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Health Risk Assessment of Heavy Metals in Soil where Medicinal Plants are grown on abandoned mine site in Fefur of Jos East LGA, Plateau State.

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Abstract

Heavy metal accumulation and biomagnification in abandoned mining environments pose significant environmental and public health concerns, particularly where contaminated soils support the growth of medicinal and edible plants. This study assessed the concentration, spatial distribution, and potential health risks associated with heavy metal contamination in abandoned tin-mining soils from Fefur, Jos East Local Government Area, Plateau State, Nigeria. Soil samples were analyzed for seven heavy metals: Manganese (Mn), Copper (Cu), Lead (Pb), Iron (Fe), Cadmium (Cd), Zinc (Zn), and Nickel (Ni), using Inductively Coupled Plasma Mass Spectrometry (ICP–MS). The potential non-carcinogenic health risks associated with the consumption of traditional medicinal plants cultivated in the area were evaluated for adults and children using Target Hazard Quotients (HQs). The results revealed elevated concentrations of heavy metals in the mine soils, with mean levels of Mn, Cu, Zn, Fe, Ni, and Pb exceeding established maximum permissible limits. Notably, Ni and Pb concentrations were substantially higher than the guideline values recommended by the World Health Organization (WHO), indicating significant contamination arising from historical mining activities. Elevated Cu concentrations further confirmed the persistence of mining-derived pollutants within the soil environment. Geographic Information Systems (GIS)-based interpolation maps showed pronounced hotspots of Pb, Ni, and Cu around abandoned mine pits and tailings, highlighting strong anthropogenic influence. Moderate concentrations extending into nearby farmlands suggest contaminant dispersion through erosion and surface runoff. Although the calculated HQ values for individual metals were below the critical threshold of one (HQ < 1), indicating a low likelihood of immediate non-carcinogenic effects, prolonged exposure through continuous ingestion of contaminated plants may result in metal bioaccumulation and potential carcinogenic risks. Continuous environmental monitoring and remediation measures are therefore recommended to safeguard ecosystem and human health.

Keywords

Heavy metals,
concentration,
soil,
medicinal plants,
growing,
Bioaccumulation, environmental
Pollution.

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INTRODUCTION

Medicinal plants have been considered as medicine by human beings since ancient times. The knowledge of herbal medicine has been accumulated for millennia by traditional healers and has been passed down from generation to generation (Claro *et al.,* 2023). According to the World Health Organization (WHO) about 80% of the populations in developing countries use herbal medicine to meet their primary healthcare requirements (Tugume and Nyakoojo, 2019). However, the safety of these plants is increasingly threatened by environmental pollution, particularly by the heavy metal contamination. (Tarek *et al.,* 2021).

Heavy metals are non-biodegradable, thus, persist in the environment and have the ability to be deposited in various body organs which poses a great threat to the human health. Heavy metals released from these sites can contaminate soils and be absorbed by medicinal plants, posing significant health risks to local populations.

Heavy metals also referred to as a group of comparatively dense and harmful elements, even in very low concentrations. This group comprises of metals and metalloids, which possess densities higher than 5 g cm-3 and atomic masses varying from roughly 60 to 200. Arsenic (As), chromium (Cr), cadmium (Cd) and copper (Cu) are a few instances of heavy metals. Heavy metals are non-biodegradable elements compared to other pollutants and are typically classified into two categories. Poisonous metals like As and Pb make up the first category, which are entirely unfavorable substances, with no biochemical advantages to human beings, and are hazardous regardless of their levels (Jadaa and Mohammed, 2023).

Over the past several decades, industrial activities in the mining and smelting sectors have caused serious environmental pollution by heavy metals on a global scale, and increase the concentrations of heavy metals in the air, soil, or water threatens human health both directly and indirectly via accumulation in the food chain. In countries with high ecological awareness, the risk of acute exposure has been minimized thanks to the enforcement of restoration laws and policies. The risk of chronic effects, however, is still there (Yadav & Sharma, 2019). Soil contamination with heavy metals is a serious global environmental problem posing risks to humans, animals, microbes, and plants and contaminating surface and Hazard quotient.

Biological organisms are incapable to degrade metals because of their non-biodegradable nature and long half-life, and they persist in their body parts and environment leading to health hazards. Heavy metals have the capability to move from contaminated soil and water and hence bio-accumulate in plants causing health risks (Khan *et al.,* 2015). Therefore, the safety of these medicinal plants and herbal preparations that are being used more often in the treatment of diseases all over the world have been increasingly threaten by environmental pollution, particularly heavy metal contamination. (Ndhlala *et al.,* 2013; Ekor, 2014)

In order to achieve one of the Sustainable Development Goal (SDG) target 3.4 which is to ensure by the year 2030, every nation can be able to decrease the rate of premature mortality from non-communicable diseases (NCDs) by one-third through prevention, treatment, and promotion of mental health and well-being. Based on 2019 estimate of global mortality data, around three-quarters of the 20.4 premature deaths among individuals between ages 30-70 years is associated to NCD (WHO 2020). Heavy metals in herbal medicines and spices especially if cultivated or collected in contaminated areas needs to be assessed to ensure they do not exceed safety limits.

Accumulation of heavy metals in plants (i.e. phytoextraction) has been well investigated under laboratory conditions. However, it is also important to determine metal levels in plant and the soil in which these plants grow to ensure the safety, efficacy and quality of medicinal plants consumed by the people (Vuyolwethu *et al.*, 2018). It is also necessary to assess the health risks of exposure to toxic heavy metals through the consumption of medicinal plants (Harmanescu, Alda, Bordean, Gogoasa, & Gergen, 2011). The overarching goal of this research is to determine the concentration of heavy metals (Pb, Cd, Cr, Zn, Ni, etc.) in selected medicinal plants and soils, evaluate the bioaccumulation of heavy metals in medicinal plants and to analyse the health risks of exposure to toxic heavy metals through the consumption of medicinal plants and spatial distribution of heavy metal contamination in soil using GIS techniques. Most existing studies focus on laboratory analysis of heavy metals but lack spatial analysis that shows the distribution and variation of contamination across locations).

Materials and Methods

Geographical location and study area

The samples are collected from sites of abandoned mining area around Fefur in Maigemu district in Jos East local government of Plateau State Nigeria. This region was host to active tin mining activities in the 1970s with productive mines now abandoned. The settlement lies approximately at latitude 9.93°N and longitude 9.18°E and falls within the Jos Plateau region. While no official population data are available specifically for Fefur, Jos East LGA had a population of 88,301 according to the 2006 National Population Census, with a projected population of about 129,900 in 2022. Figure 1 illustrates geographical locations of study area.

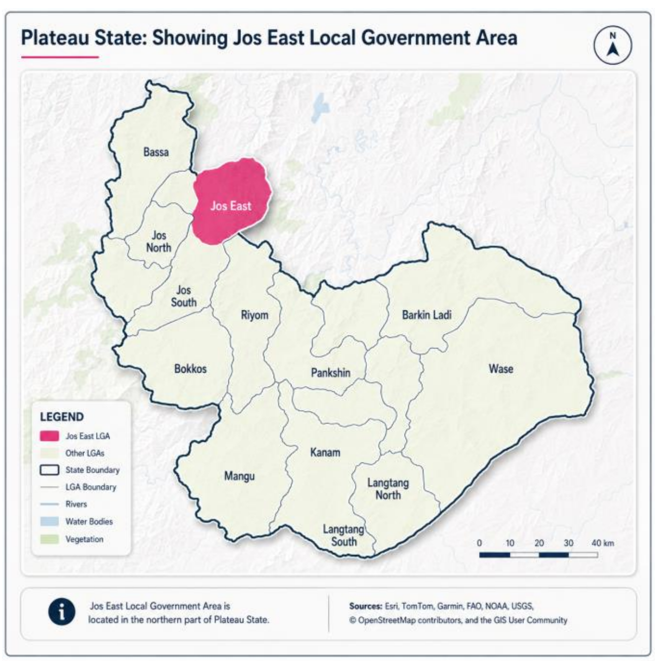

Figure 1 Map of Plateau State showing Jos East LGA

SAMPLE COLLECTION AND PREPARATION

The collection and preparation of the various study samples for analysis were carried out based on the standard methods recommended by US EPA (1996) followed by sample digestion.

Soil Samples

Soil samples were collected during the dry season from the abandoned mines located in the study area. The collected soil samples were stored in polythene bags and transported to the laboratory. All the coordinates of the sample sites were recorded using a global positioning system (GPS). The samples were air-dried at an average temperature of 25 °C for 2 weeks to remove excess moisture. Large soil clods were crushed to facilitate drying. The dried soil samples were pulverized and then stored in desiccators pending digestion and heavy metals determination.

Sample digestion

Digestion of the Soil Samples

A CEM Mars Xpress (40 closed PFA vessels) microwave oven (Matthews, NC, USA) was used for the digestion of soil samples. A triplicate of approximately 0.25 ± 0.005 g pulverized soil samples and certified reference material were weighted directly into the PTFE-TFM vessels, to which a mixture of 7.5 mL 65% HNO_3(aq) and 2.5 mL 37%HCl (aq) was added and the vessels closed immediately and transferred into the microwave.

The digestion procedure was performed using the following heating programmed: a ramp to 90 °C for 10 min then hold at 90 °C for 5 min, a ramp to 170 °C for 10 min, hold at 170 °C for 10 min and a cooling time of 30 min. The power applied was 1200W. After cooling the vessels to room temperature, the Teflon vessels were vented and opened. The clear solutions obtained were quantitatively transferred to 50 cm^3 volumetric flasks and the Teflon vessels rinsed 2-3 times with de-ionised water to dilute any possible colloids attached to the walls of the vessel and then diluted to 50 mL with de-ionized water.

MEASUREMENT OF HEAVY METALS

The heavy metals in the digested samples were determined according to the manual of each instrument. The concentrations of the target heavy metals in soil samples were determined using Perkin Elmer ELAN 9000 Inductively Coupled Plasma Mass Spectrometry (ICP- MS), while the target heavy metals in plant samples were determined using NexION 300 Inductively Coupled Plasma Mass Spectrometry (ICP- MS).

QUALITY ASSURANCE AND QUALITY CONTROL

Appropriate quality assurance procedures and precautions were carried out to ensure the reliability of the results. Deionized water was used throughout the study. Glassware was properly cleaned, and the reagents used were of analytical grade. Reagents blank determinations were used to correct the instrument readings. For validation of the analytical procedure, various samples were analyzed with Certified Reference Material (CRM). STD V16, V16, STD CDV-1 are plant-based CRMs, whereas OREAS45EA is a soil-based CRM, all were obtained from Acme Laboratories, Vancouver, Canada.

BIOACCUMULATION FACTOR

Bioaccumulation factor (BAF) is defined as the ratio of total metal concentration in plant species to that in soil, which is a measure of the ability of plant uptake and transport of metals to the shoots.

$$BAF = \frac{\text{Concentration of metal in plant part}}{\text{Concentration of metal in soil}}$$

Bioaccumulation was used to quantify the metal concentrations in both plant parts relative to the concentrations of the metals in the mining soil.

Human Health Risk Assessment

Human health risk assessment is a process used to estimate the health effects that might result from exposure to non-carcinogenic and carcinogenic chemicals (Kamunda et al., 2016). In this study, human health risk upon ingestion, dermal absorption and inhalation of contaminated soil as well as ingestion of medicinal plants grown on abandoned tin mine soil was calculated as per the model developed by USEPA and the values used for specific variables were adapted for Nigerian population statistics (Khan et al. 2013,).

Estimated daily intake of heavy metals

To appraise the health risk associated with heavy metal contamination in the studied samples, the estimated daily intake (EDI) (mg/kg/day) via ingestion, dermal absorption and inhalation for contaminated soil and ingestion of medicinal plants grown on abandoned mine soil was estimated separately based on daily dose for each heavy metal using the following formula:

$$EDI_{Soil}\ \text{ingestion} = \frac{C \times IR \times ED \times EF}{BW \times AT} \quad (2)$$

$$EDI_{Soil}\ \text{inhalation} = \frac{C \times InhR \times ED \times EF}{PEF \times BW \times AT} \quad (3)$$

$$EDI_{Soil}\ \text{dermal} = \frac{C \times SA \times AF \times ABS \times EF \times ED \times CF}{BW \times AT} \quad (4)$$

$$EDI_{Water}\ \text{ingestion} = \frac{C \times IR \times ED \times EF}{BW \times AT} \quad (5)$$

$$EDI_{Medicinal\ plants}\ \text{ingestion} = \frac{C \times IR \times ED \times EF}{BW \times AT} \quad (6)$$

Where C is the concentration of heavy metal in the samples while the other terms in the equations and the values of the parameters used to calculate EDI for the different exposure pathways for soil and for the ingestion of medicinal plants during a specified period are summarized in Appendix 1. The IR for the estimated daily consumption of soil for adults and children was estimated to be 0.345 kg person^{-1} day^{-1} and 0.173 kg person^{-1} day^{-1} respectively (Ref) whereas the IR for the estimated daily consumption of tubers for adults and children was considered to be 0.418 kg person^{-1} day^{-1} and 0.209 kg person^{-1} day^{-1} respectively (Wang *et al.*, 2013).

Hazard Quotient (HQ)

The non-carcinogenic health risk associated with heavy metals exposure through the ingestion of medicinal plants was evaluated for each heavy metal determined in this study using the hazard quotient (HQ) which was obtained by dividing the EDI of each heavy metal via the oral exposure route to its corresponding reference exposure dose (R_fD) (USEPA 1989; Kumar *et al.*, 2019) using the formula:

$$HQ = \frac{EDI}{R_fD}$$

The RfD values are the United States Environmental Protection Agency's (USEPA's) maximum permissible oral dose for a specified heavy metal. The values of RfD for Cd, Ni, Cr and Pb were 0.001, 0.02, 1.5 and 0.0035 mg kg^{-1} per day respectively taken from Integrated Risk Information System (US EPA, 2010). If HQ is less than 1, there is no obvious risk from the heavy metal over a lifetime exposure, but if HQ is greater than 1, the heavy metal may produce an adverse effect over a lifetime exposure. The higher the HQ value, the higher the probability of experiencing long term carcinogenic effects (Song et al. 2009). (Cu, Cr, Fe, Mn, Ni, Zn, Cd and Pb are 4.0×10^{-2}, 3.0×10^{-3}, 7.0×10^{-1}, $1.4.0 \times 10^{-1}$, 2.0×10^{-2}, 3.0×10^{-1}, 5.0×10^{-4}, and 3.5×10^{-3}respectively) USEPA, 2015; Kamunda et al., 2016; (Khan et al. 2013).

Hazard Index

To evaluate the potential risk to human health through more than one heavy metal in the medicinal plant samples, the hazard index (HI) has been developed (US EPA, 2000). It is the sum of the hazard quotients for all the individual heavy metals determined and it was calculated to assess the adverse effect from a mixture of heavy metals in the medicinal plants as follows (Li et al. 2015):

$$HI = \sum HQ = HQ_{As} + HQ_{Cd} + HQ_{Cu} + HQ_{Hg} + HQ_{Mn} + HQ_{Ni} + HQ_{Pb} + HQ_{Zn}$$

HI < 1 indicate that chronic risks are unlikely, whereas HIs > 1 indicate that noncancerous risks are likely to occur.

RESULTS

Results of the Certified Soil (Std Dsii) and Plants (Std Cdv-I) Reference Material Used in this Study

The results of the certified reference materials and their percentage recoveries used for validation of the analytical procedure are presented in table 1. The majority of the recoveries of heavy metals were above 80% individually, implying that the analytical method is appropriate for use. In the soil samples taken from the abandoned mined region where the medicinal plants used by residents of Fefur village community are obtained, lead had the highest percentage recovery (104.13%) and Zinc had the lowest percentage recovery (95.19%). Cadmium on the other hand, had the highest percentage recovery of (100%) in medicinal plants with Zinc having the lowest recovery (80.26%).

Table 1 Comparison between the present study and the certified reference materials of soil and plants (mg/kg)

Heavy Metal	CRM for soil (STD DS11)			CRM for plant (STD CDV-1)		
	Measured value in this study mg/kg	Certified value mg/kg	% Recovery	Measure value in this study mg/kg	Certified value mg/kg	% Recovery
Cu	144.31	149.00	96.64	7.33	8.61	85.13
Fe	3.20	3.10	103.23	0.242	0.256	94.53
Mn	1037.00	1055.00	98.29	370	385	96.1
Ni	77.90	77.70	100.26	5.40	6.4	84.38
Zn	328.40	345.00	95.19	18.70	23.3	80.26
Cd	2.33	2.37	98.31	0.04	0.04	100

Heavy metals concentration in soil and medicinal plants samples.

The results of the analysis of heavy metals concentrations in the soil samples for abandoned-mining area and the soil where medicinal plants where growing were summarized in Table 2 and Table 3 respectively. Table 2 showed that all heavy metals were detected in soil in the vicinity of the abandoned mining area. There was variation in the concentration of heavy metals among the soil samples with Mn having the highest mean concentration (295.25±117.33 mgkg¬^{1}) while Cd had the lowest mean concentration (0.03±0.00 mgkg¬^{1}).

However, the mean concentration of heavy metals analyzed in the abandoned mine soil were in decreasing order of Mn>Zn>Pb>Cu>Ni>Fe>Cd. With the exception of Fe, the mean concentration of Mn, Zn, Pb, Cu, Ni, and Cd were significantly ($p<0.05$) higher than that of the WHO maximum permissible limit established for heavy metals in soil. Table 3 showed the mean concentration of heavy metals in soil where medicinal plants, black currant and giant milk weed were growing.

With the exception of Cd, the mean heavy metal concentration in soil site where giant milk weed was growing is significantly higher when compared to the soil site where the medicinal plant, black currant was growing. However, the mean concentration of heavy metals in the soil upon which black currant is growing showed a decreased order of Mn>Zn>Pb>Cu>Ni>Fe>Cd while that of a giant milk weed decreased in the order Mn>Cu>Pb>Zn>Ni>Fe>Cd. In both soils where the two medicinal plants were growing Mn had the highest mean concentration and Cd had the lowest mean concentration. Like in the abandoned mine soil, with the exception of Fe, the mean concentration of Mn, Zn, Pb, Cu, Ni, and Cd in soil samples where the medicinal plants were growing were significantly ($p < 0.05$) higher than that of their corresponding WHO maximum permissible limit established for heavy metals in soil.

Table 2: Heavy metals concentrations in the soil samples in the vicinity of abandoned Mining area in Fefur Jos East LGA Plateau State, Nigeria

	Elements						
Sample	Cu	Fe	Mn	Ni	Zn	Cd	Pb
SS1	6.54	0.85	71.00	5.70	11.90	0.03	9.04
SS2	10.19	1.49	94.00	10.60	20.60	0.04	11.09
SS3	10.37	1.54	69.00	9.40	18.50	<0.01	11.93
SS4	10.37	1.54	69.00	9.40	18.50	<0.01	11.93
SS5	10.81	1.55	76.00	9.90	19.10	<0.01	11.99
SS6	31.65	3.76	391.00	22.80	32.50	0.03	22.98
SS7	37.65	3.94	874.00	29.50	30.70	0.02	45.68
SS8	38.61	4.20	726.00	29.30	33.50	0.02	38.13
Mean	19.52	2.36	296.25	15.83	23.16	0.03	20.35
SD	13.83	1.37	331.86	9.75	7.97	0.01	14.09
SEM	4.89	0.48	117.33	3.45	2.82	0.00	4.98
Median	10.59	1.55	85.00	10.25	19.85	0.03	11.96
Min	6.54	0.85	69.00	5.70	11.90	0.02	9.04
Max	38.61	4.20	874.00	29.50	33.50	0.04	45.68

Table 3 Mean concentration of heavy metals in soil where each medicinal plant was collected

Heavy metal	Soil on which Black currant is grown	Soil on which Giant milk weed Is grown	WHO MPL
Cu	9.03±2.16	35.97±3.77	4.60
Fe	1.29±0.39	3.97±0.22	20
Mn	78.00±13.89	663.67±247.46	313
Ni	8.57±2.55	27.20±3.81	6.20
Zn	17.00±4.54	32.23±1.42	5.00
Cd	0.04±0.01	0.02±0.01	0.09
Pb	10.69±1.49	35.60±11.56	10.0

DISCUSSION

Heavy metals distribution and occurrence in the soil depends on degree of weathering and mobility of these elements (Kulhari, et al., 2013). Soil is continuously being polluted with chemicals and heavy metals due to dynamic development of mining activity, industries etc. In turn, these pollutants and heavy metals are getting deposited in the plants growing in the polluted areas, which subsequently enter the human food chain via plant parts and/or extracts. Mean concentration results of analysis of seven heavy metals (Mn, Cu, Pb, Fe, Cd, Zn and Ni) done in leaves samples of two medicinal plant species are seen summarized in Tables 2, 3 and 4 respectively.

The descriptive statistics of the concentrations of Cu, Fe, Mn, Ni, Zn and Cd, in soil samples from mining vicinity presented in Table 2. The distribution pattern of the average concentrations of the heavy metals studied showed that Cu, Ni, Pb, and Zn, that is 19.52, 15.83, 23.16, and 20.35 are higher than the maximum permissible limit set by WHO which are: 4.6, 6.20,10 and 20.00. There is also variation seen in the results from the mean values obtained from the results of selected heavy metals in soil samples found around the area where the two medicinal plants were grown.

The results showed that Cu has 9.03 which is higher than 4.6 WHO maximum permissible limit concentration for soil. Bumhan *et al.*,2022, noted in his work that Zn and Cu are toxic to plants before they accumulate in sufficient concentration to affect animals or human. Copper is released into the environment primarily through mining, sewage treatment plant, and solid waste, welding and electrical processes. Although Cu is essential for the growth and development of plants, but at high concentration it becomes toxic and chronic exposure to copper can produce numerous physiological and behavioral disturbances. The concentration of Ni and Pb were significantly high than the permissible guidelines set by the WHO, same was also observed in a research results presented in previous studies by Khan et al., (2007) demonstrate that the plants grown on wastewater-irrigated soils contaminated with heavy metals, and pose a major health concern. All food crops studied were contaminated with Cd, Pb and Ni, partially and/or totally exceeded the permissible limits set by SEPA and WHO.

Table 3 Analysis in the soil samples collected where the medicinal plants in the abandon mine showed great variation from the values set as by WHO. Cu form the results are two times higher in the soil where black currants are grown and seven times higher in area where giant milk weed is grown than the WHO maximum permissible limit. Mn and Zn which are essential elements required by plants in moderate amount were also 2 and 4 times high maximum permissible limit for soil set by WHO as 313 and 27.4 ppm respectively. This can be bio-accumulated in plants hence affects the animals and the entire food chain since they consume the plants.

Also, Ni and Pb were also 4 times higher than the maximum permissible set by the WHO. High concentrations of Pb and Ni have high carcinogenic potential and health risks, that is, it causes the disruption of glucose utilization and initiation of apoptosis and so many other side effects in the human system. The results in this study are in agreement with the reports of Ssempijja *et al.*, 2020. Cd and Fe were found to be within the permissible limit. In medicinal plant leaves these heavy metals from the mining vicinity were detected and the results were summarized in table 4 and showed variation also, where Cu, is 2 times higher in black currant and higher also in giant milk weed, likewise Mn is 88 and 49 times higher than the recommended concentration set by WHO while Zn is also 2 and 4 times higher than WHO maximum permissible limit.

Although Mn, Zn and Cu are essential elements required both by plants and animals but they can also become toxic when in higher concentration. Example Manganese (Mn) known as an essential trace element which acts as cofactor for many enzymes. It is less toxic than any other metal, however, can cause neurological\ disorders if its concentration exceeds 5mg/m3 due to continuous exposure to manganese. Reports by Kulhari et al., (2013) also agree with this study where these essential.

Spatial Interpolation of Heavy Metals.

The interpolation process is done separately for each heavy metal (Pb, Ni and Cu), resulting in individual spatial distribution maps displayed in the following figures below

Figure 3 showing interpolation map of Nickel.

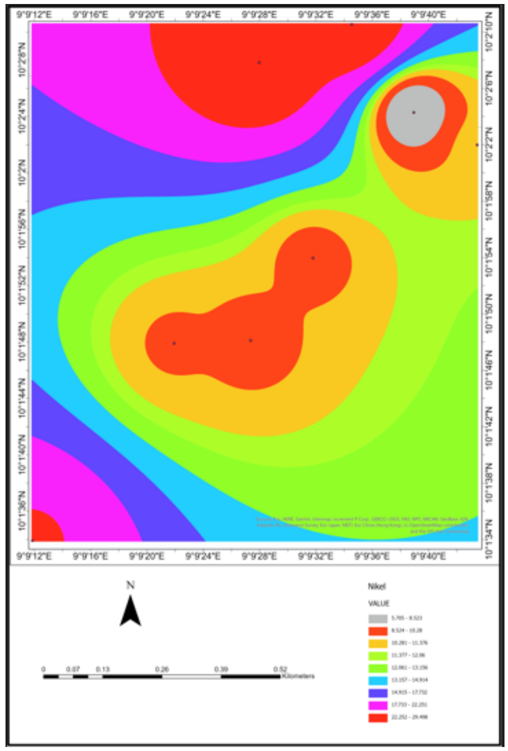

Figure 2 showing interpolation map of Lead.

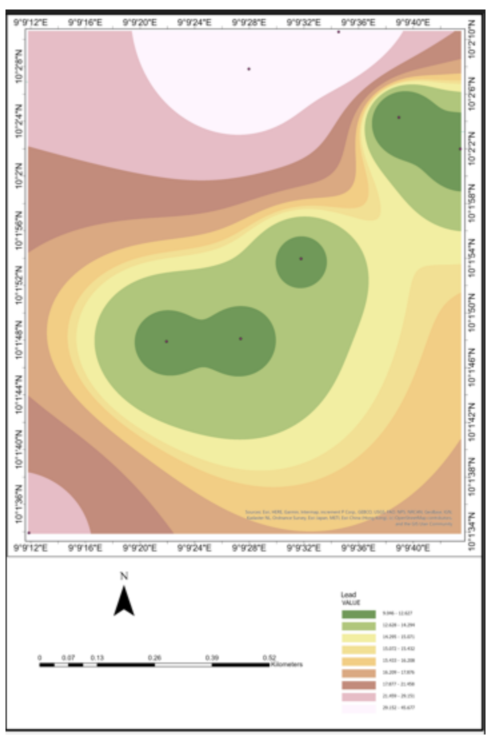

Figure 3 showing interpolation map of copper

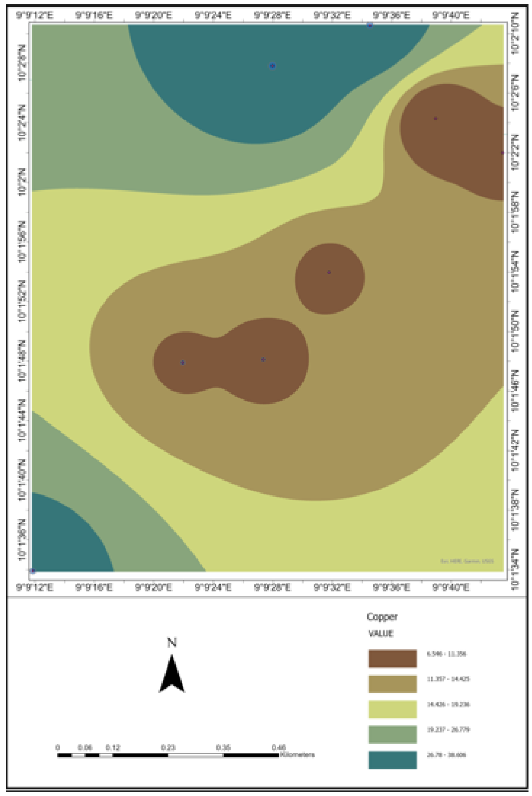

Figure 4 showing interpolation map of copper

Spatial Distribution of Lead (Pb), Nickel (Ni) and Copper (Cu) expressed in interpolation map and its Interpretation.

Spatial interpolation of heavy metals (Lead—Pb, Copper—Cu, and Nickel-Ni) in soil samples collected from the abandoned mine site in Fefur, Jos East. The results are presented using spatial distribution maps generated through Geographic Information Systems (GIS). High Pb,Ni, Cu concentrations are observed around mine tailings and abandoned pits, indicating strong anthropogenic influence. Moderate concentrations extend into nearby farmlands, suggesting dispersion through erosion and runoff. Low concentrations are found in areas farther from mining activity. The relatively uniform spread suggests that Cu may have been redistributed through environmental processes such as surface runoff and soil mixing. Although Cu levels are not as alarming as Pb, continuous accumulation could still pose ecological risks.

Environmental Implications

The spatial distribution of heavy metals indicates that the abandoned mine site is a significant source of environmental contamination. Soil contamination may reduce agricultural productivity Heavy metals can leach into groundwater systems Ecosystems in the area may be adversely affected. The integration of laboratory analysis and GIS-based interpolation provides a comprehensive understanding of contamination patterns and the results helps highlight the need for environmental monitoring, remediation strategies, and public health interventions in the study area.

CONCLUSION

This study demonstrates that abandoned tin-mining activities in Fefur, Jos East LGA, have contributed to elevated concentrations of heavy metals in both soils and medicinal plants growing within the area. ICP–MS analyses confirmed the presence of Mn, Zn, Pb, Cu, Ni, Fe, and Cd in all sampled media, with several metals exceeding the maximum permissible limits established by the World Health Organization (WHO, 2007). The occurrence of elevated metal concentrations in medicinal plants indicates active uptake from contaminated soils and subsequent transfer into plant tissues.

The average concentration pattern of heavy metals followed the order Mn > Zn > Pb > Cu > Ni > Fe > Cd in plant samples and Mn > Zn > Cu > Ni > Pb > Cd > Fe in soil samples, highlighting manganese and zinc as the dominant contaminants. Correlation analysis revealed significant positive relationships among several metals, particularly Mn, Fe, Zn, Pb, and Cu, suggesting a common source of contamination and evidence of metal bioaccumulation within the soil–plant system. In contrast, cadmium exhibited predominantly negative correlations with other metals, indicating a distinct geochemical behaviour and mobility pattern.

Although the calculated Hazard Quotients (HQs) and Hazard Index (HI) values were below the critical threshold of 1, indicating no immediate non-carcinogenic risk, the elevated concentrations recorded above WHO permissible limits raise concerns regarding long-term exposure. Continuous consumption of medicinal plants harvested from the contaminated area may result in gradual bioaccumulation of toxic metals in the human body, potentially leading to adverse health effects over time. Therefore, medicinal plants sourced from the abandoned mining environment should be used with caution, and continuous monitoring of environmental quality is strongly recommended.

SUMMARY OF FINDINGS

i. ICP–MS analysis confirmed the presence of Mn, Cu, Pb, Fe, Cd, Zn, and Ni in both soil and medicinal plant samples collected from the abandoned mine site. Several metals exceeded WHO permissible limits, indicating significant environmental contamination.

ii. Significant positive correlations were observed between heavy metal concentrations in soils and medicinal plant leaves, demonstrating the transfer and bioaccumulation of metals from soil into plant tissues.

iii. Health risk assessment revealed that the Hazard Quotient (HQ) and Hazard Index (HI) values for all investigated metals were below unity (HI < 1), suggesting a low immediate non-carcinogenic risk. However, prolonged exposure through continuous consumption may pose chronic health risks due to cumulative metal accumulation.

iv. GIS-based spatial distribution analysis showed that Pb, Ni, and Cu concentrations were highest around abandoned mine pits and tailings, reflecting strong anthropogenic influence from past mining activities. Moderate contamination levels extended into surrounding agricultural lands, indicating contaminant dispersion through erosion, runoff, and surface transport processes.

v. The contamination patterns observed confirm that abandoned mining sites act as persistent sources of heavy metal pollution, thereby posing potential ecological and public health concerns.

RECOMMENDATIONS

i. Regulatory agencies should strengthen the monitoring and enforcement of safety standards for herbal products through mandatory pre-marketing screening for heavy metal contamination.

ii. Immediate remediation of contaminated soils should be undertaken using appropriate techniques such as phytoremediation, soil stabilization, and replacement of highly contaminated soils, particularly in areas exhibiting elevated lead concentrations.

iii. Mine tailings and abandoned excavation pits should be properly contained and rehabilitated to minimize further dispersion of contaminants into adjacent farmlands and water bodies.

iv. Routine environmental monitoring programmes should be established to track temporal changes in heavy metal concentrations within soils, vegetation, and groundwater resources in mining-impacted communities.

v. Government and environmental protection agencies should implement long-term environmental surveillance systems and enforce land-use restrictions in highly contaminated zones to reduce human exposure and protect agricultural productivity.

vi. Public awareness campaigns should be conducted to educate local communities on the potential health risks associated with harvesting and consuming medicinal plants from contaminated mining environments.

REFERENCES

Harmanescu, M., Alda, L. M., Bordean, D. M., Gogoasa, I., & Gergen, I. (2011). Heavy metals health risk assessment for population via consumption of vegetables grown in old mining area; a case study: Banat County, Romania. *Chemistry Central Journal*, *5*(1).

Jamshidi-Kia FatemehZ , Lorigooini Zahra, , Amini-Khoei Hossein (2017) Medicinal plants: Past history and future perspective. Medical Plants Research Center, Basic Health Sciences Institute, Shahrekord University of Medical Sciences, Shahrekord, Iran

Jadaa1 Waleed and Mohammed Hamad (2023) Heavy Metals – Definition, Natural and Anthropogenic Sources of Releasing into Ecosystems, Toxicity, and Removal Methods – An Overview Study Independent Researcher, 1004-120 Cherryhill Place, London, ON, N6H 4N9, Canada 2 Petroleum and Gas Refinery Engineering, College of Petroleum Process Engineering, Tikrit University, 34001, Iraq * Corresponding author's e-mail: wjadaa@outlook.com

Kamunda, C., M Mathuthu and Madhuku 2016 Potential human risk of dissolved heavy metals in gold mine waters of Gauteng province ,south Africa .

Khan, Anwarzeb., Sardar Káán, Mohammad Amjad Khan, Zahir Qamar Mohammad Warsas

(2015). *The uptake and bioaccumulation of heavy metals by food plants, their effects on plants nutrients and associated health risk, a review Enviromental Sciences and pollution research*

Khan, S. A., Khan, L., Hussain, I., Marwat, K. B., & Akhtar, N. (2008). Profile of Heavy Metals in Selected Medicinal Plants. *J. Weed Sci. Res*, *14*(12), 101–110.

Kulhari Alpana, Arun Sheorayan1, Somvir Bajar2, Susheel Sarkar3, Ashok Chaudhury1 and Rajwant K Kalia (2013) Investigation of heavy metals in frequently utilized medicinal plants collected from environmentally diverse locations of north western India.

Ndhalala A R, B Ncube ,Okom A , R B Mulaudzi , S Van St aden 2013 Toxicology of some important medicinal plant.

Nas Farouk and Muhammad Ali (2018) The effect of lead on plants in terms of growing and biochemical parameters: a review 1 MOJ Ecology & Environmental Sciences Research Volume 3 Issue 4 – 2018 Department of Biological Science, Bayero University Kano, Nigeria

Tugume Patience and Nyakoojo Clement (2019) Ethno-pharmacological survey of herbal remedies used in the treatmen Patience t of paediatric diseases in Buhunga parish, Rukungiri District, Uganda BMC Complementary and Alternative Medicine (2019) 19:353.

Ssempijja Fred, Keneth Iceland Kasozi , Ejike Daniel Eze , Andrew Tamale, Sylvia Anurika Ewuzie,Kevin Matama, Justine Ekou,Paul Bogere, Regan Mujinya, Grace Henry Musoke, Jovile Kasande Atusiimirwe , Gerald Zirintunda, Muhamudu Kalange , Joel Lyada, Ritah Kiconco, Theophilus Pius , Christopher Nandala, Roland Mugisha Kamugisha , Yunusu Hamira, Edgar Mario Fernandez,1 and Simon Peter Musinguzi(2020)Consumption of Raw Herbal Medicines Is Associated with Major Public Health Risks amongst UgandansJournal of Environmental and Public Health Volume 2020, Article ID 8516105, 10 pages https://doi.org/10.1155/2020/8516105s.

WHO Guidelines for assessing quality of herbal medicines with reference tocontaminants and residues. WHO Publishers: Geneva (2007).

World Health Organization (2020) Global health estimates: Leading causes of death, World Heal. Organan. leading-causes-ofdeath (acc

Yadav Gaurav, Sharma Neha, Goel Arti, Verma Arti, Kothari S L & Choudhary D K (2023) *Trichoderma* Mediated Metal Chalator and its Role in *solanum melongena* Growth Under Heavy Metals