Seasonal Variation of Heavy Metal Concentrations in Soils and Cocoyam Tubers Around Selected Municipal Dumpsites: Assessment Using Translocation Factor and Contamination Indices

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ABSTRACT

Municipal open dumpsites are major sources of heavy metal contamination, posing significant risks to agricultural soils and food safety in developing countries. This study evaluated the seasonal distribution, soil to tuber translocation, contamination indices and human health risks of Pb, Zn, Ni, Cu, Cr and Cd in soils and cocoyam (*Colocasia esculenta*) cultivated around three municipal dumpsites in Akwa Ibom State, Nigeria. Composite soil samples were collected at three depths (0–10, 10–20, 20–30 cm) from each dumpsite and a control site, in both dry and wet seasons, to assess vertical and seasonal metal variation. Cocoyam tubers were also harvested at each location. Metals were determined by Atomic Absorption Spectrophotometry after digestion. Transfer factor (TF), contamination factor (CF), degree of contamination (C_{deg}), hazard quotient (HQ) and hazard index (HI) were computed to assess metal mobility and health risk. Metal concentrations generally decreased with soil depth, showing surface accumulation from waste deposition. The highest concentrations occurred at Ikot Ekpene (13.50 and 88.50 mg/kg in Pb and Zn, dry season), while Pb increased to 37.50 mg/kg in wet season. Transfer factors exceeded unity for Pb at Eket (TF = 1.22, dry season), and for Pb at Uyo (TF = 1.27) and Cr at Eket (TF = 1.43) in the wet season, indicating high translocation into tubers. Soil contamination was highest at Ikot Ekpene (C_{deg} = 18.36 dry season; 37.77 wet season), while tubers recorded C_{deg} values of 22.40–24.67 (dry season). Hazard indices exceeded the US EPA threshold (HI > 1.0) at all dumpsites, peaking at 11.29 (Ikot Ekpene, wet season), with Pb the major contributor to risk. Cocoyam cultivated around municipal dumpsites carries a high heavy metal exposure risk. Improved waste management and restrictions on food crop cultivation in contaminated areas are recommended.

Keywords: Heavy metals, Cocoyam (*Colocasia esculenta*), Municipal dumpsites, Translocation, Contamination indices

INTRODUCTION

Improper waste disposal has emerged as a serious environmental challenge in many developing countries, particularly in regions experiencing rapid urbanization and population growth such as Akwa Ibom State. The random and indiscriminate disposal of municipal solid waste at open dumpsites remains an obvious environmental management challenge in many urban centres in Nigeria, including Uyo which is the capital city of Akwa Ibom State. Various activities of man in recent years have increased the quantity and distribution of heavy metals in the atmosphere, land and water bodies (Ubong et al., 2023a).

Human activities like manufacturing, agricultural, domestic and industrial activities generate waste, and the way the wastes are handled, stored, collected and disposed of can pose risks to the environment and to public health (Zhu et al. 2008). Due to lack of sanitary landfills and functional waste-management infrastructure, refuse comprising domestic, commercial, agricultural, industrial and electronic waste is deposited at open sites. This has caused weathering, leaching and, in some instances, open burning thereby releasing heavy metals into the surrounding soil. Since most waste is not biodegraded, they persist in soils, accumulate over time, and may

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subsequently be redistributed within the soil profile or transported into adjacent farmland (Ebong et al., 2007; Ebong et al., 2008; Ekanem, 2015). As these wastes undergo decomposition, they release hazardous chemicals including heavy metals, hydrocarbons, persistent organic pollutants (POPs), and other toxic compounds. These contaminants may infiltrate soil and groundwater through rainfall percolation and microbial degradation processes, leading to the formation of leachate, which constitutes a major pathway for environmental contamination (Ferronato & Torretta, 2019). Toxic metals such as lead (Pb), cadmium (Cd), mercury (Hg), and arsenic (As) are frequently detected in dumpsite environments and are particularly concerning due to their persistence, toxicity, and ability to bioaccumulate in biological systems (Alloway, 2013; Tchounwou et al., 2012).

This is of particular environmental and public-health concern because, beyond threshold concentrations, they are toxic to plants, animals and humans. Soils in the vicinity of dumpsites in Nigerian cities are nonetheless frequently exploited for the cultivation of food crops because of their relatively high nutrient and organic-matter content arising from decomposed waste, despite the associated risk of toxic metal uptake by the crops (Ebong et al., 2008; Umoh & Etim, 2013). Immediately the heavy metals are absorbed from contaminated soil into edible plant tissues, they enter the human food chain and may bioaccumulate over time. These can cause renal, hepatic, neurological, cardiovascular and carcinogenic effects depending on the metal, concentrations and duration of exposure.

Commonly existing studies on heavy metal accumulation around dumpsites within Akwa Ibom State have focused on leafy vegetables, notably *Talinum triangulare* and *Carica papaya* (Ebong et al., 2007; Ebong et al., 2008), as well as on dumpsite soils generally (Umoh & Etim, 2013; Ita & Anwana, 2017). A comprehensive study of the environmental chemistry and ecotoxicology of hazardous heavy metals and metalloids shows that steps should be taken to minimize the impact of these elements on human health and the environment (Ali et al., 2019).

Comparatively little attention has been given to tuber crops such as cocoyam, which constitute a major dietary staple in southern Nigeria and whose root is in direct and prolonged contact with contaminated soil, potentially presenting a distinct uptake pathway from that of above-ground leafy vegetables. Furthermore, few studies in the state have combined soil-metal characterisation with a quantitative soil-to-crop translocation factor and a formal, Estimated Dietary Index/ hazard quotient (EDI/HQ) based human health risk assessment specific to tuber crops across both dry and wet seasons.

This study therefore evaluated the concentrations of Pb, Zn, Ni, Cu, Cr and Cd in soils (at three depths) and in cocoyam tubers sampled around three major municipal dumpsites located in Uyo, Eket and Ikot Ekpene Local Government Area in the dry and wet seasons, relative to an unimpacted control site, with the specific objectives of: (i) determining the concentration and depth-wise distribution of the six metals in dumpsite soils; (ii) calculating soil-to-tuber transfer factors to assess translocation potential; (iii) evaluating the contamination factor and degree of contamination of soils and tubers; and (iv) estimating the hazard quotient and hazard index associated with dietary consumption of cocoyam from these sites.

MATERIALS AND METHODS

Description of Study Area

This research work was carried out in some local government areas of Akwa Ibom State, Niger Delta region of Nigeria. Akwa Ibom is a state in Nigeria named after Qua Iboe River. The study was conducted around three major municipal solid waste dumpsites located in Uyo, Eket and Ikot Ekpene Local Government Areas of Akwa Ibom State, South-South (Niger Delta) geopolitical zone of Nigeria (Figure 1). Akwa Ibom State lies within the humid tropical rainforest belt and experiences two distinct seasons namely wet season (April to October) and dry season (November to March) with high annual rainfall and relative humidity typical of the Niger Delta region (Esu et al., 1999, cited in Ihedioha et al., 2017; Ebong et al., 2019).

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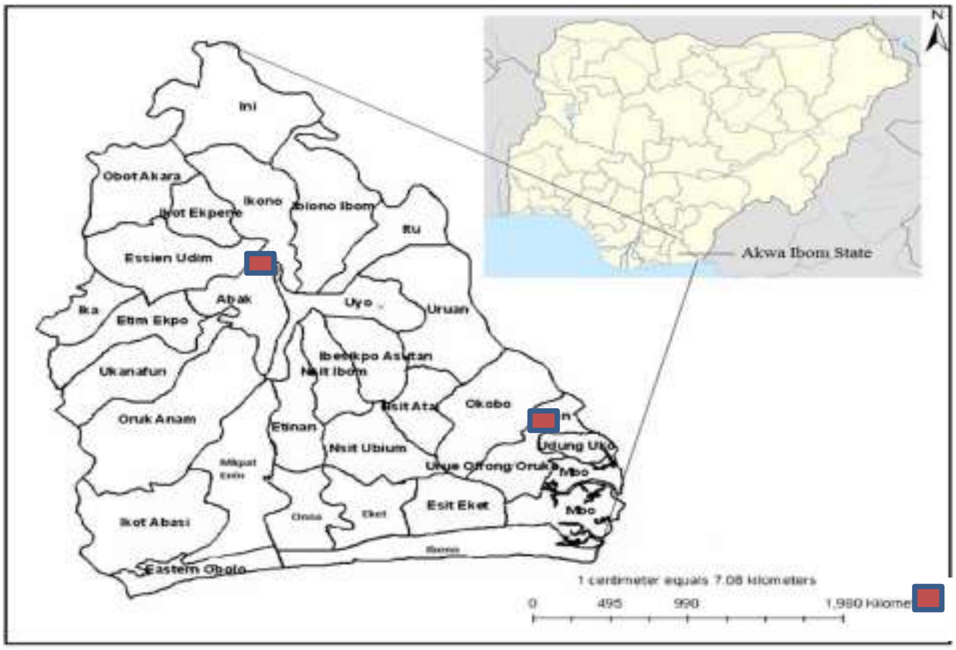

Figure 1. Map of Akwa Ibom State showing sample locations (Ite et al., 2019)

The selected dumpsites are open, unengineered sites that receive mixed municipal, domestic, artisanal waste, medical waste and electronic waste. Cocoyam and other tuber and leafy crops are cultivated within and adjacent to these dumpsites, exploiting the organically enriched soil for subsistence and commercial purposes.

Sample collections

Samples were collected from three sampling locations namely: USS; Uyo dumpsite, ESS; Eket dumpsite, and IKSS; Ikot Ekpene dumpsite. An uncontaminated site at Fulga Street, Uyo located away from any dumpsite influence, served as the control Site. Five sampling points were randomly made within each dumpsite, pooled together to form composite sample for that site. Composite soil samples were collected from each dumpsite at three depth intervals (0–10 cm, 10–20 cm and 20–30 cm) using stainless steel soil auger. A total of fifteen (15) samples were obtained at each location, thus, sixty (60) sub-samples and twelve (12) composite soil samples were collected for this study in order to evaluate the vertical distribution of the metals within the soil profile. Samples were collected in both the dry and wet seasons to capture seasonal and depth-related variation in metal distribution. At each sampling location, cocoyam tubers were also harvested from cocoyam plants grown in the corresponding soil. Soil and tuber samples were similarly obtained from the control site. All samples were placed in clean, labelled polyethylene bags and transported to the laboratory for processing and analysis.

Sample Preparation

Soil samples were air-dried at room temperature, disaggregated, debris and stones removed, then sieved through a 2 mm mesh sieve. Tuber samples were thoroughly washed with tap water followed by deionised water to remove adhering soil particles, peeled, cut into smaller pieces, oven-dried at 60–80°C to constant weight, and ground into a fine powder using a mechanical grinder.

Digestion and Heavy Metal Analysis

Approximately 1 g of the sieved samples was weighed into digestion tubes and 10 ml aqua regia (concentrated hydrogen chloride and nitric acid, ratio 3:1 vol/vol) added (United States Environmental Protection Agency (USEPA) method 3050b). The tubes were covered, heated in a water bath to 100 ◦C until a clear digest was obtained. The digests were cooled, filtered through Whatman No. 42 filter paper, diluted to a fixed volume with deionised water, and analysed for Pb, Zn, Ni, Cu, Cr and Cd using a Unicam Atomic Absorption Spectrophotometer (AAS), MODEL 939 calibrated with metal-specific standard solutions. Results are expressed in mg/kg on a dry-weight basis.

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Quality Assurance and Quality Control

All glasswares were acid-washed and rinsed with deionised water prior to use. Analytical-grade reagents were used throughout, and reagent blanks were analysed alongside samples to correct for background contamination. Working standard solutions were prepared by serial dilution of certified stock standards for instrument calibration, and the instrument response was checked periodically against the calibration curve during analysis.

Translocation Factor

The translocation (transfer) factor (TF), which quantifies the relative ability of the tuber crop to take up a given metal from the soil was calculated as the ratio of the metal concentration in the tuber to its mean concentration (average of the concentrations at all depth) in the corresponding surface soil as seen in Eqn. (1)(Ekanem, 2015):

$$TF = \frac{C_{tuber}}{C_{soil(mean)}} \qquad \text{Eqn. (1)}$$

where C_{tuber} and $C_{soil(mean)}$ are the metal concentrations (mg/kg, dry weight) in the tuber and mean concentration (average of the concentrations at all depth) in the corresponding soil respectively. A TF value greater than 1 indicates that the metal is actively accumulated in the tuber relative to the soil, while values less than 1 indicate restricted translocation (Ekere et al., 2020).

Contamination Indices

The contamination factor (CF) for each metal was calculated following the approach of Hakanson (1980), originally developed for sediment quality assessment and widely adapted for soil and plant matrices as seen in Eqn. (2) (Ajah et al., 2015):

$$CF = \frac{C_{sample}}{C_{background}} \qquad \text{Eqn. (2)}$$

where C_{sample} is the measured metal concentration in soil (average of the concentrations at all depth) or tuber and $C_{background}$ is the corresponding pre-industrial/background concentration for that metal. For this study, the background values used in the Contamination Factor (CF) calculations were derived from the control soil site (CSS; Fulga Street) using the depth-integrated mean concentration (0–30 cm).

The degree of contamination (C_{deg}) was obtained as the sum of the CF values of all metals analysed at a given site as seen in Eqn. (3) (Ebong et al., 2015):

$$C_{deg} = \sum CF_i \qquad \text{Eqn. (3)}$$

Where CF_i is the contamination factor for all the elements involved. CF values were qualitatively classified as low (CF < 1), moderate (1 ≤ CF < 3), considerable (3 ≤ CF < 6) or very high (CF ≥ 6). Degree of contamination C_{deg} values were qualitatively classified as $C_{deg} < 6$ = low; $6 \le C_{deg} < 12$ = moderate; $12 \le C_{deg} < 24$ = considerable; and $C_{deg} \ge 24$ = very high degree of contamination following the bands proposed by Hakanson (1980) and subsequently applied to terrestrial systems (Ajah et al., 2015).

Human Health Risk Assessment

The non-carcinogenic health risk associated with dietary consumption of cocoyam from the dumpsite within and adjacent farms was estimated using the hazard quotient (HQ) and cumulative hazard index (HI) approach recommended by the US EPA, which has been widely applied to food crops grown on contaminated soils in Nigeria and elsewhere (Bortey-Sam et al., 2015; Ihedioha et al., 2017; Akpan et al., 2022; Baguma et al., 2025). The hazard quotient for each metal was calculated as the ratio of its estimated daily intake (EDI) through tuber consumption to its oral reference dose (RfD) as seen in Eqns (4, 5 and 6) (Ubong et al., 2023a):

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$$EDI = \frac{(C \times IR)}{BW} \qquad \text{Eqn. (4)}$$

where C is the metal concentration in the tuber crop (mg/kg), IR is the ingestion rate of the tuber crop, taken as 0.345 kg/day (the standard USEPA default daily intake rate for a vegetable/root-crop food item), and BW is the average body weight of an adult, taken as 70 kg.

The hazard quotient for each metal was then calculated as:

$$HQ = \frac{EDI}{RfD} \qquad \text{Eqn. (5)}$$

and the hazard index, representing the cumulative non-carcinogenic risk from all metals, as:

$$HI = \sum HQ_i \qquad \text{Eqn. (6)}$$

Oral RfD used for health risk calculations are Pb (0.0035), Zn (0.300), Ni (0.020), Cu (0.040) and Cr (1.500) all in mg/kg/day. Cd was excluded from the risk calculation because it was below detection at nearly all sites. An HI (or HQ) value below 1.0 indicates that adverse health effects from the exposure are negligible, whereas a value at or above 1.0 indicates the possibility of an adverse health effect over a long time of exposure (Ubong et al., 2023b; Ihedioha et al., 2017; Bortey-Sam et al., 2015).

RESULTS

Heavy Metal Concentrations in Soil and Cocoyam Tuber Samples

Table 1: Mean concentrations of Heavy metals (mg/kg) in soil and plant samples at different sampling sites (Dry season)

Samples	Depths (cm)	Concentration of Heavy Metals (mg/kg)					
		Pb	Zn	Ni	Cu	Cr	Cd
USS	0 – 10	6.00	24.00	4.00	10.00	11.00	ND
	10-20	4.50	26.00	3.00	16.50	7.50	ND
	20– 30	3.5	13.0	2.0	4.5	5.0	3.5
ESS	0 – 10	6.50	40.00	1.50	11.50	5.50	ND
	10-20	5.50	50.50	4.50	8.00	4.50	ND
	20– 30	1.50	11.50	1.50	4.00	7.50	ND
IKSS	0 – 10	13.50	88.50	9.50	6.50	7.00	ND
	10-20	8.50	22.00	9.00	12.50	3.00	ND
	20– 30	1.0	14.5	4.0	7.0	3.00	ND
CSS	0 – 10	1.00	33.00	2.50	1.50	4.50	ND
	10-20	0.50	12.00	4.00	4.00	3.50	ND
	20– 30	1.5	1.0	1.5	1.5	1.0	ND
UYS		2.00	15.00	2.50	6.50	6.00	ND
EYS		5.50	5.00	1.00	6.00	3.50	ND
IKYS		4.00	18.00	5.50	6.00	3.00	ND
CYS		0.50	7.50	ND	1.00	0.50	ND

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USS; Uyo dumpsite, ESS; Eket dumpsite, IKSS; Ikot Ekpene dumpsite, CSS; Control soil sample, UYS; Uyo dumpsite (tuber Sample), EYS; Eket dumpsite (tuber sample), IKYS; Ikot Ekpene dumpsite (tuber sample), CYS; Control tuber sample, ND; Not detected

Table 1 presents the mean concentrations of Pb, Zn, Ni, Cu, Cr and Cd in soil (at three depths) and in cocoyam tuber samples from the three dumpsites and the control site during the dry season. Pb and Zn concentrations in the 0–10 cm surface soil (13.50 and 88.50 mg/kg, respectively) were the highest recorded at the Ikot Ekpene dumpsite (IKSS), among all sites. Generally, there was a decrease in concentrations with increasing depth at all locations, a pattern common with surface accumulation of metals from recently deposited waste and leachate. Cadmium was not detected (ND) at all sites and depths except the 20–30 cm layer at Uyo (USS), where 3.50 mg/kg was recorded. Among the cocoyam tuber samples, Pb and Cr had the lowest concentration (0.50 mg/kg in CYS, control) while Pb recorded the highest concentration among the tuber samples, at 5.50 mg/kg (EYS).

Table 2 shows that wet season concentrations were markedly higher at the Ikot Ekpene dumpsite than in the dry season, with surface soil (0–10 cm) Pb and Zn reaching 37.50 and 88.50 mg/kg respectively. By contrast, concentrations at the Eket dumpsite (ESS) were generally lower in the wet season than in the dry season, suggesting a degree of metal dilution or lateral leaching at that site under increased rainfall and infiltration. As in the dry season, metal concentrations generally decreased with soil depth. Several metals were below detection limits in tuber samples during the wet season such as Ni in UYS, Cu in EYS, Zn in IKYS and CYS, reflecting more variable uptake under wet-season conditions.

Soil to Tuber Translocation potential

Transfer factors as seen in Figures 2 and 3, varied considerably among metals, sites and seasons. In the dry season (Figure 2.), Ni showed the highest translocation potential at Uyo (TF = 0.83) and Ikot Ekpene (TF = 0.73), while Pb transfer was highest at Eket (TF = 1.22), exceeding unity and indicating that, at this site, cocoyam tubers accumulated more Pb than was present in the corresponding soil.

Table 2: Mean concentrations of Heavy metals (mg/kg) in soil and plant samples at different sampling sites (Wet season)

Samples	**Depths (cm)**	**Concentration of Heavy Metals (mg/kg)**					
		Pb	**Zn**	**Ni**	**Cu**	**Cr**	**Cd**
USS	0 – 10	2.50	23.50	5.00	7.00	8.50	ND
	10-20	1.00	33.00	2.50	4.50	11.00	ND
	20– 30	1.24	21.15	3.25	2.90	6.30	ND
ESS	0 – 10	4.50	5.00	1.50	4.00	5.50	ND
	10-20	3.00	4.00	0.50	2.00	2.50	ND
	20– 30	1.00	2.70	1.30	3.05	2.50	ND
IKSS	0 – 10	37.50	38.9	16.0	12.5	7.50	ND
	10-20	23.00	12.34	5.5	13.0	8.00	ND
	20– 30	13.50	9.72	5.5	4.50	5.50	ND
CSS	0 – 10	4.50	3.00	2.5	3.00	3.00	ND
	10-20	1.50	1.00	1.5	1.50	1.00	ND
	20– 30	1.90	0.85	0.55	1.02	0.70	ND
UYS		2.00	10.50	ND	2.50	3.00	ND
EYS		0.50	3.00	1.00	ND	5.00	ND

IKYS		14.00	ND	2.00	7.50	4.50	ND
CYS		0.50	ND	0.50	1.00	ND	ND

USS; Uyo dumpsite, ESS; Eket dumpsite, IKSS; Ikot Ekpene dumpsite, CSS; Control soil sample, UYS; Uyo dumpsite (tuber Sample), EYS; Eket dumpsite (tuber sample), IKYS; Ikot Ekpene dumpsite (tuber sample), CYS; Control tuber sample, ND; Not detected

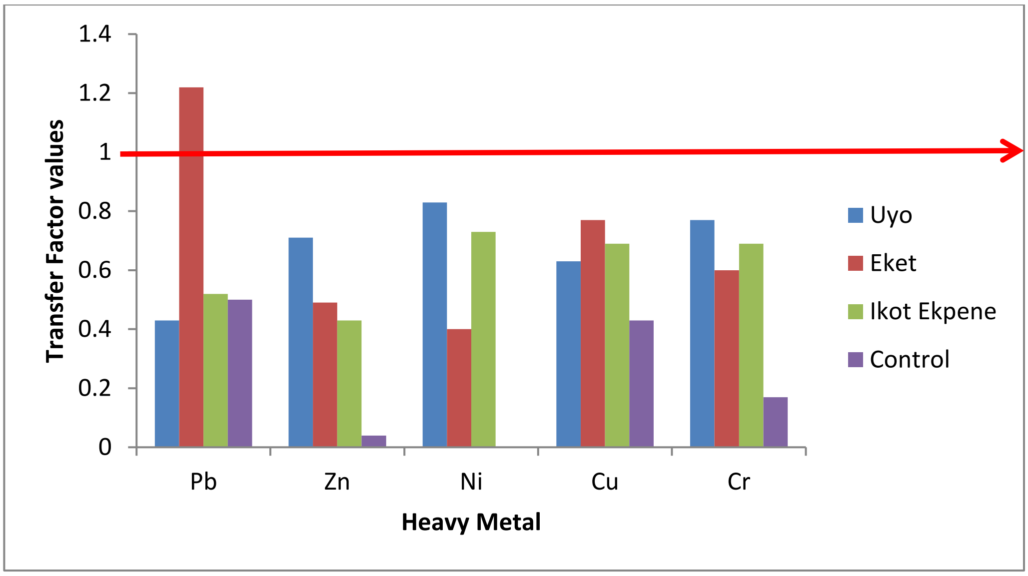

Figure 2. Transfer factors for heavy metals from soil to tuber crops at different dumpsites in Akwa Ibom State (Dry season)

In the wet season (Figure 3), transfer factor of Pb increased markedly at Uyo (TF = 1.27) and at the control site (TF = 0.95), while Cr transfer at Eket increased to 1.43, the highest TF value recorded across both seasons. Cu and Cr transfer factors were generally moderate to high (0.35–1.43) across sites and seasons, while several Zn and Ni transfer factors could not be determined (ND) in the wet season owing to non-detectable tuber concentrations.

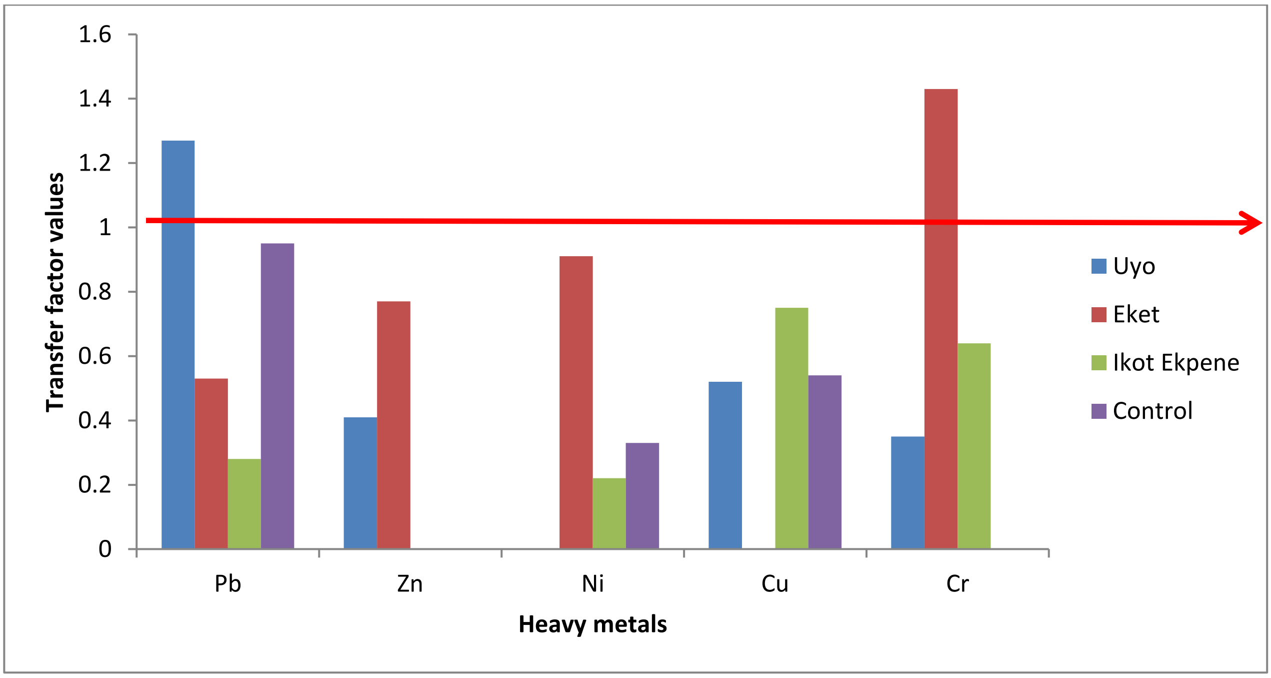

Figure 3. Transfer factors for heavy metals from soil to tuber crops at different dumpsites in Akwa Ibom State (Wet season)

Contamination Factor and Degree of Contamination

Table 3 and 4 gives results for the contamination factors and degree of contamination of each dumpsite in both seasons for soil and tuber studied respectively. Results obtained for soil samples during dry and wet seasons showed the following mean CF values for the heavy metals: (5.61 and 3.68) Pb; (2.10 and 18.51) Zn; (1.62 and 3.01) Ni; (3.84 and 3.25) Cu and (2.00 and 4.06) Cr. The obtained results indicated that based on classes of CF proposed by Hakanson (1980) as adopted in Ebong et al., 2015, Zn, Ni, and Cr moderately contaminated.

Table 3. Contamination factor (CF) and degree of contamination (C_{deg}) of soil in dry and wet seasons

Heavy metals	BACKGROUND values for dry season) (mg/kg)	Contamination Factor (Dry Season)			BACKGROUND values for wet season) (mg/kg)	Contamination Factor (Wet Season)		
		USS	ESS	IKSS		USS	ESS	IKSS
Pb	1	4.67	4.50	7.67	2.63	0.60	1.08	9.37
Zn	15.33	1.37	2.22	2.72	1.62	16.01	2.41	12.57
Ni	2.67	1.12	0.94	2.81	1.52	2.36	0.73	5.93
Cu	2.33	4.43	3.36	3.72	1.84	2.61	1.64	5.43
Cr	3	2.61	1.94	1.44	1.57	5.49	2.23	4.47
Degree of Contamination (C_{deg})		**14.21**	**12.96**	**18.36**		**27.07**	**8.09**	**37.77**

USS; Uyo dumpsite, ESS; Eket dumpsite, IKSS; Ikot Ekpene dumpsite, CSS; Control soil sample

Table 4. Contamination factor (CF) and degree of contamination (C_{deg}) of cocoyam in dry and wet seasons

Heavy metals	BACKGROUND values for dry season) (mg/kg)	Contamination Factor (Dry Season)			BACKGROUND values for wet season) (mg/kg)	Contamination Factor (Wet Season)		
		UYS	EYS	IKYS		UYS	EYS	IKYS
Pb	0.5	4.00	11.00	8.00	2.5	0.800	0.600	2.800
Zn	7.5	2.00	0.67	2.40	ND	NC	NC	NC
Ni	ND	NC	NC	NC	0.5	NC	2.000	NC
Cu	1	6.50	6.00	6.00	1	2.500	NC	7.500
Cr	0.5	12.00	7.00	6.00	ND	NC	NC	NC
Degree of Contamination (C_{deg})		**24.50**	**24.67**	**22.40**		**2.5**	**2.60**	**10.30**

UYS; Uyo dumpsite (tuber Sample), EYS; Eket dumpsite (tuber sample), IKYS; Ikot Ekpene dumpsite (tuber sample), CYS; Control tuber sample, ND; Not detected, NC; Not calculated the dumpsite soils evaluated whereas Pb and Cu showed a considerable contamination level during the dry season. During the wet season, results obtained showed Pb, Ni, Cu and Cr to considerably contaminate the sites while Zn to be highly contaminated. Results obtained in soil during dry season for the degree of contamination of each dumpsite soil by these heavy metals indicated the following: 14.21 (Uyo); 12.96 (Eket); and 18.36 (Ikot Ekpene). The obtained trend for Cdeg showed that Ikot Ekpene dumpsite soil which was within the range of considerable degree of contamination was the highest contaminated area while Eket dumpsite soil was the lowest contamination site. This may be attributed to the difference in age, size and location of these dumpsites as reported by Ebong et al., 2007. During wet season, results obtained for the degree of contamination of each dumpsite soil by these heavy metals indicated the following: 27.07 (Uyo); 8.09 (Eket); and 62.32 (Ikot Ekpene). The obtained trend for Cdeg showed that Ikot

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Ekpene dumpsite soil which was within the range of high degree of contamination was also the highest contaminated area while Eket dumpsite soil was the lowest contamination site.

Results obtained for cocoyam tuber samples during dry and wet seasons showed the following mean CF values for the heavy metals: (7.67 and 2.33) Pb; (1.69 and ND) Zn; (ND and 2.00) Ni; (6.17 and 5.00) Cu and (8.33 and ND) Cr. Based on the classification by Hakanson (1980), the obtained results indicated that Zn had low contamination factor, Pb, Cu, and Cr had high contamination factor. Contamination factor of Ni was not determined in cocoyam tuber during the dry season because its concentration was below detection. During the wet season, results obtained showed Pb and Ni had considerable contamination factor while Cu was classified to have moderate contamination factor. Contamination factor of Zn and Cr was not determined in cocoyam tuber during the wet season. Results obtained in cocoyam tuber during dry season for the degree of contamination of each dumpsite soil by these heavy metals indicated the following: 24.50 (Uyo); 24.67(Eket); and 22.40 (Ikot Ekpene).

The obtained trend for Cdeg showed that Uyo and Eket dumpsite cocoyam tuber were within the range of high degree of contamination while Eket dumpsite cocoyam tuber was the lowest contamination site but classified as having considerable degree of contamination. During wet season, results obtained for the degree of contamination of each dumpsite cocoyam tuber samples by these heavy metals indicated the following: 2.50 (Uyo); 2.60 (Eket); and 10.30 (Ikot Ekpene). The obtained trend for Cdeg showed that Ikot Ekpene dumpsite soil which was within the range of considerable degree of contamination was also the highest contaminated area while Uyo dumpsite soil was the lowest contamination site.

Hazard Quotient and Hazard Index for Adult Consumers of Cocoyam

Table 5 presents the hazard quotient (HQ) of each metal and the cumulative hazard index (HI) for adult consumers of cocoyam from the three dumpsites and the control site. In the dry season, the hazard index was dominated by the Pb HQ, ranged from 0.7041 (control) to 7.7449 (Eket), with Ikot Ekpene (5.6327) and Uyo (2.8163) also exceeding the US EPA safety threshold of 1.0.

Table 5. Hazard quotient (HQ) per metal and cumulative hazard index (HI) for adult consumers of cocoyam in both dry and wet seasons

SITES	HAZARD QUOTIENT (HQ) DRY SEASON					HAZARD INDEX (HI)
	Pb	Zn	Ni	Cu	Cr	
UYS	2.8163	0.2464	0.6161	0.8009	0.0197	**4.4994**
EYS	7.7449	0.0821	0.2464	0.7393	0.0115	**8.8243**
IKYS	5.6327	0.2957	1.3554	0.7393	0.0099	**8.0329**
CYS	0.7041	0.1232	NC	0.1232	0.0016	**0.9522**
	WET SEASON					
UYS	2.8163	0.1725	NC	0.3080	0.0099	**3.3067**
EYS	2.1122	0.0493	0.2464	NC	0.0164	**2.4244**
IKYS	9.8571	NC	0.4929	0.9241	0.0148	**11.2889**
CYS	0.7041	NC	0.1232	0.1232	NC	**0.9505**

UYS; Uyo dumpsite (tuber Sample), EYS; Eket dumpsite (tuber sample), IKYS; Ikot Ekpene dumpsite (tuber sample), CYS; Control tuber sample, NC; Not calculated. Hazard Index (HI) values ≥ 1.0 indicate a potential for adverse non-carcinogenic health effects (US EPA Standard).

In the wet season, the hazard index at Ikot Ekpene was significantly higher; 11.2889, which was the highest value recorded in the study. All the HI values were above the control site HI value (HI = 0.9505). Across both seasons and all sites, Pb was a major contributor to the hazard index, while Cd, Cr and Ni contributed comparatively little to overall risk.

DISCUSSION

The higher metal concentrations recorded at the Ikot Ekpene dumpsite, in both seasons, are similar to earlier reports of high heavy metal concentrations in dumpsite soils within Akwa Ibom State (Ukpong, 2013; Monechot et al., 2014) and reflect the influence of waste composition, dumpsite age and local hydrogeology on metal accumulation (Eddy et al., cited in Ihedioha et al., 2017). The general decrease in metal concentration with increasing soil depth observed at all three dumpsites reflects findings from comparable studies of municipal dumpsite soils elsewhere in Nigeria, where surface enrichment is attributed to the relatively immobile nature of metals such as Pb (Amusan et al., 2005). Lead tends to bind strongly to organic matter, clay minerals and Fe/Mn oxides near the soil surface rather than leaching readily to deeper layers (Ihedioha et al., 2017). The seasonal variation observed at Eket, where wet season concentrations were lower than dry season values, is due to the dilution and lateral redistribution of surface-deposited metals that can occur under increased rainfall and infiltration in tropical climates (Ajah et al., 2015). The opposite trend at Uyo and Ikot Ekpene shows continued waste deposition and leachate generation surpass any dilution effect.

The transfer factor results indicate that translocation of heavy metals from soil into cocoyam tubers in this study was metal, site and season specific, a pattern mostly reported in soil crop transfer studies (Wang et al., 2020). The comparatively high transfer factors obtained for Ni, Cu and Cr at several sites suggest that these metals are relatively bioavailable in the dumpsite soils studied. The generally lower Pb transfer factors at most sites (with the notable exceptions of Eket in the dry season and Uyo in the wet season) are due to the tendency of Pb to be strongly retained in soil rather than translocated into plant tissue (Ihedioha et al., 2017). Comparable cases of TF exceeding unity for toxic metals in root and tuber crops grown near industrial or waste impacted soils have been reported in yam grown near an industrial area in Kampala, Uganda (Baguma et al., 2025), indicating that tuber crops are not uniformly protected from soil contamination simply because the edible portion develops below ground.

The very high degree of contamination calculated for Ikot Ekpene soil in the wet season (Cdeg = 37.77), highly contributed by Zn and Pb, classifying this site among the most heavily contaminated dumpsite soils among other sampling sites. The contamination factor and degree of contamination approach used in this study, while originally developed for sedimentary systems, has been extensively adapted and applied to terrestrial and agricultural soils because it provides a standardised, background-referenced means of comparing pollution severity across sites and studies (Hakanson, 1980; Ajah et al., 2015). Similarly, elevated Cdeg values obtained for cocoyam tubers in the dry season at all three dumpsites (22.40–24.67) supports the soil contamination findings and suggest that, during the dry season, when soil moisture and dilution are lower, tuber crops are exposed to, and accumulate, a comparatively higher metal concentration.

The hazard index values obtained in this study, several of which exceeded the US EPA threshold of 1.0 indicates high potential for adverse non-carcinogenic health effects among adult consumers of cocoyam grown around these dumpsites. This finding is comparable to health risk assessments of food crops grown on contaminated soils in the Niger Delta and elsewhere in sub-Saharan Africa, where Pb has similarly been identified as the dominant contributor to dietary hazard index values exceeding unity (Bortey-Sam et al., 2015; Baguma et al., 2025). Chronic dietary exposure to Pb is of particular concern given its well known neurotoxic, nephrotoxic and haematological effects. Pb is also classified as a probable human carcinogen, and there is no known biological threshold below which it is entirely safe (Rahimzadeh et al., 2024). Cadmium, although recording the lowest absolute concentrations among the six metals studied still requires continued monitoring due to its long biological half-life, its classification as a Group 1 human carcinogen, and its well known renal and skeletal toxicity even at very low chronic exposure levels (Genchi et al., 2020; Rahimzadeh et al., 2017).

CONCLUSION

This study assessed the concentration, seasonal variations, soil to tuber translocation and human health risk of six heavy metals in soils and cocoyam tubers cultivated around three municipal dumpsites in Akwa Ibom State, Nigeria. Heavy metal concentrations, especially in Pb and Zn, were highest at the Ikot Ekpene dumpsite and generally declined with soil depth. Transfer factors indicated metal and site specific translocation into cocoyam tubers, with most of the transfer factors exceeding unity for Pb. Contamination factor and degree of contamination analysis classified soils as moderately to highly contaminated, with the most severe contamination recorded at Ikot Ekpene in the wet season. Health risk assessment revealed hazard index values mostly above the US EPA safety threshold in cocoyam tuber samples harvested around all three dumpsites in both seasons. This indicates a non-negligible risk of adverse health effects, especially from dietary lead exposure, among adult consumers of cocoyam grown at these sites. Due to this level of contamination, it is recommended that: (i) cultivation of food crops, particularly tuber crops for direct human consumption, be discouraged or strictly regulated within and adjacent to active municipal dumpsites in Akwa Ibom State. (ii) Municipal authorities should accelerate the transition from open dumping to engineered sanitary landfill or waste to resource recovery systems, to reduce the leachate source contamination of adjoining agricultural land.

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