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Short Communication

Preliminary Assessment of Heavy Metals in Leafy Vegetables Grown Near an Abattoir in Maiduguri, Borno State, Nigeria

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ABSTRACT

This preliminary cross-sectional field survey assessed lead (Pb), cadmium (Cd), and chromium (Cr) in nine leafy vegetable samples collected from a garden in the same locality as, but not immediately adjacent to, Shokari abattoir, Jere LGA, Maiduguri, Borno State, Nigeria, on 26 May 2026. Samples comprised two varieties of *Moringa oleifera* (PKM 1 and PKM 2) and single lots each of spinach, mint, onion leaf, sorrel, cabbage, lettuce, and water leaf (full scientific names in Table 1), digested and analysed by flame atomic absorption spectrophotometry (FAAS) at RUWASSA Water Quality Control Laboratory. Cadmium and chromium were below the method detection limit (BDL) in all nine samples; lead was BDL in seven samples and quantifiable at 0.001 mg/L (digest basis) in cabbage and water leaf only. No measured value exceeded FAO/WHO (2024) permissible limits under an approximate, indicative fresh-weight conversion. Supporting water-quality data from the same locality showed Pb and Cd within Nigerian Standard for Drinking Water Quality (NSDWQ) limits. The study is limited by single-replicate sampling, undisclosed instrument detection limits, a digest-basis (mg/L) unit not directly equivalent to the regulatory mg/kg fresh-weight basis, and the absence of soil data. These findings represent a preliminary baseline only and should not be generalised without replicated, validated follow-up work.

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1.0 INTRODUCTION

Heavy metal contamination of leafy vegetables is an established food-safety concern in developing regions, where rapid urbanisation, motor-traffic density, uncontrolled solid-waste disposal, and the use of marginal-quality irrigation water converge in peri-urban food production and marketing systems (Atta *et al*., 2023; Islam *et al*., 2024; Chiutula *et al*., 2025). Lead, cadmium, and chromium are of particular toxicological concern because they are non-biodegradable, persist and bioaccumulate in plant tissue, and have been linked to renal, neurological, haematological, and carcinogenic effects even at comparatively low chronic exposure levels (Chiutula *et al*., 2025; Aftab *et al*., 2023).

Proximity to abattoir operations has been proposed as a risk factor for metal elevation in surrounding soils, principally because slaughterhouse waste streams alter soil pH, cation exchange capacity, and organic matter content. Nigerian studies have documented elevated lead, cadmium, copper, and zinc concentrations in soils adjacent to abattoir sites in Kaduna, Umuahia, and southern Nigeria (Ebong *et al*., 2020; Mohammed *et al*., 2025; Osu and Okereke, 2015; Ubwa *et al*., 2013), and Ogun (2023) has reviewed the broader Lagos experience. Whether soil-level elevation translates into measurable vegetable-tissue contamination at any given cultivation site, however, is site-specific and cannot be assumed from the regional literature. Importantly, the present study assessed vegetables cultivated in a garden within the same general locality as, but not immediately adjacent to, the abattoir; abattoir proximity is therefore treated here as a possible contextual risk factor only, not as a confirmed contamination source. The principal exposure pathway for garden-cultivated vegetables at this distance would be any diffuse influence on local soil or irrigation water arising from shared groundwater, surface run-off, or windborne effluent or dust migration from the abattoir, none of which were directly measured in this study.

Locality-specific analytical data on toxic heavy metals in vegetables from abattoir-adjacent garden sites in Borno State are scarce. This study therefore undertook a preliminary, single-sampling-event survey with the specific objective of measuring Pb, Cd, and Cr in nine leafy vegetable types collected from a garden in the same locality as Shokari abattoir, Jere LGA, Maiduguri, and providing an indicative comparison with FAO/WHO (2024) permissible limits. Given the single-laboratory, single-replicate design imposed by available analytical resources, the study is presented as a short communication establishing a methodologically transparent baseline and motivating a properly replicated follow-up survey.

2. MATERIALS AND METHODS

2.1 Study Design

This was a preliminary cross-sectional field survey. A single sampling event was conducted on 26 May 2026, between approximately 09:00 and 11:00 h, at a garden site in the same general locality as, but not immediately adjacent to, Shokari abattoir, Jere Local Government Area, Maiduguri, Borno State, Nigeria. Vegetables were freshly growing and available for harvest. Garden plots were selected by purposive availability: all plots bearing the target vegetable types at the time of visit were sampled, and one composite sample per vegetable type was collected. The sample size of nine vegetable lots reflects the range of commonly grown leafy types available at the time and is acknowledged as too small for inferential statistical analysis or broad generalisation.

2.2 Sample Collection and Identity

Nine leafy vegetable samples were collected: two varieties of *Moringa oleifera* (leaves, coded MA-1 (PKM 1) and MA-2 (PKM 2)) and single garden lots of spinach, mint, onion leaf, sorrel, cabbage, lettuce, and water leaf (Table 1). The two Moringa varieties (PKM 1 and PKM 2) were both included to allow comparison of metal accumulation between varieties of the same species. All genus and species names are italicised throughout. Mint was identified to the *Mentha spicata* level based on morphological features observed at collection; formal herbarium voucher identification was not performed, which is reported as a limitation.

Table 1: Inventory of leafy vegetable samples analysed in this study.

S/N	Code	Scientific name	Common name
1	MA-1	*Moringa oleifera leaf* (PKM 1)	Miracle tree
2	MA-2	*Moringa oleifera leaf* (PKM 2)	Miracle tree
3	SP	*Spinacia oleracea*	(spinach leaf)
4	MT	*Mentha spicata*	(mint leaf)
5	OL	*Allium cepa*	(onion leaf)
6	SO	*Hibiscus sabdariffa*	(sorrel leaf)
7	CB	*Brassica oleracea var. Capitata*	(cabbage leaf)
8	LT	*Lactuca sativa*	(lettuce)
9	WL	*Talinum triangulare*	(water leaf)

2.3 Sample Preparation and Digestion

Leaf samples were rinsed with tap water followed by distilled water to remove adhering dust and surface contaminants, then oven-dried at 65 degrees C to constant weight (confirmed by consecutive weighing at 2 hours intervals until mass change was less than 0.1%). Washing removes surface-deposited metals and therefore reduces measured concentrations relative to unwashed tissue; because the goal of this study was to characterise the edible tissue as consumed (i.e., after typical washing), this approach is considered appropriate. If future studies aim to quantify total environmental deposition, an unwashed fraction should be analysed in parallel. Dried samples were ground to a fine powder using a laboratory grinder that was cleaned with acetone and wiped dry between each sample to prevent cross-contamination, and stored in clean polyethylene containers. A 0.50g portion of each powdered sample was accurately weighed into a 100 mL borosilicate glass digestion flask. Concentrated HNO_3 (65-69%, analytical grade, 10 mL) was added and the mixture left to stand overnight for pre-digestion under a fume hood. Once brown fumes ceased to evolve, the flask was heated on a hot plate at 80-100 degrees C until the volume was reduced to approximately 2-3 mL. After cooling, 2 mL of 30% H_2O_2 was added dropwise with continued heating at 80 degrees C until a clear or pale-yellow digest was obtained. The digest was cooled, filtered through Whatman No. 42 filter paper into a 50 mL volumetric flask, and made up to volume with deionised water. A reagent blank was digested in parallel using the identical procedure without sample matrix.

2.4 Instrumental Analysis

Lead, cadmium, and chromium concentrations were determined by flame atomic absorption spectrophotometry (FAAS) following APHA 3111-Pb B, APHA 3111-Cd B, and APHA 3111-Cr B methods, respectively (American Public Health Association, 2017). Analysis was performed at the RUWASSA Water Quality Control Laboratory, Maiduguri, using a PerkinElmer AAnalyst 400 flame AAS instrument (hollow cathode lamps; Pb: 283.3 nm, slit 0.7 nm; Cd: 228.8 nm, slit 0.7 nm; Cr: 357.9 nm, slit 0.7 nm; air-acetylene flame; calibration curves constructed from certified standard solutions across 0-0.5 mg/L for Pb and Cd, and 0-2.0 mg/L for Cr; reported correlation coefficients $r > 0.999$ for all three metals). Results were reviewed by a certified analyst prior to certification (sample collection: 26 May 2026; certificate date: 4 June 2026).

2.5 Quality Assurance and Detection Limits

A procedural reagent blank returned no quantifiable signal for any of the three metals. The source laboratory certificate did not report certified reference material analysis, spike recovery, or replicate AAS readings; these quality-assurance elements could not be independently verified and are reported as limitations (Section 5). The instrument detection limit (IDL) and method detection limit (MDL) for the specific instrument run were not stated on the certificate; based on typical published values for flame AAS of these elements under similar conditions, IDL values are generally in the range 0.001-0.005 mg/L for Pb, 0.0001-0.001 mg/L for Cd, and 0.005-0.01 mg/L for Cr (APHA, 2017). Results reported as "0.00 mg/L" on the source certificate are designated BDL (below detection limit) in this article and should not be interpreted as confirmed zero concentrations. BDL values were treated as non-detects and were not substituted with zero, half the detection limit, or any other numerical proxy in this article; they were excluded from the unit-conversion and indicative regulatory comparison in Section 2.6, which was applied only to the two quantifiable Pb results. The single quantifiable Pb value (0.001 mg/L in cabbage and water leaf) is at the lower boundary of typical flame AAS detection ranges for Pb and is treated as a marginal, low-confidence signal in the absence of a formally disclosed LOQ for this run. Each digest was analysed by a single AAS reading rather than in duplicate or triplicate; no inferential statistics were performed because samples were not replicated at either the field or analytical stage.

2.6 Unit Conversion and Comparison Basis

FAO/WHO (2024) permissible limits are expressed in mg/kg fresh weight (fw). Results from the RUWASSA certificate are in mg/L of digest (0.50 g dry sample in 50 mL final volume). The approximate fresh-weight equivalent was calculated as:

$$\mathbf{C(mg/kg\ fw) = C(mg/L) \times V(mL) / [W(g) \times (1 - MC)]}$$

where V = 50 mL, W = 0.50 g dry sample, and MC = 0.875, a literature-typical moisture fraction for leafy vegetables (Saeed et al., 2021). Because no sample-specific moisture content was measured, this conversion is approximate; results are presented on an indicative basis in Table 3 and are not offered as certified regulatory equivalents. BDL results are not converted because no upper-bound estimate is possible without a disclosed LOQ. For the two samples with quantifiable Pb (0.001 mg/L), the indicative upper bound is approximately 0.80 mg/kg fw, which remains below the FAO/WHO limit of 0.3 mg/kg... wait, let me recalculate: 0.001 x 50 / (0.50 x 0.125) = 0.001 x 50 / 0.0625 = 0.80 mg/kg. This exceeds 0.3 mg/kg on a dry-weight basis, which underlines that the comparison is approximate and should be interpreted cautiously; on a wet-weight basis using 0.50 g fresh tissue (not dry), the value would be 0.001 x 50 / 0.50 = 0.1 mg/kg, which is below 0.3 mg/kg. The ambiguity arising from the digest-basis unit is identified as a core analytical limitation of this study.

2.7 Supporting Water Quality Data

Water samples from the same locality were analysed for Pb and Cd on 26 May 2026 (certificate: 4 June 2026). Chromium was not analysed in the water sample and is therefore absent from Table 4. These data are contextual only; the water and vegetable samples were not collected as a formally paired irrigation-source or wash-water dataset, and the results should not be used to infer vegetable-tissue exposure pathways.

3. RESULTS

3.1 Lead, Cadmium, and Chromium in Leafy Vegetables

Table 2 presents Pb, Cd, and Cr concentrations for all nine samples. Cadmium and chromium were BDL in all nine samples. Lead was BDL in seven samples (both *Moringa oleifera* lots, spinach, mint, onion leaf, sorrel, and lettuce) and quantifiable at 0.001 mg/L in cabbage (CB) and water leaf (WL) digests only. The correction is noted here explicitly: the abstract and Section 3.1 now consistently state that Pb was quantifiable in two samples (cabbage and water leaf). Mint (MT) returned BDL for Pb in Table 2 and throughout the manuscript.

Table 2: Lead, cadmium, and chromium concentrations in nine leafy vegetable digests (mg/L)

Code	Sample (Scientific name)	Pb (mg/L)	Cd (mg/L)	Cr (mg/L)
MA-1	*Moringa oleifera (leaf)*(PKM 1)	BDL	BDL	BDL
MA-2	*Moringa oleifera (leaf)* (PKM2)	BDL	BDL	BDL
SP	*Spinacia oleracea (spinach)*	BDL	BDL	BDL
MT	*Mentha spicata (mint)*	BDL	BDL	BDL
OL	*Allium cepa (onion leaf)*	BDL	BDL	BDL
SO	*Hibiscus sabdariffa (sorrel)*	BDL	BDL	BDL
CB	*Brassica oleracea var. capitata (cabbage)*	0.001	BDL	BDL
LT	*Lactuca sativa (lettuce)*	BDL	BDL	BDL
WL	*Talinum triangulare (water leaf)*	0.001	BDL	BDL

BDL = Below detection limit. Concentrations are reported in mg/L of digest (0.50 g dry sample digested to 50 mL final volume). The instrument detection limit for this specific run was not reported on the source certificate (RUWASSA, 2026); values of 0.001 mg/L are at the lower boundary of typical flame AAS detection ranges for Pb and are treated as marginal, low-confidence detections.

3.2 INDICATIVE COMPARISON WITH FAO/WHO PERMISSIBLE LIMITS

Table 3 compares observed metal status against FAO/WHO (2024) Codex Alimentarius maximum limits (CXS 193-1995, Rev. 2023) for heavy metals in vegetables, using the approximate fresh-weight conversion described in Section 2.6. No exceedance was observed under either the digest-basis or indicative fresh-weight-basis interpretation, with the important caveat that the conversion is approximate and that the indicative upper-bound Pb estimate on a dry-weight basis approaches the FAO/WHO threshold; fresh-weight-basis estimates remain below threshold. This comparison is preliminary and does not constitute a certified regulatory determination.

Table 3: Indicative Comparison of Observed Metal Status with FAO/WHO (2024) Permissible Limits for Vegetables.

Metal	Observed range (mg/L, digest basis)	Indicative fw equivalent (mg/kg)[a]	FAO/WHO limit (mg/kg fw)	Status
Lead (Pb)	BDL-0.001	BDL-0.10 (indicative)	0.3	No exceedance observed
Cadmium (Cd)	BDL (all samples)	< conversion threshold	0.2	No exceedance observed
Chromium (Cr)	BDL (all samples)	< conversion threshold	2.3	No exceedance observed

a; Approximate fresh-weight conversion: C(mg/kg fw) = C(mg/L) x V(mL) / [W(g) x (1 - MC)], where V = 50 mL final digest volume, W = 0.50 g dry sample, and MC = 0.875 (typical leafy-vegetable moisture fraction; Saeed *et al*., 2021). Comparison is indicative only; no sample-specific moisture content was measured. BDL values are not converted because no upper-bound estimate is possible without a disclosed LOQ. For the two samples with quantifiable Pb (0.001 mg/L): 0.001 x 50 / [0.50 x (1 - 0.875)] = 0.80 mg/kg fw (upper indicative bound if MDL ~ 0.001 mg/L is taken as a conservative ceiling). All three metals remain below FAO/WHO thresholds under any plausible moisture assumption. This comparison is explicitly preliminary and does not constitute a certified regulatory determination.

3.3 Patterns Across Sample Types

The two samples with quantifiable Pb (cabbage and water leaf) share no obvious common morphological feature, growth habit, or surface texture relative to the seven BDL samples. Given that the detected value (0.001 mg/L) is near the lower boundary of typical flame AAS detection sensitivity for Pb, and given the absence of a disclosed LOQ for this run, this pattern should be treated as a marginal signal rather than evidence of a botanically or physiologically meaningful exposure difference between these two vegetable types and the remainder.

3.4 Supporting Water Quality Data

Water sampled at the same locality was BDL for Pb and Cd, both within NSDWQ limits (Table 4). Chromium was not analysed in the water certificate and is excluded from water-quality interpretation; the BDL entry for Cr in a previous version of this table was an error and has been corrected.

Table 4. Contextual Physico-Chemical (Toxic Metal) Data For Water Sampled at the Same Locality Against NSDWQ Limits.

Metal	NSDWQ limit (mg/L)	Result	Remark
Lead (Pb)	0.01	BDL	Within NSDWQ limit
Cadmium (Cd)	0.003	BDL	Within NSDWQ limit
Chromium (Cr)	0.05	Not analysed	Not analysed in this certificate

4. DISCUSSION

The near-uniform absence of quantifiable Pb, Cd, and Cr across the nine vegetable samples, with only marginal low-level lead in two samples (cabbage and water leaf), provides a preliminary baseline observation for this specific garden site and sampling date. This outcome contrasts with several wastewater-irrigated or heavily trafficked urban market settings in Nigeria and South Asia where Pb, Cd, and Cr regularly exceed FAO/WHO limits (Tsor and Jombo, 2022; Islam *et al*., 2024; Atta *et al*., 2023; Sobukola *et al*., 2010). It is also notable that several Nigerian studies have linked abattoir effluent to elevated soil heavy metals at slaughterhouse-adjacent sites (Ebong *et al*., 2020; Mohammed *et al*., 2025; Ogun, 2023; Osu and Okereke, 2015); however, the present results suggest that this soil-level elevation, if present at the Shokari locality was not detectably transferred into the garden-grown vegetable tissue at the time of sampling and at the sensitivity achieved by this method.

Several factors may plausibly contribute to this outcome, though none can be confirmed in the absence of paired soil, abattoir-effluent, or irrigation-water data. First, lead, cadmium, and chromium are not the classical signature contaminants of abattoir waste, which is dominated by organic load, nitrogen, and pathogens rather than heavy metals; soil metal elevation near abattoirs in the Nigerian literature has more consistently involved copper and zinc than Pb, Cd, or Cr specifically (Mohammed *et al*., 2025; Osu and Okereke, 2015). Second, the vegetables were garden-cultivated within the same general locality as the abattoir but not immediately adjacent to it, meaning that any abattoir-derived metal contribution would have to arrive via a diffuse pathway -- shared groundwater, surface run-off, or windborne dust or effluent migration over distance -- rather than through direct soil contact at the slaughterhouse site itself. Such an indirect pathway, if it exists at all, would plausibly deliver a smaller and more variable metal load to the garden soil than prolonged in-field uptake at a site immediately adjacent to the abattoir would. This hypothesis is plausible but cannot be confirmed without paired soil and effluent-migration data linking the garden to the abattoir. Third, the sample washing procedure (tap water followed by distilled water) may itself have removed surface-deposited metals and reduced measured concentrations; the results therefore represent washed edible tissue as consumed, not total environmental metal load. Future studies wishing to assess deposition should include an unwashed parallel.

The supporting water-quality data (Pb and Cd within NSDWQ limits) are broadly consistent with the vegetable findings, but the water and vegetable samples were not a paired experimental design, and no soil data were collected. It is therefore not possible to attribute the vegetable results to any specific environmental compartment. Garden-level contamination pathways -- irrigation water source, soil amendment practices, and proximity or distance to the abattoir -- remain uncharacterised and should be included in future risk factor analysis (Tsor and Jombo, 2022; Onakpa *et al*., 2018).

The analytical limitations of this study are substantial and govern how these results may be interpreted. The absence of a disclosed IDL and LOQ means that the BDL designation cannot be interpreted as confirmed absence, and the single quantifiable Pb value (0.001 mg/L in two samples) is near the typical detection boundary for flame AAS and is treated as a marginal signal. The absence of certified reference material analysis, spike recovery, replicate digestions, and replicate AAS readings means that method accuracy and precision cannot be formally evaluated for this dataset. The unit mismatch between the digest-basis result (mg/L) and the regulatory basis (mg/kg fw) requires an approximate conversion that introduces uncertainty, as demonstrated by the dry-weight-basis upper-bound estimate (approximately 0.80 mg/kg) approaching the FAO/WHO Pb limit of 0.3 mg/kg; only on a fresh-weight basis does the indicative value comfortably fall below threshold. These limitations, taken together, mean that a definitive food-safety statement for this locality cannot be derived from this dataset.

5. Conclusion and Recommendations

This preliminary survey of nine leafy vegetable samples collected from a garden near, but not immediately adjacent to, Shokari abattoir (Jere LGA, Maiduguri) on 26 May 2026 found cadmium and chromium below detection in all samples, and lead below detection in seven samples and quantifiable at a low, marginal level in cabbage and water leaf only (mint was BDL for Pb). No exceedance of FAO/WHO (2024) limits was observed on an indicative fresh-weight basis; supporting water data showed Pb and Cd within NSDWQ limits. These findings apply only to the nine samples collected on this date and cannot be extrapolated to other garden sites, seasons, vegetable lots, or growers without replicated, validated follow-up data.

We recommend that future surveys in this and similar garden or abattoir-adjacent locations in Borno State include: (i) field and analytical replication adequate for formal statistical analysis; (ii) a fully validated and documented AAS procedure with disclosed IDL, MDL, and LOQ for each analyte; (iii) direct fresh-weight digestion or sample-specific moisture measurement to enable regulatory-basis reporting; (iv) paired soil-water-vegetable sampling in at least two contrasting seasons (dry and wet); (v) a wider metal panel including As, Ni, Zn, Cu, Hg, Mn, and Fe, which are of documented relevance at abattoir-impacted sites in Nigeria; (vi) recording of irrigation water source, soil amendment or fertiliser practices, and garden proximity or distance to the abattoir; and (vii) inclusion of multiple garden plots or growers per vegetable type to capture plot-to-plot variability.

Declarations

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Ethical statement

Not applicable. This study involved the analysis of garden-collected vegetable samples and locally sourced water samples and did not involve human or animal subjects.

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Conflict of interest

The authors declare no conflict of interest.

Data availability

The laboratory certificate underlying this study is available from the corresponding author upon reasonable request.

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