Turkish Journal of Agriculture - Food Science and Technology, 14(2): 364-372, 2026
DOI: https://doi.org/10.24925/turjaf.v14i2.364-372.8166

Turkish Journal of Agriculture - Food Science and Technology

Available online, ISSN: 2148-127X | www.agrifoodscience.com | Turkish Science and Technology Publishing (TURSTEP)

Analysis of Heavy Metals in Soil and Medicinal Plants using Risk Assessment Indices

Oluwadurotimi O. Akintade[1,a,*], Kehinde A. Oyegoke[1,b], Fausat O. Odujebe[1,c], Grace O. Ayorinde[1,d], Gbemisola Ogunleye[2,e]

[1]*Department of Chemical Sciences, Faculty of Applied Sciences, KolaDaisi University, Ibadan, Oyo State, Nigeria.*
[2]*Department of Biological Sciences, Faculty of Applied Sciences, KolaDaisi University, Ibadan, Oyo State, Nigeria.*
[*]*Corresponding author*

ARTICLE INFO

Research Article

Received : 25.07.2025
Accepted : 23.12.2025

Keywords:
Heavy metals
Non-carcinogenic risk
Soil
Medicinal plants
Ecological risk

ABSTRACT

Studying heavy metal contamination in soil and plants is critical due to its impact on ecosystem health and human well-being. Industrialization, agriculture, and urbanization have contributed significantly to the rise of heavy metal pollution. This study investigated heavy metal levels in soil and the medicinal plants *Bryophyllum pinnatum* (BPi) *and Vernonia amygdalina* (VA) using environmental and health risk assessments. Atomic Absorption Spectrophotometry was employed to measure concentrations of manganese (Mn), iron (Fe), copper (Cu), zinc (Zn), chromium (Cr), and lead (Pb) in soil and plant parts (leaves, stems, and roots). Data were analyzed using descriptive statistics and Pearson correlation. Soil manganese concentrations ranged from 15.82 to 217.33 mg/kg (BPi) and 366.38 to 513.60 mg/kg (VA), while iron ranged from 8541.78 to 9632.78 mg/kg (BPi) and 6500.23 to 16045.03 mg/kg (VA). Concentrations of Cu, Zn, Cr, and Pb also varied. Metal levels in medicinal plants were comparable, with Mn ranging from 3.08 to 109.13 mg/kg and Fe from 36.05 to 2546.34 mg/kg. Except for Fe in soil, most metals (Mn, Cu, Zn, Cr, Pb) were below WHO permissible limits. Strong positive correlations between soil and plant metal concentrations indicated effective metal uptake. Ecological risk assessment revealed substantial soil pollution near the medicinal plants; however, health risk assessments showed hazard indices below one for both adults and children, suggesting no significant non-carcinogenic risk. Carcinogenic risk values for Pb and Cr were below hazardous thresholds, indicating minimal cancer risk. These findings support the safe use of *Bryophyllum pinnatum* and *Vernonia amygdalina* in treating cancer and malaria, as their heavy metal content remains within safe limits.

[a] *tsnakin@gmail.com* *http://orcid.org/0000-0002-4741-0993*
[b] *kehindeoyegoke7@gmail.com* *https://orcid.org/0009-0009-0219-114X*
[c] *faosiyatjebe@gmail.com* *https://orcid.org/0000-0002-4346-0168*
[d] *ayorindegrace2@gmail.com* *https://orcid.org/0009-0004-6581-6489*
[e] *geegbemz@gmail.com* *https://orcid.org/0000-0003-2344-8177*

This work is licensed under Creative Commons Attribution 4.0 International License

Introduction

Heavy metal pollution poses a silent yet significant threat to environmental integrity, subtly and profoundly altering ecosystems. Heavy metal contamination is a looming hazard in our human-influenced world, endangering environmental health and public safety (Nacaroglu et al., 2009; Mccarthy, 2014). The presence of heavy metals in soil and plants requires careful investigation due to their considerable impacts on ecosystem health and human well-being. Metals such as lead (Pb), cadmium (Cd), mercury (Hg), arsenic (As), and chromium (Cr) have become common pollutants resulting from industrialization, intensive agriculture, and urbanization. These activities have led to significant heavy metal accumulation in soils, with long-term consequences for terrestrial ecosystems (Botle et al., 2025; Adelekan and Abegunde, 2011). Heavy metal contamination causes lasting environmental and public health effects. These toxicants persist in soil, leach into groundwater, and accumulate in living organisms, perpetuating contamination through food chains and ecological networks (El Hamazaou et al., 2025). Chronic exposure has been associated with neurological diseases, respiratory ailments, and cancer, underscoring the critical need for extensive research on heavy metal pollution (Jasim, 2025).

Soil is a complex three-phase system composed of minerals and organic materials (solid phase), gases (soil atmosphere), and water. It develops over time through interactions among climate, geography, organisms, and parent materials (Hugget, 2011). Physical, chemical, and biological processes such as weathering and erosion continuously shape soil. Ecologists regard soil as an ecosystem due to its complexity and interconnections (Ponge & Jean-François, 2015).

Medicinal herbs have been used for healing thousands of years and remain vital today, providing primary healthcare for nearly 85% of the global population (Pešić, 2015). They also contribute to drug development, with 80% of synthetic pharmaceuticals derived from them (Bauer & Brönstrup, 2014). Significant advances have been made in analyzing herbal substances over the centuries.

The overarching goal of this research is to conduct a comparative analysis of heavy metal contamination in soil and selected medicinal plants (*Bryophyllum pinnatum* and *Vernonia amygdalina*) using environmental risk indices such as the Pollution Index (PI), Nemerow Pollution Index (PI_N), Ecological Risk Assessment (ERI), and Bioconcentration Factor (BF). Furthermore, health risk indices addressing both non-carcinogenic and carcinogenic concerns will be assessed.

Materials and Methods

Geographical Locations of the Study Area

Researchers collected samples from two major cities in Nigeria: Ibadan (Oyo State) and Lagos (Lagos). The VA samples were collected from Ajorosun Estate within the Ibadan district. Ibadan is divided into several local government areas (LGAs), including Akinyele, Lagelu, Egbeda, and Ibadan North. It is situated at latitude 7.3775°N and longitude 3.9470°E. Ajorosun hosts various enterprises such as medium-sized foam and chemical plants as well as plastic manufacturing facilities. The BPi samples were obtained from Oregun, a town within the Lagos Metropolitan Area. Lagos is characterized by its urban landscape and major transportation routes, situated at latitude 6.5833°N and longitude 3.3667°E. Oregun is home to diverse industries including medium-sized plastic factories, metal recycling plants, pharmaceutical companies, clay manufacturers, and other production units. The distance between Ajorosun Estate (VA) in Ibadan and Oregun (BPi) in Lagos is approximately 109.1 kilometers. Both locations face significant pollution challenges due to extensive industrial activities, inadequate waste management, and rapid urbanization. Figure 1 illustrates the geographical locations of the study areas.

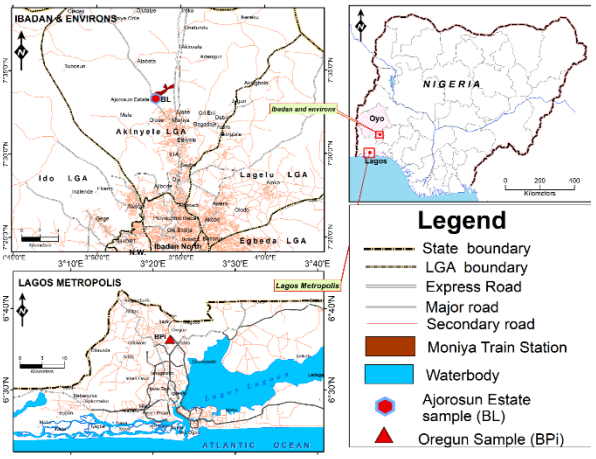

Figure 1. A map of the study region.

Plant Sample Collection

The edible parts of the medicinal plants, Miracle Leaf (*Bryophyllum pinnatum*) and Bitter Leaf (*Vernonia amygdalina*), were collected in pre-cleaned, sterilized polyethylene bags—one bag per species (Figures 2 and 3). Samples were gathered directly from privately owned farmlands with the cooperation of the farmers. Approximately 1 kg of each plant species was harvested separately from four randomly selected subsampling sites and then combined to form a composite sample. Any bruised or decayed portions were carefully removed. The remaining samples were properly packed and promptly transported to the Chemical Sciences Laboratory at KolaDaisi University in Ibadan, Oyo State, Nigeria, for further processing and analysis.

To remove adsorbed dust and particulate matter, samples were thoroughly rinsed with tap water in the laboratory before being distilled. They were then cut into small pieces using a plastic knife to facilitate drying. The samples were air-dried for five days, followed by oven drying at 50–60°C for 24 hours to eliminate moisture and achieve consistent mass. The dried materials were ground into a fine powder using an acid-washed mortar and pestle, then sieved through a 2 mm mesh sieve. Finally, the sieved samples were sealed in polyethylene bags and stored in desiccators until digestion and analysis.

Soil Sample Collection

Soil samples (1 kilogram each) were collected in clean polyethylene bags from the same sites as the plant samples, with permission from the farmers. Using a stainless steel auger, samples were taken individually at depths ranging from 0 to 20 cm. These individual samples from each site were combined to form a composite sample. The collected soil samples were securely packed, labeled, and transported to the Chemical Sciences Laboratory for pretreatment and analysis. In the laboratory, soil samples were air-dried in a dry, dust-free environment at room temperature (approximately 25°C) for five days before being oven-dried to constant weight. The dried samples were then ground using a mortar and pestle and sieved through a 2 mm mesh to ensure uniformity. Finally, the prepared soil samples were packaged in polyethylene bags and stored in desiccators until digestion and analysis.

Digestion Methods for Medicinal Plant Samples

One gram of homogenized, powdered plant sample from both BPi and VA medicinal plants was placed into a hotplate-digesting jar. To each jar, 9 mL of 10 M HNO_3 and 3 mL of 10 M HCl were added. The jars were carefully sealed and placed in a microwave digestion system. Digestion was performed at 180°C for 15 minutes until a clear solution was obtained. The resulting clear, colorless solution was filtered through Whatman No. 1 filter paper (10 µm pore size) into a 50 mL volumetric flask and adjusted to volume with 2% HNO_3. Heavy metal concentrations were determined by Atomic Absorption Spectrophotometry (AAS) using a Buck Scientific Model 210. Samples were digested and analyzed in duplicate, with results reported as mean ± standard deviation (SD). Blank solutions were prepared and analyzed under identical conditions (APHA, 2012).

Figure 2. Cathedral bells leaf *(Bryophllum pinnatum)*

Figure 3. Bitter Leaf *(Vernonia amygdalina)*

Digestion Procedures for Soil Samples

One gram of dried and homogenized soil sample was placed into hotplate digestion sample beakers in duplicates. In each vessel, 9 mL of 10 M HNO_3, 3 mL of 10 M HCl, and 5 mL of 10 M H_2O_2 were added. Digestion was carried out at 180°C for 45 minutes. The clear solutions were filtered using Whatman No. 1 filter paper (10 µm pore size) into 50 mL volumetric flasks, then diluted to the mark with 2% HNO_3, with small alterations from the optimal conditions. Heavy metals were evaluated in triplicate by AAS, with results provided as mean ± SD (APHA, 2012).

Calibration of AAS for Heavy Metal Analysis

The instrument was calibrated with a blank and five working standard solutions for each metal. Calibration curves were validated by correlation coefficients (r^2) ≥ 0.998. Instrument parameters such as plasma power, pump speed, coolant flow, and nebulizer flow were optimized according to the manufacturer's instructions to maximize signal intensity.

Environmental and Risk Assessment

The Pollution Index which measures the degree of heavy metal contamination, is calculated using the formula: (Islam et al., 2017)

$$\text{Pollution Index (PI)} = Ck / Sk \quad (1)$$

Here, PI represents the pollution index of a specific heavy metal, Ck is the measured concentration of that metal in mg/kg, and Sk corresponds to its standard background concentration in the study area (mg/kg). In this research, the baseline soil heavy metal values for Zhejiang Province served as the reference levels, set as Mn = 46.75 mg/kg, Fe = 56.90 mg/kg, Cu = 8.39 mg/kg, Zn = 44.19 mg/kg, Cr = 60.6 mg/kg, and Pb = 42.4 mg/kg. The classification of the Pollution Index (PI) for each heavy metal is summarized in Table 1.

Table 1. The Heavy Metal Pollution Index Classification Standard (Ripin et al., 2014).

G	PI	Pollution Degree	PI_N	Pollution Degree
1	PI<1	Clean	$P_N \leq 0.7$	Safe
2	1≤PI<2	Light pollution	$0.7<P_N\leq 1$	Warning line
3	2≤PI<3	Moderate pollution	$1<PI_N<2$	Light pollution
4	PI≥3	Heavy pollution	$2<PI_N<3$	Moderate pollution
5	/	/	$PI_N \geq 3$	Heavy pollution

G: Grade

Nemerow Pollution Index

To assess soil environmental quality comprehensively, the Nemerow Pollution Index (PI_N) was applied following the method of Zheng et al. (2010). This index is calculated by:

$$PI_N = \sqrt{PI^2AVE + PI^2MAX/2} \quad (2)$$

Where PIave is the mean pollution index for all heavy metals, and PImax is the highest value among them. Table 1 illustrates how PI_N is categorized.

Ecological Risk Assessment

Ripin et al (2014), introduced an ecological risk evaluation method to quantify the potential harm of heavy metal pollution in soils. The formula used is:

$$Ek = PI \times Tk \quad (3)$$

and the comprehensive risk index is:

$$RI = \sum i=1\ Eki \quad (4)$$

Here, Ek indicates the ecological risk posed by a specific heavy metal, while Tk is the toxicity coefficient assigned based on toxicity and pollution characteristics from previous studies. The coefficients used were: Mn and Zn = 1; Fe, Cu, Pb = 5; Cr = 2. RI represents an aggregated risk value from all heavy metals, with contamination levels classified as shown in Table 2.

Bioconcentration Factor

The Bioconcentration Factor (BCF) quantifies the degree to which plants accumulate heavy metals from soils and is calculated as:

$$BCF = C\ vegetable / C\ soil \quad (5)$$

where Cvegetable and Csoil represent the concentrations of heavy metals in vegetables and soil, respectively, both in mg/kg.

Table 2. Potential ecological hazard assessment indices according to Hakanson

Grade	E_k/RI	Pollution Degree
1	$E_k < 30$, or $RI < 40$	Slight negative impact
2	$30 \leq E_k < 60$, or $40 \leq RI < 80$	Moderate negative impact
3	$60 \leq E_k < 120$, or $80 \leq RI < 160$	Strong negative impact
4	$120 \leq E_k < 240$, or $160 \leq RI < 320$	Very strong negative impact
5	$E_k \geq 240$, or $RI \geq 320$	Severe negative impact

Table 3. Parameters for Health Risk Assessment Model

???	Parameter	Reference	Unit
EF	Exposure frequency	350	d/a
ED	Exposure time	Adult: 30; child: 7	A
AT	Average time	Carcinogenic: 365 × 70; non-carcinogenic: 365 × ED	D
BW	Body weight	Adult: 60; child: 26	Kg
SA	Skin area	1690	cm^2
AF	Adhesion factor	0.07	mg/cm^2
ABS	Skin absorption rate	0.001	/
PEF	Particulate emancipate factor	1.36×10^9	m^3/kg
CF	Conversion factor	1×10^{-6}	kg/mg
IRS	Soil particle intake rate	50	mg/d
IR_{in}	Soil particle intake	16	m^3/d
IRveg	Vegetable intake	Adult: 70; child: 15	g/d
C_k	Concentrations of heavy metals in soil	This study	mg/kg
Cveg	Concentrations of heavy metals in vegetable	This study	mg/kg

Table 4. Heavy metal concentration of soil -BPi samples

Plant Name	Sample	Mn	Fe	Cu	Zn	Cr	Pb
Dec BPi	Soil	191.33±1.17	9607.78±7.18	16.48±0.11	162.75±2.19	14.00±0.14	26.68±0.46
Jan BPi	Soil	217.75±1.31	9632.78±10.5	16.55±0.21	202.35±0.64	18.63±0.11	24.6±0.21
Feb BPi	Soil	200.93±0.32	9232.75±21.07	18.93±0.67	174.93±0.18	16.76±0.39	30.20±0.07
March BPi	Soil	158.20±0.07	8541.78±54.91	16.30±0.07	161.18±0.88	12.93±0.25	26.60±0.21

Values are mean ± standard deviation, BDL: below detection limit.

Table 5. Heavy metal concentration of Plant -BPi samples.

Plant Name	Sample	Mn	Fe	Cu	Zn	Cr	Pb
Dec BPi	Leaves	3.08±0.11	36.05±0.78	6.28±0.04	30.03±0.53	0.00±0.00	0.00±0.00
Dec BPi	Stem	10.3±0.28	123.1±1.63	10.63±0.11	121.45±0.21	20.75±0.21	0.00±0.00
Dec BPi	Root	72.60±0.28	2576.34±2.17	12.4±1.48	202.35±0.64	18.63±0.11	18.18±0.25
Jan BPi	Leaves	3.53±0.04	36.50±1.41	7.65±0.07	6.55±0.21	0.00±0.00	0.00±0.00
Jan BPi	Stem	16.88±0.39	172.65±0.07	8.89±0.07	41.83±0.32	0.00±0.00	0.00±0.00
Jan BPi	Root	57.45±0.28	1572.94±11.79	13.68±0.04	90.08±0.04	17.65±0.35	10.93±0.04
Feb BPi	Leaves	3.53±0.04	56.25±0.64	6.18±0.32	8.45±0.07	0.00±0.00	0.00±0.00
Feb BPi	Stem	14.53±0.04	132.63±0.32	7.25±0.14	40.63±0.04	0.00±0.00	0.00±0.00
Feb BPi	Root	54.33±0.32	1448.58±26.55	11.15±0.21	78.88±0.25	17.63±0.11	0.00±0.00
March BPi	Leaves	4.00±0.00	63.63±0.95	5.55±0.14	11.58±0.11	0.00±0.00	0.00±0.00
March BPi	Stem	13.38±0.25	142.25±0.64	6.93±0.18	35.08±0.18	0.00±0.00	0.00±0.00
March BPi	Root	59.53±0.11	1949.48±42.04	11.03±0.04	104.85±4.67	18.40±0.07	8.13±0.18

Health Risk Assessment

Health Risk Assessment applied the United States Environmental Protection Agency (USEPA) model (Moya et al., 2002) to evaluate heavy metal intake through four exposure pathways. Chronic daily intake (CDI) represents the average contaminant intake through these pathways and is calculated as:

$$CDIingest\text{-}soil = C_k \times IRSBW \times EF \times AT \times ED \times CF / BW \times AT \quad (6).$$

$$CDIveg = Cveg \times IRveg \times EF \times ED / BW \times AT \quad (7)$$

Parameters are listed with their reference values in Table 3.

Non-Carcinogenic Risk Assessment

Non-Carcinogenic Risk Assessment utilized the Target Hazard Quotient (HQ) method (Liu et al., 2013; Li et al., 2014) calculated as:

$$HQ \text{ equals } CDI/RfD \quad (8)$$

$$HI = \sum i=1 HQk \quad (9)$$

RfD denotes the reference dose for chronic exposure and HQk is the hazard quotient for each individual metal. According to USEPA (Moya et al., 2002), the reference doses for Mn, Fe, Cu, Zn, Cr, and Pb are 0.14, 0.7, 0.04, 0.3, 0.003, and 0.0035 mg/kg, respectively.

A value of HQ above 1 suggests potential non-carcinogenic health risks, while HI indicates the cumulative risk from all metals included.

Carcinogenic Risk Assessment

Carcinogenic Risk Assessment evaluated cancer risks due to heavy metals as:

$$CR = CDI \times SF \quad (10)$$

$$TCR = \sum i=1\ CRk \quad (11)$$

Where, CR is the cancer risk posed by an individual heavy metal, and SF is its slope factor. Chromium (Cr) and lead (Pb) have SF values of 0.5 and 0.0085, respectively, whereas Mn, Fe, Cu, and Zn do not have assigned slope factors (Fan et al., 2021). TCR reflects the total carcinogenic risk from all metals. Risk levels are interpreted as follows: values below 10−6 indicate negligible risk; between 10^{-6} and 10^{-4} suggest an acceptable risk range; and values exceeding 10^{-4} denote an unacceptable carcinogenic risk to the environment.

Statistical Analysis

All experimental data were analyzed using SPSS 23.0 for significant difference purpose.

Results and Discussion

Heavy Metals Concentrations in Soils

The chemical composition of medicinal plants and soil samples varied significantly across different sections of the study as shown in table 4-7.

Manganese Concentrations in Soil and Plants

Manganese (Mn) is an essential trace element required for proper plant and animal growth. Deficiency can cause severe skeletal and reproductive issues in mammals, while excessive amounts may damage human lungs and brain (Kumar & Raju, 2025). Our findings revealed significant monthly variations in manganese levels in soil and various parts of the "BPi" and "VA" plants. Soil Mn concentrations for "BPi" ranged from 217.75 mg/kg in January to 158.20 mg/kg in March. Leaf Mn levels varied between 3.08 mg/kg in December and 4.00 mg/kg in March. Stem concentrations ranged from 10.3 mg/kg in December to 16.88 mg/kg in January, and root Mn ranged from 72.60 mg/kg in December to 54.33 mg/kg in February. In "VA" samples, soil Mn peaked at 530.38 mg/kg in March and dipped to 366.38 mg/kg in February. Leaf Mn ranged from 33.85 mg/kg in January to 109.13 mg/kg in March, stem Mn from 4.73 mg/kg in December to 76.28 mg/kg in March, and root Mn ranged from 15.50 mg/kg in March to 41.23 mg/kg in January. Soil Mn levels across samples ranged from 158.20 to 217.75 mg/kg. The World Health Organization (WHO) sets the maximum permissible Mn level in medicinal plants at 200 mg/kg, with a recommended daily intake of 11 mg.

Iron Concentrations in Soil and Plants

Iron (Fe) is the most abundant essential element in plants and animals. However, excess iron may cause tissue damage and diseases including anemia and neurodegenerative disorders (Fuortes and Schenck, 2000). Significant fluctuations in Fe concentrations were observed in soil and plant parts of "BPi" and "VA." Soil Fe in "BPi" ranged between 9632.78 mg/kg (January) and 8541.78 mg/kg (March). Leaf Fe ranged from 36.05 mg/kg (December) to 63.63 mg/kg (March), stem Fe from 123.1 mg/kg (December) to 172.65 mg/kg (January), and root Fe from 1448.58 mg/kg (February) to 2576.34 mg/kg (December). In "VA," highest soil Fe was 16,045.03 mg/kg (January) and lowest 6,500.28 mg/kg (February). Leaf Fe varied from 205.45 mg/kg (March) to 437.58 mg/kg (February), stem Fe between 22.78 mg/kg (January) and 541.75 mg/kg (March), and root Fe ranged from 159.23 mg/kg (March) to 382.63 mg/kg (January). Soil Fe levels exceeded WHO limits for medicinal plants. Iron concentrations in leaves, stems, and roots of both plants surpassed the WHO recommended maximum of 20 mg/kg. WHO advises a daily iron intake of 10–28 mg (World Health Organization, 2002).

Table 6. Heavy metal concentration of soil -VA samples.

Plant Name	Sample	Mn	Fe	Cu	Zn	Cr	Pb
Dec VA	Soil	494.53±0.87	14590.38±31.78	23.58±0.32	222.08±2.58	14.73±0.11	18.55±0.28
Jan VA	Soil	513.60±3.46	16045.03±63.82	22.43±0.18	255.28±0.53	15.58±0.04	23.65±0.49
Feb VA	Soil	366.38±0.18	6500.28±6.97	5.95±0.07	18.88±0.74	13.6±0.21	0.00±0.00
March VA	Soil	530.38±0.25	7857.63±3.64	16.05±0.21	32.28±0.18	6.00±0.14	0.00±0.00

Values are mean ± standard deviation, BDL: below detection limit.

Table 7. Heavy metal concentration of plant -VA samples

Plant Name	Sample	Mn	Fe	Cu	Zn	Cr	Pb
Dec VA	Leaves	43.10±0.92	206.28±3.36	12.18±0.04	33.13±0.04	0.00±0.00	0.00±0.00
Dec VA	Stem	17.48±0.04	374.85±4.81	4.73±0.11	29.53±0.04	0.00±0.00	0.00±0.00
Dec VA	Root	27.25±0.57	350.73±1.17	4.95±0.28	58.78±0.25	0.00±0.00	0.00±0.00
Jan VA	Leaves	33.85±0.07	256.23±2.65	12.88±0.04	34.05±0.14	0.00±0.00	0.00±0.00
Jan VA	Stem	8.53±0.04	22.78±1.80	4.80±0.14	34.05±0.14	0.00±0.00	0.00±0.00
Jan VA	Root	41.23±0.04	382.63±3.57	4.13±0.04	20.63±0.39	6.15±0.14	0.00±0.00
Feb VA	Leaves	88.90±0.14	437.58±1.38	10.35±0.07	23.65±0.14	0.00±0.00	0.00±0.00
Feb VA	Stem	16.30±.56	192.23±2.86	5.18±0.11	8.00±0.07	0.00±0.00	0.00±0.00
Feb VA	Root	25.13±0.04	252.08±0.67	5.35±0.14	51.23±0.32	0.00±0.00	0.00±0.00
March VA	Leaves	109.13±1.31	205.45±0.85	14.05±0.14	17.03±0.39	0.00±0.00	0.00±0.00
March VA	Stem	76.28±0.11	541.75±2.76	8.50±0.14	19.58±0.46	0.00±0.00	0.00±0.00
March VA	Root	15.50±0.05	159.23±1.38	4.88±0.07	9.78±0.23	0.00±0.00	0.00±0.00

Table 8. Heavy metal risk index in soil.

Heavy metal	PI(Bpi)	E_k(Bpi)	PI(VA)	E_k(VA)
Mn	4.11	4.11	10.1	10.1
Fe	162.63	813.15	197.69	988.45
Cu	2.03	10.15	2.03	10.15
Zn	3.97	3.97	2.99	2.99
Cr	0.26	0.52	0.21	0.42
Pb	0.64	3.20	0.25	1.25

Table 9. Nemerow Pollution Index.

PI_N	PI_N
BPi_{soil}	116.80
VAL_{soil}	142.03

Copper Concentrations in Soil and Plants

Copper (Cu) is vital for enzyme functions and growth, but overexposure can cause health problems including metal fume fever, skin discoloration, dermatitis, and respiratory issues (Khan et al., 2008a, 2008b). Soil Cu in "BPi" ranged from 16.30 mg/kg (March) to 18.93 mg/kg (February). Leaf Cu varied from 5.55 mg/kg (March) to 7.65 mg/kg (January), stem Cu from 6.93 mg/kg (March) to 10.63 mg/kg (December), and roots from 11.03 mg/kg (March) to 13.68 mg/kg (January). In "VA," soil Cu was highest in December (23.58 mg/kg) and lowest in February (5.95 mg/kg). Leaf Cu spanned 10.35 mg/kg (February) to 14.05 mg/kg (March), stem Cu ranged 4.73 mg/kg (December) to 8.50 mg/kg (March), and root Cu ranged 4.13 mg/kg (January) to 5.35 mg/kg (February). The WHO acceptable limit for Cu in medicinal plants is 0.15 to 1.99 mg/kg.

Zinc Concentrations in Soil and Plants

Zinc (Zn) serves structural, regulatory, and catalytic enzyme roles, essential for DNA synthesis, development, brain function, bone formation, and wound healing. Yet, excess zinc can be neurotoxic (Adelekan and Abegunde, 2011). Soil Zn in "BPi" ranged from 161.18 mg/kg (March) to 202.35 mg/kg (January). Leaf Zn spanned 6.55 mg/kg (January) to 30.03 mg/kg (December), stem Zn from 35.08 mg/kg (March) to 121.45 mg/kg (December), and root Zn from 78.88 mg/kg (February) to 202.35 mg/kg (December). Soil Zn in "BL" fluctuated widely from 18.88 mg/kg (February) to 255.28 mg/kg (January). Leaf Zn ranged 17.03 mg/kg (March) to 34.05 mg/kg (January), stem Zn varied 8.00 mg/kg (February) to 34.05 mg/kg (January), and root Zn ranged 9.78 mg/kg (March) to 58.78 mg/kg (December). WHO recommends Zn levels in medicinal plants not exceed 50 mg/kg, with a daily intake around 11 mg (Khan et al., 2008b; Nacaroglu et al., 2009).

Chromium Concentrations in Soil and Plants

Chromium (Cr) is vital for cholesterol, lipid, and glucose metabolism. Deficiency causes hyperglycemia, increased body fat, and reduced sperm count, but overexposure is carcinogenic and hazardous (Shivappa et al., 2025). Soil Cr concentrations averaged 2.76 mg/kg in "BPi" and 8.73 mg/kg in "BL." Leaf Cr levels were consistently low at 0.00 mg/kg in both plants. Stem Cr concentrations varied more in "BPi" (20.75 mg/kg) than "BL" (0.00 mg/kg). Root Cr was slightly more variable in "BL" (6.15 mg/kg) than "BPi" (0.23 mg/kg). These differences suggest distinct uptake and environmental impacts. WHO acceptable Cr limit in medicinal plants is 1.5 mg/kg, with daily intake of 0.2 mg.

Lead Concentrations in Soil and Plants

Lead (Pb) is a non-essential heavy metal that causes oxidative stress by disrupting antioxidant systems (Nacaroglu et al., 2009). Elevated Pb causes anemia, colic, migraines, brain damage, and central nervous system disorders. Soil Pb concentrations showed moderate variability in "BPi" and "VA," around 5.60 mg/kg and 5.10 mg/kg, respectively. Lead in leaves remained undetectable (0.00 mg/kg) across both plants. Stem Pb varied up to 20.75 mg/kg, though many samples showed non-detectable levels. Root Pb in "BPi" showed minor variation (approximately 10.05 mg/kg), whereas "VA" roots consistently lacked detectable Pb. The WHO permissible Pb limit for medicinal plants is 10 mg/kg.

Risk Assessment for Heavy Metals Analysis

Pollution Index

The Pollution Index (PI) and Nemerow Pollution Index (PI_N) for heavy metals in soil samples from BPi and BL are presented in Tables 8 and 9.

Table 8 summarizes the heavy metal risk indices in soil, showing the values of Pk and ecological risk (Ek) for Mn, Fe, Cu, Zn, Cr, and Pb at BPi and VA locations. Soil contamination levels varied, with manganese (Mn), iron (Fe), and lead (Pb) exhibiting the highest pollution indices, while zinc (Zn) remained relatively clean. Copper (Cu) and chromium (Cr) displayed slight pollution.

Table 9 reports the Nemerow Pollution Index ($P_{N)}$, with values of 116.80 for BPi and 142.03 for VA, indicating moderate to severe soil contamination. Iron (Fe) and copper (Cu) demonstrated the highest ecological risk indices, signaling significant environmental impact. Lead (Pb) and zinc (Zn) posed moderate risks, whereas chromium (Cr) and manganese (Mn) represented lower potential ecological threats.

Due to iron and copper levels, the overall ecological risk index (RI) is notably high, at 813.15 for BPi and 998.45 for VA. Thus, iron, copper, zinc, and lead constitute the most serious heavy metal pollution hazards in the Lagos and Ibadan regions, whereas manganese and chromium present lesser ecological risks.

Bioconcentration Factor (BCF)

Bioconcentration Factor (BCF) evaluates the accumulation of heavy metals from soil into medicinal

plants. Table 10 shows BPi has a lower BCF (0.007) compared to VA (0.03). Both values are below 1, indicating effective soil enrichment regulation by the plants.

Table 10. Bioconcentration Factor of BPi and VA for medicinal plants and soil

BPi	0.007
VA	0.03

Health Risk Assessment

Non- Carcinogenic Risk Assessment for leaf samples

Non-Carcinogenic Risk Assessment for leaf samples revealed that Hazard Index (HI) values exceeding 1 reflect potential health risks (Guo et al., 2019). Figures 4 and 5 illustrate HI contributions from six heavy metals in leaves and soil. In leaf vegetables, copper contributed most significantly to HI in both BPi (42.89%) and VA (42.89%), closely followed by zinc, iron, and manganese, while chromium and lead showed no contribution. Average HI values for adults and children were below risk thresholds, with children's values consistently higher, highlighting greater vulnerability. HI results for soil samples also remained below concerning levels despite children's values being higher (Pesic, 2015). Table 11 demonstrates that neither vegetable consumption nor direct soil ingestion poses a non-carcinogenic health risk to humans.

Carcinogenic Risk Assessment

Carcinogenic Risk Assessment identified Mn, Fe, Cu, Zn, Cr, and Pb as potential carcinogens (Guo et al., 2019). However, total carcinogenic risk (TCR) values for vegetable samples were negligible for both adolescents and adults, indicating no significant cancer risk from consumption. Chromium and lead contributed zero to TCR. Data for other metals were unavailable.

Statistics Analysis

Correlation Analysis

Correlation analyses (Tables 12 and 13) showed strong statistically significant relationships among heavy metals (Mn, Fe, Cu, Zn, Cr, and Pb), suggesting common sources of contamination.

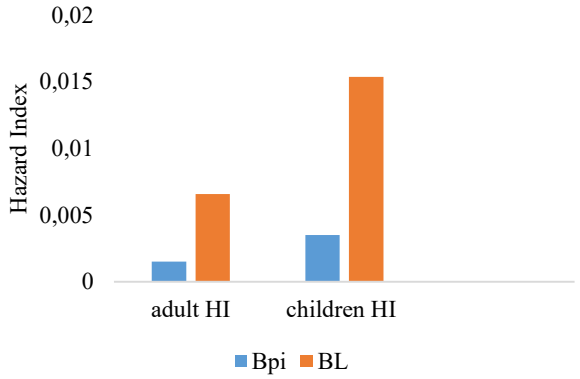

Figure 4. Non-carcinogenic risk assessment of leaf samples

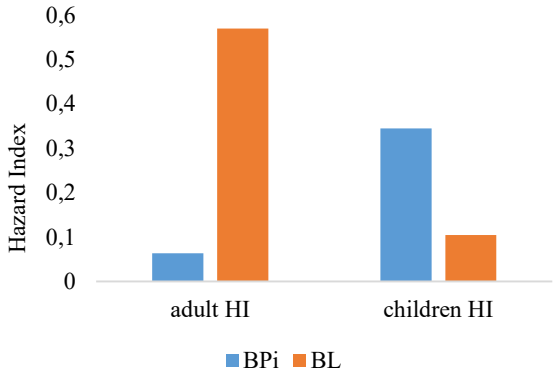

Figure 5. The non-carcinogenic risk assessment results for a soil sample

Table 11. Exposure assessment of heavy metal in BPi and VA

HM (Heavy Metal)	Age	BPi (leaves)	VA (leaves)	BPi (soil)	VA (soil)
Mn	Adult	1.11×10^{-4}	21.45×10^{-4}	43.95×10^{-5}	108.85×10^{-5}
	Children	2.60×10^{-4}	50.05×10^{-4}	239.3×10^{-5}	$592.63S\times10^{-5}$
Fe	Adult	15.12×10^{-4}	86.87×10^{-4}	211.60×10^{-5}	2570.97×10^{-5}
	Children	35.28×10^{-4}	202.69×10^{-4}	1152.07×10^{-5}	$13,997.90\times10^{-5}$
Cu	Adult	2.02×10^{-4}	3.89×10^{-4}	3.90×10^{-5}	3.89×10^{-5}
	Children	4.71×10^{-4}	9.07×10^{-4}	21.2×10^{-5}	21.15×10^{-5}
Zn	Adult	3.07×10^{-4}	6.11×10^{-4}	40.06×10^{-5}	30.2×10^{-5}
	Children	7.17×10^{-4}	14.26×10^{-4}	218.15×10^{-5}	164.42×10^{-5}
Cr	Adult	0.00	0.00	3.56×10^{-5}	2.85×10^{-5}
	Children	0.00	0.00	19.40×10^{-5}	15.53×10^{-5}
Pb	Adult	0.00	0.00	6.18×10^{-5}	2.41×10^{-5}
	Children	0.00	0.00	33.62×10^{-5}	13.12×10^{-5}

Table 12. Correlation matrix of heavy metal for BPi.

	Mn	Fe	Cu	Zn	Cr	Pb
Mn	1					
Fe	0.990	1				
Cu	0.930	0.905	1			
Zn	0.964	0.933	0.944	1		
Cr	0.707	0.633	0.789	0.834	1	
Pb	0.952	0.954	0.927	0.943	0.720	1

Table 13. Correlation matrix of heavy metal for VA

	Mn	Fe	Cu	Zn	Cr	Pb
Mn	1					
Fe	0.932	1				
Cu	0.766	0.803	1			
Zn	0.677	0.882	0.782	1		
Cr	0.867	0.915	0.601	0.740	1	
Pb	0.690	0.896	0.786	0.982	0.768	1

Conclusion

Mn, Fe, Cu, and Zn concentrations frequently exceeded WHO standards in medicinal plants, posing health risks. Chromium and lead levels generally remained within safe limits but require ongoing monitoring. The ecological risk indices provide valuable spatial insights into heavy metal pollution, guiding sustainable environmental management in Lagos and Ibadan. Risk assessments indicate the studied medicinal plants are safe for traditional use if contamination stays below threshold values.

Declarations

This study was presented at the IV. International Congress of the Turkish Journal of Agriculture - Food Science and Technology (Niğde, TURJAF 2025)

Ethical Approval Certificate

The Botany Department at the University of Ibadan, Nigeria, authorized the experimental protocols used in this study. The acceptance date was September 30th, 2024, and the numbers are UIH 23471 for *Bryophyllum pinnatum* and UIH 23476 for *Vernonia amygdalina*.

Conflict of Interest

The authors declare no conflicts of interest.

Acknowledgments

The authors thank the Department of Chemical Sciences Laboratory, KolaDaisi University, Ibadan, Oyo State, Nigeria, for providing a favorable environment for the practical sessions of this research.

References

Adelekan, B. A., & Abegunde, K. D. (2011). Heavy metals contamination of soil and groundwater at automobile mechanic villages in Ibadan, Nigeria. International Journal of Physical Sciences, 6(5), 1045–1058.

American Public Health Association (2012). Standard Methods for the examination of water and wastewater, 22nd Washington.

Bauer, A., & Bronstrup, M. (2014). Industrial natural product chemistry for drug discovery and development. Natural Product Reports, 31(1), 35-60.

Botle, A., Salgaonkar, S., Tiwari, K., Barabde, G (2025). Health Concerns and Issues Associated with Toxic Heavy Metals. Global Perspectives and Issues Associated with Toxic Heavy Metals. Pp161-193.

El Hamzaoui, E., Baghdadi, M., Hilali, A (2025). Assessment of Trace Element Contamination and associated Health Risks in Agricultural Soils of the Beni Moussa Sub-Perimila, Morocco. Springer: Modelling Earth Systems and Environment.

Huggett, R. J. (2011). What is geomorphology? In Fundamentals of geomorphology. Routledge Fundamentals of Physical Geography Series (3rd ed.). London, United Kingdom: Routledge.

Islam, M. S., Ahmed, M. K., Raknuzzaman, M., Habibullah-Al-Mamun, M., & Kundu, G. K. (2017). Heavy metals in the industrial sludge and their ecological risk: A case study for a developing country. Journal of Geochemical Exploration, 172, 41-49.

Jasim, A. K (2025). Characteristics of Sediment Pollution Study with Trace Elements in the Kufa River, Iraq. EQA-International Journal of Environmental Quality. https://doi.org//016092/issn.281-4485/21767

Khan, C. S., Coa, Q., Zheng, Y. M., Huang, Y. Z., & Zhu, Y. G. (2008a). Health risks of heavy metals with wastewater in Beijing, China. Environmental Pollution, 152(3), 686-692.

Khan, S. A., Khan, L., Hussain, I., Marwat, K. B., & Akhtar, N. (2008b). Profile of heavy metals in selected medicinal plants. Journal of Weed Sciences and Research, 14(1-2), 101–110.

Kumar, M.V. & Raju, H. P (2025). Heavy Metals in the Environment Sources, Fate and Health Implications. Springer: Groundwater Resource Management Planning Strategies. Pp 135-153.

Liu, X., Song, Q., Tang, Y., Li, W., Xu, J., Wu, J., Wang, F., & Brookes, P. C. (2013). Human health risk assessment of heavy metals in soil-vegetable systems: A multi-medium analysis. Science of the Total Environment, 463, 530-540.

Liu, Z., Ma, Z., van der Kuijp, T. J., Yuan, Z., & Huang, L. (2014). A review of soil heavy metal pollution from mines in China: Pollution and health risk assessment. Science of the Total Environment, 468, 843-853.

McCarthy, D. F. (2014). Essentials of soil mechanics and foundations: Basic geotechnics (7th ed.). London, United Kingdom: Pearson. ISBN 9781292039398. Archived from the original on 16 October 2022. Retrieved 27 March 2022.

Moya, J., & Phillips, L. (2002). Overview of the use of the U.S. EPA exposure factors handbook. International Journal of Hygiene and Environmental Health, 205, 155-159.

Nacaroglu, M., Demirkiran, A. R., & Tursun, N. (2009). Determination of some chemical properties of common cattail (Typha latifolia L.). Journal of Animal and Veterinary Advances, 8(12), 2719-2726.

Parven, S., De, A., & Gupta, A. (2022). Cu and Pb accumulation and removal from aqueous medium by Enydra fluctuation Lour. (Asteraceae)—A medicinal plant with potential for phytoremediation. Environmental Science and Pollution Research, 29, 66902-66912.

Pešić, M. (2015). Development of natural product drugs in a sustainable manner. Brief for United Nations Global Sustainable Development Report 2015. https://sustainabledevelopment.un.org/content/documents/6544118_Pesic_Development

Ponge, J.-F. (2015). The soil as an ecosystem. Biology and Fertility of Soils, 51(6), 645-648. https://doi.org/10.1007/s00374-015-1016-1.

Ripin, S., Hasan, S., Kamal, M. L., & Hashim, N. M. (2014). Analysis and pollution assessment of heavy metal in soil, Perlis. Malaysian Journal of Analytical Sciences, 18, 155-161. Shivappa, S., Amritha, K. P., Nayak, S., Chandrashakar, H.K., Thorat, S.A., Kaniyassay, A.,

Govader, N., Thiruvengadem, M., Muthusamy, A. (2025). Integration of Physio- biochemical. Biological and Molecular approaches to improve Heavy metal tolerance in plants. Springer: Biochip Journal. https://doi.org/10.1007/s13205-025-04248

World Health Organization (WHO). (2002). Traditional medicine strategy 2002-2005. Geneva, Switzerland: World Health Organization.

Zheng, N., Liu, J., Wang, Q., & Liang, Z. (2010). Health risk assessment of heavy metal exposure to street dust in the zinc smelting district, Northeast of China. Science of the Total Environment, 408, 726-733.