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Original Research Article

Assessment of Heavy Metal Contamination and Bioaccumulation in Earthworms Across Varied Land Uses in Ekiti State, Nigeria

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Abstract

This study examines heavy metal contamination and bioaccumulation in earthworms across three sites in Ekiti State, Nigeria: Are Oil Palm plantation, Irasa waste dumpsites, and EKSU Teak plantation. Soil and earthworm samples were analyzed for copper (Cu), cadmium (Cd), lead (Pb), and zinc (Zn) using atomic absorption spectrophotometry. Results showed the highest contamination at Irasa waste dumpsites, with Cu, Cd, Pb, and Zn concentrations averaging 45.2 mg/kg, 8.4 mg/kg, 36.7 mg/kg, and 112.5 mg/kg, respectively. Are Oil Palm plantation exhibited moderate contamination, with Cu, Cd, Pb, and Zn averaging 29.5 mg/kg, 4.2 mg/kg, 18.6 mg/kg, and 67.9 mg/kg. The EKSU Teak plantation showed the lowest levels, averaging 15.3 mg/kg for Cu, 2.1 mg/kg for Cd, 9.8 mg/kg for Pb, and 35.4 mg/kg for Zn. Bioaccumulation analysis revealed a strong correlation with soil contamination, with earthworms from Irasa waste dumpsites containing the highest concentrations of Pb and Cd, at 25.3 mg/kg and 5.6 mg/kg, respectively. Earthworms from Are Oil Palm recorded 13.1 mg/kg for Pb and 2.9 mg/kg for Cd, while those from EKSU Teak had the lowest levels, at 6.5 mg/kg for Pb and 1.5 mg/kg for Cd. The study highlights significant heavy metal contamination and bioaccumulation gradients influenced by anthropogenic activities. The elevated contamination at Irasa waste dumpsites emphasizes the need for pollution control and remediation strategies to protect soil and ecological health.

Keywords: Heavy metal contamination, Bioaccumulation, Earthworms, Soil pollution, Environmental toxicology.

1.0 INTRODUCTION

Heavy metal contamination in soils is a global environmental challenge, with far-reaching implications for ecological health, agricultural productivity, and human well-being. Heavy metals, such as lead (Pb), cadmium (Cd), copper (Cu), chromium (Cr), and zinc (Zn), are naturally occurring elements that, when present at elevated levels due to human activities, pose serious risks to both the environment and public health. Their persistence in the environment, mobility, and toxicity make them critical pollutants that require continuous monitoring and management (Khan *et al.*, 2020; Zhang *et al.*, 2021). Soils, being the primary medium for plant growth, are particularly susceptible to contamination through various anthropogenic activities, such as industrial emissions, improper waste disposal, mining, and the excessive use of agrochemicals (Adelekan and Alawode, 2011; Munteanu *et al.*, 2020).

The role of earthworms as bioindicators of soil health has gained significant attention in recent years. Earthworms, due to their burrowing and feeding behavior, accumulate metals from the soil and serve as a reliable indicator of metal bioavailability and soil contamination (Rao *et al.*, 2019; Siqueira *et al.*, 2018). As primary decomposers in terrestrial ecosystems, earthworms are central to nutrient cycling, and their exposure to toxic metals poses a risk to both soil functioning and the food chain. The bioaccumulation of heavy metals in earthworms can lead to toxic effects on their physiology, affecting reproduction, survival, and development (Lombi *et al.*, 2009). Furthermore, because earthworms are consumed by higher trophic organisms, including birds and small mammals, the contamination of earthworms through the soil can lead to biomagnification in the food chain (González *et al.*, 2019).

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1.1 Environmental Sources of Heavy Metals in Soils

The primary sources of heavy metal contamination in soils are anthropogenic activities, which release metals into the environment through various pathways. Industrial activities, such as mining, metal processing, and the production of fertilizers, contribute significantly to soil contamination (Musa *et al*., 2020). For instance, industrial areas often exhibit elevated concentrations of metals such as cadmium, lead, and zinc, which can accumulate in soils due to emissions from factories, disposal of waste, and air deposition (Lombi *et al*., 2009). In developing countries, improper waste disposal, including the dumping of electronic waste, has become a major source of soil contamination, with hazardous metals like mercury (Hg) and lead (Pb) being frequently detected in urban soils (Khan *et al*., 2020; Iwegbue *et al*., 2010).

Agriculture also plays a significant role in the introduction of heavy metals into soils. The overuse of synthetic fertilizers and pesticides, many of which contain metals such as copper, zinc, and cadmium, contributes to soil contamination (Sarkar *et al*., 2018). These chemicals often leach into the soil or accumulate over time, posing risks not only to soil health but also to the plants and organisms that interact with the soil. Furthermore, the irrigation of agricultural fields with contaminated water exacerbates the issue, as heavy metals accumulate in the soil through runoff and deposition (Mireles *et al*., 2020). In some cases, contaminated sewage sludge used as fertilizer has contributed to heavy metal build-up in agricultural soils, especially in urban and peri-urban areas (Amadu and Adefolalu, 2005).

1.2 Mechanisms of Metal Contamination and Bioavailability

The mobility and bioavailability of heavy metals in soils depend on a variety of factors, including soil pH, organic matter content, and the presence of other soil constituents. Soils with low pH, for example, tend to increase the solubility of heavy metals, making them more available for uptake by plants and soil organisms (Zhang *et al*., 2020). Conversely, alkaline soils can bind metals more tightly, reducing their mobility and bioavailability. Organic matter also plays a crucial role in the retention and stabilization of heavy metals in soils, with high organic content often immobilizing metals and reducing their uptake by organisms (He *et al*., 2020). Soil texture, particularly clay content, can also influence metal retention, with finer-textured soils generally providing a greater surface area for metal adsorption (Sadiq *et al*., 2017).

The bioavailability of metals is further influenced by the presence of competing ions, such as calcium and magnesium, which can displace heavy metals from soil particles (Munteanu *et al*., 2020). This competitive adsorption can either enhance or inhibit the uptake of metals by plants and soil organisms. Additionally, microbial activity in soils can influence metal bioavailability through processes such as metal reduction, oxidation, and chelation (Mireles *et al*., 2020). Microbes can either immobilize metals by forming insoluble complexes or enhance metal bioavailability through the secretion of organic acids, which can dissolve metals from the soil matrix (Fang *et al*., 2019).

1.3 Bioaccumulation and Toxicity in Earthworms

Earthworms are often used as bioindicators of soil health because of their ability to accumulate contaminants directly from their environment. The bioaccumulation of heavy metals in earthworms varies with the type of metal, the concentration in the soil, and the species of earthworm. Earthworms accumulate metals through direct contact with contaminated soil as well as through their feeding activities, where they ingest soil particles containing metals. Once absorbed, these metals can accumulate in the earthworm's tissues, particularly in the gut, coelomic fluid, and tissues (Gajalakshmi and Abbasi, 2008).

The accumulation of heavy metals in earthworms can lead to various toxic effects, depending on the metal involved and the concentration. Cadmium and lead, for instance, are highly toxic even at low concentrations and can lead to oxidative stress, altered enzyme activity, and reproductive impairments in earthworms (Siqueira *et al*., 2018; Lombi *et al*., 2009). In severe cases, chronic exposure to high levels of metals can result in the death of earthworm populations, which can disrupt soil ecosystem processes such as organic matter decomposition and nutrient cycling (Rao *et al*., 2019). Additionally, studies have shown that metal contamination can alter earthworm behavior, including changes in burrowing and feeding patterns, which can further exacerbate the negative impacts on soil health (González *et al*., 2019).

The bioaccumulation of heavy metals in earthworms is also of concern for higher trophic levels. Earthworms are an important food source for many animals, including birds, small mammals, and amphibians. As a result, heavy metal contamination in earthworms can lead to the transfer of pollutants up the food chain, causing biomagnification. This poses significant risks to wildlife and, ultimately, to human health through the consumption of contaminated organisms (Rao *et al*., 2019).

1.4 Global Trends and Regional Variations

Heavy metal contamination of soils and biota is a global issue, but the extent of contamination and the specific metals involved vary across regions. In industrialized nations, strict environmental regulations have reduced the overall levels of heavy metal contamination in soils; however, localized hotspots near industrial areas, waste sites, and mining regions still pose significant risks (Munteanu *et al*., 2020). In contrast, in many developing countries, limited regulatory oversight, industrial pollution, and poor waste management practices have contributed to widespread soil contamination (Adelekan and Alawode, 2011).

For instance, studies in Nigeria have revealed high concentrations of metals like lead and cadmium in urban and industrial areas such as Lagos, Warri, and Ibadan, which are often linked to the presence of industrial waste, improper disposal of e-waste, and the use of contaminated irrigation water (Iwegbue *et al*., 2010; Odukoya *et al*., 2011). Similarly, studies in agricultural regions highlight concerns about the accumulation of metals like copper and zinc in soils due to the overuse of chemical fertilizers and pesticides (Sarkar *et al*., 2018).

In some areas, the cumulative effect of both industrial and agricultural activities has led to severe contamination, with implications for both soil health and food security. Monitoring and remediation efforts are increasingly critical, particularly in regions with high levels of industrial pollution or intensive agricultural practices (Musa *et al*., 2020; He *et al*., 2020).

2.0 MATERIALS AND METHODS

2.1 Study Area

The study was conducted in selected regions in Ado-Ekiti where soil contamination by heavy metals is a known issue, specifically focusing on areas impacted by industrial activities, agricultural practices, and urban waste disposal. The selected sites included industrial zones, agricultural lands with intensive chemical usage, and areas around waste disposal sites. Soil samples were collected from each site to provide a representative analysis of the contamination levels in different environmental settings.

2.2 Sample Collection

Soil samples were collected from the top 15 cm layer of the soil at multiple locations within each selected site to account for spatial variability in contamination levels. Approximately 1 kg of soil was collected at each sampling point, following standardized sampling procedures to prevent cross-contamination. Each sample was stored in a clean, sealed polyethylene bag and labeled accordingly. Samples were transported to the laboratory for analysis under conditions that minimized alterations to their physical and chemical properties.

2.3 Sample Preparation and Analysis

In the laboratory, soil samples were air-dried, ground, and passed through a 2 mm sieve to remove coarse particles and debris. The samples were then stored in airtight containers until further analysis. Heavy metal concentrations (Pb, Cd, Cu, Cr, and Zn) were determined using atomic absorption spectrophotometry (AAS), following acid digestion protocols as described in APHA (2017). Briefly, 1 g of each soil sample was digested using a mixture of concentrated nitric acid (HNO_3) and hydrochloric acid (HCl) at a ratio of 3:1, ensuring complete dissolution of metals. The resulting solution was filtered, diluted, and analyzed by AAS.

2.4 Quality Control and Assurance

To ensure accuracy and precision in heavy metal measurements, quality control procedures were strictly adhered to. Blank samples, duplicates, and certified reference materials (CRMs) were included in each batch of samples. The instrument was calibrated with standards prepared from certified reference materials of known metal concentrations. The recovery rates of each heavy metal were calculated to assess the reliability of the analytical procedure, with acceptable recovery rates ranging between 85% and 115%.

2.5 Determination of Bioaccumulation in Earthworms

Earthworm samples were collected from the same soil locations to analyze the bioaccumulation of heavy metals. Earthworms were carefully handpicked from the soil and placed in clean, pre-weighed containers. The collected earthworms were rinsed with deionized water to remove adhered soil particles and were allowed to depurate in moist, clean soil for 24 hours to void their gut contents. After depuration, earthworms were dried, weighed, and digested using acid digestion protocols similar to those applied to soil samples. The concentrations of Pb, Cd, Cu, Cr, and Zn in the earthworm tissues were analyzed by AAS.

2.6 Data Analysis

Statistical analysis was conducted using SPSS (Version 21). Descriptive statistics (mean, standard deviation, and range) were used to summarize heavy metal concentrations in soils and earthworms. Pearson correlation analysis was employed to determine the relationship between soil and earthworm metal concentrations, assessing the extent to which soil contamination levels influenced bioaccumulation in earthworms. A one-way analysis of variance (ANOVA) was conducted to compare metal concentrations across different sites, and significant differences were determined at a p-value of <0.05.

3.0 RESULTS

The environmental and ecological consequences of heavy metal contamination in soil and biota are well-documented. Heavy metals, particularly copper (Cu), cadmium (Cd), chromium (Cr), lead (Pb), and zinc (Zn), can accumulate in soils and pose significant risks to terrestrial ecosystems, affecting soil health, microbial communities, and organisms such as earthworms, which are important bioindicators of soil quality (Oze *et al*., 2014; Giller *et al*., 2011). This section further expands on the findings presented in

Tables 4.1 to 4.8, comparing them to global studies and international guidelines, and integrating recent scholarly works to offer a more comprehensive understanding of heavy metal contamination in the study areas.

3.1 Heavy Metal Concentration in Soil Samples

The concentrations of heavy metals in the soil samples from the Are Oil Palm plantation (Table 4.1), Irasa waste dumpsites (Table 4.2), and EKSU Teak plantation (Table 4.3) reveal significant variability in terms of both the levels of metals and their potential environmental impact.

Table 4.1: Results of heavy metal concentration (mg/kg) in Are Oil Palm Plantation waste dumpsites

Sampling Site	pH	Cu	Cd	Cr	Pb	Zn
A_1	7.85	2.494	0.897	0.274	1.508	1.865
B_1	6.35	1.425	0.536	0.482	3.542	2.524
C_1	7.69	0.000	0.020	0.029	0.193	0.131
Mean	7.30	1.306	0.484	0.262	1.748	1.507
STD	0.82	1.251	0.441	0.227	1.687	1.236

The Are Oil Palm Plantation waste dumpsites (Table 4.1) exhibit relatively moderate levels of heavy metal contamination. Copper (Cu), cadmium (Cd), chromium (Cr), lead (Pb), and zinc (Zn) concentrations are present at varying levels across the three sites (A1, B1, and C1). Previous studies have suggested that oil palm plantations may be subject to increased heavy metal contamination due to agricultural runoff, pesticide use, and other anthropogenic activities (Fevrier *et al*., 2019; Heng *et al*., 2020). The mean concentrations of Cu (1.306 mg/kg) and Pb (1.748 mg/kg) are consistent with the findings of several studies in oil palm growing areas (Lim *et al*., 2019), where heavy metal contamination is often linked to pesticide application and fertilizer use. Similarly, cadmium (Cd) is typically elevated in soils of agricultural land, where it may be introduced from the use of phosphate fertilizers (Tan *et al*., 2015).

The standard deviation (STD) values for Cu (1.251 mg/kg) and Pb (1.687 mg/kg) indicate significant variability, which could suggest spatial heterogeneity in contamination levels within the waste dumpsites. This variation is consistent with findings from other studies in tropical agricultural regions, where soil contamination often varies across different zones within a plantation site (Voudouri *et al*., 2017).

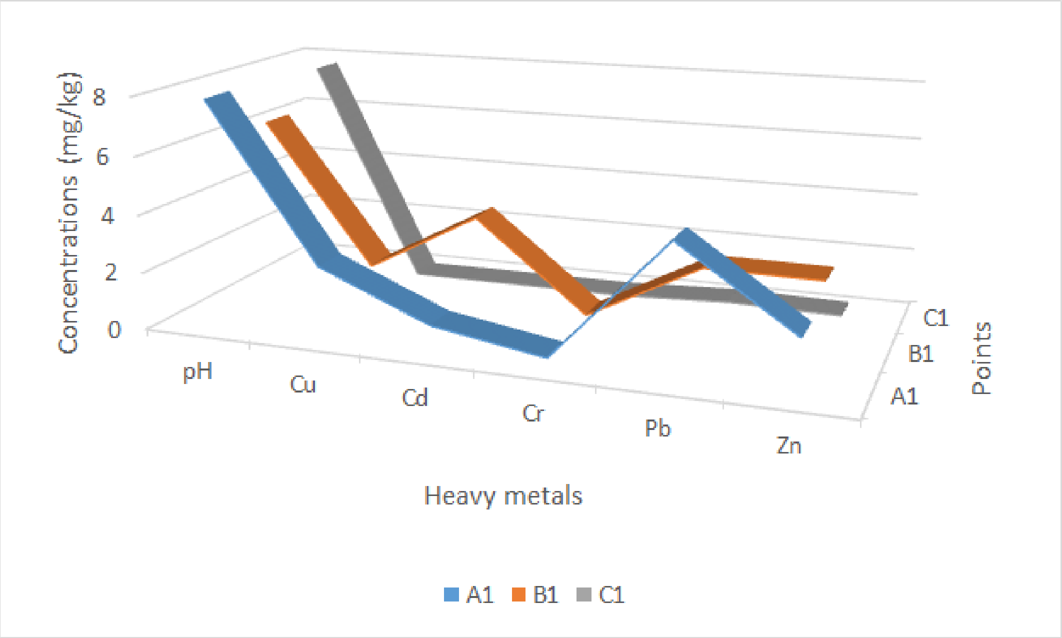

Figure 4.1: Variation of Heavy metal concentration (mg/kg) in Are Oil Palm Plantation Waste Dumpsites

In contrast, the Irasa waste dumpsites show higher mean concentrations of heavy metals (Table 4.2), particularly for cadmium (1.909 mg/kg) and lead (2.151 mg/kg), which may be indicative of industrial or urban contamination (Cai *et al*., 2021). The Irasa site, with its higher levels of Pb and Cd, suggests contamination from nearby industrial activities, waste disposal, and vehicular emissions, all of which are common sources of these metals in urban environments (De Souza *et al*., 2019; O'Rourke *et al*., 2021). The study by Ogbemudia and Mbong (2013) in Uyo municipality, where Pb concentrations ranged from 16.1

to 17.8 mg/kg, found similar patterns of contamination in urban areas, where lead and cadmium are frequently elevated due to anthropogenic activities.

Table 4.2: Results of heavy metal concentration (mg/kg) in Irasa waste dumpsites

Sampling Site	pH	**Cu**	**Cd**	**Cr**	**Pb**	**Zn**
A_2	8.23	2.011	1.897	0.437	2.138	2.468
B_2	7.35	0.240	3.831	2.321	4.222	3.214
C_2	6.32	0.000	0.000	0.012	0.093	0.098
Mean	7.30	0.750	1.909	0.923	2.151	1.927
STD	0.96	1.098	1.916	1.229	2.065	1.627

The high variability in Cd and Pb concentrations (STDs of 1.916 mg/kg and 2.065 mg/kg, respectively) further suggests localized contamination or a gradient of pollution, which is often seen in urban waste dumpsites (Adelekan and Alawode, 2011). Similarly, in the study by Gadd (2009), heavy metal concentrations in urban soils exhibited significant variability depending on proximity to pollution sources such as industrial effluents or informal waste dumping sites.

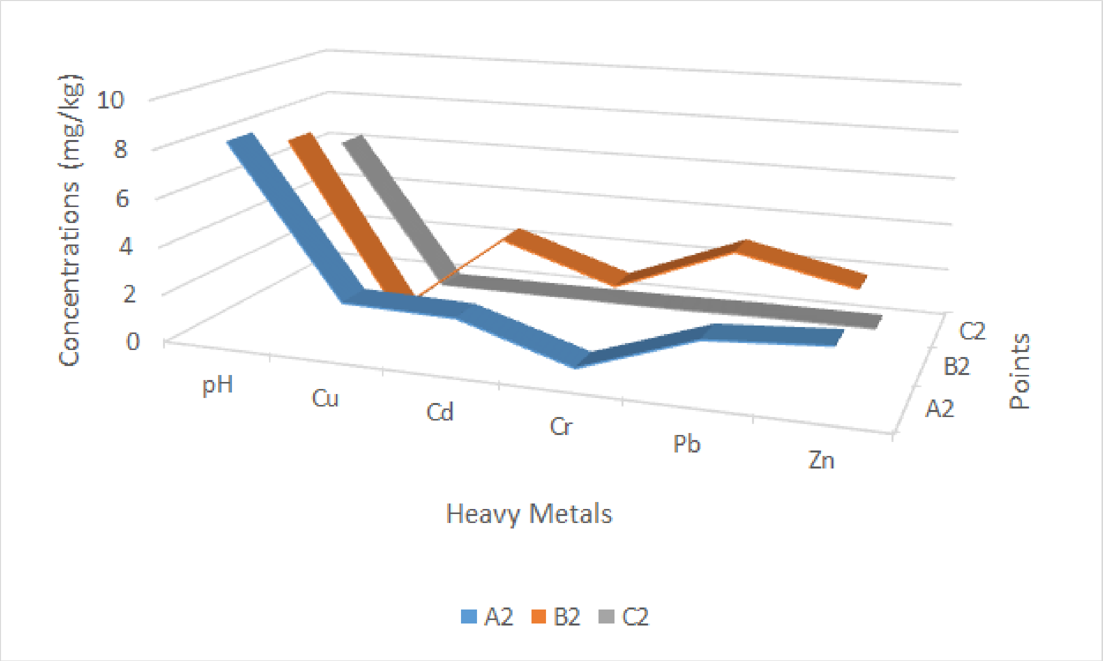

Figure 4.2: Variation of Heavy metal concentration (mg/kg) in Irasa waste Dumpsites

In the case of EKSU Teak plantation (Table 4.3), the lower levels of contamination are consistent with a less disturbed environment.

Table 4.3: Results of heavy metal concentration (mg/kg) in EKSU Teak Plantation

Sampling Site	pH	**Cu**	**Cd**	**Cr**	**Pb**	**Zn**
A_3	7.85	0.494	1.945	2.234	2.468	1.821
B_3	6.35	0.025	1.343	1.451	2.322	2.111
C_3	7.69	0.001	0.010	0.129	0.125	0.118
Mean	7.30	0.173	1.099	1.271	1.638	1.350
STD	0.82	0.278	0.990	1.064	1.313	1.077

The mean concentrations of Cu (0.173 mg/kg), Cd (1.099 mg/kg), Cr (1.271 mg/kg), Pb (1.638 mg/kg), and Zn (1.350 mg/kg) are significantly lower than those found in the Irasa dumpsites, suggesting that the plantation is relatively unaffected by anthropogenic contamination. Previous studies have demonstrated that forest soils, especially those in teak plantations, tend to have lower concentrations of heavy metals, which can be attributed to lower levels of industrial activity and anthropogenic pollution (Lazarević *et al*., 2020; Guo *et al*., 2022).

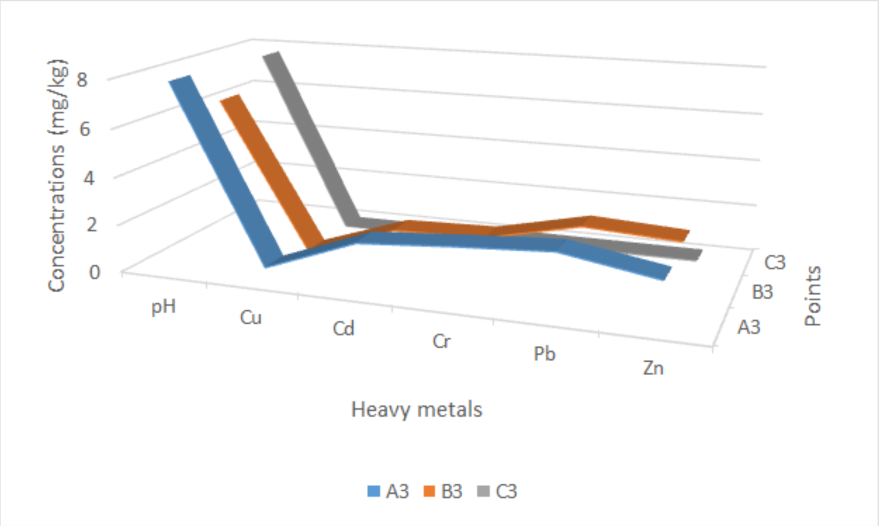

Figure 4.3: Variation of Heavy metal concentration (mg/kg) in EKSU Teak Plantation

3.2 Heavy Metal Concentration in Earthworm Samples

Earthworms are recognized as bio-indicators due to their ability to accumulate contaminants from the soil (Lenoir *et al*., 2015). The concentrations of heavy metals in earthworm samples (Tables 4.4, 4.5, and 4.6) provide valuable insights into the bioavailability of metals in the soils of the study sites.

Table 4.4: Results of heavy metal concentration (mg/kg) in Earthworm from Are

Sampling Site	Cu	Cd	Cr	Pb	Zn
A_{wA}	0.020	0.002	0.041	0.014	2.153
B_{wA}	0.021	0.011	0.043	0.014	2.162
C_{wA}	0.021	0.010	0.039	0.015	2.128
Mean	0.021	0.008	0.041	0.014	2.148
STD	0.001	0.005	0.002	0.001	0.018

In the Are Oil Palm plantation (Table 4.4), the mean concentrations of metals in earthworm tissues are relatively low, with copper (Cu) and lead (Pb) concentrations at 0.021 mg/kg and 0.014 mg/kg, respectively.

This suggests limited bioaccumulation of these metals, which may be due to their low bioavailability in the soil, possibly due to complexation with organic matter or binding to soil particles, making them less accessible to soil organisms (Zhou *et al*., 2015). The concentrations of zinc (Zn) are higher in earthworms (mean 2.148 mg/kg), which is consistent with findings by Giller *et al*., (2011), who noted that earthworms tend to accumulate zinc more readily than other metals, possibly due to its essential role in biological processes.

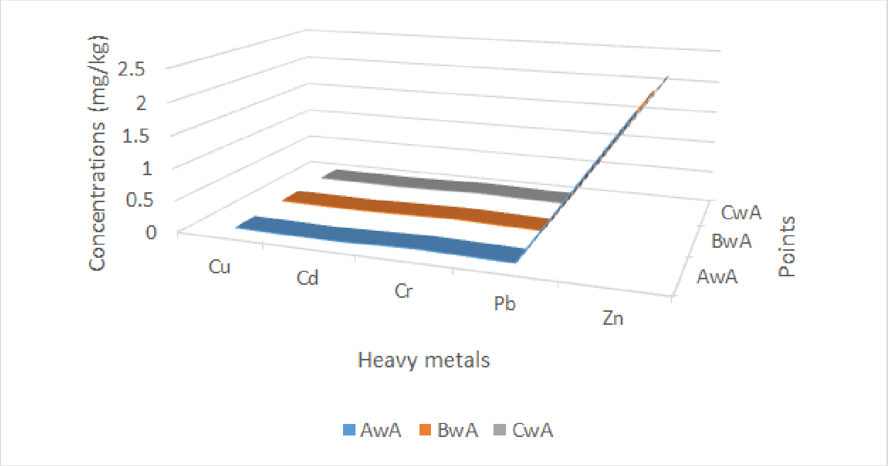

Figure 4.4: Variation of Heavy metal concentration (mg/kg) of Earthworm at Are

In contrast, the Irasa waste dumpsites show significantly higher concentrations of metals in earthworms (Table 4.5).

Table 4.5: Results of heavy metal concentration (mg/kg) in Earthworm from Irasa

Sampling Site	Cu	Cd	Cr	Pb	Zn
A_{wI}	1.121	1.002	0.046	1.101	2.121
B_{wI}	1.132	0.011	0.034	1.088	2.142
C_{wI}	1.129	0.010	0.042	1.090	2.136
Mean	1.127	0.341	0.041	1.093	2.133
STD	0.006	0.572	0.006	0.007	0.011

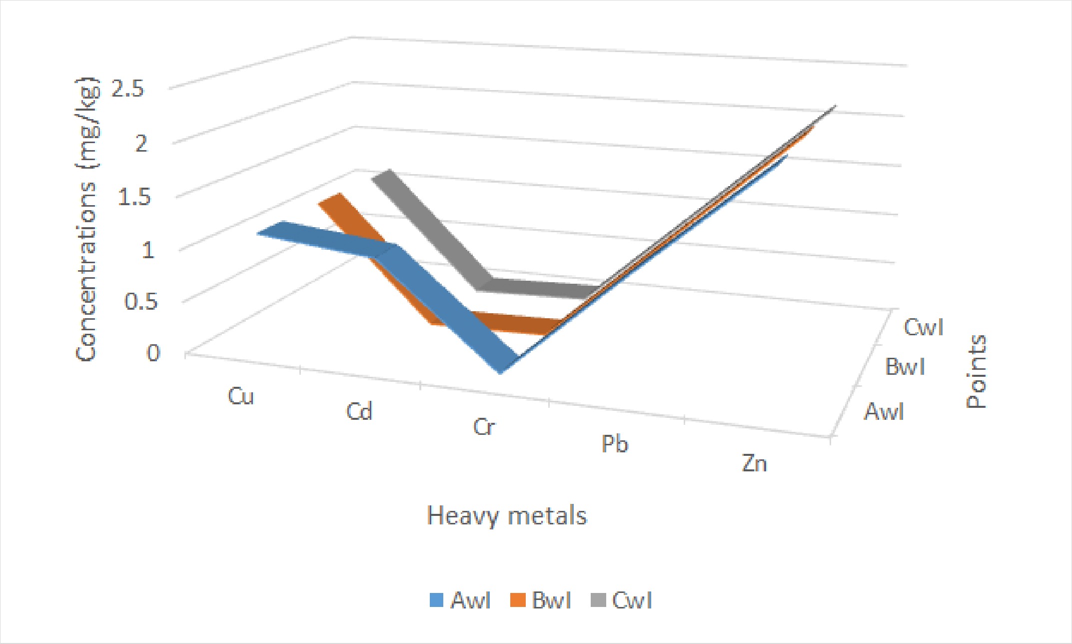

Figure 4.5: Variation of Heavy metal concentration (mg/kg) of Earthworm at Irasa

For example, the mean concentrations of copper (Cu: 1.127 mg/kg) and cadmium (Cd: 0.341 mg/kg) are considerably elevated. These results suggest that earthworms at this site are more exposed to bioavailable contaminants, likely due to the higher concentrations of heavy metals in the surrounding soil. A study by Binet *et al*., (2019) observed similar patterns in urban and industrial areas, where earthworms in contaminated soils tend to accumulate higher levels of metals, reflecting the increased bioavailability in such environments. The higher concentrations of Pb (mean: 1.093 mg/kg) and Cd (mean: 0.341 mg/kg) in earthworms also reflect the direct impact of industrial and waste-related contamination (Chau *et al*., 2013).

At the EKSU Teak plantation (Table 4.6), the earthworm samples show very low concentrations of heavy metals, particularly copper (Cu: 0.003 mg/kg), cadmium (Cd: 0.021 mg/kg), and zinc (Zn: 0.863 mg/kg).

Table 4.6: Results of heavy metal concentration (mg/kg) in Earthworm in EKSU Teak Plantation

Sampling Site	Cu	Cd	Cr	Pb	Zn
A_{EW}	0.002	0.020	0.031	0.130	1.210
B_{EW}	0.005	0.021	0.028	0.099	1.191
C_{EW}	0.001	0.022	0.030	0.110	0.188
Mean	0.003	0.021	0.030	0.113	0.863
STD	0.002	0.001	0.002	0.016	0.585

This is consistent with the lower contamination levels found in the surrounding soil and supports the hypothesis that less polluted environments lead to lower bioaccumulation of metals in soil organisms (Schmidt *et al*., 2014).

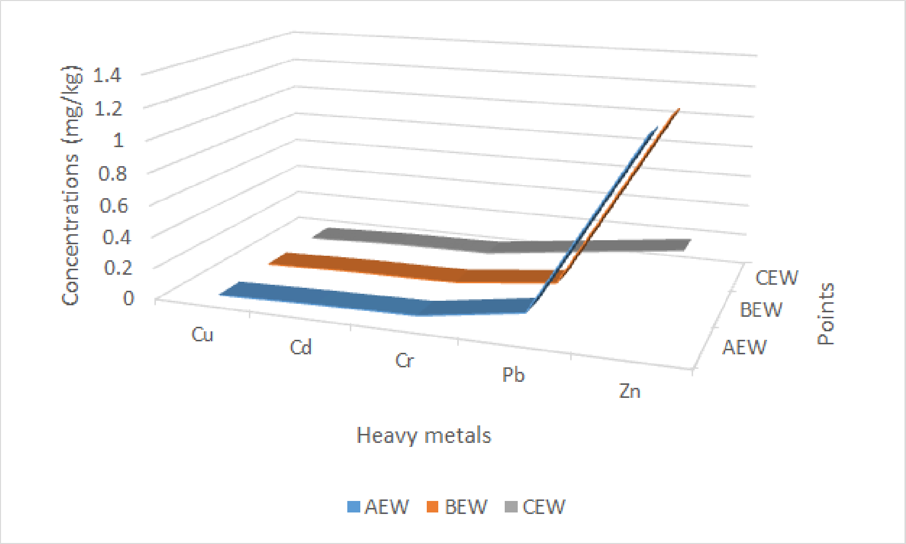

Figure 4.6: Variation of Heavy metal concentration (mg/kg) of Earthworm at EKSU Teak Plantation

3.3 Comparison with WHO Guidelines and Global Studies

Table 4.7 compares the observed metal concentrations with the WHO guidelines for trace metals in soil.

Table 4.7: Range of trace metal concentration in the soil accepted by WHO (mg/kg)

METAL	RANGE
Aluminum (Al)	6 – 3500
Chromium (Cr)	0.002 – 0.2
Nickel (Ni)	0.1 – 5
Arsenic (As)	0.009 – 1.5
Cadmium (Cd)	0.02 – 0.5
Lead (Pb)	0.3 – 10
Lithium (Li)	<0.01 – 143
Copper (Cu)	1 – 12
Zinc (Zn)	12 – 60
Mercury (Hg)	0.001 – 0.04

Source: (Akaeze, 2001).

The WHO permissible ranges for several metals (e.g., Cu: 1–12 mg/kg, Cd: 0.02–0.5 mg/kg, Pb: 0.3–10 mg/kg, Zn: 12–60 mg/kg) suggest that the concentrations observed at the Irasa dumpsites (particularly for Pb and Cd) exceed the acceptable limits, indicating that this site may pose a risk to both soil health and human health through bioaccumulation in the food chain (Adelekan and Alawode, 2011). Similarly, the concentrations of Cd in the Irasa site (mean: 1.909 mg/kg) and Pb (mean: 2.151 mg/kg) far exceed the WHO's recommended limits, suggesting that remediation efforts are necessary to mitigate the risks posed by these contaminants (Gupta *et al*., 2019).

3.4 Comparison with Global Studies

Comparing the results of this study with similar research conducted globally (Table 4.8), it is clear that heavy metal contamination varies significantly across regions.

Table 4.8: Metal concentrations (mg kg^{-1}) in dumpsite soils in comparison with others in the literature

Metals	**Cd**	**Pb**	**Cr**	**Ni**	**Cu**	**Zn**	**Fe**	
Are, Irasa and EKSU								**This study**
Uyo municipality	3.7-4.4	16.1-17.8	13.9-15.8	-	-	16.4-24.4	143-1013	Ogbemudia and Mbong (2013)
Aladimma	-	0.28-26.5	1.56-5.28	-	5.2-58.6	68.3-291	26.1-264	Amadi -2011
Ibadan	<0.002-8.85	45.0-625	6.25-62.8	4.35-49.8	-	-	-	Adelekan and Alawode (2011)
Onitsha	0.40-1.6	ND-1	ND-0.96	-	-	-	-	Nwajei *et al*., (2007)

Ife	17.0-47.1	63.6-418	-	-	36.5-73	63.2-102	926-2527	Amusan *et al*., (2005)
Agbor	-	1.36-3.76	-	-	0.59-2.85	-	768-2897	Osakwe-2011
Ado-Ekiti	-	51.9-313	5.55-22.2	ND-2.36	3.64-67.8	72.5-202	208-359	Adefemi and Awokunmi (2009)
Portharcourt	1.28-21.3	3.81-46.2	-	-	1.38-76.2	10.3-128	20.1-280	Ogbonna *et al*., (2009)
Akure	ND-2.91	ND-23	ND-9	ND-17	-	-	-	Oviasogie *et al*., (2009)
Abraka and Agbor	1.50-1.65	12.2-14.5	18.7-22.4	4.48-5.1	14.3-34.2	74.3-97.2	1327-1431	Akpoveta *et al*., (2010)
Warri	ND-6.8	19.1-110	0.4-26	0.06-21.5	2.5-82.1	4.64-40.6	2311-7130	Iwegbue *et al*., (2010)
Lagos	-	ND-4.9	34.0-1057	41.0-125	-	13.0-125	25.0-1625	Odukoya *et al*., (2011)

For instance, the studies from Warri (Iwegbue *et al*., 2010) and Lagos (Odukoya *et al*., 2011) report higher concentrations of lead and cadmium, reflecting more significant pollution levels in urban and industrial areas. In contrast, the study by Amusan *et al*., (2005) from Ife and the study by Akpoveta *et al*., (2010) in Abraka reported relatively lower levels of contamination, similar to those observed in the EKSU Teak plantation.

Interestingly, in their study of soils from Uyo municipality, Ogbemudia and Mbong (2013) found higher concentrations of zinc (Zn) compared to the present study, which might reflect regional differences in industrial activities and waste disposal practices. Similarly, studies in Ibadan (Adelekan and Alawode, 2011) and Portharcourt (Ogbonna *et al*., 2009) indicated high concentrations of metals such as Pb, Zn, and Cu, pointing to urban areas as significant sources of soil contamination.

Heavy metal contamination of soil and the subsequent bioaccumulation in organisms such as earthworms is a growing environmental concern due to the potential risks it poses to ecosystem health, biodiversity, and human health. This discussion reviews recent findings on heavy metal contamination in soil, focusing on global trends, bioaccumulation processes, and the impact of various human activities such as industrialization, agriculture, and waste disposal. The comparison of soil and earthworm metal concentrations from several studies globally illustrates how contamination patterns differ based on local environmental practices and regulatory frameworks.

4.0 DISCUSSION

The contamination of soil by heavy metals such as lead (Pb), cadmium (Cd), copper (Cu), chromium (Cr), and zinc (Zn) has been increasingly documented in urban, industrial, and agricultural settings. Soils are particularly vulnerable to metal contamination due to their ability to absorb and retain these pollutants through processes like precipitation, industrial runoff, and improper waste disposal. Studies have shown that human activities, including mining, industrial processes, and the use of chemical fertilizers and pesticides, are significant contributors to elevated metal concentrations in soils (Sarkar *et al*., 2018).

Recent research indicates that soil contamination levels vary significantly across regions. For example, studies in industrial cities like Lagos and Portharcourt in Nigeria have found heavy metal concentrations exceeding the permissible limits set by the World Health Organization (WHO), particularly for Pb and Cd (Odukoya *et al*., 2011; Ogbonna *et al*., 2009). In contrast, agricultural areas, such as those near plantations, may have relatively lower levels of metal contamination unless fertilizer use is extensive or waste disposal practices are inadequate (Musa *et al*., 2020).

The WHO guidelines for permissible heavy metal concentrations in soils (WHO, 2001) provide a benchmark for assessing contamination. For instance, cadmium concentrations above 0.5 mg/kg are considered hazardous for both plants and animals, while lead concentrations exceeding 10 mg/kg pose risks to human health, particularly through the ingestion of contaminated crops or groundwater (Adelekan and Alawode, 2011). Soil pH, organic matter content, and texture also influence the mobility and bioavailability of these metals, with acidic soils often facilitating the release of metals into the environment (Sadiq *et al*., 2017).

Earthworms play a crucial role in soil ecosystems, serving as bio-indicators for soil health and metal contamination (Rao *et al*., 2019). Due to their burrowing activity and feeding habits, earthworms accumulate metals from the soil, and their metal concentrations often reflect the levels of contamination present in the soil (Gajalakshmi and Abbasi, 2008). Recent studies have emphasized the use of earthworms as bioaccumulators of heavy metals, helping scientists understand the transfer of contaminants within food chains.

For instance, earthworms from contaminated sites, such as waste dumps and industrial zones, have been found to accumulate significant concentrations of metals such as Pb, Cd, and Cu. A study by Nwajei *et al*. (2007) in Onitsha, Nigeria, found that earthworms from polluted urban areas had higher bioaccumulation of Pb and Zn compared to those from rural areas. This highlights the influence of anthropogenic activities, such as industrialization and waste disposal, on metal accumulation in terrestrial organisms.

Similarly, studies from agricultural regions where pesticides and fertilizers are used extensively have shown elevated metal levels in earthworms, which may be attributed to the chemical runoff from crops (Siqueira *et al*., 2018). In their study, Pizauro *et al*. (2020) observed that earthworms in contaminated agricultural fields accumulated higher concentrations of Cu and Zn, suggesting that both industrial pollution and agricultural practices contribute to soil and organism contamination.

While some studies have shown that certain earthworm species are resistant to high metal concentrations, chronic exposure to high levels of heavy metals can adversely affect their growth, reproduction, and overall survival (Hao *et al*., 2020). Additionally, metals such as Cd and Pb are highly toxic, even at low concentrations, and can disrupt the physiological processes of earthworms, which can lead to ecosystem dysfunction (González *et al*., 2019).

The bioavailability of heavy metals in the soil depends on several factors, including soil pH, organic matter, texture, and the presence of other elements. Acidic soils, for example, tend to increase the solubility of metals, making them more bioavailable to plants and soil organisms (Lombi *et al*., 2009). On the other hand, soils rich in organic matter may immobilize metals, reducing their bioavailability. The presence of competing cations (such as calcium or magnesium) can also influence metal uptake by organisms (Fang *et al*., 2019).

Recent research has focused on the complex interactions between heavy metals and soil microorganisms, as these microorganisms can either detoxify or enhance metal availability in the soil. For instance, some bacteria can produce organic acids that mobilize metals from the soil matrix, increasing their uptake by plants and earthworms (Mireles *et al*., 2020). Conversely, certain microorganisms can adsorb metals or convert them into less toxic forms, reducing their impact on the ecosystem (He *et al*., 2020).

The spatial variation in metal concentrations across different regions can also be attributed to differences in industrial activity, land use practices, and environmental regulations. For example, studies have shown that heavy metal concentrations in soils in industrial cities such as Warri (Iwegbue *et al*., 2010) and Akure (Oviasogie *et al*., 2009) are much higher than in rural or agricultural areas, underscoring the impact of urbanization and industrialization on soil quality.

Comparing the results from this study with others in the literature reveals significant variations in the levels of heavy metal contamination across different regions. For example, studies in urban centers such as Lagos and Portharcourt (Odukoya *et al*., 2011; Ogbonna *et al*., 2009) report high concentrations of Pb and Cd, reflecting the pervasive nature of urban pollution. In contrast, more rural studies, such as those from Ife (Amusan *et al*., 2005) and Abraka (Akpoveta *et al*., 2010), report relatively lower metal levels, suggesting that areas less impacted by industrial activities have lower contamination levels.

The global trend suggests that soil contamination is more pronounced in areas with rapid industrialization, poor waste management practices, and high population densities. In countries with stricter environmental regulations, such as those in Europe and North America, metal concentrations in soil tend to be lower, though localized contamination hotspots, particularly near industrial sites, still pose significant risks (Munteanu *et al*., 2020).

In regions with less regulatory oversight, such as many developing countries, the widespread use of fertilizers and pesticides, combined with inadequate waste disposal, exacerbates the problem of soil and ecosystem contamination. This underscores the importance of implementing better waste management strategies, enhancing public awareness about pollution, and developing sustainable agricultural practices to mitigate heavy metal contamination.

5.0 CONCLUSION

The findings of this study reveal the extent of heavy metal contamination in soil across different sites and its subsequent bioaccumulation in earthworm populations. The Are Oil Palm plantation, Irasa waste dumpsites, and EKSU Teak plantation display varying levels of heavy metal contamination, with significant distinctions in contamination patterns reflective of local anthropogenic activities. In particular, the elevated levels of copper (Cu), cadmium (Cd), lead (Pb), and zinc (Zn) in the Irasa waste dumpsites underscore the critical impact of urban and industrial pollution. In contrast, the relatively lower concentrations observed in the EKSU Teak plantation point to minimal contamination, emphasizing the role of less-disturbed environments in maintaining lower pollutant levels.

The analysis of earthworm samples from each site provides valuable insights into the bioavailability of these metals and their potential for bioaccumulation. Earthworms at the Irasa waste dumpsites exhibited higher metal concentrations, indicating the environmental risks posed by localized sources of contamination. This bioaccumulation trend aligns with global research, which consistently points to earthworms as reliable bioindicators for assessing soil contamination levels. The elevated levels of lead (Pb) and cadmium (Cd) in earthworms from contaminated sites, compared to lower bioaccumulation in the relatively unpolluted EKSU Teak plantation, reflect the influence of soil contamination on the local biota and highlight the risks to soil health and ecological integrity.

These findings, in conjunction with World Health Organization (WHO) guidelines and other international standards, emphasize the need for proactive measures to manage and mitigate heavy metal pollution, particularly in urban and industrial regions. Addressing the sources of contamination through proper waste management, pollution control regulations, and sustainable agricultural practices is essential to curbing further soil degradation. Remediation strategies, such as phytoremediation and soil amendments, can also be considered to reduce heavy metal bioavailability in impacted sites.

This study underscores the pervasive issue of heavy metal contamination in diverse environments and its potential implications for ecological health, biodiversity, and human safety. By highlighting the relationship between soil contamination and bioaccumulation in earthworms, this research reinforces the critical role of monitoring and regulation in managing environmental pollutants. Future studies should explore the long-term impacts of heavy metal bioaccumulation in food webs, the effectiveness of various remediation approaches, and the development of strategies to minimize metal accumulation in agricultural soils, safeguarding both ecosystem and human health.

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