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Comparative Analysis of Concentrations of Heavy Metals in Mining Sites and Community Soils, Jos Plateau State, Nigeria

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ABSTRACT
Mining plays a critical role in economic development, particularly in mineral-rich regions such as Jos and its environs in Nigeria. However, the unchecked expansion of both legal and illegal mining operations has raised growing concerns about environmental sustainability and public health. This study investigates the impacts of mining activities on soil and water quality in selected mining zones around Jos, and compares heavy metal contamination in soils from active mining sites and adjacent communities in Jos Plateau State, Nigeria. The research aimed to evaluate the spatial distribution and ecological risks posed by heavy metals, including cadmium (Cd), lead (Pb), selenium (Se), chromium (Cr), etc. Soil samples were collected from four mining sites (Wildlife Park, Rantiya, Rayfield, and Mista Ali) and nearby residential areas, and analyzed using Atomic Absorption Spectrophotometry (AAS). Results revealed severe contamination in mining sites with Cd (2.98 mg/kg mean), Pb (71.26 mg/kg), and Se (67.47 mg/kg) exceeding WHO permissible limits. Community soils showed lower but still concerning levels, indicating pollutant dispersion. Iron concentrations were notably high in Rantiya (982.20 mg/kg), suggesting leaching from mining waste. Statistical analysis confirmed significant differences ($p < 0.05$) between mining and community soils, with strong correlations between metal concentrations and proximity to mining activities. The findings highlight substantial ecological and public health risks, including potential bioaccumulation in crops and chronic exposure hazards. Immediate interventions are recommended. This study underscores the need for sustainable mining practices to mitigate long-term ecological degradation in the Jos Plateau region. In conclusion, effective remediation efforts and policy reforms are crucial to mitigate the harmful impacts of mining activities and to safeguard environmental and human health in the region.

Keywords:
Concentrations,
Heavy Metals,
Mining Sites,
Community Soils

INTRODUCTION

Mining plays crucial role in Nigeria's socio-economic development, particularly in regions like the Jos Plateau, which has a long history of tin and columbite extraction. For over a century, this region has been a hub of mining operations, providing livelihoods for many and contributing to the nation's industrial and infrastructural growth.

However, alongside its economic benefits, mining activities—especially those that are artisanal and poorly regulated have led to widespread environmental degradation, threatening both ecosystem integrity and public health (Omotehinse & Ako,2019). The environmental implications of mining are multifaceted and particularly concerning when it comes to the contamination of natural resources such as soil and water.

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Mining often involves the excavation and processing of ore, activities which release significant quantities of heavy metals and radionuclides into the surrounding environment. In regions where these operations are undertaken without adequate environmental safeguards, pollutants such as lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg) can persist in the soil and leach into surface and groundwater systems, posing serious ecological and human health risks (Adekiya *et al*., 2024; Isinkaye *et al*., 2025).

The Jos Plateau area now bears the scars of unregulated mining practices, which include thousands of abandoned mine ponds, radioactive mine tailings, and heavily contaminated soil and water systems. Communities within districts such as Barkin-Ladi, Mista Ali, and Rayfield are particularly vulnerable, having been situated near these abandoned mining fields. The persistence of heavy metals and naturally occurring radionuclides in the environment has led to long-term contamination that can severely impact soil fertility, reduce agricultural productivity, and threaten food and water safety (Lar *et al*., 2013; Isukuru *et al*., 2024).

Despite the growing body of literature on the environmental effects of mining, there remains a significant lack of localized data specific to the Jos region of Nigeria, where both legal and illegal mining operations are widespread. Previous studies have often generalized the impacts of mining across broader geographic areas without addressing site-specific variations in contamination levels, ecosystem vulnerability, or community exposure. Moreover, limited research has combined both soil and water quality assessments in the same study, especially in relation to heavy metal pollution and its potential risks to agriculture and public health. There is also a notable deficiency in studies that translate scientific findings into actionable policy recommendations tailored to the socio-economic and environmental context of mining communities in Nigeria. This study addresses these gaps by providing site-specific data, analyzing both soil and water parameters, and proposing context-relevant mitigation strategies.

Empirical studies have confirmed that heavy metal accumulation from mining activities significantly alters the physicochemical characteristics of soil and water, degrading their quality and usefulness. For instance, investigations in other Nigerian mining regions, such as Ilesha and Kebbi, have shown elevated levels of toxic metals that exceed permissible limits set by regulatory bodies, thereby highlighting the urgency of similar assessments in Jos and its environs (Joseph *et al*., 2024; Adekiya *et al*., 2024). These contaminants do not merely remain in situ—they often bioaccumulate in plants and animals and eventually find their way into human bodies through direct contact or via the food chain (Kyowe *et al*., 2024; Akinpelumi *et al*., 2023).

Mining also influences the structure and composition of surrounding ecosystems. Soil erosion, deforestation, and sedimentation of water bodies are common consequences, leading to altered hydrology and reduced biodiversity. Furthermore, the release of radioactive elements and polycyclic aromatic hydrocarbons from mining waste has intensified ecological stress in affected areas, with long-term implications for both environmental and public health (Dill, 2015; Akinpelumi *et al*., 2023).

In light of these challenges, this study seeks to critically assess the extent of soil and water contamination in selected mining areas around Jos, Plateau State. The focus was on delineating abandoned mining sites, collecting and analyzing soil and water samples from these locations, and evaluating the concentration of heavy metals and other toxic substances. The study also aims to interpret the implications of such contamination for human health, agricultural viability, and broader ecological stability.

By addressing these concerns, the research contributes to ongoing efforts to monitor environmental quality, mitigate public health risks, and inform sustainable mining policies in Nigeria. A better understanding of the spatial extent and severity of contamination in Jos can also aid in prioritizing remediation efforts and developing community-centered environmental management strategies.

MATERIALS AND METHODS

The Study Area

Jos, the capital city of Plateau State, is located in the North-Central region of Nigeria. It lies between latitudes 9°56′N and 10°15′N and longitudes 8°47′E and 9°00′E, covering an area of approximately 1,800 square kilometers (see figure 1). The study focuses on Jos North and South, located between latitudes 9^{0} 52’ 45.82’’N and longitudes 8^{0} 50’ 36.10’’E.The city is situated on the Jos Plateau, a region characterized by its undulating terrain, rocky outcrops, and extensive mineral deposits. At an elevation of about 1,200 meters above sea level, Jos enjoys a cooler climate compared to the surrounding lowland areas, with an average annual temperature of 22°C and distinct wet and dry seasons.

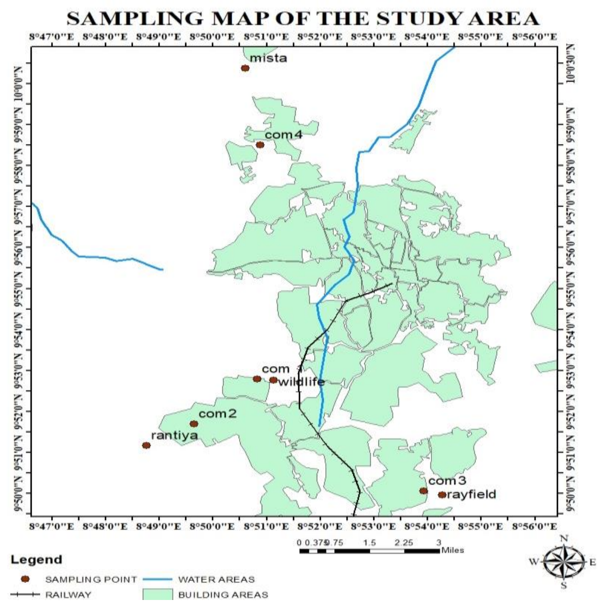

Figure 1: Map of the study area where samples were collected

Sample Collection

Soil samples were collected from both active mining zones and nearby residential areas in Rantiya, Rayfield, Wildlife, and Mista Ali to assess potential contamination disparities. Surface soils (0–15 cm depth) were collected using a sterilized stainless-steel auger, homogenized, and stored in pre-cleaned polyethylene bags to prevent cross contamination. Sampling locations were georeferenced using GPS coordinates, and field notes documented site-specific observations.

Sample Preparation

Collected soils were refrigerated at 4 °C during transport and storage to prevent microbial or chemical alteration. Prior to analysis, samples were air-dried, sieved through a 2-mm mesh, and digested using a 3:1 mixture of concentrated nitric acid (HNO_3) and perchloric acid ($HClO_4$). The sample digestion followed method the United States Environmental Protection Agency (USEPA) method 3050B as updated in the 2025 SW-846 compendium (USEPA, 2025), and corresponds with standard protocols such as NEMI Method 3030H for soil and sludge analysis (NEMI, n.d.). Studies comparing acid ratios confirm the 3:1 HNO_3:$HClO_4$ mixture yields effective recovery for metals such as Zn, Cu, and Cr in soil matrices (Detmann *et al.*,2015).

Heavy Metals Analysis

Digested samples were analysed for heavy metals such as (lead (Pb), cadmium (Cd), chromium (Cr), zinc (Zn), copper (Cu), and arsenic (As)) were analyzed using an Atomic Absorption Spectrophotometer (Buck Scientific Model 205) at the National Institute of Mining and Geology (NIMG), Jos. Quality control measures followed USEPA QA/QC guidelines and APHA (2017) standards, and included the use of certified reference materials (CRMs), procedural blanks, and triplicate analysis to ensure accuracy and precision (USEPA, 2002; APHA, 2017).

Soil pH and temperature were measured in situ using a multi-parameter analyser (GNST

-500), as these factors significantly influence the mobility and bioavailability of heavy metals in the soil environment (Kabata-Pendias& Mukherjee, 2007).Concentrations of heavy metals were interpreted against permissible limits from international and national regulatory bodies, including the World Health Organization (WHO, 2007), Food and Agriculture Organization (FAO, 2006), and Nigerian Environmental Standards and Regulations Enforcement Agency (NESREA, 2011), to assess potential ecological and human health risks.

RESULTS AND DISCUSSION

The results of this research were obtained from different samples collected from 8 different locations for soil samples respectively, as shown in Table (1)

Table 1: Sampling data sheet for the study area

S/N	Sample collection Points for both Soil	Mining Sites	Communities
1	Wildlife	9° 52' 45.82''N 8° 51' 7.75''E	9° 52' 47.58''N 8° 50' 49.63''E
2	Rantiya	9° 51' 10.73''N 8° 48' 45.69''E	9° 51' 42.30''N 8° 49' 38.84''E
3	Rayfield	9° 49' 57.55''N 8° 54' 16.38''E	9° 50' 3.68''N 8° 53' 55.62''E
4	Mista Ali	10° 0' 22.68''N 8° 50' 36.10''E	9° 58' 30.09''N 8° 50' 52.55''E

The analytical results obtained from soil samples collected from both mining sites and adjacent communities are presented in Tables 2 and 3. These measurements were conducted using the Atomic Absorption Spectrophotometer (Buck Scientific 205 model) to quantify heavy metal concentrations, while soil pH and temperature were determined using the high-precision GNST-500 multi-parameter analyzer. The acquired data were systematically compared against World Health Organization (WHO) permissible limits to evaluate the degree of heavy metal contamination and its potential environmental and public health impacts.

Table 2: pH and temperature for mining sites/ communities soil sample

Mining Sites	pH	Temperature
Wildlife	7.0	23°
Rantiya	7.1	21°
Rayfield	6.9	20°
Mista Ali	6.8	24°
Total	27.8	88°
Mean	6.95	22°
WHO Permissible	6.0 – 7.5	15^{0}C- 35^{0}
limit control	0.000	0.000

pH and temperature for communities soil sample

Community Sites	pH	Temperature
Wildlife	7.2	20°
Rantiya	7.4	25°
Rayfield	7.32	21°
Mista Ali	7.34	24°
Total	29.72	90°
Mean	7.31	22.5°
WHO Permissible unit	60° -7.5°	15° -35°
Control	0.000	0.000

Soil quality is a critical factor influencing agriculture, vegetation growth, and ecosystem sustainability. The pH and temperature of both mining site and community soils (Table 4) shows that the pH of mining site soils ranges from 6.8 to 7.1, with a mean value of 6.95, while the pH of community soils is slightly higher, ranging from 7.2 to 7.34 (mean: 7.315). Both values fall within the WHO permissible limit for soil (6.0 – 7.5), indicating that the soils are moderately neutral. The slight decrease in pH at mining sites suggests potential acidification due to mining activities, possibly from exposure to oxidized minerals or chemical residues from mining processes.This pattern aligns with findings from Shehu *et al.* (2023), who observed minimal alteration in soil pH at the Kataeregi mining site (6.08 to 8.12), suggesting that the degree of mining-induced acidification varies depending on geology and mining intensity. In contrast, the relatively higher pH in community soils suggests minimal mining-related alterations, indicating a more stable natural soil environment.

Soil temperature is essential for microbial activity, root development, and overall ecosystem balance. The temperature of mining site soils ranges from 20° to 24° with a mean of 22°, while community soil temperatures range from 20° to 25°, with a mean of 22.5°. These values fall within the WHO recommended range for soil temperature (15° – 30°). The slight increase in temperature in community soils could be attributed to reduced moisture retention, urbanization, and exposure to direct sunlight (Amusan *et al.*, 2005; Shehu *et al.*, 2023). In contrast, mining site soils may have lower temperatures due to mineral content variations, increased soil porosity, and water retention effects caused by excavation activities (Kabata-Pendias& Mukherjee, 2007). In terms of comparing analysis results for both study sites, mining site soils show a slightly lower pH than community soils, which may be attributed to metal leaching, acid mine drainage, or soil disturbance from mining activities. Thisobservation aligns with previous findings from mining regions in Nigeria, where mining activities have led to subtle but measurable decreases in soil pH, especially when sulfide-rich ores are exposed to air and water (Adelekan and Abegunde, 2011). The temperature differences between mining and community soils are not substantial, indicating that mining does not significantly impact soil thermal properties.

concentrations 2-5 times higher than the WHO permissible limit (0.8-1.5 mg/kg) aligning with findings from similar artisanal mining zones in Nigeria where cadmium accumulation has been linked to industrial discharge and ore oxidation (Adelekan and Abegunde, 2011).

Table 3: Heavy metal analysis result for mining site soil samples results

Mining Site	Cd mg/kg	As mg/kg	Pb mg/kg	Cr mg/kg	Se mg/kg	Cu mg/kg	Fe mg/kg	Ni mg/kg
Wildlife Park	2.1306	1.8000	82.400	1.0360	78.530	4.7945	98.615	9.8471
Rantiya	2.5568	1.2000	66.140	0.9411	65.530	0.8667	982.20	1.0071
Rayfield	4.2613	0.4000	61.250	0.4705	59.15	0.3656	123.70	1.0431
Mista Ali	2.9829	0.6000	75.254	1.5882	66.660	1.0000	124.56	4.9280
TOTAL	11.9316	4.000	285.044	4.0358	269.87	7.0268	1329.075	16.8253
MEAN	2.983	1.000	71.261	1.009	67.468	1.757	332.269	4.206
WHO PERMISSIBLE	0.8-1.5	10	85	100	0.5-2	36	98.62-123.7	35
CONTROL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 3 shows that the analysis of soil samples from active mining sites and adjacent communities in Jos Plateau State reveals significant heavy metal contamination, demonstrating clear environmental degradation from mining operations. Soil samples collected from Wildlife Park, Rantiya, Rayfield, and Mista Ali showed excessive concentrations of multiple toxic metals, with several exceeding World Health Organization (WHO) safety thresholds. Cadmium (Cd) contamination was particularly severe, with Rayfield (4.2613 mg/kg) and Rantiya (2.5568 mg/kg) showing Chronic exposure to Cd in such concentrations poses serious health risks including renal dysfunction, bone demineralization, and soil microbial toxicity (Jarup & Akesson, 2009). Lead (Pb) concentrations approached dangerous levels at Wildlife Park (82.4 mg/kg) and Mista Ali (75.254 mg/kg), nearing the WHO upper limit of 85 mg/kg and creating significant risks of neurological disorders, especially in children. The lead levels observed here mirror those documented in Zamfara State and Ilesha, where Pb poisoning events have had devastating consequences (Lo et al., 2012).The most alarming contamination involved selenium (Se), with Wildlife Park (78.530 mg/kg) and Mista Ali (66.660 mg/kg) showing concentrations 30-150 times above the WHO guideline (0.5-2 mg/kg). These extreme levels threaten local ecosystems through potential soil degradation and bioaccumulation in the food chain.Similar Se pollution has been reported in Chinese mining regions, though not to the degree seen here indicating a critical risk to both local food chains and human health (Wu *et al.*, 2020). While chromium (Cr) levels at Mista Ali (1.5882 mg/kg) and Wildlife Park (1.0360 mg/kg) remained below the 100 mg/kg WHO limit, their presence still warrants concern due to chromium's carcinogenic potential and ability to cause skin irritation. Iron (Fe) contamination was notably high at Rantiya (982.20 mg/kg), indicating substantial metal leaching from mining operations. Copper (Cu) levels varied across sites, while nickel (Ni) concentrations, though below the WHO limit of 35 mg/kg, showed measurable contamination at Wildlife Park (9.8471 mg/kg) and Mista Ali (4.9280 mg/kg). Similar multimetal accumulation patterns have been reported in Jos and Enyigba, where mining tailings have contributed to elevated trace metal loads in both soil and nearby water bodies (Oti, 2015). These findings collectively demonstrate widespread soil contamination that threatens both ecosystem health and human populations in the Jos Plateau region.

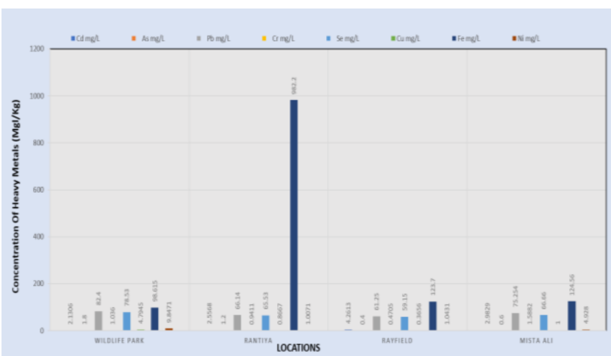

Figure 2: Bar chart presenting heavy metal concentrationsin soil samples from mining sites

Figure 2 shows a bar chart that illustrates the heavy metal concentrations in soil samples from different mining sites in Jos, Plateau State. These findings indicate that direct mining site water sources in Jos are heavily contaminated and unsuitable for human consumption without proper treatment. The presence of heavy metals strongly suggests pollution from mining activities, tailings, and mineral leaching into water sources.

Table 4 revealed that the extent of mining pollution dispersion, soil samples were collected from residential and agricultural areas surrounding active mining sites in Wildlife Park, Rantiya, Rayfield, and Mista Ali. The analysis revealed concerning patterns of heavy metal contamination extending beyond immediate mining zones, though generally at lower concentrations than found at direct mining sites.

Table 4: Heavy metal analysis result for mining site communities soil samples results

Mining Site	Cd mg/kg	As mg/kg	Pb mg/kg	Cr mg/kg	Se mg/kg	Cu mg/kg	Fe mg/kg	Ni mg/kg
Wildlife Park	0.8522	0.3000	10.28	0.7647	40.61	0.6000	95.674	4.6254
Rantiya	0.2784	0.6000	12.780	0.0705	39.82	0.5668	95.328	0.7553
Rayfield	0.9829	0.3210	7.928	0.2352	28.980	0.2834	88.945	0.8273
Mista Ali	0.2784	0.3210	15.657	1.8235	58.54	0.6332	122.83	2.9136
TOTAL	2.3919	1.542	46.645	2.8939	167.95	2.0834	402.777	9.1216
MEAN	0.598	0.386	11.661	0.723	41.988	0.521	100.694	2.280
WHO PERMISSILE LIMIT	0.8-1.5	10	85	100	0.5-2	36	98.62-123.7	35
Control	0.000	0.000	0.000	0.000	0.000	0.000	0.000	

Cadmium (Cd) contamination persists as a significant issue, with Rayfield (0.9829 mg/kg) and Wildlife Park (0.8522 mg/kg) showing levels approaching or exceeding safety thresholds. The continued presence of cadmium in community soils demonstrates the migration of mining pollutants into areas used for residence and agriculture.This pattern mirrors observations by Orosun et al. (2023), who reported Cd concentrations above permissible levels in soils from North-Central Nigeria mining fields, marking a persistent hazard to soil health and human exposure pathways. Lead (Pb) concentrations, while reduced compared to mining sites, remain problematic at Mista Ali (15.657 mg/kg) and Rantiya (12.780 mg/kg), posing risks to soil fertility and creating pathways for human exposure through groundwater leaching and crop uptake.Lead is known for its long-term soil persistence, groundwater infiltration, and potential bioaccumulation in food crops (Ekere*et al*., 2022). Comparable lead contamination in residential soils was documented in Lagos and Ibadan, Nigeria, where topsoil Pb ranged up to 419 mg/kg, substantially exceeding thresholds in densely populated areas.

Selenium (Se) contamination shows particularly widespread distribution, with Mista Ali (58.54 mg/kg) and Wildlife Park (40.61 mg/kg) maintaining alarmingly high levels that far exceed safety standards.These values indicate extreme contamination and surpass levels reported in similar studies across Nigeria, where Se concentrations near abandoned mining areas averaged between 2–5 mg/kg (Oladeji *et al.*, 2023). Chromium (Cr) levels at Mista Ali (1.8235 mg/kg) indicate selective transport of certain mining pollutants into residential areas with potential implications for local water sources and agricultural systems.which does not align with the work of Samaila *et al*,(2025) The migration of Cr into surrounding areas reflects trends observed in studies from lead-zinc mining communities in southeastern Nigeria, where Cr dispersal was linked to both topography and water runoff (Onwubuya et al., 2022). Iron (Fe) and Nickel (Ni) concentrations demonstrate a distance-decay pattern, decreasing as one moves away from active mining zones, suggesting these metals have more limited environmental mobility, this indicates limited environmental mobility of these metals, as observed in other Nigerian mining districts such as Ishiagu and Oshiri, where similar trends were associated with reduced leaching due to heavy particle size and lower solubility in water (Obaje *et al.*, 2021). The presence of heavy metals in community soils at these concentrations carries significant implications for human and environmental health. Bioaccumulation of metals like Se, Cr, Ni, and Fe in crops introduces toxins into the food chain, affecting local food security and increasing the likelihood of chronic diseases such as kidney dysfunction, neurological disorders, and cancer (Jarup, 2003; Aremu *et al.*, 2020). These findings underscore the need for expanded environmental monitoring and remediation efforts in mining-adjacent communities

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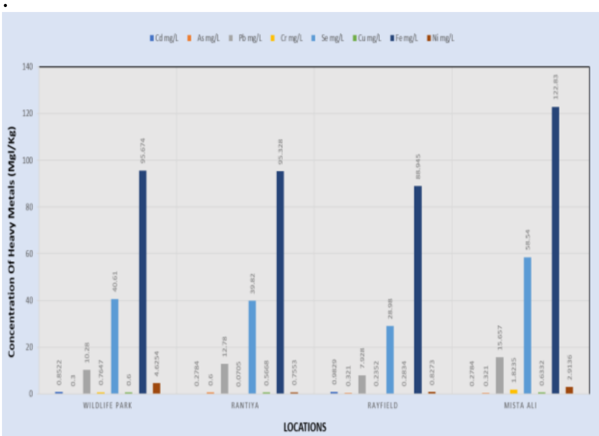

Figure 3: Bar chart presenting heavy metal concentrations in soil samples from Community sites

Figure 3 indicates that bar chart presents comparative heavy metal concentrations in community soil samples across Jos Plateau State. While contamination levels remain below those found at active mining sites, detectable cadmium, lead, and selenium concentrations across all sampled locations indicate persistent environmental impacts from mining operations. Notably, Mista Ali emerges as a contamination hotspot, exhibiting the highest metal concentrations across multiple parameters and representing a potential high-risk zone for human exposure. These findings demonstrate the spatial dispersion of mining-derived pollutants into surrounding communities, with clear implications for environmental and public health monitoring.

CONCLUSION

This study demonstrates significant heavy metal contamination in soils across mining sites and adjacent communities in Jos Plateau State, Nigeria. Comparative analysis revealed elevated concentrations of cadmium, lead, selenium, and iron in mining areas, with measurable dispersion into surrounding communities. Mista Ali emerged as a particular hotspot, though all sampled locations showed contamination exceeding WHO guidelines for soil quality. These findings indicate that current mining practices contribute substantially to soil degradation, posing risks to agricultural systems and public health through potential bioaccumulation in food crops. To mitigate these impacts, several measures should be prioritized. Environmental monitoring programs must be strengthened to regularly assess soil quality, with strict enforcement of existing regulations for mining operations. Agricultural use of severely polluted soils should be restricted to prevent food chain contamination, while alternative land use strategies are developed. Community health initiatives should include regular screenings for heavy metal exposure, particularly in vulnerable populations, accompanied by education programs on soil contamination risks. Mining companies must be held accountable for land rehabilitation post-operation, adopting sustainable practices that minimize soil degradation. These interventions require coordinated efforts between regulatory agencies, mining operators, and local communities to balance economic development with environmental protection. Without immediate action, continued soil contamination may lead to long-term ecological damage and public health consequences in the Jos Plateau region.

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