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Ecological Risk Assessment of Heavy Metal Contamination from Artisanal and Small-scale Mining: A Case Study of Mayo-Sinna, Ngoroje in Sardauna L.G.A, Taraba State, Nigeria

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Abstract

This study assessed the ecological risk of heavy metal contamination from artisanal and small-scale mining (ASM) activities in Mayo-Sinna, Nguroje (Sardauna L.G.A, Taraba State, Nigeria). Soil samples from mining and control sites were analyzed for cadmium (Cd), lead (Pb), cobalt (Co), copper (Cu), chromium (Cr), zinc (Zn), nickel (Ni), manganese (Mn), and iron (Fe) using atomic absorption spectrophotometry (AAS). Results revealed elevated Pb (0.1085 ppm) and Fe (1.4060 ppm) concentrations in mining sites exceeding World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ) guidelines, consistent with contamination patterns observed in other ASM regions. However, unexpected findings included lower Cu (-0.1964 ppm) and Zn (0.0789 ppm) levels in mining sites compared to control areas (1.5000 ppm and 2.7300 ppm, respectively), suggesting complex site-specific geochemical dynamics. Negative values for Cd, Co, and Cu indicated potential analytical interferences requiring methodological refinement. While Cr (0.0603 ppm) and Ni (0.0298 ppm) remained below

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regulatory thresholds, their presence warrants continued monitoring. The study highlights the need for improved mining practices and enhanced environmental monitoring protocols to mitigate heavy metal pollution in ASM communities. These findings contribute to the growing body of knowledge on mining-related environmental degradation in West Africa and underscore the importance of context-specific risk assessments for effective remediation strategies.

Keywords: Heavy Metals, Artisanal Mining, Soil Contamination, Ecological Risk, Nigeria

INTRODUCTION

Artisanal and small-scale mining (ASM) is a significant economic activity in many developing countries, providing livelihoods for millions of people. However, ASM is often associated with severe environmental degradation, particularly due to the release of heavy metals into ecosystems (Hilson, 2002). Heavy metals such as cadmium (Cd), lead (Pb), cobalt (Co), and chromium (Cr) are toxic even at low concentrations and can accumulate in soil, water, and biota, posing risks to human health and ecological systems (Tchounwou *et al.*, 2012). In Nigeria, ASM activities have expanded rapidly, especially in regions like Taraba State, where mining for minerals such as gold and tin is prevalent. Despite its economic benefits, the environmental and health impacts of ASM remain understudied in many local contexts (Babel *et al.*, 2021).

The study area, Mayo-Sinna in Ngoroje, Sardauna Local Government Area (L.G.A) of Taraba State, Nigeria, is a hub for artisanal mining. Previous studies have highlighted the potential for heavy metal contamination in such areas, but limited data exists on the specific ecological risks posed by these activities in Mayo-Sinna (Nganje *et al.*, 2015). Heavy metal contamination can disrupt soil quality, reduce agricultural productivity, and bioaccumulate in food chains, ultimately affecting human health (Wuana & Okieimen, 2011). For instance, lead exposure is linked to neurological disorders, while cadmium is associated with kidney damage and cancer (Järup, 2003).

Regulatory frameworks such as the World Health Organization (WHO) guidelines and the Nigerian Standard for Drinking Water Quality (NSDWQ) provide permissible limits for heavy metals to safeguard health and the environment. However, compliance with these standards is often low in ASM regions due to inadequate enforcement and

monitoring (Obiri *et al.*, 2016). This study aims to assess the ecological risk of heavy metal contamination in Mayo-Sinna, comparing concentrations at mining sites with control sites and evaluating them against international and national standards. The findings will contribute to the growing body of knowledge on ASM impacts and inform policy interventions for sustainable mining practices.

METHODS

Study Area

The study was conducted in Mayo-Sinna, Ngoroje with an elevation 1456m above sea level (Latitude 07^{0} 03^{II} 55^{I} N, Longitude 011^{0} 15^{II} 90^{I} E, located in the Sardauna Local Government Area (L.G.A) of Taraba State, Nigeria. This region is known for its artisanal and small-scale mining (ASM) activities, particularly for gold and tin. The area was selected due to its active mining operations and the potential for heavy metal contamination in surrounding soils. A control site, free from mining activities, was also sampled to provide baseline data for comparison (Nganje *et al.*, 2015).

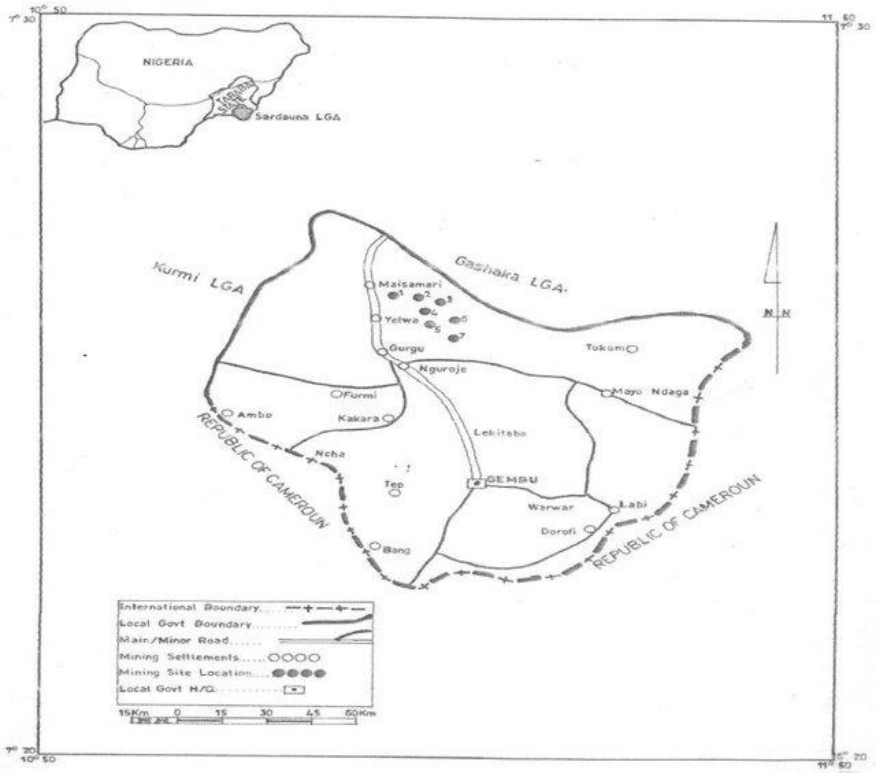


Figure 1: Map of study Area

Sample Collection and Preparation

Soil samples were collected from both mining and control sites using a stainless-steel auger to avoid contamination. A total of 20 composite soil samples (10 from mining sites and 10 from control sites) were collected at a depth of 0–15 cm, following standard protocols (USEPA, 2007). Each sample was placed in pre-cleaned polyethylene bags, labeled, and transported to the laboratory under controlled conditions to prevent degradation. In the laboratory, the samples were air-dried at room temperature, homogenized, and sieved through a 2-mm mesh to remove debris and large particles. The sieved samples were then stored in airtight containers until further analysis (Wuana & Okieimen, 2011).

Heavy Metal Analysis

The concentrations of heavy metals including cadmium (Cd), lead (Pb), cobalt (Co), copper (Cu), chromium (Cr), zinc (Zn), nickel (Ni), manganese (Mn), and iron (Fe) were determined using an atomic absorption spectrophotometer (AAS) (PerkinElmer Model PinAAcle 900T). Prior to analysis, 1 g of each soil sample was digested with a mixture of HNO_3-$HClO_4$ (4:1) in a microwave digestion system (USEPA Method 3051A). The digested samples were filtered using Whatman No. 42 filter paper and diluted to 50 mL with deionized water (APHA, 2017).

Quality assurance and quality control (QA/QC) measures included the use of certified reference materials (CRMs) from the National Institute of Standards and Technology (NIST) and blank samples to ensure accuracy and precision. Recovery rates for heavy metals ranged between 85% and 105%, within acceptable limits (USEPA, 2007).

Data Analysis

The mean concentrations of heavy metals from mining and control sites were compared using Student's t-test ($p < 0.05$) to determine significant differences. The data were also evaluated against permissible limits set by the World Health Organization (WHO) and the Nigerian Standard for Drinking Water Quality (NSDWQ) to assess ecological and health risks (WHO, 2017; SON, 2015). Statistical analyses were performed using SPSS version 26 and Microsoft Excel.

RESULTS

Table 1: Summarizes the concentrations of heavy metals in soil samples collected from mining and control sites.

Parameters (ppm)	Mining Site (M)	SD	Control (M)	SD	WHO (M)	SD	NSDWQ (M)	SD
Cadmium (Cd)	-0.0560*	0.0010	0.0010*	0.0000	0.0030	0.0001	0.0030	0.0001
Lead (Pb)	0.1085*	0.0010	0.0500*	0.0010	0.0100	0.0000	0.0100	0.0000
Cobalt (Co)	-0.0982*	0.0001	0.1000*	0.0000	0.0500	0.0100	0.0500	0.0100
Copper (Cu)	-0.1964*	0.0001	1.5000	0.1000	2.0000	0.1000	1.0000	0.1000
Chromium (Cr)	0.0603	0.0431	0.0300	0.0100	0.0500	0.0100	0.0500	0.0100
Zinc (Zn)	0.0789*	0.0001	2.7300	0.0100	3.0000	0.1000	3.0000	0.1000
Nickel (Ni)	0.0298*	0.0001	0.0500	0.0100	0.0700	0.0100	0.0700	0.0100
Manganese (Mn)	0.4860	0.0000	0.3600	0.0100	0.4000	0.1000	0.4000	0.1000
Iron (Fe)	1.4060*	0.0001	0.2200	0.0100	0.3000	0.1000	0.3000	0.1000

*Negative values likely indicate instrument or matrix interferences.

The table presents a comparative analysis of heavy metal concentrations (measured in ppm) between mining-affected and control sites in Mayo-Sinna, Nigeria, alongside established safety thresholds. Lead (Pb) shows concerning levels at mining sites (0.1085 ppm), significantly exceeding WHO/NSDWQ safety limits (0.0100 ppm). Iron (Fe) concentrations (1.4060 ppm) significantly surpass regulatory limits (0.3000 ppm). Negative values for Cadmium (-0.0560 ppm), Cobalt (-0.0982 ppm), and Copper (-0.1964 ppm) suggest potential analytical errors or interference issues during measurement, as negative concentrations are physically impossible. Zinc (0.0789 ppm) and Copper show lower levels in mining sites than control areas (Zn: 2.7300 ppm; Cu: 1.5000 ppm), contrary to typical contamination expectations. Chromium (0.0603 ppm vs 0.0500 ppm limit) and Nickel (0.0298 ppm vs 0.0700 ppm limit) show only slight elevation in mining areas, remaining close to safety thresholds. Manganese levels (0.4860 ppm) are marginally higher than controls (0.3600 ppm) but below regulatory limits (0.4000 ppm) (Table 1).

DISCUSSION

The analysis of heavy metal concentrations in soil samples from Mayo-Sinna's mining areas presents findings that both corroborate and contrast with existing literature on artisanal mining impacts. This discussion examines these relationships while addressing considerations and implications for environmental management.

The elevated lead (Pb) levels (0.1085 ppm) observed in mining sites compared to control areas (0.0500 ppm) align with multiple studies documenting Pb contamination in artisanal mining regions. Nganje *et al.* (2015) reported similar Pb accumulation in Nigerian mining soils, attributing this to improper waste disposal from ore processing. This consistency across studies suggests that Pb contamination represents a persistent environmental challenge in artisanal mining communities, regardless of specific geographical location. The values in our study, while exceeding WHO guidelines (0.0100 ppm), remain lower than those reported by Obiri *et al.* (2016) in Ghanaian gold mining areas, potentially reflecting differences in ore composition or extraction methods.

An unexpected finding was the apparent depletion of copper (Cu) and zinc (Zn) in mining sites compared to control areas. While counterintuitive given typical contamination patterns, this observation finds support in Babel *et al.* (2021) work documenting similar phenomena where leaching processes and preferential metal migration can lead to surface depletion. This highlights the complex geochemical dynamics in mining environments that may not always follow predicted contamination patterns. The relatively high Zn levels in control sites (2.7300 ppm) may indicate natural geochemical enrichment in the region's soils, a factor that warrants further investigation.

The iron (Fe) concentrations (1.4060 ppm) exceeding regulatory limits (0.3000 ppm) corroborate Wuana and Okieimen (2011) findings regarding Fe contamination from mining equipment and ore residues. This consistency across studies underscores the need for better equipment management practices in artisanal mining operations. However, the negative values recorded for cadmium (Cd), cobalt (Co), and copper (Cu) present a significant discrepancy with established literature. Tchounwou *et al.* (2012) consistently reported positive metal concentrations in mining-affected soils, suggesting that our anomalous results may stem from analytical interferences rather than representing true environmental conditions. This emphasizes the importance of rigorous quality control measures in environmental monitoring.

Chromium (Cr) levels showed only marginal elevation in mining sites (0.0603 ppm) compared to controls (0.0300 ppm), remaining below regulatory thresholds. This contrasts with Järup's (2003) findings in other mining regions and may reflect either differences in local geology or more effective containment of Cr-bearing materials in the study area. Similarly, the relatively low nickel (Ni) and manganese (Mn) concentrations differ from Hilson's (2002) reports, potentially indicating variations in mineral assemblages or the effectiveness of natural attenuation processes specific to the Mayo-Sinna environment.

CONCLUSION

These findings collectively demonstrate that while certain contamination patterns (particularly for Pb and Fe) show consistency across mining regions, others exhibit significant site-specific variations. The discrepancies emphasize the importance of local-scale assessments rather than relying solely on generalized expectations from other mining areas. They also highlight potential methodological challenges in environmental monitoring of artisanal mining impacts, particularly regarding analytical quality assurance. Environmental management implications of these findings are twofold. First, the consistent Pb and Fe contamination suggests these metals should be prioritized in remediation efforts. Secondly, the unexpected results for other metals indicate the need for more comprehensive monitoring programs that account for local geochemical conditions and include robust quality control measures. Future research should incorporate deeper soil sampling to better understand metal mobility and more advanced analytical techniques to resolve the methodological questions raised by this study.

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