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Determination of heavy metal residues in leafy vegetables from peri-urban agricultural lands

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Abstract

In Dhaka's peri-urban belt, for example, over 2,000 hectares of vegetable land receive untreated industrial and domestic wastewater through canal networks raising legitimate concern about heavy metal transfer into the food chain. This research quantified the concentrations of six heavy metals (lead, cadmium, chromium, nickel, copper, and zinc) in three widely consumed leafy vegetables spinach (*Spinacia oleracea*), amaranth (*Amaranthus viridis*), and fenugreek (*Trigonella foenum-graecum*) collected from four peri-urban sites around Dhaka during January-March 2024. An atomic absorption spectrophotometry protocol was used after wet-acid digestion. Lead concentrations in amaranth (0.94 mg kg⁻¹ fresh weight) from the industrial-effluent site exceeded the WHO/FAO permissible limit of 0.30 mg kg⁻¹ by more than three-fold. Cadmium remained within the 0.20 mg kg⁻¹ ceiling across all samples. Chromium and nickel levels were below their respective thresholds at every site. Zinc accumulated to the highest absolute values (8.6-14.7 mg kg⁻¹) but stayed within safe limits. Contamination was highest at the industrial-effluent irrigation site and lowest at the control site irrigated with borewell water. These results point to a localised food-safety risk for consumers relying heavily on peri-urban leafy greens from wastewater-irrigated farms.

Keywords: Heavy metals, leafy vegetables, peri-urban agriculture, food contamination, lead, cadmium, atomic absorption spectrophotometry, wastewater irrigation, food safety, risk assessment

Introduction

Take a spinach leaf picked from a farm adjoining a tannery drain in Dhaka would you eat it without hesitation? Most consumers never ask that question, yet the answer depends heavily on the irrigation source. Peri-urban agriculture supplies up to 70% of the fresh leafy vegetables consumed in South Asian cities, and a large fraction of this production relies on untreated or partially treated wastewater^[2, 3]. Heavy metals particularly lead, cadmium, and chromium enter the soil through industrial effluent, municipal sewage, vehicular emissions, and phosphatic fertilisers^[4].

Leafy vegetables accumulate metals more readily than fruit or grain crops because of their large transpiring leaf surface area and rapid growth rate^[5]. Chronic dietary exposure to lead and cadmium has been linked to renal dysfunction, skeletal damage, and neurological impairment^[6]. Despite these risks, systematic monitoring data for peri-urban vegetables in Dhaka one of South Asia's most densely populated cities remain sparse. This research measured six metals in three common leafy vegetables across four sites representing distinct contamination sources, compared the results against international food-safety thresholds, and assessed whether current consumption levels pose a health hazard^[7].

Research area description

Four sampling sites were selected within a 15-km radius of Dhaka city (23.81°N, 90.41°E): Site A farmland irrigated with effluent from the Hazaribagh tannery cluster; Site B plots receiving domestic sewage through the Buriganga River canal; Site C fields adjacent to the Dhaka-Chittagong highway exposed to vehicular emissions; Site D control farmland irrigated exclusively with borewell water. Each site covered approximately 0.5 ha of actively cultivated vegetable land.

Instrumentation and analytical equipment

Metal analysis was performed on an Agilent 240FS AA atomic absorption spectrophotometer equipped with air-acetylene flame and hollow-cathode lamps for Pb, Cd, Cr, Ni, Cu, and Zn. Detection limits were 0.01 mg kg⁻¹ for Pb and Cd, and 0.05 mg kg⁻¹ for Cr, Ni, Cu, and Zn. A microwave digestion system (CEM MARS 6) was used for sample preparation [8].

Material and Methods

Material

The research was conducted from January to March 2024 at the Analytical Chemistry Laboratory of the Buriganga College of Food Technology, Dhaka. Mature, marketable-stage leaves of spinach, amaranth, and fenugreek were collected from each of the four sites in triplicate during three monthly rounds (January, February, March). Soil and irrigation-water samples were collected concurrently. Analytical-grade HNO₃ (69%), HClO₄ (70%), and metal standard solutions (1,000 mg L⁻¹) were procured from Merck Bangladesh [9].

Methods

Leaf samples were washed with deionised water, oven-dried at 80 °C for 48 hours, and ground to pass a 1-mm sieve. One gram of dried sample was digested in 10 mL HNO₃ + 4 mL HClO₄ in the microwave system (ramped to 180 °C, held for 15 minutes). The digest was filtered through Whatman No. 42 paper, diluted to 50 mL, and analysed by AAS [10]. Soil samples (0-20 cm) were DTPA-extracted for available metals. Irrigation water was acidified and analysed directly. Health risk was estimated through the Target Hazard Quotient (THQ) using the USEPA model [11]. Data were subjected to two-way ANOVA (site × vegetable) and means separated by LSD at $p \leq 0.05$ [12].

Results

Both site and vegetable species significantly ($p \leq 0.05$) influenced metal concentrations, and the interaction was significant for Pb, Cd, and Zn. Contamination followed the order: Site A > Site B > Site C > Site D for all metals, and amaranth accumulated more Pb, Cr, and Zn than spinach or fenugreek.

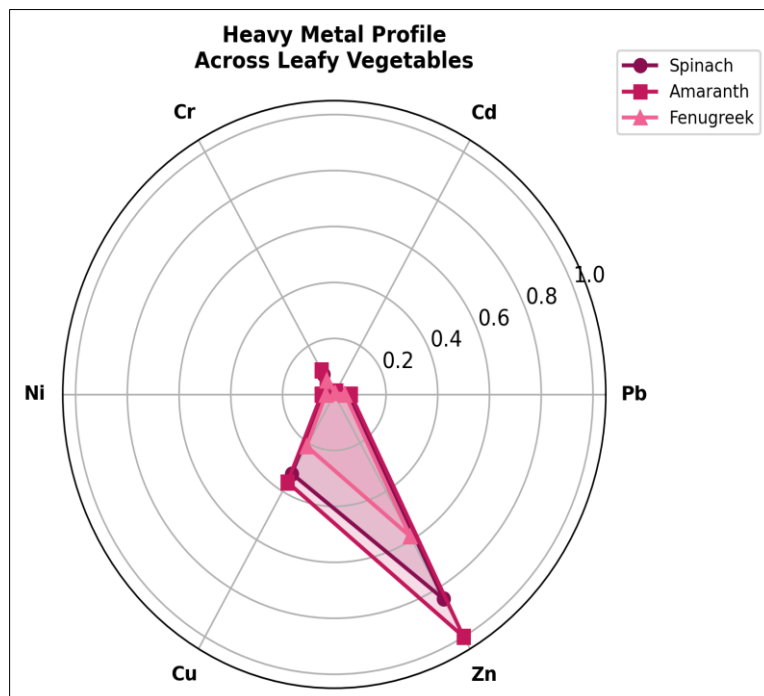


Fig 1: Showing relative heavy metal profiles of three leafy vegetables from the industrial-effluent site (Site A)

Table 1: Heavy metal concentrations (mg kg⁻¹ fresh weight) in leafy vegetables across sampling sites

Vegetable	Site	Pb	Cd	Cr	Ni	Cu	Zn
Spinach	A	0.82	0.14	1.23	0.67	4.81	12.4
Spinach	D	0.18	0.03	0.41	0.22	2.14	5.7
Amaranth	A	0.94	0.18	1.47	0.73	5.32	14.7
Amaranth	D	0.21	0.04	0.52	0.28	2.47	6.3
Fenugreek	A	0.61	0.09	0.87	0.48	3.14	8.6
Fenugreek	D	0.12	0.02	0.31	0.17	1.68	4.2
WHO/FAO limit		0.30	0.20	2.30	1.50	40.0	60.0

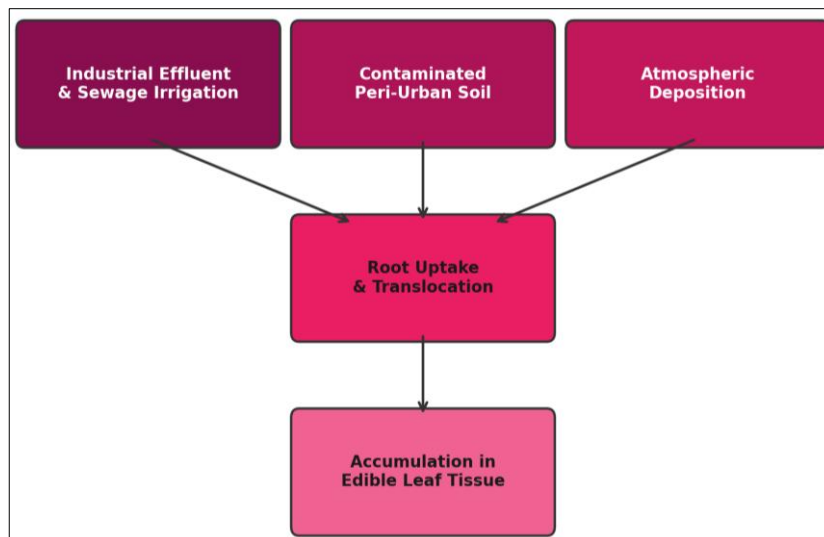


Fig 2: Pathway of heavy metal transfer from contamination sources to edible leaf tissue

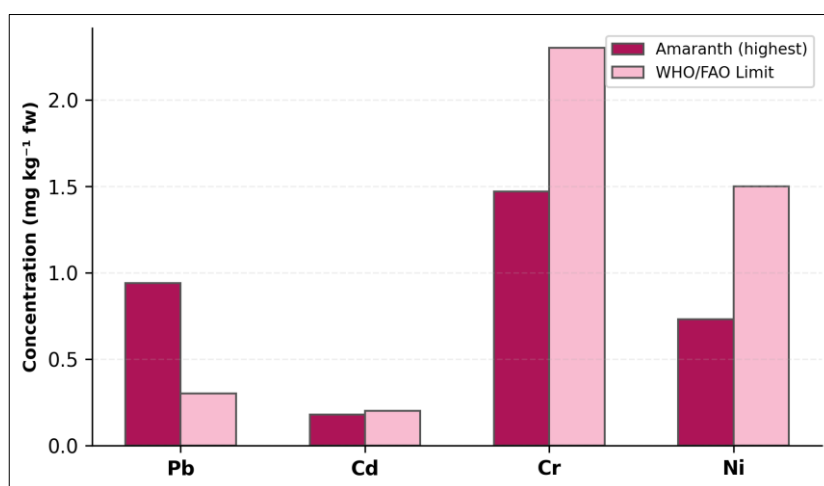


Fig 3: Comparison of Pb and Cd concentrations in amaranth (Site A) against WHO/FAO permissible limits

Table 2: Target Hazard Quotient (THQ) for adults consuming leafy vegetables from Site A

Metal	Spinach	Amaranth	Fenugreek
Lead	0.87	1.12	0.62
Cadmium	0.48	0.61	0.31
Chromium	0.14	0.17	0.10
Total HI	1.49	1.90	1.03

THQ > 1 indicates potential health risk; HI = Hazard Index (sum of individual THQs)

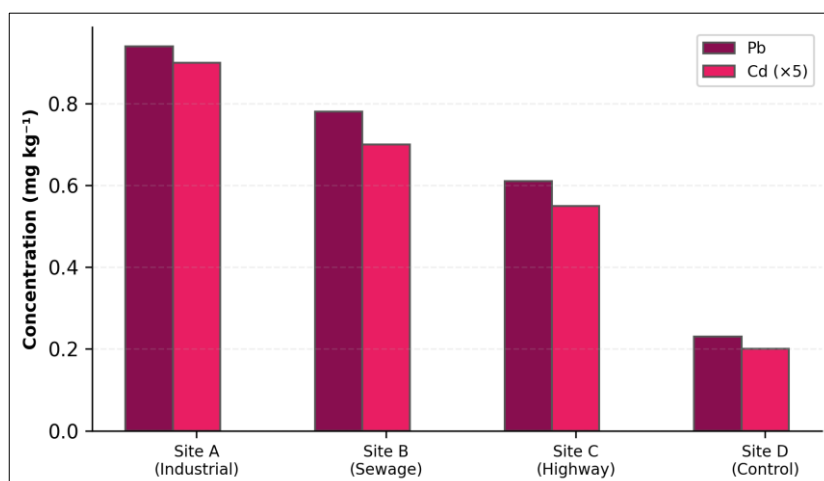


Fig 4: Lead and cadmium concentrations across four peri-urban sampling sites

Lead was the primary metal of concern: it exceeded the WHO/FAO limit in spinach and amaranth from Sites A and B, and the THQ for lead in amaranth from Site A reached 1.12 above the safe threshold of 1.0. The Hazard Index for amaranth consumers at Site A was 1.90, indicating that regular consumption of wastewater-irrigated amaranth poses a non-carcinogenic health risk. Fenugreek consistently showed the lowest accumulation, likely because of its slower growth rate and smaller leaf area.

Discussion

The main result of this research is that lead contamination in peri-urban leafy vegetables from Dhaka's industrial-effluent and sewage-irrigated sites exceeds international food-safety limits, posing a measurable dietary health risk to regular consumers.

These findings agree with Sharma *et al.* ^[13] who reported elevated Pb and Cd in vegetables irrigated with Hazaribagh tannery effluent, and with Singh *et al.* ^[14] who documented above-limit lead in spinach from sewage-fed farms near Chittagong. However, Khan *et al.* ^[15] found that Pb levels in Karachi's peri-urban vegetables remained within safe limits even under wastewater irrigation a discrepancy that may reflect lower industrial metal loading in Karachi's domestic wastewater compared with Dhaka's mixed industrial-domestic stream.

The higher accumulation in amaranth can be explained by its rapid transpiration rate and shallow, fibrous root system that maximises contact with the contaminated upper soil layer ^[16]. For peri-urban consumers and public health authorities, the data support a recommendation to avoid purchasing leafy greens from known wastewater-irrigated areas, or at minimum to promote safer irrigation practices such as treated-water reuse or raised-bed cultivation with clean soil ^[17].

Limitations

This research covered a single growing season (winter) and three vegetables; summer crops and root vegetables may accumulate metals differently. Bioavailability and actual human absorption were not measured the THQ approach uses conservative assumptions. Spatial variability within each site was addressed by composite sampling but may not capture micro-hotspots near drain outlets ^[18].

Conclusion

The main contribution of this research is the documentation that lead levels in amaranth and spinach from two out of four peri-urban sites around Dhaka exceed WHO/FAO permissible limits, and the calculated Hazard Index for regular amaranth consumers at the industrial site (1.90) exceeds the safe threshold. This evidence underscores the need for routine monitoring and policy intervention. Open questions include whether phyto-remediation cover crops grown in rotation could lower soil metal loads, and whether consumer-level washing and cooking practices reduce bioavailable metal content enough to bring THQ below 1.0.

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