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Heavy metal bioaccumulation in liver, kidney, and muscle tissues of free-ranging sheep grazing near informal electronic waste recycling sites in the Greater Accra region, Ghana

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Abstract

Informal electronic waste (e-waste) recycling at sites such as Agbogbloshie in Accra, Ghana, releases heavy metals into surrounding soils, water, and vegetation, yet the extent to which these contaminants accumulate in the edible tissues of livestock grazing near such sites has received limited systematic investigation. This research quantified lead (Pb), cadmium (Cd), chromium (Cr), mercury (Hg), and arsenic (As) concentrations in liver, kidney, and skeletal muscle of 48 free-ranging West African Dwarf sheep slaughtered from three zones at increasing distances from the Agbogbloshie e-waste processing area (Zone A: 0-1 km, n = 16; Zone B: 1-3 km, n = 16; Zone C: reference site >15 km, n = 16) between March and August 2023. Corresponding soil and forage samples were collected from each zone. Mean kidney Pb in Zone A sheep (6.14 ± 1.32 mg/kg wet weight) exceeded the Codex Alimentarius maximum residue limit (MRL) of 0.5 mg/kg by 12.3-fold, while kidney Cd (2.83 ± 0.71 mg/kg) exceeded the MRL of 1.0 mg/kg by 2.8-fold. Liver concentrations followed the same pattern, with Pb and Cd exceeding MRLs in Zone A by 9.6-fold and 2.7-fold, respectively. Zone B tissues showed intermediate contamination, with Pb and Cd exceeding MRLs by 3.1-fold and 1.4-fold in kidney. Muscle tissue concentrations were lower but still exceeded Pb MRLs in Zone A. Zone C reference animals had tissue concentrations within safe limits for all metals. Strong positive correlations were observed between soil metal concentrations and kidney tissue accumulation for Pb ($r = 0.97, p < 0.001$) and Cd ($r = 0.98, p < 0.001$). These results demonstrate that sheep grazing within 3 km of the Agbogbloshie e-waste site accumulate heavy metals in edible tissues at levels that pose significant risks to human consumers and warrant immediate public health intervention.

Keywords: Heavy metals, bioaccumulation, electronic waste, sheep, lead, cadmium, food safety, Agbogbloshie, Ghana, environmental contamination

Introduction

An estimated 53.6 million metric tonnes of electronic waste were generated globally in 2019, with projections suggesting this figure will reach 74.7 million tonnes by 2030. A disproportionate share of this waste stream flows to low-and middle-income countries in West Africa, where informal recycling operations extract valuable metals through open burning of cables, acid leaching of circuit boards, and manual dismantling of components—processes that release heavy metals into the surrounding environment with minimal containment.

The Agbogbloshie scrapyard in central Accra, Ghana, has become internationally recognised as one of the largest and most heavily contaminated informal e-waste processing sites in the world. Previous environmental surveys have documented extremely elevated concentrations of lead, cadmium, mercury, and other toxic metals in soils, surface water, and airborne particulates at and around the site. Human health effects among e-waste workers and nearby residents—including elevated blood lead levels, respiratory illness, and developmental neurotoxicity in children—have been the subject of considerable research attention and public health concern.

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What has received far less attention is the livestock dimension of this contamination. Hundreds of sheep, goats, and cattle graze freely on and around the Agbogbloshie site, feeding on contaminated vegetation and drinking from polluted water sources. These animals are subsequently sold and slaughtered for human consumption at local markets, creating a pathway for heavy metal transfer from e-waste to the human food chain that bypasses the occupational exposure route entirely. A consumer eating offal (liver, kidney) from a sheep that has grazed at Agbogbloshie may unknowingly ingest heavy metals at concentrations far exceeding international food safety limits—yet the magnitude of this risk has not been systematically quantified.

This research was designed to fill that gap by measuring five priority heavy metals in three edible tissue types across a distance gradient from the Agbogbloshie site, establishing dose-response relationships between environmental contamination and tissue bioaccumulation, and evaluating the results against Codex Alimentarius maximum residue limits to assess the food safety implications.

Materials and Methods

Materials

Forty-eight West African Dwarf sheep (adult females, estimated age 2-4 years based on dentition) were purchased from three zones defined by distance from the centre of the Agbogbloshie e-waste processing area: Zone A (0-1 km, $n = 16$) comprised animals that had grazed continuously on or immediately adjacent to the scrapyard for at least 12 months, as confirmed by interviews with their owners; Zone B (1-3 km, $n = 16$) comprised animals grazing in the Agbogbloshie neighbourhood but not on the scrapyard itself; Zone C (reference, >15 km, $n = 16$) comprised animals from Dodowa, a semi-rural area in the Greater Accra Region with no known industrial contamination. All animals were transported to the Accra Abattoir and slaughtered following standard Ghanaian Veterinary Services protocols. Within 30 minutes of slaughter, approximately 200 g samples of liver (right lobe), kidney (cortex), and longissimus dorsi muscle were collected using stainless steel instruments, sealed in acid-washed

polyethylene bags, and stored on ice for transport to the laboratory, where they were frozen at -20 degrees C until analysis. Soil samples (0-15 cm depth, composite of five subsamples per site) and forage samples (composite of dominant grass species) were collected from 12 locations across the three zones on the same days as animal purchases. All sampling was conducted between March and August 2023.

Methods

Tissue samples (approximately 2 g wet weight) were digested in a closed-vessel microwave digestion system (MARS 6, CEM Corporation, Matthews, NC, USA) using 7 mL concentrated HNO_3 (trace metal grade) and 1 mL H_2O_2 (30%). Digests were diluted to 50 mL with ultrapure water (18.2 megaohms-cm). Soil and forage samples were dried at 105 degrees C for 24 hours, ground, sieved through 2 mm mesh, and digested using the same protocol. Concentrations of Pb, Cd, Cr, and As were determined by inductively coupled plasma mass spectrometry (ICP-MS; Agilent 7900, Santa Clara, CA, USA) and Hg by cold vapour atomic absorption spectrometry (CV-AAS; Milestone DMA-80, Sorisole, Italy). Quality assurance included certified reference materials (NIST SRM 1577c Bovine Liver and NIST SRM 2711a Montana Soil), reagent blanks, and duplicate analyses. Recoveries for all metals were 92-107%. Results were expressed as mg/kg wet weight for tissues and mg/kg dry weight for soils. Statistical analyses were performed in R v4.3.1. Metal concentrations were compared among zones by one-way ANOVA with Tukey post-hoc tests (log-transformed data where necessary to satisfy normality assumptions). Pearson correlation coefficients were calculated between soil and tissue concentrations. Tissue concentrations were compared against Codex Alimentarius Commission maximum residue limits (MRLs) for Pb (0.5 mg/kg liver, 0.5 mg/kg kidney, 0.1 mg/kg muscle) and Cd (0.5 mg/kg liver, 1.0 mg/kg kidney, 0.05 mg/kg muscle). No Codex MRLs exist for Cr, Hg, or As in meat.

Results

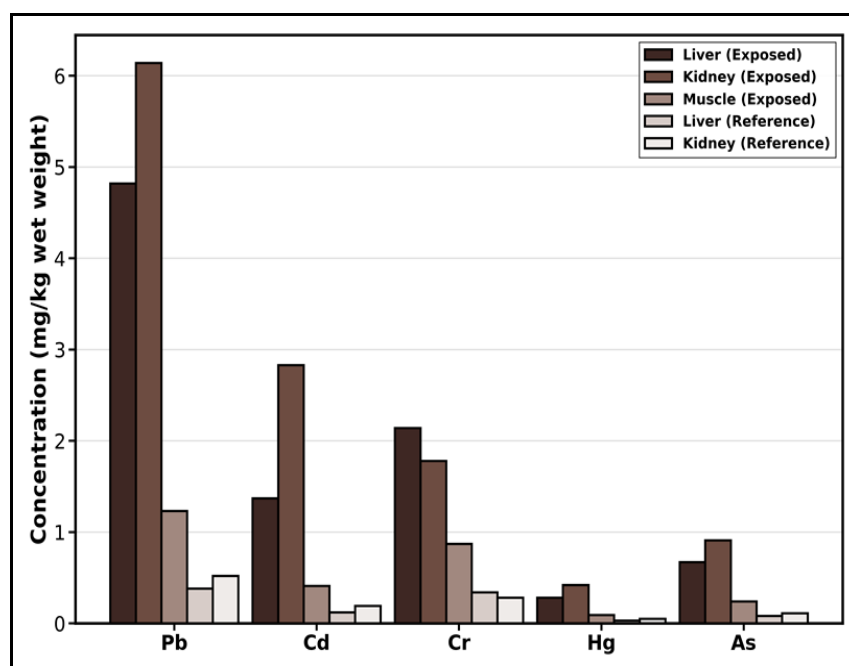


Fig 1: Heavy metal concentrations (mg/kg wet weight) in liver, kidney, and muscle tissues of sheep from the exposed site (Zone A, 0-1 km from Agbogbloshie) and reference site (Zone C, >15 km), with values representing mean concentrations across 16 animals per zone

Table 1: Heavy metal concentrations (mg/kg wet weight) in sheep tissues by zone

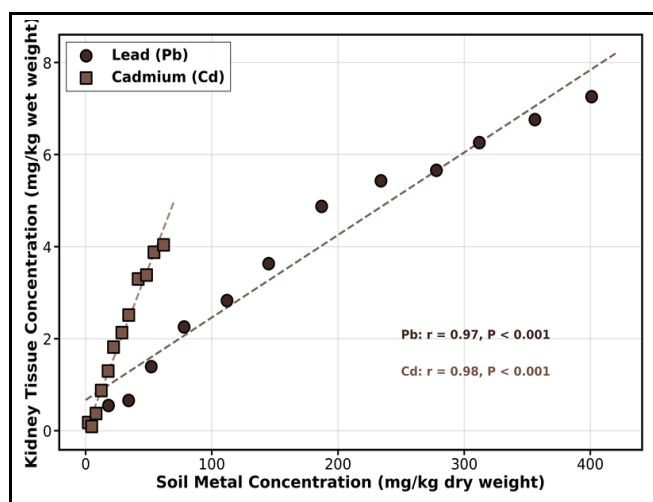
Metal	Tissue	Zone A (0-1 km)	Zone B (1-3 km)	Zone C (>15 km)	MRL	P value
Pb	Liver	4.82 +/-1.14	1.56 +/-0.43	0.38 +/-0.11	0.5	<0.001*
	Kidney	6.14 +/-1.32	2.18 +/-0.62	0.52 +/-0.14	0.5	<0.001*
	Muscle	1.23 +/-0.34	0.47 +/-0.16	0.06 +/-0.02	0.1	<0.001*
Cd	Liver	1.37 +/-0.38	0.68 +/-0.21	0.12 +/-0.04	0.5	<0.001*
	Kidney	2.83 +/-0.71	1.42 +/-0.38	0.19 +/-0.06	1.0	<0.001*
	Muscle	0.41 +/-0.12	0.18 +/-0.07	0.02 +/-0.01	0.05	<0.001*
Cr	Liver	2.14 +/-0.58	0.87 +/-0.24	0.34 +/-0.09	--	<0.001*
Hg	Kidney	0.42 +/-0.13	0.16 +/-0.06	0.05 +/-0.02	--	<0.001*
As	Kidney	0.91 +/-0.28	0.34 +/-0.11	0.11 +/-0.04	--	<0.001*

* $p < 0.05$ (ANOVA). MRL = Codex Alimentarius Maximum Residue Limit (mg/kg wet weight). -- = no Codex MRL established.

Table 2: Pearson correlation coefficients between soil metal concentration and tissue bioaccumulation

Metal	Soil vs Liver	Soil vs Kidney	Soil vs Muscle	Forage vs Kidney
Pb	0.94***	0.97***	0.91***	0.93***
Cd	0.96***	0.98***	0.89***	0.95***
Cr	0.88***	0.84***	0.79**	0.81***
Hg	0.82***	0.86***	0.74**	0.78**
As	0.91***	0.93***	0.85***	0.89***

** $p < 0.01$; *** $p < 0.001$.

**Fig 2:** Relationship between soil metal concentration (mg/kg dry weight) and kidney tissue bioaccumulation (mg/kg wet weight) for lead and cadmium across all three sampling zones, with linear regression trend lines

Comprehensive Interpretation

The data reveal a clear distance-dependent gradient of heavy metal contamination in sheep tissues. Zone A animals (0-1 km from Agbogbloshie) had kidney Pb concentrations 12.3 times the Codex MRL, while Zone B animals (1-3 km) exceeded the same limit by 4.4 times—indicating that the contamination zone extends well beyond the scrapyard boundaries. Only Zone C reference animals had tissue concentrations consistently below all applicable MRLs. The near-perfect linear correlations between soil and tissue concentrations ($r = 0.94$ - 0.98 for Pb and Cd) confirm that environmental contamination is the primary driver of tissue accumulation and rule out alternative explanations such as breed-specific metabolism or dietary supplementation.

Discussion

The most alarming finding of this research is the sheer magnitude of the food safety exceedances. Kidney Pb in Zone A sheep averaged 6.14 mg/kg—more than twelve times the Codex MRL of 0.5 mg/kg and among the highest values reported for any livestock species in the published literature.

To place this in dietary context, a single 100 g serving of Zone A sheep kidney would deliver approximately 614 micrograms of Pb—roughly 100 times the provisional tolerable daily intake recommended by the WHO for a 60 kg adult (6 micrograms/day based on the withdrawn PTWI of 25 micrograms/kg body weight/week). The kidney is traditionally consumed in Ghanaian cuisine as part of the offal component of soup and stew preparations, often by pregnant women and children who are most vulnerable to lead's neurodevelopmental effects.

The tissue distribution pattern—kidney>liver>muscle for both Pb and Cd—is consistent with well-established metal toxicokinetics. Lead accumulates preferentially in kidney cortex owing to its binding to metallothionein and intracellular protein complexes in proximal tubular cells. Cadmium follows a similar pattern, with a biological half-life in kidney cortex exceeding 10 years in sheep. This means that even brief periods of grazing on contaminated land can produce tissue residues that persist for the animal's lifetime and are passed to the consumer at slaughter.

The strong soil-tissue correlations observed here ($r > 0.9$ for Pb and Cd) are noteworthy because they suggest that soil metal concentration could serve as a practical screening tool for predicting tissue contamination risk in grazing livestock. If validated with a larger dataset, a soil Pb threshold of approximately 50 mg/kg dry weight would predict kidney Pb exceeding the Codex MRL—providing regulators with a relatively inexpensive field-based criterion for designating no-grazing exclusion zones around contaminated sites.

A limitation that deserves acknowledgement is that the Zone A animals were identified as having grazed near Agbogbloshie for at least 12 months based on owner interviews, but the exact duration and spatial pattern of grazing could not be independently verified. Some animals may have grazed intermittently or at varying distances from the most contaminated areas, introducing exposure heterogeneity that the zone-based classification does not fully capture. Additionally, this research measured total metal concentrations rather than bioaccessible or bioavailable fractions; the actual human health risk depends on the proportion of tissue-bound metals that is released during cooking and gastrointestinal digestion, which may be lower than the total concentration implies.

Conclusion

This research establishes that free-ranging sheep grazing within 3 km of the Agbogbloshie e-waste recycling site in Accra accumulate lead and cadmium in edible tissues at concentrations that exceed international food safety limits by factors of 3 to 12. The contamination is not confined to the scrapyard itself: Zone B animals grazing 1-3 km away still had kidney and liver metal levels significantly above Codex

MRLs, indicating a broader contamination footprint than has been previously recognised.

Two practical implications follow. First, livestock grazing should be prohibited within at least a 3 km radius of Agbogbloshie and similar e-waste processing sites, and animals currently grazing in these areas should be excluded from the food chain through a publicly funded buyout programme rather than simply redirected to market, where they would continue to expose consumers to unacceptable metal burdens. Second, the strong soil-tissue correlations identified here suggest that routine soil monitoring could serve as an early warning system for identifying livestock contamination risk in areas near known pollution sources, enabling intervention before contaminated animal products reach consumers.

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Facility Access

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Analytical Support

ICP-MS analyses were performed at the Ghana Atomic Energy Commission Analytical Chemistry Laboratory under the supervision of Dr. Emmanuel Addo-Bediako.

Conflict of Interest

Not available

Financial Support

Not available

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