UMYU Journal of Pure and Industrial Chemical Research
Volume 3, Issue 1, 2025, 37-52
E-ISSN: 2814-1628, P-ISSN: 2814-1636

Environmental Risk Assessment of Chromium Contamination in Gutu Mine Spoil, Minna, Niger State, Nigeria.

Bagudu Shehu Ezekiel[1]*, Egharevba Felix[2], Medjor Weltime Odeguonor[3]

[1]Department of Chemical Sciences, Taraba State University, Jalingo, Taraba State, Nigeria
[2]Department of Chemistry, Ambrose Alli University, Ekpoma, Edo State, Nigeria
[3]Department of Chemical Sciences, Taraba State University, Jalingo, Taraba State, Nigeria

*Corresponding author:
bagudu.shehuezekiel@gmail.com

Received: 8th May, 2025
Revised: 21st June, 2025
Accepted: 30th July, 2025

Abstract

An assessment of environmental risk factors of artisanal mining activities was conducted on Gutu mine-spoil, Minna, Niger State, Nigeria, to ascertain the level of environmental pollution or contamination. The investigation was motivated by reports of skin inflammation and febrile illness outbreaks in surrounding villages. Heavy metal concentrations in the earth materials were determined using inductively coupled plasma (ICP) spectrometry. Parameters such as pH, particle size distribution, total organic carbon, and electrical conductivity were also determined using standard methods. Results showed that Pb had a mean value of 1.20±0.0 ppm; Co, 0.41±0.0 ppm; Cd, 0.01±0.0 ppm; Fe, 15.4±1.2 ppm; Mn, 7.70±0.1 ppm; Ti, 1.18±0.0 ppm; As, 0.02±0.0 ppm; and Cr, 0.2953 ppm. Among the heavy metals analyzed, only Cr (0.3 ppm) exceeded the WHO standard of 0.2 ppm for mine spoils. The contamination/pollution index of Cr was 1.5, indicating severe pollution. The overall risk factor for the heavy metals was 27.36, suggesting slight risk. Geo-accumulation indices for the metals were below unity, indicating moderate pollution.

Keywords: Artisanal mining, Contamination index, Environmental risk, Gutu mine-spoil, Heavy metals, ICP spectrometry.

INTRODUCTION

Environmental pollution by heavy metals is an all-time issue of public concern considering its negative consequences. Heavy metals pose major threats to quality living and existence of man and animals when they occur above permissible limits. Originating from small scale mines and even abandoned mines, heavy metals contaminate streams, rivers and sediments as well as agricultural products. This could result in metal poisoning in areas where water from such streams serves as sources of domestic water. It was widely reported that deaths of at least 163 people including 111 children occurred between March and June 2010. There were also reports of a series of lead poisonings in Zamfara State, Nigeria in year 2010 [1]. It was also reported that in Minna, Niger State Gutu communities were plagued with dermatitis as a result of mining activities. Nigerian Federal Ministry of Health, reported 355 cases in Gutu area with 46% fatality [2]. Niger State leads the States with illegal mining in Nigeria, according to the latest reports by Nigeria Extractive industries Transparency Initiative (NEITI) [3] Mine spoils within and around Gutu communities of Minna hosts some quartz veins that are gold bearing [3].The most common occupational diseases that workers are likely to develop as a result of long-term exposure in the gold mining environment are silicosis, silico-tuberculosis, pulmonary tuberculosis (TB), obstructive airways disease, occupational asthma, oral and/or nasal cavity erosions, diseases owing to ionizing radiation, noise-induced hearing loss, whole body and hand-arm vibration syndrome, as well as repetitive strain injuries [4]. Mining remains one of the most hazardous occupations in the world, not only in terms of short-term injury and loss of life, but also due to long-term impacts such as cancers and respiratory conditions, including silicosis, asbestosis and pneumoconiosis. [5]

This investigation aims to assess the environmental risks associated with heavy metal contamination in Gutu mine spoil, Minna, Niger State, Nigeria, by identifying hazardous heavy metals to miners and evaluating key pollution indices such as the geo-accumulation index, contamination index, enrichment factors, and ecological risk factors.

MATERIALS AND METHODS

The materials that were used in the investigation are: Conical flask, Fire-resistant crucibles of 150 mL, Iron cups, Cupels (60 mm), Shaft furnace (BCS 8.02) with an operating temperature of 1070-1100^{0}C, Cupellation furnace of 20 kW (S 73/HS). Inductively coupled plasma spectroscopy

(ICP-OES) (5900 ICP-OES-Agilent), Autosampler (SPS 3), Micropipettes (P-1000), Conductivity meter (Model CC-01), Droppers (IH-17161), pH meter (pH 110), Global positioning system (5.2 GPS), Weighing balance. In ICP-OES, the plasma itself excites the sample atoms, and the emitted light from these excited atoms is analyzed across a broad spectral range using an optical spectrometer.

Methods

Inductively coupled plasma spectrophotometer (ICP) (5900 ICP-OES-Agilent) was used in determining the heavy metals in Gutu mine spoil as well as gold. 4 drops of ferroin indicator was added to the sample and titrated with 0.8 M $FeSO_4$. As the end point is approached, the solution takes on a greenish colour and then changes to a dark green. At this point, $FeSO_4$ is added drop- by-drop until the colour changes from blue – green to reddish – grey. The end point was delayed and 1.0 mL of $K_2Cr_2O_7$ was added and the end point was then reached. About 2-5 g of the sample was taken into a conical flask, 10 mL of a mixture of concentrated Nitric acid and per chloric acid were added and the mixture is placed on an hot plate for an hour until the brown fumes starts foaming and the fume changes gradually to whitish which showed that the samples have been completely digested.

The digested samples were allowed to cool and later made up to 50 mL mark with purified water, the mixture was filtered through filter paper and the clean, clear filtrate was taken for heavy metal analysis using ICP. The instrument was powered and allowed to initialize for about 10 minutes. The plasma was switched on which supplies fuel to the machine. (Argon of very high purity is the fuel being used by ICP). The wavelengths of heavy metals and gold were selected. The blank analysis was done by aspirating 1 % nitric acid into the machine so as to guide against any interference and carry over. The concentrations of various standards prepared were run to calibrate the equipment.

Sampling Site

The sampling area for this study is Gutu Community, located along Maitumbi Road in Minna, Niger State, Nigeria. Gutu is a small rural settlement situated at an elevation of approximately 10 meters above sea level, with coordinates lying around 10°00′N and 6°00′E. The community is characterized by visible excavated mine pits and a desert-like landscape dominated by heavy wind activity. The environment shows clear evidence of extensive mining operations, which have significantly altered the natural landscape. The dominant occupations in Gutu Community include farming and animal husbandry, especially cattle rearing. The community is inhabited by a mix of ethnic groups, including the Igbo, Hausa, and Gbagi, all of whom depend heavily on the surrounding land for their livelihoods. Based on the observed landscape and community layout, five sampling points were identified to reflect different environmental exposures and human activity zones. These sampling points were strategically selected to include locations near active and abandoned mine pits, farmland, cattle tracks, windward and leeward zones of spoil heaps, and areas showing signs of ecological recovery. The coordinates for these points based on the central coordinates of 10°N, 6°E are as follows: Sample 1 (SP1) (10.0005°N, 6.0003°E) near the central spoil heap; SP2 (10.0010°N, 6.0012°E) on the edge of the spoil near active farmland; SP3 (9.9998°N, 6.0008°E) near a cattle route close to a shallow pit; SP4 (10.0002°N, 5.9995°E) on the windward side of the spoil area; SP5 (10.0015°N, 6.0000°E) in the downwind leachate dispersion zone (Figure 1).

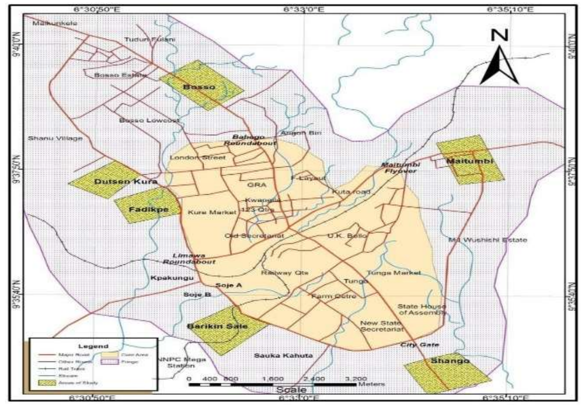

Figure 1. Gutu mine spoil, Minna, Niger State, Nigeria.

Sampling

The sampling method adopted for this study involved manual excavation and collection of mine spoil from a gold mining pits with an approximate depth of 5 meters, located at the Gutu mining site, Minna, Niger State, Nigeria. Access into those pits were achieved using a combination of locally available tools including shovels and hand-digging implements. Safety precautions were observed, and the excavation was assisted by miners familiar with the pits structure to reach the target depths safely. Five integrated samples were collected from different positions at the 5-meter depths. These positions were strategically chosen to capture the spatial variability of the spoil material. The designated sampling points within the pits include:

Each of these points was 5 meters deep, ensuring broad coverage of the spoil. Equal quantities of spoil (50 g each) were scooped from these five points using a clean, rust-free shovel and transferred into pre-labeled, contamination-free plastic containers.

These five sub-samples were then thoroughly mixed on a clean polythene sheet to form one aggregate (composite) sample representing the entire five pits. This composite sample was air-dried indoors at ambient temperature to avoid contamination by airborne particles or direct sunlight, which could alter chemical properties.

Once dry, 50 g of the sample was weighed and subjected to pulverization using a Ball Bearing Machine Crusher (Retsch PM 200). This process involved high-energy milling that reduced the aggregate sample to a fine homogenous powder suitable for chemical analysis. The powdered sample was then stored in airtight containers for ICP-OES procedures.

This method ensured that the collected material accurately represented the geochemical properties of the spoil at that depth, while minimizing sampling errors and environmental contamination, in line with procedures adapted from [6].

RESULTS AND DISCUSSION

The data for the physicochemical parameters of the Gutu mine-spoil sample are shown in Table1.

*p*H

In Table 1 is shown the mean *p*H value of the Gutu mine-spoil sample. Soil *p*H is a crucial factor that influences the mineralization, mobility, or transport of metals in soil. The mobility of metals generally decreases as soil *p*H increases, because metal hydroxides and carbonates become less soluble and may precipitate or form stable organic complexes [7]. Soil *p*H, together with organic matter, largely determines the exchangeable metal fractions, which are easily leached into water systems or taken up by crops.

Soil pH was measured using a *p*H meter (*p*H 110). A 1:2.5 soil-to-distilled water suspension was prepared, stirred, and allowed to settle before inserting the *p*H electrode into the supernatant for direct reading. The *p*H value obtained in this study was 6.43, which is slightly acidic. In this pH range, the mobility of heavy metals is moderately low, though some may still remain bioavailable.

Electrical Conductivity (EC)

As shown in Table 1, the electrical conductivity of the soil was found to be 50.8 µS/cm. High EC values in mining pits are commonly due to the presence of heavy metal ions and other soluble salts. These ions increase the soil's ionic conductivity, contributing to altered chemical dynamics at the site [8]. Despite the acidic pH, high ion concentration can still increase EC substantially. EC was determined using a conductivity meter (Model CC-01). A soil-to-water ratio of 1:5 was used. The mixture was stirred and allowed to settle, and the conductivity of the extract was measured using the EC probe inserted into the solution.

Total Organic Carbon (TOC)

Soil organic carbon plays a vital role in promoting soil structure, aeration, water retention, and erosion control. It also contributes to metal immobilization through complexation. As presented in Table 1, the

total organic carbon content in the Gutu mine-spoil sample was 2.67%, which falls within the FAO's recommended range for good quality agricultural soil.

TOC was measured using the Walkley-Black method. A known weight of soil (typically 0.5 g) was treated with potassium dichromate ($K_2Cr_2O_7$) and concentrated sulfuric acid, then titrated with ferrous ammonium sulfate to determine the amount of organic carbon oxidized. The following formula was used.

$$\text{Organic Carbon } \% = 3\left(1 - \frac{\frac{T}{S}}{W}\right)$$

Particle Size Distribution (PSD)

Particle size distribution is essential in determining soil classification and its ability to retain or transmit water and solutes. It influences drainage, erosion potential, and metal transport in soils. The particle size data (Table 1) offers insight into the soil's textural class, which is vital for interpreting contamination risks.

Table 1. Physicochemical Parameters of Gutu Gold Mine

Parameter (mg/kg)	Concentration (mg/kg)	WHO/FAO (2007) Standards
Li	0.09±0.0	
Na	30.1±1.3	
K	17.40±0.2	
Rb	0.70±0.0	
Be	0.01±0.0	
Mg	24.7±0.0	
Ca	34.1±0.6	
Sr	0.20±0.0	
Ba	2.10±0.0	
Cu	0.40±0.0	100
Ag	0.10±0.0	
Au	0.17±0.0	
Pt	0.01±0.0	
Zn	0.50±0.0	60
Cr	0.30±0.0	0.2
Co	0.41±0.0	54.6
Pb	1.20±0.0	100
Cd	0.01±0.0	5
Fe	15.4±1.2	20
Hg	0.01±0.0	180
Mn	7.70±0.1	160
Al	0.01±0.0	3
Ti	1.18±0.0	120
Sr	0.18±0.0	100
As	0.02±0.0	10
pH	6.43±0.1	6–7
Electrical conductivity (mS/m)	50.8±0.6	110–150
Total organic carbon (%)	2.70±0.1	0.5–7.5
% Silt	7.01±0.2	10–20
% Clay	72.0±0.6	20–30
% Sand	20.1±0.5	50–70

PSD was determined using the hydrometer method. The soil sample was dispersed in a sodium hexametaphosphate solution and agitated thoroughly. The suspension was then transferred to a graduated cylinder, and a hydrometer was used to record readings at specified intervals (2 mins and 2 hrs) to differentiate sand, silt, and clay fractions based on sedimentation rates. The following formula was used in the determination.

$$\% \text{ Sand} = \frac{\text{residue}}{\text{sample}} \text{x}100$$

$$\% \text{ Silt} = \frac{\text{residue}}{\text{sample}} \text{x}100$$

$$\% \text{ Clay} = 100 - (\% \text{ Silt} + \% \text{ Sand})$$

Chromium (Cr)

Chromium (Cr) plays a vital role in the metabolism of cholesterol, fat, and glucose. Its deficiency causes hyperglycemia (high blood sugar level), elevated body fat, and decreased sperm count, while at high concentration it is toxic and carcinogenic [9]. As shown in Table 1, the Cr concentration is around 0.3±0.0 mg/kg which is above the WHO limit (0.2mg/kg). Soluble and un-adsorbed Chromium complexes can leach from soil into groundwater. Chromium is associated with allergic dermatitis in humans [10]. It therefore follows that the people of Gutu community could be affected by chromium mediated skin diseases related such as eczema, dandruff, red rashes and itching among others.

Zinc (Zn)

Zinc (Zn) is the second least available metal found in the analyzed soil samples, with a mean concentration of 0.5±0.0 mg/kg, which is below unity as shown in Table 1. Although the Zn concentration is relatively low, this may be attributed to high uptake by plant roots and its translocation to aerial parts via transpiration, without significant remobilization through the phloem [11]. According to Alloway, 2008, zinc mobility in soil is influenced by factors such as pH, organic matter, and plant activity, with deficiencies commonly observed in tropical soils due to leaching or biological uptake. Similar patterns have been reported by [12], who documented low Zn concentrations in soils of similar climatic regions. In comparison, [13] noted that soils surrounding mining sites in Nigeria also displayed sub-optimal zinc levels, largely due to plant extraction and limited natural abundance. Nevertheless, the concentration of Zn in this study remains below the World Health Organization/Food and Agriculture Organization (WHO/FAO) permissible limit of 60 mg/kg [14], indicating no immediate ecological or public health concern.

Copper (Cu)

The observed value of 0.40±0.0 mg/kg is consistent with studies by [15], who noted low Cu levels in agricultural soils in Nigeria, typically well below the 100 mg/kg threshold.

Iron (Fe)

Iron levels (15.4 ± 1.2 mg/kg) are below toxic thresholds and reflect typical values for tropical soils [16]. Iron is usually abundant due to its geogenic nature but rarely exceeds harmful limits.

Cadmium (Cd)

Cadmium is highly toxic even at low concentrations, but its observed value (0.01±0.0 mg/kg) is well below the WHO limit of 5 mg/kg. Similar low values were reported by [17] in non-industrial areas.

Lead (Pb)

With a concentration of 0.02±0.0 mg/kg, the value is far below the WHO/FAO permissible limit (100 mg/kg), corroborating results from studies in non-urban Nigerian soils [18].

Arsenic (As)

At 0.02±0.0 mg/kg, arsenic levels are within safe limits, agreeing with reports by [19], which emphasize arsenic's typically low natural abundance in Nigerian soils.

Mercury (Hg)

Detected at 0.01±0.0 mg/kg, mercury levels are non-toxic and align with values from comparable studies [20], especially in soils not directly exposed to industrial pollutants.

Contamination/pollution index (CPI)

This specifies the degree of contamination of an area [14]. PI = concentration of metals in site/Target value often specified by regulatory agency.

In Table 2, is shown the contamination/pollution index CPI of the heavy metals of sample from Gutu mine-spoil. The value of the contamination/pollution index of Cr 1.50 (standard 0.2) indicates slight pollution as shown in Table 3 while the CPI for the rest of the heavy metals in this study (Table 2) fall within WHO/FAO limit.

Table 2. Contamination/Pollution Index for Heavy Metals

Heavy Metals	CPI	FAO/WHO
Zn	0.0081	60
Cr	1.50	0.2
Co	0.0075	54.6
Pb	0.012	100
Cd	0.0018	5
Cu	0.0039	100
Fe	0.77	20
Hg	0.0000055	180
Mn	0.048	160
Al	0.00033	3
Ti	0.0098	120
Sr	0.0018	100
As	0.0014	6–7

Table 3 shows the classification in terms of level of significance of CPI Enrichment factor of metals in soil (EF)

Enrichment factor of metals in soil (EF)

This specifies how enriched a site is with respect to metal concentration used to distinguish between metals originating from human activities and those of natural processes [21].

$$\mathrm{EF} = \frac{\mathrm{Cn(test\ element)}}{\mathrm{Cn(reference\ metal\ in\ sample\ Fe)}} + \frac{\mathrm{Bn(test\ element)}}{\mathrm{Bn(reference\ element\ Fe)}}$$

Where:

Cn (test) = conc. of test metal in sample

Cn (ref) = conc. of reference metal in sample.

Bn (test) = background conc. of test metal in crystal rock

Bn (ref) = background conc. of reference metal in crystal rock

Table 3 shows the classification in terms of level of significance of CPI.

The enrichment factor (Ef) of the heavy metals in the sample are shown in Table 4.

Table 3. Significance of Interval of Contamination/Pollution Index

CPI	Significance
<0.1	Very slight contamination
0.10-0.25	Slight contamination
0.26-0.50	Moderate contamination
0.51-0.75	Severe contamination
0.76-1.00	Very severe contamination
1.10-2.00	Slight pollution
2.10-4.00	Moderate pollution
4.10-8.00	Severe pollution
8.10-16.0	Very severe pollution
>16.0	Excessive pollution

[Adopted from 22]

Table 4. Enrichment factor (EF) of the heavy metals in Gutu-mine spoil

Heavy Metals	EF
Zn	26.22377622
Cr	8.766233766
Co	55.90909091
Pb	490.9090909
Cd	272.7272727
Cu	24.06417112
Fe	1
Hg	610.5834464
Mn	28.63636364
Al	0.000505051
Ti	0.731404959
Sr	2.045454545
As	38.96103896

Table 5. Enrichment Factors (Ef)

EF Values	**Significance**
< 2	Deficiency in mineral enrichment
2–5	Moderate enrichment
5–20	Significant enrichment
20–40	Very high enrichment
>40	Extremely high enrichment

[Adopted from 23]

Table 6. Enrichment Factors (Ef)

RI Values	Risk Level	Significance
<40	A	Slightly
$40 \leq RI < 80$	B	Medium
$80 \leq RI < 160$	C	Strong
$160 \leq RI < 320$	D	Very strongly
$RI \geq 320$	E	Extremely

[Adopted from 24]

Ecological risk factor (RI):

The potential ecological risk index (RI) is defined as a sum of the risk factors (Pb, Cd, Cu, Zn, and Cr) [23]. Ecological risk factor RI equals the sum of the risk factors (Pb, Cd, Cu, Zn and Cr).

$RI = \Sigma_i{}^n = 1 \quad E_r{}^i$: Tfi = toxic response factor for each metal.

The value of the risk factor for the heavy metals was found to be 27.36 which indicates a slightly risk factor as when considered against the adopted level of significance in Table 6. The results show that, the risk level of the metals in the soil sample is A and interpreted to be slight in significance. This is in concert with Pawara area is a mining district in the eastern region of Cameroon. Mining in the area is generally artisanal and semi-mechanized, practiced by the local miners and immigrants from neighboring African countries and China [25].

Table 7. Geoaccumulation Index (Igeo)

Igeo Values	Significance
<0	Practically unpolluted (class 1)
0–1	Unpolluted to moderately polluted (class 2)
1–2	Moderately polluted (class 3)
2–3	Moderately to strongly polluted (class 4)
3–4	Strongly polluted (class 5)
4–5	Strongly polluted to strongly polluted (class 6)
>5	Extremely polluted (class 7)

[Adopted from 26]

Geoaccumulation index (IGeo)

The geoaccumulation index (Igeo) was used to assess heavy metal contamination of sediments and it builds on the background level of natural fluctuations including very low anthropogenic input [27]. It is determined by the following formula.

$$Igeo = Log2\frac{Cn}{1.5bn}$$

Where:

Cn = concentration of metals in the sample

bn = background concentration in crystal abundant values of metals (CAV)

The geo accumulation indices for all the heavy metals in the study were evaluated and their values were found to be less than unity (1) which shows that the soil was practically unpolluted by this assessment as shown in Table 7.

CONCLUSION

The environmental risk assessment of Gutu mine spoil in Minna, Niger State, has highlighted chromium (Cr) as the principal contaminant of concern, within a broader context of physicochemical influences and trace metal presence. The soil's slightly acidic pH (6.43) and moderate electrical conductivity (50.8 µS/cm) create conditions that can sustain the mobility and bioavailability of chromium and other potentially toxic metals.

Although the Total Organic Carbon (2.67%) and clay-rich texture (72%) suggest some natural capacity for metal retention, they may also enhance heavy metal accumulation over time. The measured Cr concentration (0.3

mg/kg) exceeds the WHO/FAO guideline limit of 0.2 mg/kg, pointing to potential ecological and human health risks. While the levels of Zn, Cu, Fe, Cd, Pb, As, and Hg were below international threshold values, their combined ecological impact remains noteworthy.

The contamination/pollution index (CPI) classified chromium as slightly polluting, and enrichment factor (EF) results showed very high anthropogenic influence, especially for Cr, Cd, Pb, and Hg. The ecological risk index (RI = 27.36) placed the site within a slight risk category, and geoaccumulation index (Igeo) values under 1 confirmed minimal current pollution.

Collectively, these indicators reveal that while chromium is not yet causing severe environmental degradation, it represents a clear and emerging threat within the Gutu mine spoil area, warranting continued surveillance and site-specific risk mitigation strategies.

CONFLICT OF INTEREST

Authors declared no conflict of interest.

FUNDING

There was no funding received for this work.

ETHICAL STATEMENT

This work required no ethical statement.

References

[1] Bartrem C. Lead Poisoning Outbreak in Zamfara State, Nigeria. *Journal of Environmental Health Research*, 2017; 27(3): 233–241.

[2] Tirima S. Field Survey Report: Zamfara Lead Poisoning Crisis. *WHO & MSF Collaborative Reports*, 2010; Nigeria.

[3] Endean M. Environmental Impact of Mining in Nigeria. *Nigerian Federal Ministry of Health Annual Report*, 2016; Abuja, Nigeria.

[4] Shinkafi AA, Ibrahim BA, Salisu M. Geological Mapping and Mineralization in Gutu Area, Minna. *Nigerian Journal of Geoscience*, 2021; 8(1): 45–53.

[5] Farag A, Harper DD, Brumbaugh WG. Occupational Health Implications of Heavy Metal Exposure in Artisanal Mining. *Toxicology and Industrial Health*, 2015; 31(12): 1091–1099.

[6] Agboola A, Hassan MO, Olayemi J. Health Hazards of Gold Mining Activities in Nigeria. *International Journal of Occupational and Environmental Medicine*, 2020; 11(2): 81–90.

[7] Busobozi P. Heavy Metal Concentration in Mining Soils of Kigezi Region, Uganda. *Journal of African Environmental Studies*, 2018; 12(2): 123–134.

[8] Cances B, Ponthieu M, Castrec-Rouelle M, Aubry E, Benedetti MF. Metal ions speciation in a soil and its solution:

Experimental data and model results. *Geoderma*, 2003; 113(3–4): 341–355.

[9] Chishti KA, Khan FA, Hussain J, et al. Estimation of heavy metals in seeds of *Silybum marianum* grown in Pakistan. *Journal of Basic and Applied Science*, 2011; 7(1): 45–49.

[10] Scragg A. Environmental Biotechnology. 2nd ed. *Oxford University Press*, 2006.

[11] Kumar B, Smita M, Singh S, et al. Mechanism of zinc absorption in plants. *Reviews in Environmental Science and Bio/Technology*, 2016; 15: 89–109.

[12] Singh A, Prasad SM, Tripathi RD. Heavy metal stress and phytoremediation strategies: An overview. *Environmental Reviews*, 2014; 22(1): 1–10.

[13] Ogundele DT, Adio AA, Oladele E. Heavy metals concentrations in plants and soil along heavy traffic roads in North Central Nigeria. *Journal of Environmental Chemistry and Ecotoxicology*, 2015; 7(7): 63–70.

[14] WHO/FAO. Codex Alimentarius Commission: Food Additives and Contaminants. *Joint FAO/WHO Food Standards Programme*, 2001; Rome.

[15] Adefemi SO, Asaolu SS, Olaofe O. Assessment of the physico-chemical status of water samples from major dams in Ekiti State, Nigeria. *Pakistan Journal of Nutrition*, 2007; 6(6): 657–659.

[16] Onianwa PC. Monitoring heavy metal levels in fruits and vegetables in Nigeria. *Environmental Monitoring and Assessment*, 2001; 69(2): 223–228.

[17] Iwegbue CMA, Nwajei GE, Iyoha EH. Metal contamination of soil and dust in Delta State, Nigeria. *Environmental Research Journal*, 2007; 1(1–4): 1–6.

[18] Adejumo AA, Ola YA, Ogunyemi KA. Levels of lead in soils of urban and sub-urban areas of Ibadan, Nigeria. *International Journal of Physical Sciences*, 2011; 6(31): 7203–7207.

[19] Nwuche CO, Ugoji EO. Effects of heavy metal pollution on soil microbial activity. *International Journal of Environmental Science & Technology*, 2008; 5(3): 409–414.

[20] Bloemen HJ. Human exposure to metals and associated health risks. *Toxicological Profile Reports*, 1995; 7: 105–117.

[21] Mana CB, Biaye EA, Takoudjou PM, et al. Ecological risk assessment in soils of Eastern Cameroon. *Earth*, 2022; 3(3): 907–924.

[22] European Public Health Alliance (EPHA). Heavy Metal Toxicity and Public Health Concerns. *EPHA Report*, 2009; Brussels, Belgium.

[23] Binggan W. Ecological Risk Assessment of Heavy Metals in Soil. *Environmental Monitoring and Assessment*, 2010; 169(1–4): 407–417.

[24] Mana CB, Biaye EA, Takoudjou PM, et al. Ecological risk assessment in soils of Eastern Cameroon. *Earth*, 2022; 3(3): 907–924.

[25] Ugwumba E. Evaluation of Geoaccumulation Index of Metals in Soil. *Nigerian Journal of Environmental Science*, 2015; 10(4): 101–110.

[26] Müller G. Schwermetalle in den Sedimenten des Rheins—Veränderungen seit 1971. *UWSF-Z Umweltchem Ökotox*, 1975; 7(3): 133–149.