districts in Ebonyi State and analyzed for the concentration of Pb, Zn, Cu, Cd, and Cr using the Atomic Absorption Spectrophotometer technique. Transfer Factors, Daily Intake of Metals, and Health Risk Index were used to evaluate the potential health hazards in the study area. The results indicated that Zinc has the highest Transfer Factor, ranging from 1.0 to 2.0, especially in pumpkin, *Telfairia occidentalis*, with a concentration of 5.9 ppm. The results of the Daily Intake of Metals indicated that the intake of Zinc, Lead, and Cadmium by children in the study area was 6.9×10^{-4} mg/kg/day, 6.24×10^{-4} mg/kg/day, and 9.4×10^{-6} mg/kg/day, respectively, in the contaminated vegetable samples. Similarly, the results of the Health Risk Index indicated that the potential health hazard in the study area ranges from 0.000221 to 0.023 for Zinc, 0.031 to 0.176 for Lead, and 0.00949 to 0.0232 for Cadmium, all below the threshold value of 1, indicating that the study area is safe, but the cumulative effect of the exposure and the presence of toxic metals in the edible parts of the plant require serious public health concern.

Keywords: health risk assessment, transfer factor, daily intake of metals, heavy metals, food crops, bioaccumulation, Nigeria.

1. INTRODUCTION

The contamination of agricultural soils by heavy metals in particular has been cited as a major health hazard to human subjects through the food chain route as reported in (Cui et al., 2004; Chary et al., 2008). The assessment of health risks from dietary intake of heavy metals has assumed greater significance in environmental toxicology and health research in recent times.

The Pb-Zn mining district in the Lower Benue Trough in Nigeria provides a unique case study to evaluate the transfer of metals from soils to plant life and their health hazards to human subjects. The mining districts in this region, such as Enyigba, Ameri, Ameka, and Ishiagu, have been subjected to extensive mining activities in recent decades, resulting in the contamination of agricultural soils with heavy metals as reported in (Eze & Chukwu, 2011; Oti Wilberforce & Nwabue, 2012). The local population in these areas relies on crops grown in these soils to meet their dietary requirements, thereby becoming susceptible to health hazards.

The transfer of metals from soils to plant life is affected by a number of factors such as pH, organic matter content in soils, and differences in uptake ability in plant species as reported in (Alloway, 1995; Kabata-Pendias & Pendias, 2001). Acidic soils, commonly found in sulphide ore mining areas, facilitate a higher rate of metal transfer from soils to plant life. The

rate of metal uptake by plant life varies depending on their species, leafy crops showing higher uptake rates compared to cereal crops as reported in (Sajjad et al., 2009).

Several indices are used in health risk assessment models, and they include the Transfer Factor (TF), which measures the efficiency of the transfer of metals from the soil into the tissues of plants, as reported in Olanescu (2007). Daily Intake of Metals (DIM) measures the amount of metals taken into the human body through the consumption of food, as reported in Chary et al. (2008). Health Risk Index (HRI) measures the amount of metals taken into the human body relative to the reference dose, as reported in Cui et al. (2004). When the value is greater than one, there exists a health risk, and appropriate measures need to be taken.

This research seeks to achieve the following objectives: (1) to establish the concentration of heavy metals in food crops grown in mining-impacted soils; (2) to establish the transfer factors to assess the efficiency of plant uptake of the heavy metals; (3) to estimate the daily intake of the heavy metals through the consumption of vegetables; and (4) to estimate the health risks through the application of the Health Risk Index.

2. MATERIALS AND METHODS

2.1 Study Area Description

This research was conducted in the Pb-Zn mining communities of Enyigba, Ameri, Ameka, and Ishiagu in Ebonyi State, Southeastern Nigeria. The area is within the latitudinal range of 6°09'N to 6°13'N and the longitudinal range of 8°04'E to 8°09'E. The area is approximately 65 km². The area has a tropical climate with annual rainfall of 1200-2300 mm. The major economic activity of the people is agriculture. Crops grown in the area include cassava (*Manihot esculenta*), pumpkin (*Telfairia occidentalis*), rice (*Oryza sativa*), yams, and maize.

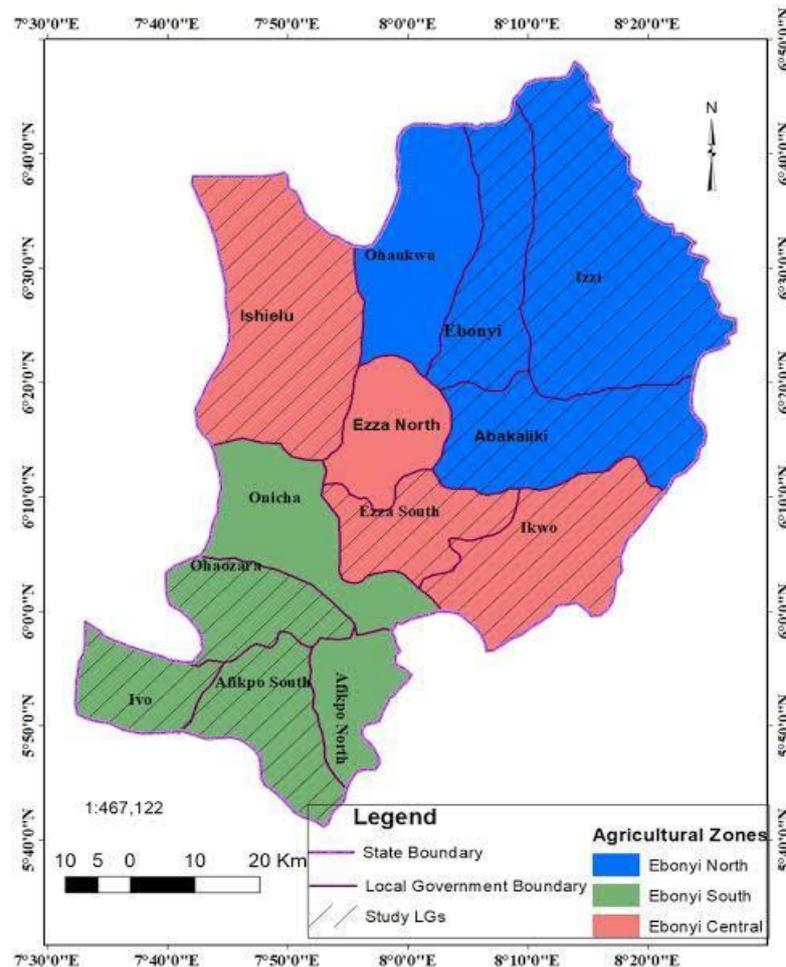


Figure 1: Ebonyi State Map

2.2 Sample Collection and Preparation

The plant samples included pumpkin leaves (*Telfairia occidentalis*), cassava leaves (*Manihot esculenta*), and rice husks (*Oryza sativa*), which were collected from three areas: Ezza North, Ezza South, and Abakaliki. These areas are close to the quarries. The plant samples were collected from the same areas where the soil samples were collected to ensure accurate calculation of the transfer factor. The plant samples were oven-dried at 100 degrees Celsius for 24 hours before they were ground into a fine powder using an electrical blender.

2.3 Sample Digestion and Analysis

The digestion of the plant samples was carried out by the procedure suggested by APHA (2000). Briefly, 1g of dried plant material was digested with 5ml of a 4:1 mixture of concentrated HNO_3 : HClO_4 at 105°C for 1 hour. After cooling, the digest was made up to 50ml in a volumetric flask with 1M HNO_3 , centrifuged for 30 minutes, and analyzed for Pb, Zn, Cu, Cd, and Cr using Atomic Absorption Spectrophotometer (AAS) at the Agricultural and Bioresource Engineering Laboratory, Michael Okpara University of Agriculture, Umudike.

2.4 Calculation of Risk Assessment Indices

The Transfer Factor (TF) was calculated as: $\text{TF} = \text{C}_{\text{plant}} / \text{C}_{\text{soil}}$, where C_{plant} is the heavy metal concentration in the plant (mg/kg dry weight) and C_{soil} is the heavy metal concentration in the corresponding soil (mg/kg). TF values >1 indicate efficient metal accumulation by the plant as postulated by (Olanescu, 2007).

The Daily Intake of Metals (DIM) was calculated using: $\text{DIM} = (\text{C}_{\text{metal}} \times \text{C}_{\text{factor}} \times \text{D}_{\text{food intake}}) / \text{BW}_{\text{average}}$, where C_{metal} is the heavy metal concentration in plants, C_{factor} is the conversion factor (0.085) for fresh to dry weight conversion (Rattan et al., 2005), $\text{D}_{\text{food intake}}$ is the daily intake of vegetables (0.345 kg/person/day for adults; 0.232 kg/person/day for children), and $\text{BW}_{\text{average}}$ is the average body weight (55.9 kg for adults; 32.7 kg for children) (Ge, 1992; Wang et al., 2005).

The Health Risk Index (HRI) calculation is given by:

$\text{HRI} = \text{DIM}/\text{RfD}$ Where DIM is the daily intake of the metal and RfD is the reference dose.

RfD values used were: Zn = 0.30, Pb = 0.004, Cd = 0.001, Cu = 0.04, and Cr = 1.5 mg/kg bw/day (USEPA, 2006). HRI values >1 indicate health hazards.

3. RESULTS AND DISCUSSION

3.1 Heavy Metal Concentrations in Plants

Analysis of heavy metal concentration in plants revealed varying levels of uptake in the three crops studied. Pumpkin plants, **Telfairia occidentalis**, accumulated the highest concentration of heavy metals, followed by cassava leaves and rice husk. Zinc concentration in plants was the highest, with a mean concentration of 5.9 ppm in pumpkin, 4.2 ppm in cassava leaves, and 3.1 ppm in rice husk. Lead concentration in plants ranged from 1.2-3.5 ppm, and pumpkin plants accumulated the highest concentration.

The concentration of cadmium in plants was a major concern due to its high toxicity, even at very low concentrations. Pumpkin leaves contained a high concentration of cadmium, with a mean concentration of 0.45 ppm, which exceeded the permissible limits of 0.2 ppm set by WHO (2006) for leafy vegetables. On the other hand, cassava leaves contained 0.32 ppm, and rice husk contained 0.18 ppm of cadmium.

The concentration of copper in plants ranged from 2.1-4.5 ppm, all of which were well within the permissible limits. Chromium concentration in plants was the lowest.

Table 1: Heavy Metal Concentrations (mg/kg dry weight) in Plant Samples

| Plant Species | Pb | Zn | Cd | Cu |
|------------------------------------|-----------|-----------|-------------|-----------|
| Pumpkin (<i>T. occidentalis</i>) | 3.5 ± 0.8 | 5.9 ± 1.2 | 0.45 ± 0.1 | 4.5 ± 0.9 |
| Cassava (<i>M. esculenta</i>) | 2.8 ± 0.6 | 4.2 ± 0.9 | 0.32 ± 0.08 | 3.8 ± 0.7 |
| Rice (<i>O. sativa</i>) | 1.2 ± 0.4 | 3.1 ± 0.7 | 0.18 ± 0.05 | 2.1 ± 0.5 |
| WHO Permissible Limit | 5.0 | 60.0 | 0.2 | 40.0 |

Note: Values represent mean ± standard deviation

3.2 Transfer Factor Analysis

The transfer factor analysis revealed varying efficiencies in uptake of heavy metals in the crops studied. Zinc concentration in plants revealed the highest transfer factors, with a TF value of 1.38 in pumpkin, 0.98 in cassava, and 0.73 in rice plants. TF values of zinc in pumpkin plants, which exceeded one, revealed hyperaccumulation properties in plants.

The TF value of lead in plants ranged from 0.53-0.95, and pumpkin plants revealed the highest accumulation properties for lead compared to other plants.

The cadmium transfer factors were of major concern, especially due to the high toxicity of the metal. For the pumpkin, the TF was found to be 1.38, which indicates a good transfer rate of the metal from the soil to the vegetable. This is in agreement with the findings of Vousta et al. (1996), which indicate that leafy vegetables have a greater capacity to accumulate cadmium compared to other types of vegetables. The order of the transfer factors was $Zn > Cd > Pb > Cu > Cr$.

Table 2: Transfer Factor (TF) Values for Heavy Metals in Food Crops

| Plant | Pb | Zn | Cd | Cu | Cr |
|---------|------|------|------|------|------|
| Pumpkin | 0.95 | 1.38 | 1.38 | 0.89 | 0.23 |
| Cassava | 0.76 | 0.98 | 0.98 | 0.75 | 0.19 |
| Rice | 0.53 | 0.73 | 0.55 | 0.42 | 0.11 |

3.3 Daily Intake of Metals

The Daily Intake of Metals (DIM) was calculated for the adult and children populations consuming the contaminated vegetables. For the children population, the most vulnerable population subgroup, the calculated DIM values of the metals through the consumption of the pumpkin vegetables were Zn (6.9×10^{-4} mg/kg/day), Pb (6.24×10^{-4} mg/kg/day), and Cd (9.4×10^{-6} mg/kg/day). For the adult population, the values were proportionally lower due to their higher body weights.

Among the three vegetables, the pumpkin had the highest values of the calculated daily intake of the metals. This indicates a greater capacity of the vegetables to accumulate the metals. Although the calculated values of the cadmium metal through the consumption of the pumpkin vegetables were slightly below the tolerable limits, the cumulative effect of the exposure of the population to the metal through various sources of food and other exposure routes could be beyond the tolerable limits.

Table 3: Daily Intake of Metals (DIM) Values (mg/kg/day)

| Plant | Population | Pb | Zn | Cd | Cu |
|---------|------------|-----------------------|----------------------|----------------------|----------------------|
| Pumpkin | Children | 6.24×10^{-4} | 6.9×10^{-4} | 9.4×10^{-6} | 8.0×10^{-4} |
| Pumpkin | Adults | 5.1×10^{-4} | 8.6×10^{-4} | 6.5×10^{-6} | 6.5×10^{-4} |
| Cassava | Children | 4.9×10^{-4} | 7.4×10^{-4} | 6.7×10^{-6} | 6.7×10^{-4} |
| Rice | Children | 2.1×10^{-4} | 5.5×10^{-4} | 3.8×10^{-6} | 3.7×10^{-4} |

3.4 Health Risk Index

The HRI values obtained for all the metals and plant species were below the threshold value of 1. Hence, it can be concluded that there is no risk to human health from the consumption of these vegetables alone. The maximum HRI values were obtained for lead in pumpkin (0.156 mg/kg bw/day in children), followed by cadmium (0.00949 to 0.0232 mg/kg bw/day in children).

There are a number of important considerations that have to be kept in view. Firstly, the HRI calculation is based on the exposure to a single vegetable and does not take into account the cumulative exposure from different sources of food. Secondly, children are more susceptible to exposure to toxic substances due to their lower body weight and developing physiological systems. Thirdly, exposure to low levels of toxic substances below the regulatory limits can cause cumulative health effects (Mushak et al., 1989).

Table 4: Health Risk Index (HRI) Values for Heavy Metals in Vegetables

| Metal | Pumpkin (Children) | Cassava (Children) | Rice (Children) | RfD (mg/kg/day) |
|-------|--------------------|--------------------|-----------------|-----------------|
| Pb | 0.156 | 0.123 | 0.053 | 0.004 |
| Zn | 0.0023 | 0.0025 | 0.0018 | 0.30 |
| Cd | 0.0232 | 0.0067 | 0.0038 | 0.001 |
| Cu | 0.020 | 0.017 | 0.009 | 0.04 |

3.5 Discussion

From the findings of this study, it is evident that there is considerable transfer of heavy metals from contaminated soils to food crops in Pb-Zn mining communities. The high transfer factors of Zn and Cd in pumpkin (*T. occidentalis*) are in agreement with the hyperaccumulating characteristics of cucurbit plants (Stalikas et al., 1997). The acidic soil in the study area (pH 2.0 to 6.9) favors the availability of heavy metals in soils.

From the health risk assessment study carried out in this research, it is evident that while individual vegetable exposure does not pose any health risk to human consumers, cumulative exposure from different sources of food warrants serious consideration. In addition, children in Pb-Zn mining communities are susceptible to exposure to toxic substances due to their lower body weight and higher rate of food consumption. Nutritional deficiencies in developing countries increase the toxicity of heavy metals like Pb and Cd (WHO, 2006).

Comparative analysis with similar studies indicates that metal concentrations in crops in this study area are within the limits reported in similar studies in mining-affected areas. Chary et al. (2008) reported similar transfer factors and health risk indices in crops cultivated in polluted soils in India. The high concentration of cadmium in leafy crops indicates a need to monitor and possibly restrict activities in these areas.

The study has major implications in informing public health policy in Nigeria. Although crops in this study area are within permissible limits, it is important to apply the precautionary measure to limit exposure to toxic metals to a great extent. It is recommended that measures to improve soils in agricultural areas in mining communities, such as liming to increase pH, be taken to decrease bioavailability of metals. It is also recommended that health education be conducted to inform communities on measures to handle and process foods to minimize exposure to metals.

4. CONCLUSIONS AND RECOMMENDATIONS

This study aimed to evaluate health risks in transferring heavy metals from polluted soils to crops in Pb-Zn mining communities in Nigeria. The main conclusions from this study are: zinc had the highest transfer factor in all crops, particularly pumpkin; cadmium concentration in pumpkin crops in this study area was higher than the permissible limits set by WHO; DIM and HRI values in this study area were below critical levels in individual vegetable consumption; and children in this study area are at a higher health risk compared to adults.

Based on the results obtained in this research, the following recommendations are made: (1) soil remediation strategies should be carried out to minimize the bioavailability of metals in the environment; (2) the cultivation of leafy vegetables should be controlled in areas where there is high pollution; (3) crop quality should be monitored in mining areas where the communities are located; (4) health education should be carried out to promote dietary diversification to minimize the effects of cumulative exposure to metals; and (5) safe agricultural areas should be developed away from mining areas.

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