

AN ASSESSMENT OF HEAVY METALS CONTAMINATION ON FARMLAND ECOSYSTEMS AND ITS IMPLICATIONS FOR ELEPHANT HEALTH IN COASTAL VILLAGES OF EPE, LAGOS STATE, NIGERIA

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ABSTRACT

Heavy-metal contamination in agricultural landscapes poses increasing ecological and health risks, particularly for large herbivores inhabiting human-dominated ecosystems such as the coastal communities surrounding Epe, Lagos State, Nigeria. This study evaluated seasonal and spatial patterns of cadmium (Cd), copper (Cu), manganese (Mn), zinc (Zn), lead (Pb), chromium (Cr), iron (Fe), and nickel (Ni) in soils, surface water, forage plants (*Ficus exasperata*, *Musa paradisiaca*, and *Spondias mombin*), and elephant fecal matter collected from Ogogo, Okenla, and Bojukuru during the wet (July 2023) and dry (January 2024) seasons, with concentrations determined using atomic absorption spectrophotometry and seasonal differences tested using paired t-tests. Results revealed pronounced spatial and seasonal variability, with Cd and Pb concentrations in soils, water sources, and forage frequently exceeding international guideline thresholds and elevated levels detected in elephant fecal samples, indicating dietary uptake and potential bioaccumulation. These findings demonstrate that elephants in coastal agro-ecosystems are chronically exposed to multiple heavy metals through forage consumption, soil ingestion, and contaminated water, emphasizing the need for sustained environmental monitoring and targeted mitigation strategies to safeguard wildlife health and ecosystem integrity.

Keywords: Heavy metals; Epe; *Loxodonta africana*; bioaccumulation; agro-ecosystems; seasonal variation

INTRODUCTION

Heavy-metal contamination of agricultural landscapes is an accelerating global problem with profound implications for ecosystem function, food safety, and wildlife health (Rashid *et al.*, 2023). Metals such as cadmium (Cd), lead (Pb), chromium (Cr), nickel (Ni), copper (Cu), and zinc (Zn) persist in soils. They can enter agro-ecosystems through multiple pathways: industrial and mining effluents, atmospheric deposition and dust, irrigation with contaminated water, agrochemicals, sewage sludge, and animal manures, producing chronic contamination "hotspots" in farmland and peri-urban agriculture (Angon *et al.*, 2024). Once introduced, these elements are not biodegradable and may be retained in soil matrices for decades, where their mobility and bioavailability are governed by soil texture, pH, organic matter, redox conditions, and seasonal hydrology (Tong *et al.*, 2025). From an ecological perspective, the persistence and mobility of heavy metals create long-term environmental reservoirs that can influence trophic interactions, nutrient cycling, and ecosystem stability, making

contaminated agricultural landscapes potential sources of chronic exposure for both humans and wildlife (Alloway, 2013; Nagajyoti *et al.*, 2010).

Plants growing on contaminated soils can accumulate heavy metals in roots, stems, and edible tissues, creating a direct exposure pathway to herbivores and humans (Iyama *et al.*, 2021). The extent of metal uptake varies by species, phenology, and soil chemistry. However, numerous studies document that food crops and forage species may contain concentrations of Cd, Pb, Cr, and Ni that exceed health-based guidelines, particularly in landscapes affected by mining, industrial effluent, or intensive agrochemical use (Wen *et al.*, 2024). In addition to foliar uptake, incidental soil ingestion (geophagy), ingestion of dust on leaves, and consumption of contaminated water are key exposure routes for large herbivores that range across farmland-wildland mosaics (Afzal & Mahreen, 2024). These exposure pathways form the theoretical basis of trophic transfer and bioaccumulation, whereby contaminants originating in soil and water move through plants and subsequently into herbivores, potentially magnifying ecological and physiological risks at higher trophic levels (Gall *et al.*, 2015; Zhang *et al.*, 2021).

Large terrestrial herbivores, including elephants (*Loxodonta africana*) that use farmland edges and peri-agricultural habitats, are particularly vulnerable to multi-pathway exposure due to their high daily intake of vegetation and soil, broad dietary breadth, and long lifespans that favour bioaccumulation (Tuomikoski, 2022). Evidence from dung and non-invasive matrices indicates that wild elephants and other megaherbivores can carry measurable burdens of toxic metals (Pb, Cd, Cr, Ni, and others) that reflect landscape-level contamination and anthropogenic influence (Perera *et al.*, 2024). These burdens have potential consequences for individual health (reproductive impairment, immunosuppression, oxidative stress), behaviour, and population resilience. However, species-specific toxic thresholds and long-term outcomes remain poorly characterized (Snell-Rood *et al.*, 2024). Consequently, monitoring heavy metals in elephant-associated environmental matrices provides an important ecological indicator of landscape contamination and a non-invasive approach for assessing wildlife exposure to environmental pollutants (Espin *et al.*, 2016).

Seasonality and land-use heterogeneity critically shape exposure dynamics. Dry seasons often concentrate metals in surface soils and vegetation via reduced leaching, evaporative concentration, and enhanced dust deposition. In contrast, wet seasons may mobilise bound metals and promote downstream transport into water bodies used for irrigation and drinking (Luo *et al.*, 2024). The

result is a temporally variable exposure landscape in which elephants and other wildlife experience pulses of exposure that can complicate risk assessment and management. Understanding these seasonal patterns is therefore essential for identifying periods of elevated ecological risk and for developing effective monitoring and mitigation strategies.

Despite mounting global evidence of heavy-metal contamination in croplands, including recent high-resolution syntheses suggesting that 14–17% of global cropland may be contaminated above safety thresholds (Hou et al., 2025), critical knowledge gaps persist for farmland–wildlife interfaces in West Africa. Regionally specific studies confirm the presence of heavy metals in Nigerian agricultural soils and crops (Iyama et al., 2021; Oyebamiji et al., 2024), yet few studies integrate multi-matrix sampling (soil, water, forage, dung) with ecological and health assessments of sympatric megafauna. Furthermore, coastal agro-ecosystems, such as those surrounding Epe in Lagos State, represent dynamic interfaces where agricultural activity, human settlements, and wildlife habitats intersect, potentially intensifying contaminant exposure pathways for wide-ranging species such as elephants.

This study, therefore, aims to fill these gaps by characterising seasonal and spatial patterns of heavy metals across farmlands, soils, forage plants, surface waters and elephant faeces in coastal and agrarian landscapes adjacent to elephant-use areas. Specifically, the study investigates (i) the concentration and distribution of selected heavy metals in soil, water, and forage plants, (ii) the extent to which these metals are reflected in elephant fecal samples as indicators of dietary exposure, and (iii) seasonal differences in contamination patterns between wet and dry periods. It is hypothesised that heavy-metal concentrations will vary significantly across environmental matrices and seasons, with higher levels during the dry season and detectable bioaccumulation signals in elephant fecal matter reflecting landscape-level contamination (Eisler, 2000; Alloway, 2013).

MATERIALS AND METHODS

Description of the Study Area

The study was conducted in Epe, Epe Local Government Area of Lagos State, located on the northern bank of the coastal Lagos Lagoon. Epe is well connected by road to Ijebu-Ode and Ikorodu, and is part of the buffer-zone communities of the Omo Forest Reserve. This reserve is situated between latitudes 6°35'–7°05' N and 4°19'–4°40' E in Southwestern Nigeria, approximately 135 km northeast of Lagos, 120 km east of Abeokuta, and 80 km east of Ijebu-Ode (Chima et al., 2013).

Epe spans 965 square kilometers, comprising 641 square kilometers of land and 324 square kilometers of water bodies (Lagos Bureau of Statistics, 2014). It is divided into three zones: Epe, Eredo, and Ikosi-Ejirin. The area experiences a tropical wet-and-dry climate with two peaks of rainfall, separated by a brief, relatively dry period typically occurring in August. The annual rainfall ranges from 1,700 to 2,200 mm, and the mean relative humidity is around 80%.

Most residents of Epe depend on fishing and farming for their livelihood, though fishing is seasonal. The land is rich in forest resources, and various crops are cultivated, including rice, coconut, yams, cassava, cocoa, palm trees, bananas, plantains, maize, and vegetables. Additionally, the region is endowed with extractable resources, including silica sands, fish, reptiles, shrimp, and bitumen (Oyekale et al., 2013). These natural assets provide significant opportunities for both agriculture and resource

extraction.

Sample Collection

Samples of plants, soil, water, and elephant fecal matter were collected during the wet season (July 2023) and dry season (January 2024) in order to capture seasonal variations in heavy-metal concentrations. Sampling locations were selected based on proximity to elephant habitats and evidence of anthropogenic activities, including agricultural fields, waste disposal sites, and expanding residential developments.

Plant Sampling

Three plant species, Sandpaper (*Ficus exasperata*), Plantain (*Musa paradisiaca*), and Hog Plum (*Spondias mombin*), were selected for their prevalence in elephant diets and widespread distribution across the study area. At each location (Ogogo, Okenla, Bojukurudu), four replicate samples (n = 4) of leaves from each plant species were collected per season. Leaves were taken from mature plants at a height of 1–2 m to ensure consistency. Samples were washed with distilled water to remove surface contaminants, air-dried, and stored in polyethylene bags for laboratory analysis.

Soil Sampling

Soil samples were collected from the 0–15 cm surface layer, which represents the most biologically active zone and is strongly influenced by anthropogenic inputs and plant root interactions. At each sampling location and season, four replicate samples (n = 4) were obtained using a stainless-steel auger to minimize contamination.

Collected soil samples were air-dried in shade, gently crushed using a porcelain mortar and pestle, and sieved through a 2-mm mesh sieve to remove stones and organic debris. Processed samples were stored in airtight polyethylene bags until digestion and analysis.

Water Sampling

Surface water samples were collected from streams and small water bodies located near elephant foraging areas. At each site and season, one representative sample (n = 1) was collected in 1-L polyethylene bottles that had been cleaned with 10% nitric acid (HNO₃) and rinsed with distilled water to prevent contamination or metal adsorption.

Immediately after collection, samples were acidified with 2 mL of concentrated nitric acid to maintain a pH < 2, thereby stabilizing dissolved metals and preventing precipitation. Samples were then stored at 4°C in an ice chest and transported to the laboratory for analysis.

Elephant Fecal Sampling

Elephant fecal samples were collected opportunistically from fresh dung piles (<24 hours old) identified during field surveys in known elephant activity areas. Freshness was determined by moisture content, odor, and the absence of insect colonization.

At each location and season, four replicate samples (n = 4) were collected using sterile gloves and placed into labelled polyethylene bags. Samples were subsequently air-dried under ambient laboratory conditions and homogenized prior to digestion to ensure uniformity.

Sample selection and analytes

The following heavy metals were analyzed: Cadmium (Cd), copper (Cu), manganese (Mn), zinc (Zn), lead (Pb), chromium (Cr), iron (Fe), and nickel (Ni). These metals were selected because they are widely recognized as priority toxic metals in environmental toxicology and ecological risk assessments, owing to their persistence, toxicity, and potential for bioaccumulation in ecological food webs (Tchounwou *et al.*, 2012; Kaur *et al.*, 2019).

Instrumental analysis

All digested samples were analyzed using Atomic Absorption Spectrophotometry (AAS). Element-specific wavelengths and operating conditions for flame or graphite furnace AAS were selected in accordance with standard analytical procedures and manufacturer guidelines (Welz & Sperling, 1999; APHA, 2017). Calibration curves were established using multi-point standard solutions, and quality control procedures included reagent blanks, spiked samples, and certified reference materials to ensure analytical accuracy and precision.

Plant Sample Preparation (Wet Digestion)

Approximately 1.0 g of oven-dried and finely ground plant material was digested using a tri-acid mixture consisting of 1 mL H₂SO₄, 8 mL HNO₃, and 1 mL HClO₄. The mixture was heated gradually on a digestion block until a clear solution was obtained, indicating complete digestion of organic matter.

The digested sample was then cooled, diluted with distilled water, filtered, and made up to a known volume for subsequent metal analysis. This procedure follows standard wet digestion methods used for plant and food metal analysis (Omonona *et al.*, 2019).

Fecal sample preparation

Approximately 0.5 g of dried fecal material was weighed into Borosil glass digestion tubes. Concentrated nitric acid and perchloric acid were added in a 4:1 ratio following procedures described by Gupta (2013).

The samples were digested in a water bath for 5–6 hours until a clear solution was obtained. To remove residual organic compounds and lipids, 3–4 drops of 30% hydrogen peroxide (H₂O₂) were added. After cooling, samples were diluted to a final volume of 10 mL with deionized water and transferred into sterile vials for analysis (Palma *et al.*, 2015; McGeehan *et al.*, 2020).

Soil Sample Preparation (Microwave Acid Digestion)

Approximately 0.3 g of sieved soil was transferred into a polytetrafluoroethylene (PTFE) digestion vessel. The sample was mixed with 6 mL of HNO₃ (65%), 3 mL of HCl (37%), and 0.25 mL of H₂O₂.

Digestion was performed in a microwave extraction system following the USEPA (1996) acid digestion protocol. The digestion process lasted 30 minutes, after which the solution was allowed to cool to room temperature.

The digested solution was diluted to 250 mL with distilled water, allowed to stand for 15 hours, and then filtered through Whatman No. 1 filter paper to remove particulate matter (Element, 2007).

Water Sample Digestion

Water samples were digested using the method described by Omonona (2019). A 100 mL aliquot of the water sample was transferred into a beaker, and 5 mL of concentrated nitric acid was added.

The mixture was heated on a hot plate and evaporated to approximately 20 mL. After cooling, an additional 5 mL of nitric acid was added, and the process was repeated until the solution became clear. The digest was filtered, and the volume was adjusted to 100 mL with distilled water (Element, 2007).

Data Analysis

Heavy metal concentrations were expressed as mean ± standard deviation for replicate samples (n = 4 for plant, soil, and fecal samples; n = 1 for water samples).

Seasonal percentage change was calculated using:

$$\begin{aligned} & \% \text{Change} \\ &= \frac{(\text{Dry Season Concentration} - \text{Wet Season Concentration})}{\text{Wet Season Concentration}} \\ & \times 100 \end{aligned}$$

Results were compared with World Health Organization (WHO) guideline values for plants and water (WHO, 2017) and Swedish Environmental Protection Agency soil quality standards (SEPA, 2009).

Statistical differences between wet and dry seasons were evaluated using a paired t-test at a 95% confidence level (p < 0.05) using SPSS version 25.0.

RESULTS

Seasonal variation in heavy metal concentrations in Sandpaper (*Ficus exasperata*)

Table 1 presents the seasonal variation in heavy metal concentrations in *Ficus exasperata* during the wet and dry seasons across the study locations. At Ogogo, Cd concentration increased markedly from 3.33 ± 1.72 mg/kg in the wet season to 5.28 ± 0.52 mg/kg in the dry season, representing a 58.6% rise and far exceeding the WHO limit of 0.2 mg/kg. Conversely, Cu declined slightly by 16.8%, from 9.87 ± 4.64 mg/kg to 8.21 ± 7.64 mg/kg, but remained close to the permissible limit of 10 mg/kg. Mn recorded a marginal increase of 8.5%, while Zn decreased by 32.5%, dropping from 16.68 ± 8.26 mg/kg to 11.26 ± 3.21 mg/kg. Furthermore, Pb rose by 53.3%, reaching 2.79 ± 2.03 mg/kg, thus exceeding the WHO guideline of 2 mg/kg. Similarly, Cr increased by 33.4%, from 7.31 ± 1.45 mg/kg to 9.75 ± 1.78 mg/kg, substantially exceeding the permissible limit of 1.5 mg/kg. In contrast, Fe showed a minor reduction (–3.4%), whereas Ni declined slightly by 8.7%, though both metals remained above the WHO limit of 1.5 mg/kg.

At Okenla, Cd concentration nearly doubled (an 89.0% increase), rising from 2.81 ± 1.35 mg/kg in the wet season to 5.31 ± 0.84 mg/kg in the dry season, far above the acceptable threshold. In contrast, Cu showed a 23.7% decline, while Mn exhibited a pronounced decrease of 25.7%, dropping from 119.63 ± 24.97 mg/kg to 88.92 ± 6.44 mg/kg, though still within the WHO limit of 200 mg/kg. Notably, Zn increased by 52.0%, indicating greater accumulation during the dry period, while Pb decreased sharply by 60.6%. In addition, Cr concentration increased by 43.4%, from 8.44 ± 2.18 mg/kg to 12.10 ± 1.47 mg/kg, exceeding the permissible standard by a wide margin. Moreover, Fe levels rose slightly by 6.1%, and Ni declined moderately by 24.1%, yet both remained above the WHO guideline value.

At Bojukurudu, Cd increased by 57.0%, from 2.63 ± 0.98 mg/kg in the wet season to 4.13 ± 0.84 mg/kg in the dry season, again surpassing the WHO limit. In contrast, Cu decreased slightly by 8.4%, while Mn recorded a substantial reduction of 36.6%, from

135.94 ± 47.86 mg/kg to 86.26 ± 9.85 mg/kg. Similarly, Zn rose by 33.6%, whereas Pb and Cr decreased by 35.1% and 15.8%, respectively. In the same vein, Fe displayed a notable 43.9% increase, reaching 163.60 ± 72.44 mg/kg in the dry season, while

Ni dropped significantly by 48.8%, from 3.34 ± 0.57 mg/kg to 1.71 ± 0.74 mg/kg.

Table 1: Seasonal Variation in Heavy Metal Concentrations (mg/kg) in Sandpaper (*Ficus exasperata*) Across Coastal Farmlands of Epe, Lagos State, Nigeria

Location	Season / % Change	Cd	Cu	Mn	Zn	Pb	Cr	Fe	Ni
Ogogo	Wet	3.33 ± 1.72	9.87 ± 4.64	89.67 ± 11.90	16.68 ± 8.26	1.82 ± 0.96	7.31 ± 1.45	119.78 ± 45.55	2.64 ± 1.24
	Dry	5.28 ± 0.52	8.21 ± 7.64	97.33 ± 15.90	11.26 ± 3.21	2.79 ± 2.03	9.75 ± 1.78	115.72 ± 2.78	2.41 ± 0.64
	% Change	+58.6%	-16.8%	+8.5%	-32.5%	+53.3%	+33.4%	-3.4%	-8.7%
Okenla	Wet	2.81 ± 1.35	9.63 ± 3.75	119.63 ± 24.97	10.09 ± 2.88	4.85 ± 1.66	8.44 ± 2.18	115.86 ± 40.18	3.40 ± 1.14
	Dry	5.31 ± 0.84	7.35 ± 3.35	88.92 ± 6.44	15.34 ± 5.23	1.91 ± 1.58	12.10 ± 1.47	122.94 ± 26.79	2.58 ± 0.99
	% Change	+89.0%	-23.7%	-25.7%	+52.0%	-60.6%	+43.4%	+6.1%	-24.1%
Bojukurudu	Wet	2.63 ± 0.98	8.34 ± 2.35	135.94 ± 47.86	10.06 ± 3.80	5.61 ± 3.60	8.16 ± 1.42	113.74 ± 15.75	3.34 ± 0.57
	Dry	4.13 ± 0.84	7.64 ± 1.98	86.26 ± 9.85	13.43 ± 2.24	3.64 ± 2.41	6.87 ± 2.33	163.60 ± 72.44	1.71 ± 0.74
	% Change	+57.0%	-8.4%	-36.6%	+33.6%	-35.1%	-15.8%	+43.9%	-48.8%
	WHO Permissible Limit	0.2	10	200	50	2	1.5	450	1.5

Note. Values represent mean ± standard deviation (n = 4 per location per season). Percentage change indicates relative variation between dry and wet seasons.

Source: Field survey, 2024

Seasonal variation in heavy metal concentrations in Plantain (*Musa paradisiaca*)

The seasonal variation in heavy metal concentrations in *Musa paradisiaca* plants during the wet and dry seasons across the study locations is presented in Table 2.

At Ogogo, Cd concentration increased substantially from 3.55 ± 1.78 mg/kg in the wet season to 5.56 ± 0.91 mg/kg in the dry season, representing a 56.6% rise and remaining far above the WHO limit of 0.2 mg/kg. Conversely, Cu showed a slight reduction of 2.4%, from 10.23 ± 3.31 mg/kg to 9.98 ± 3.88 mg/kg, yet it remained close to the permissible threshold of 10 mg/kg. Mn exhibited a minor decrease of 3.2%, while Zn recorded a marked increase of 66.7%, rising from 12.96 ± 3.95 mg/kg to 21.61 ± 7.28 mg/kg, though still within the WHO limit of 50 mg/kg. Pb declined moderately by 16.2%, from 4.93 ± 1.27 mg/kg to 4.13 ± 1.38 mg/kg, but both values were above the acceptable 2 mg/kg guideline. Similarly, Cr decreased slightly by 16.0%, from 7.80 ± 2.22 mg/kg to 6.55 ± 0.98 mg/kg, yet remained substantially higher than the WHO limit of 1.5 mg/kg. In contrast, Fe concentration increased by 37.4%, reaching 196.22 ± 62.85 mg/kg in the dry season, while Ni declined by 44.6%, from 4.10 ± 2.47 mg/kg to 2.27 ± 0.33 mg/kg, both of which were still above the WHO threshold of 1.5 mg/kg.

At Okenla, Cd concentration dropped sharply by 47.3%, from 4.93 ± 1.12 mg/kg in the wet season to 2.60 ± 1.77 mg/kg in the dry season, but remained well above the WHO limit. Cu also decreased

slightly by 7.8%, from 8.58 ± 2.70 mg/kg to 7.91 ± 1.74 mg/kg, maintaining values within the acceptable limit. Mn declined notably by 24.0%, from 105.30 ± 17.03 mg/kg to 79.99 ± 18.01 mg/kg, which is still within the 200 mg/kg guideline. In contrast, Zn increased marginally by 5.4%, while Pb concentration decreased by 22.9%, from 6.19 ± 1.48 mg/kg to 4.77 ± 1.48 mg/kg, both exceeding the WHO permissible limit. Interestingly, Cr showed a slight increase of 7.0%, from 6.56 ± 0.89 mg/kg to 7.02 ± 1.97 mg/kg, maintaining values substantially above the safe threshold. Fe increased by 18.4%, from 134.60 ± 30.38 mg/kg to 159.35 ± 5.78 mg/kg, still below the WHO limit of 450 mg/kg, while Ni rose moderately by 16.5%, from 3.87 ± 1.16 mg/kg to 4.51 ± 1.08 mg/kg, both above the permissible 1.5 mg/kg guideline.

At Bojukurudu, Cd concentration declined markedly by 50.5%, from 3.84 ± 2.02 mg/kg in the wet season to 1.90 ± 1.49 mg/kg in the dry season, but both values remained above the WHO standard. In contrast, Cu increased by 27.9%, rising from 8.52 ± 1.03 mg/kg to 10.90 ± 1.76 mg/kg, slightly surpassing the permissible limit. Mn showed a negligible reduction of 1.7%, from 105.93 ± 13.89 mg/kg to 104.17 ± 10.81 mg/kg, maintaining values within the acceptable range. Zn, however, showed a sharp 87.7% increase, rising from 10.77 ± 1.93 mg/kg to 20.21 ± 4.28 mg/kg, though still below the WHO limit. Pb also increased by 20.8%, while Cr rose modestly by 10.9%, with both metals remaining above their permissible limits. Fe concentration increased considerably by 23.8%, from 150.09 ± 37.75 mg/kg to 185.80 ± 59.86 mg/kg, still below the 450 mg/kg threshold, whereas Ni decreased significantly by 47.1%, from 4.93

± 0.86 mg/kg to 2.61 ± 0.96 mg/kg. However, both values exceeded the WHO permissible value of 1.5 mg/kg.

Table 2: Seasonal Variation in Heavy Metal Concentrations (mg/kg) in Plantain (*Musa paradisiaca*) Across Coastal Farmlands of Epe, Lagos State, Nigeria

Location	Season / % Change	Cd	Cu	Mn	Zn	Pb	Cr	Fe	Ni
Ogogo	Wet	3.55 ± 1.78	10.23 ± 3.31	95.43 ± 12.73	12.96 ± 3.95	4.93 ± 1.27	7.80 ± 2.22	142.82 ± 25.10	4.10 ± 2.47
	Dry	5.56 ± 0.91	9.98 ± 3.88	92.38 ± 29.86	21.61 ± 7.28	4.13 ± 1.38	6.55 ± 0.98	196.22 ± 62.85	2.27 ± 0.33
	% Change	+56.6%	-2.4%	-3.2%	+66.7%	-16.2%	-16.0%	+37.4%	-44.6%
Okenla	Wet	4.93 ± 1.12	8.58 ± 2.70	105.30 ± 17.03	13.96 ± 6.77	6.19 ± 1.48	6.56 ± 0.89	134.60 ± 30.38	3.87 ± 1.16
	Dry	2.60 ± 1.77	7.91 ± 1.74	79.99 ± 18.01	14.72 ± 0.80	4.77 ± 1.48	7.02 ± 1.97	159.35 ± 5.78	4.51 ± 1.08
	% Change	-47.3%	-7.8%	-24.0%	+5.4%	-22.9%	+7.0%	+18.4%	+16.5%
Bojukurudu	Wet	3.84 ± 2.02	8.52 ± 1.03	105.93 ± 13.89	10.77 ± 1.93	3.27 ± 1.40	6.14 ± 2.43	150.09 ± 37.75	4.93 ± 0.86
	Dry	1.90 ± 1.49	10.90 ± 1.76	104.17 ± 10.81	20.21 ± 4.28	3.95 ± 2.19	6.81 ± 1.72	185.80 ± 59.86	2.61 ± 0.96
	% Change	-50.5%	+27.9%	-1.7%	+87.7%	+20.8%	+10.9%	+23.8%	-47.1%
	WHO Permissible Limit	0.2	10	200	50	2	1.5	450	1.5

Note. Values represent mean \pm standard deviation (n = 4 per location per season). Percentage change indicates the variation from the wet to the dry season (positive = increase; negative = decrease).

Source: Field survey, 2024

Seasonal variation in heavy metal concentrations in Hog Plum (*Spondias mombin*)

Table 3 presents the seasonal variation in heavy metal concentrations in *Spondias mombin* plants during the wet and dry seasons across the study locations. At Ogogo, Cd concentration declined sharply by 50.2%, from 4.58 ± 1.86 mg/kg in the wet season to 2.28 ± 0.87 mg/kg in the dry season, although both values were well above the WHO permissible limit of 0.2 mg/kg. Cu increased marginally by 4.9%, from 11.53 ± 4.13 mg/kg to 12.10 ± 6.38 mg/kg, slightly exceeding the WHO limit of 10 mg/kg. Mn showed a substantial reduction of 51.3%, from 203.45 ± 53.45 mg/kg to 99.16 ± 13.78 mg/kg, moving from marginally above to well within the permissible range of 200 mg/kg. Zn concentration decreased by 12.9%, from 15.93 ± 7.19 mg/kg to 13.87 ± 3.10 mg/kg, both of which are within the acceptable 50 mg/kg limit. Pb increased moderately by 22.3%, reaching 2.30 ± 0.88 mg/kg, slightly above the 2 mg/kg WHO limit. Cr, on the other hand, declined considerably by 37.8%, from 7.59 ± 3.18 mg/kg to 4.72 ± 1.90 mg/kg, though both concentrations remained far above the 1.5 mg/kg threshold. Fe remained stable, showing only a slight 0.4% decrease between seasons, while Ni increased markedly by 34.7%, from 4.12 ± 2.35 mg/kg to 5.55 ± 3.07 mg/kg, substantially exceeding the WHO limit of 1.5 mg/kg.

At Okenla, Cd concentration decreased by 39.9%, from 5.51 ± 2.18 mg/kg in the wet season to 3.31 ± 0.84 mg/kg in the dry season, remaining far above the WHO permissible limit. Cu showed a moderate reduction of 13.1%, from 11.64 ± 2.98 mg/kg to 10.12 ± 3.54 mg/kg, both values slightly exceeding the 10 mg/kg guideline. Mn levels declined by 29.3%, from 164.13 ± 78.09 mg/kg to 116.09 ± 47.07 mg/kg, but remained well within the 200 mg/kg limit.

Similarly, Zn concentration fell sharply by 36.7%, from 16.69 ± 6.84 mg/kg to 10.57 ± 1.57 mg/kg, remaining below the permissible limit. Pb rose slightly by 12.7%, from 2.37 ± 1.46 mg/kg to 2.67 ± 1.36 mg/kg, both marginally above the WHO limit. Cr exhibited a notable 27.0% decline, from 8.88 ± 2.96 mg/kg to 6.48 ± 2.10 mg/kg, yet both readings remained substantially above the permissible 1.5 mg/kg value. Fe showed near constancy, increasing by 0.4%, from 115.64 ± 8.00 mg/kg to 116.05 ± 18.35 mg/kg, staying below the WHO threshold of 450 mg/kg, whereas Ni increased significantly by 50.9%, from 3.93 ± 1.97 mg/kg to 5.93 ± 1.21 mg/kg, well above the 1.5 mg/kg guideline.

At Bojukurudu, Cd concentration decreased markedly by 38.2%, from 5.11 ± 1.17 mg/kg in the wet season to 3.16 ± 1.36 mg/kg in the dry season, both of which were substantially higher than the WHO permissible limit. Cu increased dramatically by 70.7%, from 6.96 ± 2.28 mg/kg to 11.88 ± 1.64 mg/kg, slightly exceeding the 10 mg/kg standard. Mn also declined by 37.5%, from 138.82 ± 39.86 mg/kg to 86.83 ± 13.91 mg/kg, maintaining values within the 200 mg/kg limit. Zn decreased by 29.5%, from 15.27 ± 4.00 mg/kg to 10.76 ± 2.45 mg/kg, both well within the permissible range. Pb concentration decreased by 31.2%, from 3.65 ± 0.81 mg/kg to 2.51 ± 0.77 mg/kg, although both values remained above the 2 mg/kg guideline. In contrast, Cr increased by 22.5%, from 6.22 ± 1.97 mg/kg to 7.62 ± 2.21 mg/kg, exceeding the acceptable threshold of 1.5 mg/kg. Fe showed a minor increase of 6.4%, from 112.22 ± 16.60 mg/kg to 119.44 ± 27.32 mg/kg, still below the WHO limit, while Ni decreased by 30.9%, from 6.48 ± 2.49 mg/kg to 4.48 ± 2.01 mg/kg, both of which exceeded the 1.5 mg/kg permissible level.

Table 3: Seasonal Variation in Heavy Metal Concentrations in Hog Plum (*Spondias mombin*) Across Coastal Farmlands of Epe, Lagos State, Nigeria

Location	Season / % Change	Cd	Cu	Mn	Zn	Pb	Cr	Fe	Ni
Ogogo	Wet	4.58 ± 1.86	11.53 ± 4.13	203.45 ± 53.45	15.93 ± 7.19	1.88 ± 1.28	7.59 ± 3.18	114.88 ± 27.44	4.12 ± 2.35
	Dry	2.28 ± 0.87	12.10 ± 6.38	99.16 ± 13.78	13.87 ± 3.10	2.30 ± 0.88	4.72 ± 1.90	114.43 ± 19.42	5.55 ± 3.07
	% Change	-50.2%	+4.9%	-51.3%	-12.9%	+22.3%	-37.8%	-0.4%	+34.7%
Okenla	Wet	5.51 ± 2.18	11.64 ± 2.98	164.13 ± 78.09	16.69 ± 6.84	2.37 ± 1.46	8.88 ± 2.96	115.64 ± 8.00	3.93 ± 1.97
	Dry	3.31 ± 0.84	10.12 ± 3.54	116.09 ± 47.07	10.57 ± 1.57	2.67 ± 1.36	6.48 ± 2.10	116.05 ± 18.35	5.93 ± 1.21
	% Change	-39.9%	-13.1%	-29.3%	-36.7%	+12.7%	-27.0%	+0.4%	+50.9%
Bojukurudu	Wet	5.11 ± 1.17	6.96 ± 2.28	138.82 ± 39.86	15.27 ± 4.00	3.65 ± 0.81	6.22 ± 1.97	112.22 ± 16.60	6.48 ± 2.49
	Dry	3.16 ± 1.36	11.88 ± 1.64	86.83 ± 13.91	10.76 ± 2.45	2.51 ± 0.77	7.62 ± 2.21	119.44 ± 27.32	4.48 ± 2.01
	% Change	-38.2%	+70.7%	-37.5%	-29.5%	-31.2%	+22.5%	+6.4%	-30.9%
WHO Permissible Limit		0.2	10	200	50	2	1.5	450	1.5

Note. Values represent mean ± standard deviation (n = 4 per location per season). Percentage change indicates the variation from the wet to the dry season (positive = increase; negative = decrease).

Source: Field survey, 2024

Seasonal Variation in Heavy Metal Concentrations in Elephant Fecal Samples

The seasonal variation in heavy metal concentrations in elephant fecal samples across the study locations is presented in Table 4. At Ogogo, cadmium (Cd) concentration decreased markedly from 6.42 ± 1.41 mg/kg in the wet season to 3.56 ± 2.17 mg/kg in the dry season, representing a 44.6% reduction. Similarly, copper (Cu) declined by 49.5%, from 10.21 ± 3.50 mg/kg to 5.16 ± 3.69 mg/kg, while manganese (Mn) dropped moderately by 20.8%, from 10.07 ± 2.36 mg/kg to 7.98 ± 3.27 mg/kg. In contrast, zinc (Zn) showed a slight increase of 4.3%, reaching 15.17 ± 3.36 mg/kg in the dry season. Lead (Pb) and chromium (Cr) both recorded substantial declines of 48.9% and 18.3%, respectively. Iron (Fe) also decreased by 31.6%, while nickel (Ni) increased by 48.3%, indicating possible seasonal enrichment through dietary or soil ingestion pathways.

At Okenla, cadmium concentration declined from 6.24 ± 1.15 mg/kg in the wet season to 4.40 ± 1.62 mg/kg in the dry season (-29.5%), and copper followed a similar pattern, dropping by 45.2%.

Conversely, manganese increased slightly (+10.7%) from 8.99 ± 1.50 mg/kg to 9.95 ± 6.90 mg/kg, while zinc declined by 24.2%. Lead (Pb) decreased slightly (-9.2%), and chromium (Cr) exhibited a sharp decline of 63.6%, from 5.08 ± 0.80 mg/kg to 1.85 ± 0.54 mg/kg. Iron (Fe) dropped by 40.0%, while nickel (Ni) increased moderately (+31.0%) in the dry season. These variations suggest lower exposure to most metals during the dry season, likely due to reduced vegetation moisture and feeding range.

At Bojukurudu, cadmium concentration declined sharply from 9.62 ± 0.76 mg/kg to 3.89 ± 1.30 mg/kg, representing a 59.6% decrease. Copper (Cu) showed a marginal increase of 2.8%, while manganese (Mn) rose significantly by 47.1% in the dry season. Zinc (Zn) exhibited a pronounced reduction (-58.3%), decreasing from 17.78 ± 5.82 mg/kg to 7.41 ± 1.62 mg/kg. Lead (Pb), chromium (Cr), and iron (Fe) decreased by 44.5%, 14.6%, and 31.5%, respectively. Nickel (Ni), however, increased by almost 92% (+91.8%), indicating a potential seasonal bioaccumulation effect.

Table 4: Seasonal Variation in Heavy Metal Concentrations (mg/kg) in Elephant Fecal Samples Across Coastal Farmlands of Epe, Lagos State, Nigeria

Location	Season / % Change	Cd	Cu	Mn	Zn	Pb	Cr	Fe	Ni
Ogogo	Wet	6.42 ± 1.41	10.21 ± 3.50	10.07 ± 2.36	14.54 ± 3.67	5.60 ± 1.44	4.43 ± 2.75	15.59 ± 4.41	2.90 ± 1.79
	Dry	3.56 ± 2.17	5.16 ± 3.69	7.98 ± 3.27	15.17 ± 3.36	2.86 ± 1.04	3.62 ± 1.19	10.67 ± 3.17	4.30 ± 3.76
	% Change	-44.6%	-49.5%	-20.8%	+4.3%	-48.9%	-18.3%	-31.6%	+48.3%
Okenla	Wet	6.24 ± 1.15	8.42 ± 1.32	8.99 ± 1.50	18.68 ± 7.89	3.26 ± 0.77	5.08 ± 0.80	14.69 ± 6.47	2.71 ± 0.45
	Dry	4.40 ± 1.62	4.61 ± 2.99	9.95 ± 6.90	14.17 ± 8.25	2.96 ± 1.93	1.85 ± 0.54	8.81 ± 2.79	3.55 ± 2.31
	% Change	-29.5%	-45.2%	+10.7%	-24.2%	-9.2%	-63.6%	-40.0%	+31.0%
Bojukurudu	Wet	9.62 ± 0.76	6.18 ± 1.32	6.87 ± 1.77	17.78 ± 5.82	4.72 ± 1.77	4.24 ± 1.89	13.82 ± 3.66	1.71 ± 0.80
	Dry	3.89 ± 1.30	6.35 ± 1.26	10.11 ± 4.69	7.41 ± 1.62	2.62 ± 1.76	3.62 ± 1.58	9.47 ± 3.07	3.28 ± 2.05
	% Change	-59.6%	+2.8%	+47.1%	-58.3%	-44.5%	-14.6%	-31.5%	+91.8%

Note. Values represent mean ± standard deviation (n = 4 per location per season). Percentage change indicates the variation from the wet to the dry season (positive = increase; negative = decrease).

Source: Field survey, 2024

Seasonal Variation in Heavy Metal Concentrations in Soil Samples

The seasonal variation in heavy metal concentrations in soil samples across the study locations during the wet and dry seasons is presented in Table 5. At Ogogo, cadmium (Cd) concentration increased substantially from 0.67 ± 0.37 mg/kg in the wet season to 1.32 ± 0.34 mg/kg in the dry season, representing a 97.0% increase, likely due to reduced leaching and enhanced accumulation under drier conditions. Copper (Cu) also rose moderately by 35.2%, from 5.75 ± 2.06 mg/kg to 7.78 ± 1.64 mg/kg. In contrast, manganese (Mn) and zinc (Zn) decreased sharply by 70.4% and 62.6%, respectively, likely due to leaching and reduced binding to organic matter during the wet season. Lead (Pb) and chromium (Cr) increased slightly by 19.0% and 24.3%, respectively, while iron (Fe) dropped drastically by 87.2%, from 294.72 ± 64.84 mg/kg to 37.77 ± 14.71 mg/kg, reflecting possible seasonal translocation or uptake by vegetation. Nickel (Ni) also declined significantly (-63.6%). Except for Cd, all metals remained within the Swedish soil quality limits, though the elevated Cd concentration exceeded the 0.4 mg/kg permissible limit, indicating potential anthropogenic input.

At Okenla, Cd concentration decreased sharply from 1.55 ± 1.63 mg/kg in the wet season to 0.40 ± 0.18 mg/kg in the dry season (-74.2%), suggesting possible dilution or leaching effects. Copper (Cu) also decreased by 29.5%, while manganese (Mn) and zinc

(Zn) showed pronounced declines of 80.7% and 57.1%, respectively. Lead (Pb) recorded a slight reduction of 6.1%, whereas chromium (Cr) exhibited a marked increase (+231.1%) from 2.54 ± 2.02 mg/kg to 8.41 ± 3.38 mg/kg, indicating possible enrichment from dry-season dust or runoff accumulation. Iron (Fe) declined drastically (-84.1%), and nickel (Ni) decreased by 50.5%. Similar to Ogogo, Cd concentration in the wet season exceeded the Swedish permissible limit, while concentrations of other metals were far below the thresholds, indicating minimal contamination risks.

At Bojukurudu, Cd decreased slightly from 0.84 ± 0.53 mg/kg to 0.65 ± 0.52 mg/kg (-22.6%), remaining above the 0.4 mg/kg permissible limit in both seasons. Copper (Cu) showed a marginal decrease of 6.7%, while manganese (Mn) and zinc (Zn) recorded substantial reductions of 61.2% and 77.7%, respectively. Lead (Pb) concentration, however, increased markedly (+142.2%) from 4.36 ± 2.52 mg/kg to 10.56 ± 2.95 mg/kg, possibly due to atmospheric deposition or dry-season dust inputs. Chromium (Cr) also doubled (+105.0%), rising from 1.59 ± 1.20 mg/kg to 3.26 ± 2.65 mg/kg, while iron (Fe) declined by 56.3%. Nickel (Ni) increased moderately (+32.0%) from 3.53 ± 1.88 mg/kg to 4.66 ± 1.21 mg/kg. Despite these variations, all metal levels remained well below the Swedish maximum permissible limits, except Cd, which consistently exceeded the limit.

Table 5: Seasonal Variation in Heavy Metal Concentrations (mg/kg) in Soil Samples Across Coastal Farmlands of Epe, Lagos State, Nigeria

Location	Season / % Change	Cd	Cu	Mn	Zn	Pb	Cr	Fe	Ni
Ogogo	Wet	0.67 ± 0.37	5.75 ± 2.06	43.48 ± 8.25	44.61 ± 6.99	4.68 ± 2.57	4.11 ± 2.93	294.72 ± 64.84	4.40 ± 0.92
	Dry	1.32 ± 0.34	7.78 ± 1.64	12.88 ± 2.57	16.68 ± 6.96	5.57 ± 2.11	5.11 ± 2.41	37.77 ± 14.71	1.60 ± 0.80
	% Change	+97.0%	+35.2%	-70.4%	-62.6%	+19.0%	+24.3%	-87.2%	-63.6%
Okenla	Wet	1.55 ± 1.63	9.53 ± 2.71	114.43 ± 49.53	46.78 ± 22.61	7.81 ± 3.56	2.54 ± 2.02	289.72 ± 101.18	6.36 ± 2.48
	Dry	0.40 ± 0.18	6.72 ± 2.13	22.03 ± 7.92	20.08 ± 5.34	7.33 ± 3.57	8.41 ± 3.38	45.91 ± 31.87	3.15 ± 0.22
	% Change	-74.2%	-29.5%	-80.7%	-57.1%	-6.1%	+231.1%	-84.1%	-50.5%
Bojukurudu	Wet	0.84 ± 0.53	9.19 ± 4.47	92.91 ± 35.03	63.39 ± 55.87	4.36 ± 2.52	1.59 ± 1.20	195.94 ± 51.50	3.53 ± 1.88
	Dry	0.65 ± 0.52	8.57 ± 4.57	36.03 ± 14.23	14.15 ± 9.14	10.56 ± 2.95	3.26 ± 2.65	85.71 ± 48.56	4.66 ± 1.21
	% Change	-22.6%	-6.7%	-61.2%	-77.7%	+142.2%	+105.0%	-56.3%	+32.0%
	Maximum Permissible Limit (Sweden)	0.4	100	NA	350	80	120	NA	35

Note. Values represent mean ± standard deviation (n = 4 per location per season). Percentage change indicates the variation from the wet to the dry season (positive = increase; negative = decrease).

Source: Field survey, 2024

Seasonal Variation in Heavy Metal Concentrations (mg/L) in Water Samples

Table 6 presents the seasonal variation in heavy metal concentrations in water samples during the wet and dry seasons across the study locations. At Ogogo, Cd concentration increased slightly from 0.07 ± 0.00 mg/L in the wet season to 0.08 ± 0.00 mg/L in the dry season, representing a 14.3% increase. This value is far above the WHO limit of 0.003 mg/L, suggesting contamination possibly from runoff, waste discharge, or agricultural inputs. Copper (Cu) decreased slightly (-12.5%) from 0.08 mg/L to 0.07 mg/L, remaining well below the 2 mg/L limit. Manganese (Mn) recorded a sharp decline (-88.9%) from 0.09 mg/L to 0.01 mg/L, likely due to precipitation and sedimentation during the dry season. Zinc (Zn) remained stable at 0.03 mg/L, well below the 3 mg/L threshold. In contrast, lead (Pb) increased sharply by 166.7%, from 0.03 mg/L to 0.08 mg/L, exceeding the WHO limit of 0.01 mg/L, suggesting potential input from vehicular or industrial emissions. Chromium (Cr) declined drastically (-67.9%) from 0.28 mg/L to 0.09 mg/L, while iron (Fe) and nickel (Ni) decreased by 55.6% and 84.6%, respectively, though Fe (0.04 mg/L) remained below the 0.3 mg/L limit.

At Okenla, Cd showed a pronounced reduction from 0.12 mg/L in the wet season to 0.02 mg/L in the dry season (-83.3%), but both values still exceeded the WHO guideline of 0.003 mg/L. Copper

(Cu) declined by 71.4%, from 0.07 mg/L to 0.02 mg/L, while manganese (Mn) and zinc (Zn) also dropped by 50.0% and 78.6%, respectively, indicating significant dilution effects during rainfall. Lead (Pb) remained unchanged at 0.04 mg/L, exceeding the permissible limit, while chromium (Cr) remained constant at 0.09 mg/L, surpassing the 0.05 mg/L limit. Iron (Fe) increased slightly by 25.0%, from 0.04 mg/L to 0.05 mg/L, within safe limits, while nickel (Ni) decreased markedly (-75.0%) from 0.04 mg/L to 0.01 mg/L, remaining below the 0.07 mg/L threshold.

At Bojukurudu, Cd decreased moderately by 25.0%, from 0.12 mg/L to 0.09 mg/L, both values well above the WHO limit, suggesting persistent contamination. Copper (Cu) dropped slightly (-20.0%) from 0.10 mg/L to 0.08 mg/L, while manganese (Mn) declined sharply (-66.7%) from 0.03 mg/L to 0.01 mg/L. Zinc (Zn), however, increased markedly (+200.0%) from 0.02 mg/L to 0.06 mg/L, possibly due to evaporation concentration or anthropogenic discharge during the dry period. Lead (Pb) showed a slight increase (+11.1%) from 0.09 mg/L to 0.10 mg/L, remaining well above the WHO limit, while chromium (Cr) increased by 30.0%, exceeding the 0.05 mg/L guideline. Iron (Fe) remained stable at 0.05 mg/L, within acceptable levels, whereas nickel (Ni) declined substantially (-80.0%) from 0.05 mg/L to 0.01 mg/L.

Table 6: Seasonal Variation in Heavy Metal Concentrations (mg/L) in Sampled Water Across Coastal Farmlands of Epe, Lagos State, Nigeria

Location	Season / % Change	Cd	Cu	Mn	Zn	Pb	Cr	Fe	Ni
Ogogo	Wet	0.07	0.08	0.09	0.03	0.03	0.28	0.09	0.13
	Dry	0.08	0.07	0.01	0.03	0.08	0.09	0.04	0.02
	% Change	+14.3%	-12.5%	-88.9%	0.0%	+166.7%	-67.9%	-55.6%	-84.6%
Okenla	Wet	0.12	0.07	0.06	0.14	0.04	0.09	0.04	0.04
	Dry	0.02	0.02	0.03	0.03	0.04	0.09	0.05	0.01
	% Change	-83.3%	-71.4%	-50.0%	-78.6%	0.0%	0.0%	+25.0%	-75.0%
Bojukurudu	Wet	0.12	0.10	0.03	0.02	0.09	0.10	0.05	0.05
	Dry	0.09	0.08	0.01	0.06	0.10	0.13	0.05	0.01
	% Change	-25.0%	-20.0%	-66.7%	+200.0%	+11.1%	+30.0%	0.0%	-80.0%
	WHO (2017) Guidelines for drinking water	0.003	2	0.4	3	0.01	0.05	0.3	0.07

Note. Values represent (n = 1 per location per season). Percentage change indicates the variation from the wet to the dry season (positive = increase; negative = decrease).

Source: Field survey, 2024

DISCUSSION

The present study demonstrates clear seasonal and spatial variation in heavy-metal concentrations in foliage, soil, water, and faecal matter within the coastal village ecosystems of the Epe region, Lagos State, Nigeria. It raises substantive concerns regarding the potential exposure of the local elephant population to multiple metals via trophic and environmental pathways. The elevated concentrations of cadmium (Cd), chromium (Cr), lead (Pb), nickel (Ni), and other metals in plants, soils, and water suggest substantial anthropogenic loading and limited natural attenuation during the dry season. Globally, heavy-metal contamination arises via industrial discharges, agricultural runoff, atmospheric deposition, and geogenic weathering, with these metals being persistent, bioavailable, and prone to bioaccumulation and biomagnification across trophic levels (Saravanan *et al.*, 2024).

The results demonstrate clear seasonal shifts in heavy metal concentrations across soil, fecal (three plant species), and water samples. In general, the dry season is associated with elevated concentrations of certain non-essential metals (e.g., Cd, Cr, Pb, Ni) in vegetation and soils. At the same time, wet-season effects appear to lead to dilution in water and increased leaching in soils. This pattern is consistent with documented mechanisms of heavy metal accumulation. During dry periods, reduced leaching and enhanced resuspension of dust or fine particulates can increase soil and plant uptake. In contrast, wet seasons often promote dilution but also mobilization of metals into water bodies. For instance, heavy metals in coastal environments tend to accumulate in sediments during dry spells and remobilize with rainfall and runoff (Ouma *et al.*, 2022).

In the vegetation compartment, the conspicuous exceedances of WHO (or other permissible) limits for toxic metals such as Cd, Cr, and Pb in the three plant species suggest active uptake or surface deposition of these metals in foraging plants. This is consistent with other Nigerian studies reporting elevated heavy metal uptake in crops and medicinal plants from contaminated zones (Yahaya *et al.*, 2025). Plants can act as both sinks and sources of metals for herbivores. Elevated metal concentrations in foliage at undisturbed and disturbed sites indicate that animals feeding on such vegetation may be exposed through ingestion. In grazing ecosystems, contamination of forage has been recognised as a key route of exposure for wildlife and livestock (Hejna *et al.*, 2018). The fact that concentrations vary by species and by season highlights the importance of plant selection and phenology in exposure risk. In soils, elevated Cd concentrations (and seasonal increases) indicate anthropogenic input and limited self-cleaning under dry conditions. Studies in Nigerian coastal and mangrove environments also document heavy metal enrichment in sediments and soils due to industrial and agricultural runoff (Chris & Anyanwu, 2022). Water samples, though generally showing lower absolute values than soils or plants, nonetheless revealed concentrations of Cd and Pb above WHO limits in several instances, underscoring that the aqueous pathway remains a viable route of exposure for both wildlife and humans.

Although direct measurements of elephants in this region were not obtained in the present study, the documented ecosystem contamination patterns have strong implications for elephant exposure and health in the coastal villages of Epe. Large terrestrial herbivores such as elephants often forage on a wide variety of vegetation, ingest soil or dust (geophagy, root-foraging), and drink

surface water, all of which are potential pathways for heavy metal uptake. Evidence from other elephant studies corroborates this pathway. For example, a study of semi-captive elephants found that chronic heavy metal exposure through diet and environmental sources may affect reproductive performance and health status (Tuomikoski, 2022). More recently, dung studies of wild Asian elephants found significantly elevated levels of Pb, Cd, Cr, Ni, and Cu in areas correlated with anthropogenic activity (Perera *et al.*, 2024). Moreover, heavy metal exposure in wildlife is increasingly recognized as a conservation health concern, particularly in Africa, where mining, agriculture, and urbanisation drive metal emissions (Yabe *et al.*, 2010)

In this study, the uptake of metals such as Cd, Cr, and Pb by forage plants to levels above safe limits signals a risk of bioaccumulation in elephant tissues via ingestion of contaminated plants or soils. Elevated soil and plant concentrations in the dry season also suggest that seasonal foraging behaviour may exacerbate exposure. If elephants rely on dry-season forage in impacted locales, their intake of contaminated vegetation may increase. The detection of elevated Ni in some vegetation or fecal proxies in other studies further illustrates that “essential” trace metals may also accumulate to supra-physiological levels and become toxic. This corroborates the findings of Tahir *et al.* (2023), who reported that metals such as Pb and Cd have been associated with reproductive toxicity in mammals.

From a health-outcome perspective, heavy metals such as Cd, Pb, Cr, and Ni are associated with a range of sub-lethal and chronic effects in mammals, including renal and hepatic dysfunction, endocrine disruption, oxidative stress, impaired reproduction, and increased susceptibility to disease (Tuomikoski, 2022). For elephants, long-lived, large-bodied mammals with extensive exposure windows, the risk of bioaccumulation is heightened, and the ecological cost may manifest as reduced reproductive output, increased morbidity, or behavioural changes (Snell-Rood *et al.*, 2024). Additionally, seasonal patterns showing higher vegetation uptake during the dry season suggest that dry-season stress (reduced forage availability) may compound the risk of contaminant exposure. Elephants may browse less-preferred plants or soils with elevated metal content when preferred forage is scarce, thus increasing dietary exposure. The simultaneous contamination of water in this environment further raises concern: suboptimal water quality may force elephants to rely on compromised sources, thereby increasing exposure both directly (drinking) and indirectly (mud/soil ingestion). The broader coastal ecosystem vulnerability to heavy metal contamination reinforces the plausibility of multi-pathway exposure in the Epe coastal system (El-Sharkawy *et al.*, 2025).

This study highlights significant seasonal and spatial variation in heavy metal concentrations across vegetation, soils, water, and elephant fecal proxies in the coastal village ecosystems of Epe, Lagos State. Elevated levels of cadmium, chromium, lead, and nickel in forage plants, soils, and water, often exceeding WHO and other permissible limits, underscore the potential for chronic exposure and bioaccumulation in local elephant populations via trophic and environmental pathways. Seasonal peaks, particularly during the dry season, indicate that forage scarcity may exacerbate metal intake, posing sub-lethal health risks including oxidative stress, renal and hepatic dysfunction, and reproductive impairment. It is recommended that regular monitoring of heavy metal levels in vegetation, soils, and water be conducted in the Epe coastal ecosystem, coupled with targeted management strategies to

mitigate anthropogenic contamination and safeguard elephant health.

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