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Trophic Level Variations of Heavy Metals in Feathers of Birds from Awotan Landfill in Ibadan Nigeria

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Abstract

Global pollution from urbanization and technology exerts pressure on ecosystems through xenobiotics, especially heavy metals, which bioaccumulate and biomagnifies across food chains and trophic levels. In Nigeria, poorly managed landfills remain critical pollution hotspots, contributing to biodiversity loss and necessitating non-invasive ecotoxicological assessments. This study analyzed 13 metals (Fe, Mn, Zn, Cu, Co, Cr, Cd, Pb, Ni, Al, B, Se, Hg) in feathers of four bird species: Hirundo aethiopica and Anthus leucophrys (insectivores), Streptopelia senegalensis (granivore), and Turdus pelios (omnivore) using FAAS. Diversity indices and abundance were estimated via point counts, while ANOVA tested inter-trophic variation. Results showed elevated iron levels in insectivores (2.6985 ± 0.1975 ppm) compared to granivores (2.0100 ± 0.3172 ppm). Insectivores also accumulated higher levels of Cd, Co, Cr, Ni, Se, and Hg, whereas granivores consistently had lower concentrations. Significant differences were detected across trophic levels ($p < 0.05$). Findings indicate landfills serve as reservoirs of heavy metal pollution, with resident birds acting as effective sentinels of bioaccumulation, asymmetry, and ecosystem stress. Feather-based monitoring offers a reliable tool for tracking contaminant fate and predicting ecological risk.

Keywords: Bioaccumulation and Biomagnification, Non-invasive Ecological Hazard Assessment, Toxic Heavy Metals, Avian Feathers, Ecological Declination and Stress

INTRODUCTION

Environmental pollutants contaminate air, water, and soil, stressing ecosystems and biota. Human activities link closely to morbidity and mortality by impairing key biological functions (Usman *et al.*, 2023). Poor solid waste management remains a major challenge (Alimba *et al.*, 2006; Oshode *et al.*, 2008) due to contaminants like heavy metals (Bakare *et al.*, 2022). Urbanization and population growth increase waste generation, with landfills releasing leachates into groundwater, surface water, and gases into the atmosphere (Oshode *et al.*, 2008). Unlike degradable pollutants, heavy metals are toxic, persistent, and prone to ecological accumulation with long half-lives. These include transition and post-transition metals (Nkwononwo *et al.*, 2020), lanthanides, actinides (Adepoju-Bello *et al.*, 2009), and metalloids (Igwe *et al.*, 2005) characterized by high density (Tchounwou *et al.*, 2012). Sources are both natural (ores, rocks) and anthropogenic: agriculture, metallurgy, energy production, atmospheric deposition, and waste discharge (Odika *et al.*, 2020).

Some metals are trace nutrients, others strictly toxic (Ayeni, 2014). Their bioavailability depends on pH, soil type, adsorption, and temperature, influencing toxicity at trace levels. Speciation affects solubility and transfer within soil, water, and sediments. Via bioaccumulation and biomagnification, metals disrupt ecosystems (Ali *et al.*, 2019) and intensify at higher trophic levels. Non-biodegradability makes bioaccumulation problematic, as metals build up when uptake exceeds detoxification (Eagles-Smith *et al.*, 2016), and birds are often used as bioaccumulative sentinels (Heys *et al.*, 2016).

Monitoring heavy metals requires examining sources, persistence, and fate while soil, water, and air chemical monitoring reveals contamination (Pyagay *et al.*, 2020), it often misses biological effects (Swaileh & Sansur, 2006). Biomonitoring using biological markers offers direct ecological insights (Rutkowska, 2018). Species and communities serve as pollution sentinels, reflecting ecosystem health, contamination pathways, and pollutant transfer through food webs (Gomez-Ramirez *et al.*, 2021). Birds are particularly sensitive and widespread bioindicators of heavy metals. Due to ethical concerns over invasive tissue sampling (Acampora *et al.*, 2017), researchers are shifting toward non-invasive methods (Garcia-Fernandez *et al.*, 2013; Adeogun *et al.*, 2022).

Feathers are prominent biomonitoring sentinels (Garcia-Fernandez *et al.*, 2013). They reliably reflect internal metal concentrations, are easily collected and stored, and can be sampled across ages and sexes (Rutkowska *et al.*, 2018). Feathers often contain higher metal loads than other tissues (Malik & Zeb, 2009; Zamani-Ahmad *et al.*, 2010) and are especially valuable for monitoring threatened species. Birds in anthropogenic landscapes are vulnerable, with feather contamination linked to developmental instability and dietary exposure (Malik & Zeb, 2009; Zamani-Ahmad Mahmoodi *et al.*, 2010). Thus, feather-based assessments provide a reliable framework to evaluate toxic heavy metal (THM) accumulation and bioaccumulation patterns in avian trophic networks.

MATERIALS AND METHODS

Study Area

Ibadan, the capital of Oyo State, is one of Nigeria's largest cities, with approximately 3,080 sq. km and generating over 996,102 tons of solid waste annually (Amuda *et al.*, 2014). The landfill lies 200–25 meters above sea level at latitude 07°27.59'N and longitude 03°50.93'E, along Apete-Awotan-Akufo Road, Apete, Ido Local Government Area, Ibadan. It receives municipal wastes from commercial, domestic, educational and industrial sources around the metropolis (Ogunseiju *et al.*, 2015).

Sampling

Bird surveys at the Awotan landfill were conducted between June and October 2021 following standard protocols (Edegbene, 2018). Sampling occurred weekly, with three visits in June and August, four in July, and one each in September and October. Both area counts and point counts were employed, the latter at three stations spaced 150 m apart: Point A (waste-dumping zone), Point B (vegetated area), and Point C (relatively an undisturbed site). Birds were observed for 5–20 minutes per station and identified to species level. Counts were done during peak activity periods: 06:30–11:00, 13:00–16:00, and 16:00–18:00 hrs. Observations took place while moving through the landfill and from elevated vantage points, with species confirmation aided by catalogues and identification manuals (Adeyanju *et al.*, 2013). Complementary mist-netting followed procedures adapted from Adeyanju (2013).

Sampling points were randomly chosen considering avian habits and site characteristics. Three mist nets (20 × 10 m and 30 × 10 m, mesh sizes 25–45 mm) were positioned along likely flight paths or high-activity zones. Nets were installed at 06:30 hours and monitored every 10–20 minutes throughout the day, using improvised wooden poles for support.

Diversity Indices Analysis for Point Count Data

Margalef index (d)

It was used to measure the species richness of Awotan landfill using the formula below:

$$(d) = S-1 \div LnN$$

Where;

d- Margalef index
S- total number of species
N- total number of individuals
Ln-Natural log

Shannon Weiner diversity indices (H)

The point count data of avian fauna encountered in Awotan was analyzed using the Shannon Weiner diversity indices state below:

$$H= -\sum^{s} PIlnpi$$

Where;

PI- proportion of individual species
s- total number of species in the community
ln- natural logarithm
i- i^{th} species
H- Shannon Weiner diversity

Pielou evenness index

It measures the evenness or equitability of the community and was determined using the formula below:

$$Evenness = H \div \log s$$

Where;

H- Shannon Weiner index
s- number of species/taxa
Log- Naperian log

Simpson's Diversity index (D)

It was used in comparing the diversity between avian fauna obtained from the point count data, taking into account species richness and evenness. It was calculated using the formula below:

$$D = \sum n (n-1) \div N-1$$

Where;

D-Dominance
n- Total number of individuals per species
N- Total number of organisms of all species counted in a point or station

Avian sampling

Birds were tagged using plastic avian leg rings to avoid recapturing and for future reference (Bergan *et al.*, 2011). The captured birds (n=50) were weighed using electronic sf-400 and morphometric measurements (head length, beak/bill length, digit length, wing length, tail length and weight) were recorded. The total head length, beak/bill length, digit length, wing length, tail length, and weight were taken from two individuals (n=2) of the Ethiopian swallow species (Hirundo aethiopica) to determine symmetry or asymmetry related to flight and morphometry. Two to four flight feathers from both wings were carefully removed from the right and left wings of the birds (Rutkowska *et al.*, 2018) to avoid stressing or injuring the birds. Specific factors such as collection time, feather type, and feeding pattern were also noted (Garcia-Fernandez *et al.*, 2013). The sampling process and analysis were non-invasive; birds were released after sampling, and collected feathers were stored in labeled Ziploc bags.

Sample Analysis: Feather Digestion and Metal Assay

Feathers were rinsed thrice with distilled water, oven-dried at 80°C (HVP-16426927), and homogenized using a ceramic mortar and pestle. Approximately 0.1 mg of powdered material was weighed (BA-T series analytical balance), digested in 2 mL of 70% HNO_3, and heated at 120°C for 24 hours. After cooling, samples were filtered (0.4 µm) and diluted to 25 mL with deionized water. Metal concentrations were measured using a Fast-Sequential Atomic Absorption Spectrophotometer (FAAS, Buck Scientific 210).

Statistical Analysis

One-way ANOVA was used to compare the differences in heavy metal concentrations in the feathers across various bird species and trophic levels at a significance level of $p < 0.05$.

RESULTS

A total of 702 individual birds, representing four families, were recorded at the Awotan landfill. These included two resident-migrant species (Turdus pelios and Anthus leucophrys) and two resident species. Hirundo aethiopica was the dominant species (Tables 1a, 1b). Mist-net captures yielded 50 birds, with H. aethiopica accounting for 74% (n=36), Streptopelia senegalensis 24% (n=12), and single captures of Turdus pelios and Anthus leucophrys (2% each) (Table 2). Species distribution by sampling point is shown in Table 3. Morphometric analyses included linear and mass measurements, with symmetry assessments conducted on H. aethiopica via bilateral wing, tail, and centrum comparisons (Tables 4a, 4b). Biodiversity metrics (Margalef, Shannon–Wiener, Simpson, and Pielou indices) indicated varying species abundance and diversity across sampling points (Tables 5a, 5b). Feather analyses detected 12 metals (Fe, Mn, Zn, Cu, Co, Cr, Cd, Ni, Al, B, Se, Hg), while lead (Pb) was undetected.

Concentrations varied among species and trophic levels (Tables 6, 7; Fig. 4a–c).

Table 1a: Area count checklist of avian species

Month	Common Name	Family	Scientific Name	Number Observed	% Occurrence
June	Ethiopian Swallow	Hirundinidae	*Hirundo aethiopica*	150	69.12
	Laughing Dove	Columbidae	*Streptopelia senegalensis*	65	29.95
	African Thrush	Turdidae	*Turdus pelios*	1	0.46
	Plain-Backed-Pipit	Motacillidae	*Anthus leucophrys*	1	0.46
			Total	217	100
July	Ethiopian Swallow	Hirundinidae	*Hirundo aethiopica*	120	58.25
	Laughing Dove	Columbidae	*Streptopelia senegalensis*	85	41.26
	African Thrush	Turdidae	*Turdus pelios*	1	0.49
			Total	206	100
August	Ethiopian Swallow	Hirundinidae	*Hirundo aethiopica*	135	62.5
	Laughing Dove	Columbidae	*Streptopelia senegalensis*	80	37.04
	African Thrush	Turdidae	*Turdus pelios*	1	0.46
			Total	216	100
September	Ethiopian Swallow	Hirundinidae	*Hirundo aethiopica*	8	50
	Laughing Dove	Columbidae	*Streptopelia senegalensis*	7	43.75
	African Thrush	Turdidae	*Turdus pelios*	1	6.25
			Total	16	100
October	Ethiopian Swallow	Hirundinidae	*Hirundo aethiopica*	35	74.47
	Laughing Dove	*Columbidae*	*Anthus leucophrys*	12	25.53
			Total	47	100

Table 1b: Summary table for the point count observation data

Common name	Family	Species Name	Number observed	% Occurrence
Laughing dove	*Columbidae*	*Streptopelia senegalensis*	249	35.47%
Ethiopian swallow	*Hirundinidae*	*Hirundo aethiopica*	448	63.82%
Plain-Backed-Pipit	*Motacillidae*	*Anthus leucophrys*	3	0.43%
African Thrush	*Turdidae*	*Turdus pelios*	2	0.29%
	Total		702	100%

Table 2: Mist net data of avian species encountered

Foraging behavior	Common name	Family	Species Name	Number observed	% Occurrence
Granivore	Laughing dove	Columbidae	Streptopelia senegalensis	12	24%
Insectivores	Ethiopian swallow	Hirundinidae	Hirundo aethiopica	36	72%
	Plain-Backed-Pipit	Motacillidae	Anthus leucophrys	1	2%
Omnivore	African Thrush	Turdidae	Turdus pelios	1	2%
		Total		50	100%

Species	N	Weight	Head Length	Beak	Full Tarsus	Digit	Wing
Ethiopian Swallow	36	12.610±2.678	3.831±0.322	0.600±0.209	0.273±0.431	1.247±0.258	9.600±0.498
Laughing dove	12	96.000±11.078	5.217±1.211	1.450±0.243	3.967±0.33	2.517±0.248	10.900±2.674
Plain-Backed-Pipit	1	32.000±0	4.600±0	1.200±0	5.000±0	2.000±0	9.100±0
African Thrush	1	68.000±0	5.600±0	1.700±0	5.100±0	2.700±0	10.500±0

Table 3: Avian species trapped in various sections

Points	Ethiopian Swallow	Laughing dove	African thrush	Plain-backed-Pipit	Total (point)
A	8	2	0	0	10
B	9	8	0	1	18
C	20	1	1	0	22
Total (species)	37	11	1	1	50

Table 4a: Morphometric measurements of Avian Species captured

Species	N	Weight	Head Length	Beak	Full Tarsus	Digit	Wing
Ethiopian Swallow	36	12.610±2.678	3.831±0.322	0.600±0.209	0.273±0.431	1.247±0.258	9.600±0.498
Laughing dove	12	96.000±11.078	5.217±1.211	1.450±0.243	3.967±0.33	2.517±0.248	10.900±2.674
Plain-Backed-Pipit	1	32.000±0	4.600±0	1.200±0	5.000±0	2.000±0	9.100±0
African Thrush	1	68.000±0	5.600±0	1.700±0	5.100±0	2.700±0	10.500±0

Values are given as mean ± standard deviation showing significance difference ($p < 0.05$)

Table 4b: Asymmetric measurements of the two Ethiopian Swallows

Morphometric Species	Right Wing Length	Left Wing Length	Symmetry	Left First Outer Tail	Right First Outer Tail	Symmetry	Centrum (Inner Tail Feather)
Ethiopian Swallow 1	9.9	9.9	Symmetric	5.8	5.9	Asymmetric	3.6
Ethiopian Swallow 2	10.4	10.5	Asymmetric	5.0	5.1	Asymmetric	3.9

Table 5a: Monthly biodiversity indices during the sampling period

Biodiversity indices	June	July	August
Margalef Index (Species richness)	0.668	0.379	0.758
Shannon Weiner Index (Diversity)	0.357	0.164	0.330
Simpson index (Dominance)	0.179	0.767	0.527
Pielou Index (Evenness)	0.357	0.136	0.288

Table 5b: Biodiversity indices for respective sampling points

Biodiversity indices	Point A	Point B	Point C
Margalef Index (Species richness)	0.435	0.692	0.647
Shannon Weiner Index (Diversity)	0.217	0.377	0.211
Simpson index (Dominance)	0.644	0.418	0.745
Pielou Index (Evenness)	0.217	0.300	0.157

Table 6: Mean concentration of heavy metals in analyzed feather samples

Metals (μ/g-ppm)	Species	Laughing Dove	Ethiopian Swallow	Plain-Backed-Pipit	African Thrush
	Trophic level	*Granivore*	*Insectivore*	*Insectivore*	*Omnivore*
	Status	*Resident*	*Resident*	*Resident-migrant*	*Resident-migrant*
	N	*3*	*3*	*2*	*2*
Manganese		0.633±0.0096	0.0643±0.0143	0.0900±0.0100	0.0585±0.0015
Iron		2.0100±0.3172	NA	2.6985±0.1975	NA
Zinc		0.1687±0.0110	0.1587±0.0195	0.1970±0.110	0.1350±0.0010
Cobalt		0.0007±0.0012	0.0003±0.0006	0.0005±0.0005	0.0015±0.0015
Chromium		0.0003±0.0006	NA	0.0005±0.0005	NA
Cadmium		0.0003±0.0006	NA	0.0005±0.0005	NA
Copper		0.0010±0.0010	NA	0.0010±0.0010	NA
Lead		ND	NA	ND	NA
Nickel		0.0003±0.0006	0.0007±0.0012	0.0005±0.0005	0.0010±0.0010
Aluminum		0.0357±0.0025	0.0287±0.0025	0.0240±0.0010	0.0495±0.0015
Boron		0.0137±0.0015	0.0180±0.0010	0.0185±0.0005	0.0245±0.0015
Selenium		0.0433±0.0015	0.0480±0.0017	0.0310±0.0020	0.0615±0.0035
Mercury		0.0213±0.0015	0.0270±0.0000	0.0120±0.0010	0.0330±0.0114

Values are given as mean ± standard deviation showing significance difference ($p<0.05$) of heavy metal concentrations in analyzed feathers

Note: NA - Not analyzed; **ND** -Not detected

Table 7: Mean concentration of heavy metals across trophic levels

Metals (μ/g-ppm)	Trophic level	Granivore	Insectivore	Omnivore
	Status	*Resident*	*Resident-migrant*	*Resident-migrant*
	N	*3*	*5*	*2*
Manganese		0.633±0.0096	0.0772±0.0122	0.0585±0.0015
Iron		2.0100±0.3172	2.6985±0.1975	NA
Zinc		0.1687±0.0110	0.1779±0.0153	0.1350±0.0010
Cobalt		0.0007±0.0012	0.0006±0.0009	0.0015±0.0015
Chromium		0.0003±0.0006	0.0005±0.0005	NA
Cadmium		0.0003±0.0006	0.0005±0.0005	NA
Copper		0.0010±0.0010	0.0010±0.0010	NA
Lead		ND	ND	ND
Nickel		0.0003±0.0006	0.0006±0.0015	0.0010±0.0010
Aluminum		0.0357±0.0025	0.0383±0.0023	0.0495±0.0015
Boron		0.0137±0.0015	0.0275±0.001	0.0245±0.0015
Selenium		0.0433±0.0015	0.0395±0.0027	0.0615±0.0035
Mercury		0.0213±0.0015	0.0125±0.0005	0.0330±0.0114

Values are given as mean ± standard deviation showing significance difference ($p<0.05$) of heavy metal concentrations in birds feathers across trophic levels (granivore, insectivore and omnivore) from Awotan landfill

Note: NA - Not analyzed; **ND -** Not detected

DISCUSSION

Abundance and Diversity

The point count method evaluates avian relative abundance within habitats (Edegbeine, 2018). At the Awotan landfill, surveys revealed Ethiopian Swallows as the most prevalent species (63.82%, n=448), followed by Laughing Doves (35.47%, n=249), African Thrush (0.43%, n=3), and Plain-backed Pipit (0.28%, n=2). Monthly fluctuations in abundance were observed (Table 1a, 1b & 1c). Landfills often serve as resource-rich habitats due to continuous food disposal, which may explain the high bird presence (Osterback *et al.*, 2015; Oka, 2016; Plaza & Lambertucci, 2017). Urban-adapted species such as Ethiopian Swallows display omnivorous or scavenging behaviors (Marasinghe *et al.*, 2018). Species diversity is further influenced by anthropogenic activity, biotic interactions, and environmental heterogeneity (Protasov *et al.*, 2009).

Diversity indices revealed spatial and temporal variation. Fifty individuals from four families were recorded across three sites: Point A (active dump), Point B (vegetated area without landfill activity), and Point C (inactive dump). Margalef's index was highest at Point B, moderate at Point C, and lowest at Point A (Table 5a, 5b). Shannon Wiener diversity peaked in June, declined in July, and increased again in August, with Point B consistently showing the greatest diversity. Simpson's dominance index was highest at Point C, followed by Point A, while Point B exhibited the least dominance. July recorded the strongest dominance effect, suggesting reduced diversity consistent with pollution-driven resilience shifts where tolerant species outcompete sensitive taxa (Khan, 2016). Pielou's evenness indicated the most equitable species distribution in July, followed by August, with June being the least even. Spatially, Point B had the highest evenness, followed by Points A and C. Declines in evenness are linked to environmental stress, where pollutant-driven disturbances disrupt community balance (Faiz & Fakhar, 2016).

Overall, the Awotan landfill exhibited lower species richness and diversity relative to a stable local community. The observed variation in diversity and dominance likely reflects site-specific stresses and human impacts.

Heavy Metal Concentrations in Species

Heavy metal pollution in landfills has been widely reported, with evidence of bioaccumulation and biomagnification across trophic levels (Hammed *et al.*, 2017; Marasinghe *et al.*, 2018; Kinuthia *et al.*, 2020). Previous research confirms that the Awotan landfill is contaminated, exposing resident biota, including birds, toxic metals (Olagunju *et al.*, 2020; Oladejo *et al.*, 2020; Adesogan & Omonigho, 2021). In this study, ten birds representing four species were analyzed (Table 6): Ethiopian Swallow (n=3), Laughing Dove (n=3), African

Thrush (n=2), and Plain-backed Pipit (n=2). Metal concentrations varied significantly among species and trophic levels ($p < 0.05$). Ethiopian Swallows exhibited the order Zn > Mn > Se > Al > Hg > B > Ni > Co, while Laughing Doves showed high Fe but negligible Pb (0.000 µg/g), following the pattern Fe > Zn > Mn > Se > Al > Hg > B > Cu > Co > Cr/Cd/Ni > Pb. African Thrushes recorded the highest Al, B, Se, Ni, and Hg levels, with the order Zn > Se > Mn > Al > Hg > B > Co > Ni. The Plain-backed Pipit demonstrated elevated Zn, Fe, and Mn but minimal Hg, Ni, Cd, and undetectable Pb, in the order Fe > Zn > Mn > Se > Al > B > Hg > Cu > Cr/Cd/Co/Ni > Pb. These interspecific variations reflect differences in diet and trophic ecology, with insectivores, granivores, and omnivores accumulating metals in distinct patterns (Jayakumar & Muralidharan, 2011). The findings underscore landfill-driven contamination and avifaunal vulnerability to heavy metal exposure across ecological niches.

Heavy Metal Concentrations across Avian Trophic Levels

Table 7 shows varying concentrations of heavy metals across trophic levels. High iron concentrations were detected, with insectivores (*Hirundo aethiopica, Anthus leucophrys*) showing the greatest levels, followed by granivores (*Streptopelia senegalensis*). Although within previously reported ranges (Einoder *et al.*, 2018; Adesakin, 2021), levels exceeded safe limits (50–80 ppm), suggesting landfill inputs from metal and electronic wastes. Elevated iron may induce haemosiderosis and impair reproduction and moulting. Zinc, a common landfill contaminant (Alloway, 2005; Ngole & Ekosse, 2012), exceeded thresholds (Adesakin, 2021). Insectivores accumulated the most zinc, omnivores the least. Despite its metabolic role, excessive zinc is toxic.

Mercury concentrations increased with trophic level, peaking in insectivores and lowest in granivores. Levels were below those reported by Keller *et al.* (2013), though some approached toxic thresholds (Evers *et al.*, 2008). Mercury likely originates from electronics and industrial waste, bioaccumulating through insect or soil ingestion (Ab-Latif *et al.*, 2015). Neurotoxic and hereditary risks remain high (Evers *et al.*, 2008). Cadmium occurred at very low levels (<2 µg/g; Abdullah *et al.*, 2015). Although insectivores showed higher accumulation, overall values suggest limited contamination. Still, Cd exposure is linked to reproductive, renal, and developmental anomalies (Burger, 2008).

Cobalt and chromium were detected at low concentrations, though omnivores carried more cobalt. While cobalt is essential, excess amounts can impair thyroid and pulmonary health (Atashi *et al.*, 2009). Chromium inputs, from industrial and waste sources (Jaishankar *et al.*, 2014), were below thresholds but remain mutagenic (Patlolla *et al.*, 2008). Nickel levels were low (<5 µg/g; Abdullah *et al.*, 2015), with no trophic differences. Although widely used in alloys and electronics (Ngole & Ekosse, 2012), nickel exposure disrupts moulting, liver function, and immunity especially in avian species (Zivkov *et al.*, 2017).

Manganese varied significantly across trophic levels, peaking in insectivores. Likely derived from fuel combustion and waste disposal, excess manganese can cause anemia, skeletal deformities, and behavioral disorders (Summers *et al.*, 2011). Copper was below toxic thresholds (Jaynadeh *et al.*, 2016), but insectivores accumulated the most. While essential, excess copper disrupts growth, endocrine, and reproductive functions (Stern, 2010).

Boron, mainly from detergents and agrochemicals, was highest in insectivores and lowest in omnivores. Aluminum was highest in omnivores, consistent with ingestion of contaminated soil or prey. Its oxidative stress effects are well documented (Slaninova *et al.*, 2014). Selenium peaked in omnivores, with values ranging from below to above WHO thresholds (Adesakin, 2021). Likely sources include electronics, metallurgy, and landfill leachates (Mehdi *et al.*, 2013). Chronic exposure can induce musculoskeletal defects and feather loss (Meschy, 2010). Lead was undetected, though its presence in landfill waste poses potential risks, including anemia, reproductive failure, and mortality in birds (Einoder *et al.*, 2018).

Asymmetry and Asymmetric Morphometry of Birds

Ecosystem stability can be assessed through morphological indicators such as fluctuating asymmetry (FA), a subtle deviation from bilateral symmetry caused by developmental instability under stress (Lajus *et al.*, 2015). Pollution, heavy metals, and persistent organic pollutants have been strongly associated with increased FA and change of body physiology in wildlife, particularly birds (Jawad *et al.*, 2020). FA is widely used in biomonitoring because it reflects the combined influence of extrinsic stressors (contamination, habitat degradation) and intrinsic constraints (genetic load, inbreeding) on organismal development. In birds, wings and tail feathers are frequently used due to their aerodynamic and ecological significance. While natural asymmetry exists in primary feathers for flight efficiency, stress-induced asymmetry will reduce maneuverability, stability, and migration performance.

In this study, Ethiopian swallows (*Hirundo aethiopica*) from Awotan landfill were examined. Morphometric analysis showed asymmetry in wing length for the individual, but tail feathers showed asymmetry in both count and additional wing asymmetry in the second bird. Such deviations likely reflect environmental stresses from bioaccumulation, landfill contamination, consistent with earlier reports linking heavy metals especially mercury to avian feather asymmetry (Clarkson *et al.*, 2012). Asymmetry in feathers can alter flight energetics, prolong migration stops, and ultimately reduce survival in avian species. At the community level, such traits signal ecosystem degradation, making FA a sensitive biomonitoring tool and a potential early warning indicator for wildlife conservation (Cuervo & Retrepo, 2007).

CONCLUSION

Landfills act as critical drivers of ecological stress. Findings from Awotan landfill reveal substantial heavy metal pollution. Avian species exhibited bioaccumulation across trophic levels, underscoring both ecosystem vulnerability and the utility of birds as bioindicators. Feather based assays proved to be an efficient non-invasive biomonitoring tool, positing contamination patterns linked to trophism and waste-soil-food exposure. Notably metal loads in Ethiopian swallow species, points to associations with developmental instability and asymmetry, reinforcing the role of avian biomonitoring as an early warning system for environmental health and sustainability.

Data Availability

The data supporting this study are available from the corresponding author upon reasonable request.

Conflict of Interests

The authors declare no conflict of interest related to this study.

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