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RESEARCH ARTICLE

Assessment of the Potential Ecological Risks of Heavy Metals in Soil and Water Around Lunzu Solid Waste Dumpsite

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Abstract The indiscriminate dumping of municipal solid waste in Malawi, particularly at Lunzu dumpsite in Blantyre, has raised significant environmental concerns due to the potential contamination of surrounding soils and water sources by heavy metals (HMs). This study assessed the concentrations, spatial distribution, and ecological risks of selected heavy metals, cadmium (Cd), lead (Pb), copper (Cu), zinc (Zn), iron (Fe), manganese (Mn), and cobalt (Co) in soil and groundwater around the dumpsite. Samples were collected at varying distances (0-250 m radius from the dumpsite) during both dry and wet seasons and analyzed using Flame Atomic Absorption Spectrophotometry (AAS). In soil, the highest concentrations were recorded at the dumpsite center during the dry season: Cd at 3.08 mg/kg, Cu at 316.18 mg/kg, and Pb at 80.00 mg/kg, exceeding the WHO and EU permissible limits. In the wet season, metal concentrations were lower but still elevated, with Cd at 2.77 mg/kg, Zn at 635.22 mg/kg, and Pb at 72.00 mg/kg. In water samples, the maximum concentrations during the dry season were Cd at 0.02 mg/L, Pb at 0.14 mg/L, and Fe at 1.56 mg/L, which exceeded WHO drinking water standards, particularly for cadmium and lead. Correlation analysis revealed strong positive relationships among most metals and soil organic carbon (SOC), suggesting common pollution sources and the role of organic matter in metal retention. Water samples also revealed elevated concentrations of cadmium and lead, with levels surpassing WHO, EU, and Malawi Bureau of Standards (MBS) guidelines, posing serious health risks to nearby communities. Contamination assessment indices like the contamination factor (CF), geo-accumulation index (I_{geo}), enrichment factor (EF), and potential ecological risk index (PERI) consistently identified cadmium and mercury as the most ecologically hazardous metals. The spatial trend showed a decline in metal concentrations with increasing distance from the dumpsite, confirming the dumpsite as the primary contamination source.

Keywords: heavy metal pollution, refuse dumpsites, soil contamination, water contamination, Potential Ecological Risk Index, Lunzu, Malawi

1 Introduction

Waste generation has been an issue for communities since the beginning of civilization. The rapid increase in urbanization and industrialization has led to a significant increase in waste generation, necessitating the establishment of solid waste disposal facilities [1]. Globally, the problem of municipal solid waste management (MSWM) remains a major challenge in municipal cities, especially in developing countries, where cities and towns are experiencing problems of population growth and urbanization [2]. The increase in population and urbanization has led to a corresponding rise in municipal solid waste (MSW) generation in cities and towns, creating an urgent need for effective waste disposal and management facilities. According to the World Bank's publication "What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050," global MSW generation is projected to reach 3.4 billion tons by 2050 [3]. This growth is primarily driven by ongoing urbanization, which will worsen even more with the United Nations' estimation that nearly 70% of the global population will reside in urban areas by 2050. Additionally, daily activities significantly contribute to MSW production, posing challenges to waste reduction efforts. In many developing countries, limited resources and expertise hinder proper waste treatment and management [3]. Dumpsites continue to play a vital role in waste management strategies, especially in resource-limited settings. They are a

key facility, particularly in developing countries, where they serve as an essential element of overall waste management efforts.

Rapid urbanization and population growth in sub-Saharan Africa have led to increasing volumes of municipal solid waste, placing substantial pressure on existing waste management systems. In developing countries, municipal solid waste management faces acute challenges due to inadequate infrastructure, financial constraints, and limited technical expertise. Malawi, like many developing countries, faces serious challenges in the segregation, collection, treatment, and safe disposal of solid waste. Waste generated in Malawi is estimated at 0.65 to 0.95 kg per capita daily, totaling around 42 million tons annually, yet only 20-30% is properly collected and managed [4]. The prevalent reliance on open dumping, especially at sites like the Lunzu solid waste dumpsite in Blantyre rural, significantly contributes to environmental degradation through leachate formation, open burning, and heavy metal (HM) contamination of surrounding ecosystems [5]. In both urban and rural centers such as Blantyre, open dumping remains the predominant waste disposal method due to limited infrastructure, financial constraints, and insufficient policy implementation and monitoring [6]. The result is the accumulation of heterogeneous waste materials, including household, industrial, and hazardous waste, without appropriate containment or treatment. In Malawi, like most developing countries, open dumping and burning of municipal solid waste are usually considered the easiest and cheapest means of waste disposal. This waste accumulates predominantly in open dumpsites, as only a very small fraction is recycled or treated. There is no centralized and modern system of waste management; rather, the system is based on collection, transportation, and dumping, as well as uncontrolled burning. In most cases, the wastes are indiscriminately disposed of, the net impact results in the obstruction of drainage and causing pollution to water bodies due to a lack of effective and efficient waste management programs in many cities and towns.

Heavy metals (HMs) from dumpsites, including cadmium (Cd), lead (Pb), mercury (Hg), copper (Cu), zinc (Zn), iron (Fe), manganese (Mn), and cobalt (Co), pose severe and long-term ecological and health hazards. These metals are primarily sourced from electronic waste, batteries, metal scraps, and industrial residues disposed of in open dumpsites [7, 8]. Once released into the environment, heavy metals are persistent, non-biodegradable, and capable of bioaccumulation, making them particularly dangerous. In soils, these metals disrupt microbial activity, reduce fertility, and impair plant growth, thereby lowering agricultural productivity [9]. Through plant uptake, HMs can enter the food chain, leading to bioaccumulation in crops consumed by humans and animals [10]. Long-term exposure to these contaminants is strongly linked to serious health problems, such as neurological disorders, kidney diseases, reproductive issues, weakened immune systems, and various cancers.

These effects are well-established [11, 12]. Furthermore, open burning of this waste leads to the ejection of hazardous emissions/particles into the environment, among which are volatile organic compounds (VOCs), particulate matter, and semi-volatile organic compounds (SVOCS) that result from the open burning of waste [13]. Crops cultivated in contaminated soils may absorb these metals, leading to bioaccumulation in the food chain. Ingestion of contaminated produce can cause serious health risks in humans, including neurological damage, reproductive disorders, immune suppression, and various cancers [14, 15]. Groundwater and surface water are also vulnerable to contamination through leachate percolation and runoff, particularly during the rainy season. Communities relying on untreated groundwater for domestic use face chronic exposure risks [16]. HMs are persistent pollutants that can accumulate in soil and water, posing a significant threat to human health and the ecosystem [17, 18]. When heavy metals contaminate the soil, they alter its chemical composition and can significantly affect soil health and fertility [19]. This alteration can lead to reduced agricultural productivity, as heavy metals interfere with plant growth and development. Many plants can accumulate these toxic metals through their roots, which may then enter the food chain. The uptake of heavy metals by crops poses serious risks, as these metals can lead to toxic effects in humans and animals consuming contaminated produce. Additionally, heavy metal toxicity can impact soil-dwelling organisms, disrupting the important ecological interactions within soil ecosystems that contribute to nutrient cycling and soil structure maintenance.

Water sources, particularly groundwater and surface water bodies, are also at risk from heavy metal contamination originating from dumpsites. Rainwater can leach through waste materials, carrying dissolved metals into nearby streams, rivers, and lakes. This contamination poses severe threats to aquatic life, disrupting ecosystems and leading to bioaccumulation of heavy metals in fish and other aquatic organisms. As these contaminated aquatic species become part of human diets, the risks and impact of heavy metal exposure increase, resulting in extensive and multifaceted potential ecological risks, leading to potential long-term health issues, as

earlier alluded to, such as developmental delays, neurological disorders, and various forms of cancer [14]. Ecologically, the disruption caused by heavy metals can result in diminished biodiversity, as sensitive species become endangered or extinct. This imbalance within the affected ecosystems can have cascading effects, altering food webs and ecosystem processes, posing a significant risk, particularly to human health. Prolonged exposure to heavy metals through contaminated water and food leads to serious health issues. Lead exposure, for example, is known to cause severe neurological impacts, especially in children. Mercury exposure can harm the immune system, disrupt endocrine functions, and damage the nervous system.

The Lunzu solid waste dumpsite, like many others in developing countries, may represent a significant source of HM contamination. Understanding the extent of HM pollution around such sites is crucial for assessing the associated ecological risks and developing effective mitigation strategies. This study aims to determine the concentration levels of selected HMs in soil and water samples collected around the Lunzu solid waste dumpsite, located in Blantyre rural, Malawi. Furthermore, the study will assess the potential ecological risks associated with these HMs using established indices and guidelines. The findings will contribute to the scientific understanding of the environmental impact of the dumpsite and inform the development of appropriate environmental management plans.

2 Materials and Methods

2.1 Study Area and Sampling Sites

Lunzu is a vibrant town in the Blantyre District of Malawi, in the country's southern region. The town serves as a key residential area and a commercial center for the surrounding communities in Blantyre rural. Lunzu town is known for its bustling markets, local shops, and small-scale agricultural activities, reflecting the livelihood of many of its residents. Lunzu town is located at a Latitude of approximately -15.7856° S and a longitude of approximately 35.0191° E. The town is surrounded by landscapes, including rolling hills and agricultural land, which adds to its natural beauty. One significant problem affecting Lunzu is solid waste management, particularly in its market area. The dumpsite for the entire trading center exists between the market and the Maoni River below it and poses environmental and health challenges. The dumpsite receives waste from the market, residential areas, and other business entities (like bottle stores, abattoirs, agricultural waste, etc.). The dumpsite is characterized by large piles of uncollected garbage, including food waste, plastic, e-waste, scrap metals, and other refuse. Such a site typically poses challenges related to waste management, including odor, leachate pollution, heavy metal pollution, and potential impacts on nearby water resources and communities. Figure 1(A) shows the map of Blantyre District, which shows the location of the Lunzu market and dumping sites, and Figure 1(B) illustrates a partial view of waste in the dumpsite.

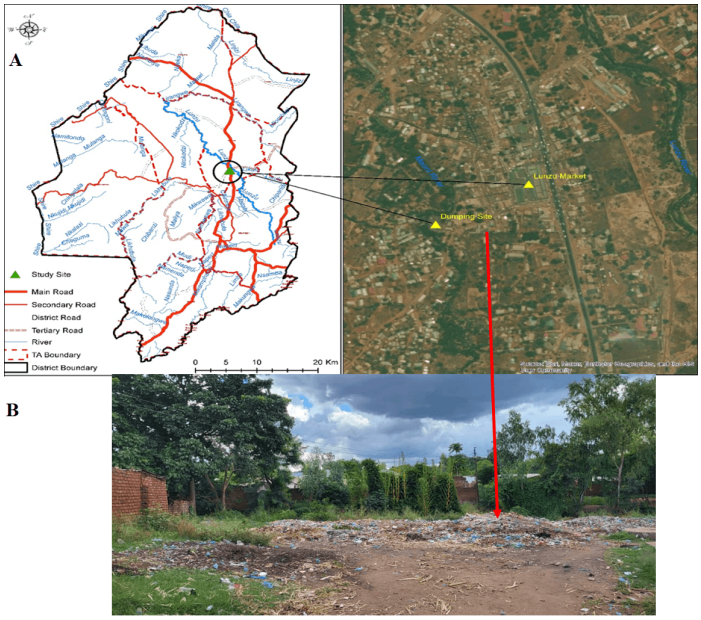

Figure 1 (A). Map of Blantyre City showing the location of Lunzu market and dumpsite; (B). View of waste heaps in the dumpsite

2.2 Sampling Methodology

2.2.1 Soil Sampling

Soil samples were randomly scooped from a depth of 0-15 cm using a soil auger at different points in the dumpsite. Samples were collected from 0 m radius, 50 m radius, 100 m radius, 150 m radius, 200 m radius, and 500 m radius from the dumpsite, and six (6) samples were randomly collected from each sampling point. The control site is 5 km from the dumpsite, has a sparse population, and is unaffected by anthropogenic activities. All the samples were transferred into air-tight polythene bags for further analysis in the laboratory. The samples were collected in both the dry season (October 2024) and wet season (March 2025). The collected samples were later air-dried to homogenized samples with the help of a mortar and pestle. The ground samples were passed through a 2 mm sieve before digestion for heavy metal analysis.

2.2.2 Water Sampling

Water samples were collected from two seasons (dry and wet seasons) from surface water bodies (e.g., streams, boreholes, wells) within proximity to the dumpsite. Ten (10) water samples were collected from each season. One liter of water samples was collected from each end in polyethylene bottles. Samples were also collected in triplicate at each location. These bottles were cleaned using nitric acid and rinsed twice with deionized water. A digital portable multiparameter probe (Hanna HI 991301 pH/EC/TDS meter) was used to measure the pH, electrical conductivity, and total dissolved solids in situ. A turbidity meter (Oakton TN-100 Turbidity Meter) measured the turbidity of the water samples. Samples for heavy metals analysis were acidified with a few drops of concentrated HCl added to preserve the samples for the analyses and stored in ice-crested coolers while being transported, following standard procedures recommended by the American Public Health Association, the laboratory for chemical analysis.

2.3 Quantification of heavy metals

2.3.1 Soil and Water Sample Digestion

Soil samples were digested using a suitable acid digestion method (aqua regia digestion) to extract the HMs. Approximately 2 g of the sieved soil samples were digested for 3 hours at 85 °C in 12 mL of aqua regia (3:1 HCl-HNO_3 v/v) using a hot plate in a fume cupboard until white fumes were observed. The sample was cooled to room temperature and then diluted with 20 mL of distilled water. The mixture was filtered to complete the digestion [20]. The digested samples were then analyzed for Cd, Zn, Cu, Fe, Mn, Pb, and Co concentrations using a flame atomic absorption spectrophotometer (Agilent Technologies, USA).

Water samples were digested using the standard method. In this method, 10 mL of 69% concentrated nitric acid was added to 25 mL of the sample, and the mixture was evaporated on a hot plate in a fume cupboard until the brown fumes disappeared, leaving white fumes. 50 mL of distilled water was added, and the solution was concentrated by evaporation on a hot plate to 25 mL. Subsequently, 25 mL of distilled water was added to make up the volume to 50 mL, which was then filtered and ready for the atomic absorption spectrophotometer. All samples were determined in triplicate.

2.3.2 Heavy Metal Determination

A flame atomic absorption spectrophotometer (Agilent Technologies, USA) was used to determine metals. The AAS was calibrated daily using a standard solution. The analysis of the samples was performed only if the r^2 of the calibration curve was greater than 0.99. For the same set of metals, calibration standards for each metal were prepared from certified stock solutions. Cd, Zn, Cu, Fe, Mn, Pb, and Co concentrations were detected at the wavelengths of 228.8 nm, 213.9 nm, 324.8 nm, 284.3 nm, 279.5 nm, 217.0 nm, and 240.7 nm, respectively, using air-acetylene flame under pre-selected conditions.

2.4 Statistical Analysis

The concentration data for heavy metals in soil and water samples were analyzed to determine the mean, standard deviation, and concentration ranges. Descriptive statistics and pollution indices were generated using SPSS (version 25) and SigmaPlot. A one-way ANOVA at a 0.05 significance level was applied to identify significant differences in heavy metal concentrations among the selected areas around the dumpsites. Multivariate techniques, including principal component analysis (PCA), correlation matrix analysis, and general linear models (GLM), were

also performed to explore patterns and relationships in the data. Microsoft Excel was used to prepare charts and tables, and the results were subsequently used to assess contamination levels and potential ecological risks.

2.5 Contamination assessment

To analyze the heavy metal contents (Cd, Zn, Cu, Fe, Mn, Pb, and Co) in soil and ecological risk assessment, various geochemical indices have been developed [21]. The indices differ in terms of reference baselines, and many researchers have applied the average shale values or the average crustal abundance data as the baseline. However, many researchers believe that the best alternative for baseline reference is unpolluted sediments in the study area [22, 23].

2.6 Contamination Factor (CF)

This index was used to assess the degree of contamination of each HM in the soil samples. This indicates the average metal concentration ratio from the sample to the background concentration. CF was calculated using the following equation 1:

$$CF = \frac{C_m}{C_B} \tag{1}$$

Where C_m is the metal concentration in the soil sample, and C_B, is the background concentration of the same metal in the soil (using either local background data or a reference value appropriate for the soil type). If local background data is unavailable, using literature values is acceptable. A CF $<$ 1: indicates low (minimal) contamination; 1$\leq$ CF $<$3 indicates moderate contamination; 3$\leq$ CF$<$6 indicates high contamination and CF $>$6 indicates (very high) or extreme contamination.

2.6.1 Pollution Load Index (PLI)

The pollution load index (PLI) allows a comparison of pollution loads between locations at different periods [24]. The PLI provides a single value representing the overall degree of metal pollution at a particular location. It is calculated as the nth root of the product of the CF values for each metal at that location (equation 2).

$$PLI = (CF_1 \times CF_2 \times CF_3 \times \ldots \times CF_n)^{\frac{1}{n}} \tag{2}$$

Where PLI stands for the pollution index , is the contamination factor for each heavy metal and *n, the* number of heavy metals. The PLI can be classified into five categories (Table 1).

Table 1 Categories of PLI

Category	Risk Status
PLI $<$ 1	no pollution
1 $<$ PLI $<$ 2	low pollution
2 $<$ PLI $<$ 3	moderate pollution
3 $<$ PLI $<$ 4	high pollution
PLI $>$ 4	extremely high pollution

2.6.2 Geo-accumulation Index (I_{geo})

The index of geo-accumulation (I_{geo}) introduced by Muller (1969) [25] is used to assess metal pollution in a soil sample. It enables us to assess the level of contamination by comparing the concentrations at the dumpsite with the natural concentration at the reference point [25] According to him, I_{geo} values of trace metals were interpreted as shown in Table 2. It can also be applied to assess the contamination of different environments. The index is calculated as in equation 3.

$$I_{\text{geo}} = \log_2 \left(\frac{\text{Concentration}_m}{1.5 \times \text{ Concentration}_B} \right) \tag{3}$$

where, is the mean concentration of the specific metal analysed and is the background concentration of the specific heavy metal. A correction factor of 1.5 was used to correct the effects of parental materials of the soil and natural fluctuations of given matter content in nature, and small changes caused by human activities.

The factor 1.5 is used because of possible variations of the background data due to lithological variations. The world's average shale and soil are among the materials often used to provide

Table 2 Geo-accumulation pollution classes

Sub Index	Quality Grade
$I_{geo} \leq 0$	Uncontaminated
$0 < I_{geo} \leq 1$	Uncontaminated to moderately contaminated
$1 < I_{geo} \leq 2$	Moderately contaminated
$2 < I_{geo} \leq 3$	Moderately to heavily contaminated
$3 < I_{geo} \leq 4$	Heavily contaminated
$4 < I_{geo} \leq 5$	Heavily to extremely contaminated
$I_{geo} \geq 5$	Extremely contaminated

background metal levels. The geochemical background values for the studied heavy metals are unavailable; thus, the concentration at the control point is used as the background value for the naturally occurring metals in the study area.

2.6.3 Enrichment Factor (EF)

EF is used to evaluate the soil heavy metal pollution status. Because iron (Fe) is abundant in soil and free from anthropogenic contribution, it is commonly used for normalization. Mathematically, EF is expressed as follows:

$$CF = \frac{C_{\text{sample}}}{C_{\text{background}}} \tag{4}$$

The contamination factor (CF) was used in this study to provide a quantitative measure of the extent to which the observed metal concentration in the sample exceeds the natural background levels. CF greater than 1 indicates varying degrees of contamination, with higher values indicating higher levels of contamination compared to background levels. Enrichment factors are classified as shown in Table 3.

Table 3 Enrichment factor classification

Sub Index	Enrichment Level
EF < 1	No enrichment
$1 >$ EF < 3	Minor enrichment
$3 <$ EF < 5	Moderate enrichment
$5 <$ EF < 10	Moderately severe enrichment
$10 <$ EF < 25	Severe enrichment
$25 <$ EF < 50	Very severe enrichment
EF > 50	Extremely severe enrichment

2.6.4 Potential Ecological Risk Index (PERI)

In this study, the Potential Ecological Risk Index (PERI) was first introduced and developed by Hakanson [26]. This comprehensive method considers various factors, including the toxicity of specific metals and their concentrations in soil and the ecological sensitivity of the receiving environment, producing a risk value that categorizes the level of concern. The PERI is calculated using the following formula [27]:

$$\text{PERI} = \sum_{i=1}^{n} E_r^i \tag{5}$$

$$E_r^i = T_r^i \times C_f \tag{6}$$

$$C_f = \frac{C_i}{C_o} \tag{7}$$

Where Ci is the metal content in the soil and C_0 is the background value [28]. Table 4 shows the contamination level depending on the value obtained.

Table 4 Classification of Eir and PERI based on the obtained value [28]

E_r^i	Risk factor	PERI	Ecological risk intensity
$E_r^i \leq 40$	Low ecological risk	PERI < 150	Low ecological risk
$40 < E_r^i \leq 80$	Moderate ecological risk	$150 <$ PERI < 300	Moderate ecological risk
$80 < E_r^i \leq 160$	Considerable ecological risk	$300 <$ PERI < 600	high ecological risk
$160 < E_r^i \leq 320$	high ecological risk	PERI ≥ 600	Significantly high ecological risk
$E_r^i > 320$	Very high ecological risk		

3 Results and Discussion

3.1 Concentration of heavy metals in soil

The concentrations of heavy metals in soil samples around the dumpsite revealed a pattern of spatial variability, with significantly higher levels detected at the center of the dumpsite and gradually decreasing with distance. At the dumpsite center, cadmium reached 3.08 mg/kg, well above the WHO and EU thresholds of 0.05 mg/kg and 1.4 mg/kg, respectively, indicating potential toxicity. Similarly, zinc peaked at 705.80 mg/kg and copper at 316.18 mg/kg, both exceeding EU guideline limits of 300 mg/kg and 140 mg/kg, respectively, suggesting anthropogenic input likely from industrial waste. Lead levels were also elevated, reaching values of 80.00 mg/kg at 0 m, surpassing the WHO limit of 10 mg/kg, highlighting the risk of lead exposure [29]. Although cobalt has no formal WHO or EU threshold, its concentration of 28.18 mg/kg exceeded ecological screening levels for plant toxicity, raising concern for long-term bioaccumulation. Natural elements such as iron and manganese were the most abundant, consistent with their typical presence in tropical soils, but their elevated values near the dumpsite indicate leachate enrichment [26]. Concentrations of most metals decreased with increasing distance, with values at a 250 m radius approaching or falling within acceptable environmental limits. This spatial trend strongly suggests that the dumpsite is a major source of heavy metal contamination in the surrounding soils. (see Table 5)

Table 5 Mean concentrations of heavy metals in soil samples (mg/kg) during the wet season are compared with international guidelines (WHO and EU) as well as the Malawi Bureau of Standards (MBS) guidelines

Dist* (m)	Cd (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Pb (mg/kg)	Co (mg/kg)
0	3.08 ± 0.74	705.80 ± 84.91	316.18 ± 66.29	23,916.98 ± 3,449.23	600.12 ± 63.39	80.00 ± 27.58	28.18 ± 0.74
20	2.58 ± 2.09	416.75 ± 48.81	38.40 ± 1.91	21,383.10 ± 5,027.95	359.15 ± 64.21	55.50 ± 43.84	26.50 ± 3.04
50	0.75 ± 0.00	67.54 ± 0.38	14.12 ± 1.38	11,417.20 ± 294.37	299.82 ± 48.05	24.75 ± 1.77	13.10 ± 0.00
100	1.18 ± 0.04	57.25 ± 25.78	17.50 ± 3.39	12,524.57 ± 730.19	337.60 ± 65.48	22.25 ± 6.01	12.92 ± 1.03
250	0.15 ± 0.00	46.32 ± 38.56	6.72 ± 2.86	15,420.18 ± 5,722.37	339.50 ± 47.31	14.25 ± 3.89	12.92 ± 0.67
WHO	0.3	-	2	3	0.5	0.1	0.05
EU	1.5		140		0.5	150	
MBS	0.01	15	2	3	1.5	0.05	-

Note: * Dist = Distance from the dumpsite

Pearson correlation coefficients were calculated to assess the relationships between the concentrations of different heavy metals in soil samples around Lunzu Dumpsite during the dry season. The results in Table 6 revealed strong to very strong positive correlations among most metals. Particularly, cadmium showed a very strong correlation with lead (r = 0.97) and cobalt (r = 0.95), suggesting that these metals may originate from similar anthropogenic sources or have similar environmental behavior. Zinc was strongly correlated with lead (r = 0.99) and cobalt (r = 0.96), while copper also exhibited strong correlations with manganese (r = 0.99) and zinc (r = 0.89). These strong associations imply possible co-migration or simultaneous deposition processes influenced by leachate movement from the dumpsite, aligning with findings by Edogbo et al. (2020) [27, 28], who observed similar associations at Nigerian dumpsites.

Table 6 Pearson correlation coefficients between heavy metals in soil samples during the dry season

	Cd	Zn	Cu	Fe	Mn	Pb	Co
Cd	1						
Zn	0.94	1					
Cu	0.75	0.89	1				
Fe	0.86	0.94	0.76	1			
Mn	0.75	0.90	0.99	0.80	1		
Pb	0.97	0.99	0.87	0.91	0.86	1	
Co	0.95	0.96	0.73	0.96	0.75	0.96	1

Table 7 presents the mean concentrations of heavy metals in soil samples collected during the wet season at varying distances from the dumpsite. Results show elevated cadmium, lead, and copper levels at the dumpsite center, with concentrations decreasing with distance, indicating anthropogenic contamination from waste disposal. Notably, cadmium and lead at 0 m radius exceeded WHO guidelines of 0.05 mg/kg and 0.10 mg/kg, respectively, while copper surpassed EU limits of 140 mg/kg. Wet-season concentrations were generally lower than dry-season values, likely due to rainfall-driven leaching and dilution [16, 29]. However, the persistence of

high metal levels, particularly cadmium and lead, underscores ongoing pollution risks. Iron and manganese remained dominant due to natural soil composition, but were enriched near the dumpsite.

Table 7 Mean concentrations of heavy metals in soil samples (mg/kg) during the wet season are compared with international guidelines (WHO and EU) as well as the Malawi Bureau of Standards (MBS) guidelines

Dist* (m)	Cd	Zn	Cu	Fe	Mn	Pb	Co
0	2.77 ± 0.67	635.22 ± 76.42	284.56 ± 59.66	21,525.28 ± 3,104.31	540.11 ± 57.05	72.00 ± 24.82	25.36 ± 0.67
20	2.32 ± 1.88	375.08 ± 113.93	34.56 ± 1.72	19,244.79 ± 4,525.16	323.24 ± 57.79	49.95 ± 39.46	23.85 ± 2.74
50	0.68 ± 0.00	60.79 ± 0.34	12.71 ± 1.24	10,275.48 ± 264.93	269.84 ± 43.25	22.28 ± 1.59	11.79 ± 0.00
100	1.06 ± 0.04	51.53 ± 23.20	15.75 ± 3.05	11,272.11 ± 657.17	303.84 ± 58.93	20.03 ± 5.41	11.63 ± 0.93
250	0.14 ± 0.00	43.92 ± 36.63	6.38 ± 2.72	14,649.17 ± 5,436.25	322.55 ± 44.98	13.54 ± 3.70	12.27 ± 0.64
WHO	0.3	-	2	3	0.5	0.1	0.05
EU	1.5		140		0.5	150	
MBS	0.01	15	2	3	1.5	0.05	-

Note: * Dist = Distance from the dumpsite

3.2 Correlation analysis between heavy metals in the wet season

Pearson correlation analysis of heavy metal concentrations in soil during the wet season revealed strong to very strong positive correlations among most metals, with correlation coefficients exceeding 0.95. This suggests that these metals likely originate from a common anthropogenic source, such as waste leachate from the dumpsite. For instance, Cd showed a near-perfect correlation with Pb (r = 0.99), indicating similar environmental behavior and deposition patterns. Similarly, Zn and Cu were also strongly correlated (r = 0.98), further supporting the possibility of co-contamination from industrial or domestic waste. Iron and manganese, which are naturally occurring soil components, exhibited moderate correlations with the other metals, implying partial influence from the dumpsite but also potential natural background contributions. (see Table 8)

Table 8 Pearson correlation coefficients between heavy metals in soil samples during the wet season

	Cd	Zn	Cu	Fe	Mn	Pb	Co
Cd	1						
Zn	0.98	1					
Cu	0.98	0.98	1				
Fe	0.73	0.76	0.76	1			
Mn	0.68	0.69	0.67	0.58	1		
Pb	0.99	0.98	0.99	0.78	0.64	1	
Co	0.97	0.97	0.97	0.71	0.65	0.98	1

3.3 Soil organic carbon analysis in the dry season

Soil Organic Carbon (SOC) content generally decreased with increasing distance from the Dumpsite, as shown in Figure 2. The highest SOC concentration was recorded at 0 meters, reflecting the influence of continuous deposition of organic waste at the center of the dumpsite. SOC levels steadily declined with distance, measuring 3.12 % at a 20 m radius and 1.19% at a 100 m radius, indicating a reduction in organic matter input away from the dumpsite. A slight increase in SOC was observed at 250 m radius; this anomaly may be attributed to natural soil processes such as localized vegetation cover, accumulation of plant residues, microbial activity, or slight topographical variations that promote organic matter retention [29]. The general decline of SOC with distance aligns with the expected pattern, where proximity to waste disposal activities results in higher organic carbon enrichment. These findings highlight the role of dumpsite activities in modifying soil organic matter distribution patterns in the surrounding environment.

3.4 Relationship Between Heavy Metals, Dry Season, and Soil Organic Carbon (SOC)

Table 9 represents the coefficients between soil organic carbon (SOC), heavy metal concentration, and distance from Lunzu dumpsite.

The correlation analysis demonstrated strong positive relationships between Soil Organic Carbon (SOC) and the concentrations of heavy metals, particularly lead, zinc, cobalt, and

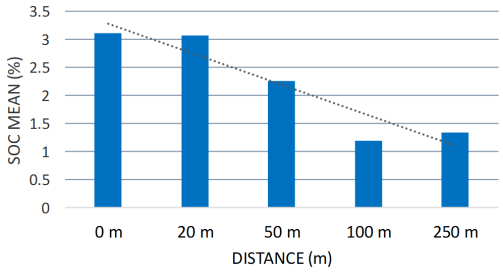

Figure 2 Variation of Soil Organic Carbon Content (Mean) in Soil Samples at Different Distances from the Dumpsite

Table 9 Pearson Correlation Coefficients Between Soil Organic Carbon (SOC), Heavy Metals Concentration, and Distance from Lunzu dumpsite

Metal	Correlation (r)
Distance	-0.80
Cd	0.84
Zn	0.85
Cu	0.62
Fe	0.78
Mn	0.58
Pb	0.88
Co	0.90

cadmium. These correlations imply that organic matter plays a crucial role in the retention of heavy metals in soil, likely through the formation of stable organo-metallic complexes. This finding aligns with the literature, which states that organic carbon enhances heavy metal adsorption in soils [3]. Conversely, SOC was negatively correlated with distance from the dumpsite, suggesting that the organic matter content decreases with increasing distance, possibly due to reduced waste input and microbial degradation. This trend supports the notion that waste decomposition at the dumpsite contributes both to organic matter enrichment and metal loading in nearby soils. The presence of toxic metals like cadmium and lead in soil close to agricultural zones is concerning, as crops cultivated in these areas may absorb these metals and enter the food chain. Moreover, communities relying on nearby groundwater sources for drinking and domestic use may be exposed to chronic metal toxicity.

3.5 Concentration of heavy metals in water during the dry season

Table 10 shows the mean values for the concentration of heavy metals in water during the dry season.

Table 10 Concentration of heavy metals in water during the dry season

Sample	Cd (mg/L)	Zn (mg/L)	Cu (mg/L)	Fe (mg/L)	Mn (mg/L)	Pb (mg/L)	Co (mg/L)
W 1	0.02	0.07	0.02	1.55	0.06	0.10	0.07
W 2	0.01	0.06	0.02	1.56	0.05	0.14	0.08
W 3	0.01	0.06	0.04	0.67	0.07	0.11	0.06
WHO	0.003	3	2	0.3	0.1	0.01	-
EU	0.005	5	2.0	0.2‘	< 0.05	0.01	-
MBS	0.01	15	2	3	1.5	0.05	-

Water quality analysis revealed varying levels of heavy metals in water sources located near Lunzu dumpsite, with several values exceeding both WHO and EU guidelines as well as the Malawi Bureau of Standards (MBS) permissible limits. Cadmium and lead were the most concerning, registering average concentrations of 0.01 mg/L and 0.11 mg/L, respectively. While cadmium concentrations met MBS limits, they exceeded WHO and EU guidelines, highlighting a potential regulatory gap and health concern. Lead, on the other hand, surpassed both WHO and MBS limits, indicating a clear risk to public health.

Iron and manganese concentrations were also elevated, with iron measured at 1.50 mg/L, which is five times above the WHO standard, and manganese at 0.07 mg/L, slightly below

the limit. These findings align with observations that leachate from decomposing organic and metal-containing waste can facilitate the migration of heavy metals into nearby surface and groundwater systems, particularly through rainfall infiltration and runoff processes [16]. The presence of copper and zinc, though within acceptable limits, further supports this theory, as these metals are commonly associated with corrosion of waste and batteries. The detection of cobalt, although its average concentration was 0.07 mg/L, lacks both WHO, EU, and MBS regulatory benchmarks; its long-term environmental and health implications remain underexplored, calling for precautionary monitoring.

3.6 Concentration of heavy metals in water during the wet season

Table 11 shows the mean values for the concentration of heavy metals in water during the wet season.

Table 11 Concentration of heavy metals in water during the wet season

Sample	Cd (mg/L)	Zn (mg/L)	Cu (mg/L)	Fe (mg/L)	Mn (mg/L)	Pb (mg/L)	Co (mg/L)
W 1	0.06	0.06	0.01	1.85	0.09	0.16	0.05
W 2	0.02	0.06	0.02	1.85	0.06	0.15	0.07
W 3	0.03	0.05	0.03	0.79	0.09	0.16	0.07
WHO	0.003	3	2	0.3	0.1	0.01	-
EU	0.005	5	2.0	0.2‘	< 0.05	0.01	-
MBS	0.01	15	2	3	1.5	0.05	-

The wet season water samples revealed elevated concentrations of heavy metals, with cadmium and lead posing the most risks. Cadmium levels ranged from 0.02 to 0.06 mg/L, exceeding the WHO limit of 0.003 mg/L in all samples, while Pb concentrations ranged from 0.15-0.16 mg/L, which also surpassed the WHO, EU, and MBS guidelines of 0.01 mg/L and 0.05 mg/L, respectively, indicating severe contamination. Iron and manganese were also notably high, with iron peaking at 1.85 mg/L and manganese reaching 0.09 mg/L, nearing the regulatory threshold of 0.4 mg/L. These elevated levels likely result from increased leaching during rainfall, which mobilizes metals from the dumpsite into nearby water bodies [16]. In contrast, zinc and copper remained within permissible limits, though their presence underscores the dumpsite's role as a persistent pollution source.

3.7 Contamination assessment

In this study, contamination factor (CF), Pollution load index (PLI), Geo-accumulation index (I_{geo}), potential ecological risk index (PERI), and enrichment factor were calculated to determine pollution, contamination pattern, and potential risk due to exposure to ecological sensitivity, concentration, and toxicity of heavy metals in soil.

3.7.1 Contamination factor

The contamination factor values during the dry season revealed varying degrees of metal pollution at different distances from the dumpsite. Cadmium consistently recorded the highest CFs with values such as 1.52×10^{-1} at the dumpsite and peaking at 2.23×10^{-1} at 20 m radius, indicating significant contamination. Other metals like copper, lead, and zinc showed generally lower contamination factors across all locations. These lower values suggest relatively minor contamination for these metals. The spatial variation, with declining CFs further from the dumpsite, supports the view that the site is the point source of heavy metal contamination during the dry season [16, 26]. (see Table 12)

Table 12 The Contamination factors of heavy metals from different sampling sites in the dry season

Sampling Points*	Cd	Zn	Cu	Fe	Mn	Pb	Co
0 m	1.52×10^{-1}	2.58×10^{-2}	3.19×10^{-2}	1.64×10^{-3}	6.46×10^{-3}	1.74×10^{-2}	3.17×10^{-3}
20 m	2.23×10^{-1}	1.32×10^{-2}	1.93×10^{-2}	2.56×10^{-3}	5.66×10^{-3}	7.50×10^{-3}	2.97×10^{-3}
50 m	1.91×10^{-1}	6.07×10^{-3}	1.84×10^{-2}	2.07×10^{-3}	7.86×10^{-3}	1.08×10^{-2}	2.22×10^{-3}
100 m	1.57×10^{-1}	6.46×10^{-3}	9.71×10^{-3}	1.40×10^{-3}	3.60×10^{-3}	9.71×10^{-3}	1.81×10^{-3}
250 m	1.66×10^{-1}	7.24×10^{-3}	1.99×10^{-2}	2.35×10^{-3}	7.66×10^{-3}	9.67×10^{-3}	1.66×10^{-3}

Note: * Sampling points: distance from dumpsite

During the wet season, contamination factors showed patterns consistent with the dry season, with slight reductions likely due to leaching and dilution by rainfall. Cadmium again registered

the highest CFs, with values ranging from 1.41×10^{-1} at the dumpsite to 1.92×10^{-1} at 20 m radius, suggesting persistent and significant pollution. Other metals like zinc, Copper, and lead exhibited lower contamination factors that generally reflected minor to moderate contamination. The overall similarity in spatial patterns between seasons, with higher values near the source and decreasing outward, reinforces the role of the dumpsite as a central contamination hotspot [30]. (see Table 13)

Table 13 The Contamination of heavy metals from different sampling sites in the wet season

Sampling Points*	Cd	Zn	Cu	Fe	Mn	Pb	Co
0 m	1.41×10^{-1}	2.01×10^{-2}	3.01×10^{-2}	1.54×10^{-3}	6.35×10^{-3}	1.00×10^{-2}	2.11×10^{-3}
20 m	1.92×10^{-1}	1.11×10^{-2}	1.53×10^{-2}	2.41×10^{-3}	4.11×10^{-3}	7.11×10^{-3}	2.92×10^{-3}
50 m	1.46×10^{-1}	5.41×10^{-3}	1.11×10^{-2}	2.00×10^{-3}	7.00×10^{-3}	1.01×10^{-2}	2.00×10^{-3}
100 m	1.59×10^{-1}	5.91×10^{-3}	9.01×10^{-3}	1.27×10^{-3}	2.09×10^{-3}	8.60×10^{-3}	1.21×10^{-3}
250 m	1.64×10^{-1}	7.01×10^{-3}	1.99×10^{-2}	2.01×10^{-3}	6.69×10^{-3}	8.71×10^{-3}	1.41×10^{-3}

Note: * Sampling points: distance from dumpsite

3.7.2 Pollution load index

PLI values ranged from 0.7 to 1.84, showing a clear spatial variation with proximity to the dumpsite (Figure 3). The highest PLI was recorded at 20 m with a PLI value of 1.84, indicating moderate pollution levels due to the combined influence of cadmium, lead, and other metals. beyond a 50 m radius, the PLI dropped, suggesting a lower but still polluted site. At 50 m radius and 250 m radius, the PLI values dropped below the threshold of 1.0, with 0.98 at 50 m radius and 0.71 at 250 m radius, indicating no pollution or only baseline/background levels of contamination. This pattern supports the interpretation that metal pollution from the dumpsite is largely localized, with measurable impact within a 100 m radius and diminishing significantly with distance [31].

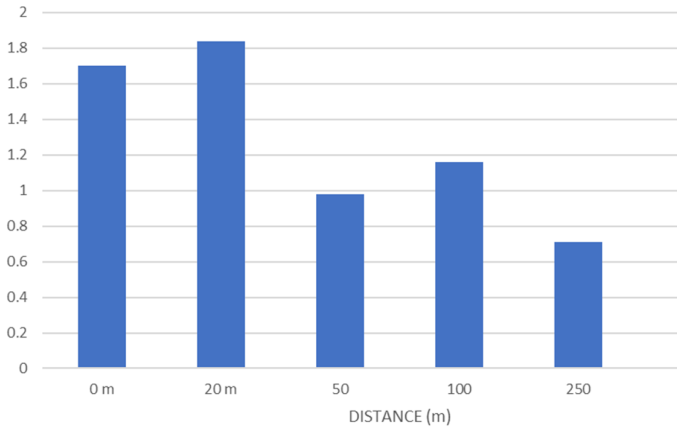

Figure 3 Values of the pollution load index relative to the distance from the dumpsite

3.7.3 Geoaccumulation index (I_{geo})

The Geo-Accumulation Index (I_{geo}) results for the dry season presented in Figure 4 indicate that the majority of the heavy metals recorded negative I_{geo} values across all sampling locations. The negative I_{geo} suggests that the concentrations of these metals in the soil during the dry season remained close to natural background levels, implying minimal anthropogenic accumulation. Although there were minor variations across distances, no metal exceeded the threshold denoting notable pollution. This pattern points to limited accumulation of heavy metals during the dry season, despite the proximity to the dumpsite, likely due to reduced leaching and limited waste decomposition under dry conditions.

The Geo-Accumulation Index (I_{geo}) results for the wet season are presented in Figure 5. The wet season I_{geo} values largely mirrored those of the dry season, with most metals remaining in the practically unpolluted category. Negative I_{geo} values were again dominant, suggesting minimal geochemical disturbance. These values classify the soils as unpolluted, even though the rainy season could enhance the leaching and spread of contaminants. The persistence of negative I_{geo}values suggests that, despite the higher potential for metal mobility due to rainfall,

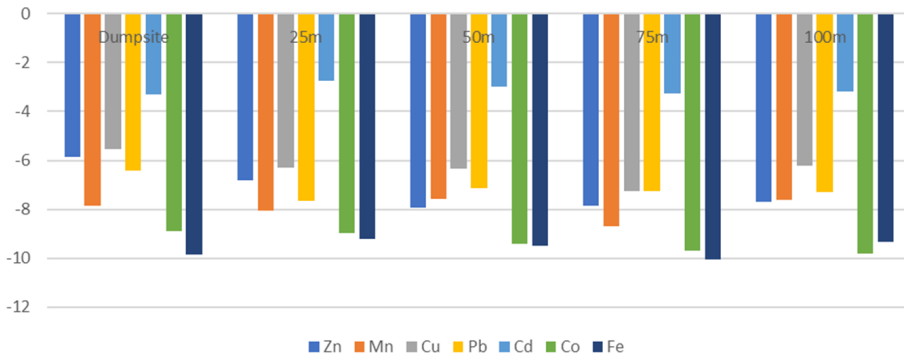

Figure 4 The geoaccumulation index (I_{geo}) of heavy metals from different sampling sites in the dry season

the levels of these metals in the soil did not accumulate beyond background concentrations to pose a contamination threat. This consistency across both seasons implies limited anthropogenic input or metal accumulation from the dumpsite during the study period.

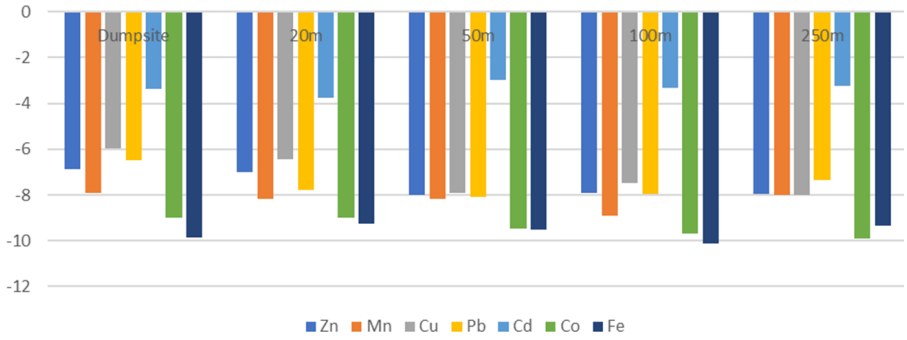

Figure 5 The geoaccumulation index (I_{geo}) of heavy metals from different sampling sites in the wet season

3.7.4 Enrichment Factor

The enrichment factor (EF) analysis during the dry season (Table 14) revealed significant enrichment of cadmium, with EF values reaching 111.85 at a 100 m radius, indicating severe anthropogenic input. Moderate to severe enrichment was noted for copper and lead, especially at proximal sites. These findings strongly suggest the presence of non-natural sources, possibly linked to industrial or medical waste. The extreme EF values of cadmium particularly highlight its persistent presence in the dumpsite environment.

Table 14 Enrichment of different heavy metals from different sampling points, with Fe being a background level heavy metal in the dry season

Sampling Points	Cd	Zn	Cu	Mn	Pb	Co
Dumpsite	92.92	15.75	19.51	3.95	10.65	1.94
20 m	87.27	5.18	7.57	2.21	2.93	1.16
50 m	92.33	2.93	8.89	3.80	5.22	1.07
100 m	111.85	4.60	6.92	2.57	6.91	1.29
250 m	70.69	3.08	8.49	3.26	4.12	0.71

In the wet season, as presented in Table 15, the EF values remained high for cadmium, especially at 100 m radius with a value of 98.66, although there was a slight reduction compared to the dry season, possibly due to dilution from rainfall. Copper and lead maintained moderate enrichment close to the dumpsite. The other metals, including Zn, Mn, Cu, Fe, and Co, exhibited low EF values across all distances. This consistency across seasons indicates that cadmium remains the most enriched and anthropogenically influenced metal, reinforcing its significance as the primary pollutant of concern in the Lunzu dumpsite area. These patterns collectively reinforce the dumpsite as a persistent source of heavy metal enrichment, with rainfall contributing to spatial redistribution but not sufficient dilution of critical contaminants, cadmium [24, 29].

Table 15 Enrichment of different heavy metals from different sampling points, with Fe being a background level heavy metal in the wet season

Sampling Points	Cd	Zn	Cu	Mn	Pb	Co
0 m (dumpsite)	73.11	12.20	14.01	2.01	8.42	1.11
20 m	60.17	4.28	7.00	1.91	1.78	1.02
50 m	71.41	1.99	7.19	3.60	5.10	0.90
100 m	98.66	3.33	6.11	1.57	4.98	1.10
250 m	66.32	2.45	8.20	3.01	3.33	0.57

3.7.5 Potential ecological risk index

The potential ecological risk index for the dry season is presented in Table 16. The Potential Ecological Risk Index (PERI) results during the dry season highlight cadmium as the principal ecological threat among the assessed metals. Cadmium demonstrated considerable risk, with values like 4.56 at the dumpsite and 6.69 at 20 m. In contrast, other metals had PERI values well below 1.0, suggesting low ecological risk. The pronounced hazard posed by cadmium highlights the need to address potential bioaccumulation and toxicity to soil organisms and surrounding ecosystems, especially considering their environmental persistence and mobility [31, 32].

Table 16 Potential Ecological risk Index of heavy metals from different sites in the dry season

Sampling Points	Cd	Zn	Cu	Fe	Mn	Pb	Co
0 m	4.56	2.58×10^{-2}	0.16	1.64×10^{-3}	6.46×10^{-3}	8.71×10^{-2}	$6.33\times10\text{-}^{3}$
20 m	6.69	1.32×10^{-2}	0.10	2.56×10^{-3}	5.66×10^{-3}	3.75×10^{-2}	5.94×10^{-3}
50 m	5.73	6.07×10^{-3}	0.09	2.07×10^{-3}	7.86×10^{-3}	5.40×10^{-2}	4.44×10^{-3}
100 m	4.71	6.46×10^{-3}	0.05	1.40×10^{-3}	3.60×10^{-3}	4.85×10^{-2}	3.63×10^{-3}
250 m	4.98	7.24×10^{-3}	0.10	2.32×10^{-3}	7.66×10^{-3}	4.84×10^{-2}	3.33×10^{-3}

During the wet season, the ecological risk profiles remained similar to the dry season (Table 17), with cadmium maintaining its dominance as the most ecologically threatening metal. PERI values remained above 4.00 across most locations and peaked at 5.91 at a 20 m radius, suggesting that seasonal runoff does little to mitigate its presence. The risk associated with other metals remained low, consistent with the dry season findings. The persistence of Cd as a risk factor in both seasons emphasizes the need for targeted mitigation strategies to address cadmium contamination around the dumpsite area. These findings underline the chronic nature of cadmium contamination, which persists even during increased rainfall and potential dilution [33].

Table 17 Potential Ecological Index of heavy metals from different sites in the wet season

Sampling Points	Cd	Zn	Cu	Fe	Mn	Pb	Co
0 m (dumpsite)	4.01	2.00×10-2	0.11	1.11×10-3	6.11×10-3	7.11×10-2	6.13×10-3
20 m radius	5.91	0.98×10-2	0.10	2.02×10-3	5.21×10-3	3.20×10-2	5.14×10-3
50 m radius	4.31	5.01×10-3	0.06	2.00×10-3	6.57×10-3	4.02×10-2	4.00×10-3
100 m radius	4.00	5.17×10-3	0.02	1.11×10-3	2.23×10-3	3.11×10-2	3.31×10-3
250 m radius	4.31	7.12×10-3	0.09	2.23×10-3	5.16×10-3	3.03×10-2	3.02×10-3

These findings align with previous *Environmental Monitoring and Assessment* (EMA) studies that report elevated levels of cadmium and lead around waste dumpsites, with contamination decreasing as distance from the source increases [34, 35]. Like those studies, cadmium emerged as the dominant contributor to ecological risk indices in our data. However, whereas EMA-based research has documented moderate to heavy geoaccumulation ($I_{geo} \geq 2$) for cadmium and lead near older or poorly managed sites, our study generally observed negative I_{geo} values, indicating limited geochemical enrichment at the Lunzu dumpsite. This difference likely reflects the smaller scale and shorter operational history of Lunzu relative to sites reported in other environmental monitoring assessment studies [3, 36]].

4 Conclusion and Recommendations

This study assessed the concentration and distribution of heavy metals such as Fe, Co, Mn, Cu, Cd, Pb, and Zn in soil and water samples collected at and around Lunzu Market dumpsite

in Blantyre, Malawi, during both the dry and wet seasons. The results revealed significant contamination, with varying patterns between soil and water samples across distances and seasons.

In the soil, the concentration of heavy metals during the dry season generally followed the sequence Fe $>$ Mn $>$ Zn $>$ Cu $>$ Pb $>$ Co $>$ Cd, and during the wet season, Fe $>$ Zn $>$ Mn $>$ Cu $>$ Pb $>$ Co $>$ Cd. In water samples, the concentration order was Cu $>$ Fe $>$ Mn $>$ Pb $>$ Co$>$ Cd. At the dumpsite, and Mn $>$ Cu $>$ Fe $>$ Pb $>$ Co $>$ Cd at borehole 1. Notably, manganese concentrations in soil exceeded the WHO permissible limit of 0.5 mg/kg at the dumpsite and slightly at 25 m from the dumpsite center. In water, Mn concentrations surpassed the WHO limit of 0.02 mg/L at multiple points, including the dumpsite. Similarly, cadmium levels exceeded WHO thresholds at the dumpsite and Boreholes 1 and 2. Chromium concentrations were also above permissible limits at Borehole 1.

The contamination assessment using various indices showed cadmium consistently exhibited the highest CF in both seasons, followed by Cu, Zn, Pb, and Mn. Copper displayed moderate enrichment at 25 m radius, 50 m radius, 75 m radius, 100 m radius, and 125 m radius. Zinc and manganese showed moderate enrichment at the dumpsite and nearby locations, while lead showed enrichment at 50 m and 100 m. Chromium exhibited minor enrichment at the dumpsite and surrounding distances. Cadmium showed high EF values, with EF $>$ 50, indicating severe enrichment.

Contamination Degree values were highest at the dumpsite, decreased slightly at 25 m radius, peaked again at 50 m (49.39), and fluctuated across other points, with the highest contamination recorded at 100 m. The Geoaccumulation Index in soil showed metals like zinc, manganese, and copper had negative I_{geo} values, indicating low accumulation or depletion. Cadmium showed slightly elevated values compared to the other metals, particularly at 25 m radius and 125 m radius. The presence of manganese, cadmium, and chromium in concentrations beyond permissible limits poses substantial health risks. The bioaccumulation of these metals in the food chain and water sources increases exposure risks for surrounding communities. This, therefore, calls for need for the following recommendations:

(1) Attention and actions by relevant authorities to minimize and prevent this toxic and heavy metal contamination in soil and water by retarding leachate movement through appropriate re-design of the dumping site or new dumpsite with proper foundations;

(2) Enhanced waste management: Incorporate waste management matters into the overall agenda of running the market affairs. For instance, a committee should be set up to oversee matters of waste management or appoint responsible persons for the waste management matters (within the existing committee, which is responsible for running the affairs of the market). The dumpsite should be managed more effectively to minimize heavy metal leaching into the surrounding environment. Among the issues to be looked into are the implementation of waste segregation, waste for wealth strategies, containment of hazardous materials, and regular monitoring of soil and water quality.

(3) Public awareness and policy reform: The general public should be sensitized and educated on waste management and the health risks associated with poor waste management, including heavy metal contamination, targeting communities living near dumpsites. Furthermore, stricter waste management regulations should be enforced.

Therefore, it can be concluded that the dumpsite could partly contaminate the soil and waters around the study dumpsite, with other contributing factors like an industrial site up the river and natural sources. Some of the researchers found that pollutant

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Author Contributions

All authors have read and approved the manuscript. E.V: Conceptualization, Methodology, Writing-Original Draft, Supervision; L.M: Investigation, Data Collection, Visualization; V.G: Data Curation, Formal Analysis, Writing-Review. The final manuscript was read and approved by all authors.

Data Availability

The data supporting the findings of this study are available within the article.

Ethical Statement

All authors have read, understood, and complied as applicable with the statement on "Ethical responsibility of Authors" as found in the Instructions for Authors.

Conflicts of Interest

No potential conflicts of interest was reported by the authors.

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