Ecotoxicological Assessment of Heavy Metal Contamination in Water Samples from Mayo-Sinna (Nguroje), Taraba State, Nigeria

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Abstract

This study presents a comprehensive ecotoxicological assessment of heavy metal contamination in surface water samples from Mayo-Sinna (Nguroje), a prominent artisanal and small-scale mining (ASM) community in Taraba State, Nigeria. The concentrations of cadmium (Cd), lead (Pb), cobalt (Co), copper (Cu), chromium (Cr), zinc (Zn), nickel (Ni), manganese (Mn), and iron (Fe) were quantified using atomic absorption spectrophotometry (AAS). Measured values were evaluated against benchmark limits established by the World Health Organization (WHO) and the Nigerian Standard for Drinking Water Quality (NSDWQ). Risk characterization was conducted using the Hazard Quotient (HQ) model, a ratio-based approach that compares exposure levels to toxicological reference values. The HQ for lead (Pb) was 2.20, exceeding safety thresholds by 120%, while iron (Fe) recorded an HQ of 3.74, corresponding to a 274.4% exceedance, both indicating significant ecotoxicological and public health threats. Conversely, HQ values for Cd, Co, Cu, Cr, Zn, Ni, and Mn remained below unity, with exceedances ranging from –98.2% to –45.5%, suggesting negligible current risk. These findings underscore the environmental consequences of poorly regulated ASM operations and highlight the urgent need for routine water quality monitoring, enforcement of environmental standards, and implementation of site-specific remediation strategies to safeguard both ecosystem and human health.

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1. Introduction

Heavy metal contamination remains one of the most pervasive and enduring environmental challenges, particularly in areas affected by artisanal and small-scale mining (ASM). These pollutants, often released in trace quantities, have the potential to accumulate and persist in aquatic environments, exerting chronic toxic effects on aquatic organisms, compromising water quality, and posing significant risks to human health and biodiversity (Ochieng *et al*., 2008; Nganje *et al*., 2010) [9, 7]. The persistence and bioaccumulative nature of metals such as lead (Pb), cadmium (Cd), and iron (Fe) make them especially hazardous, even at low concentrations.

In Nigeria, ASM significantly contributes to rural livelihoods and local economies; however, the sector is characterized by informal operations with limited regulatory oversight. This regulatory vacuum has facilitated the unchecked release of heavy metals into terrestrial and aquatic systems, particularly in mineral-rich regions. Taraba State, located in northeastern Nigeria, is one such region where ASM activities are intensifying, with known deposits of lead, zinc, and iron being mined using rudimentary techniques that exacerbate environmental degradation. Mayo-Sinna, situated within the Nguroje area of Sardauna Local Government Area on the Mambilla Plateau, is a prominent ASM hub in Taraba State.

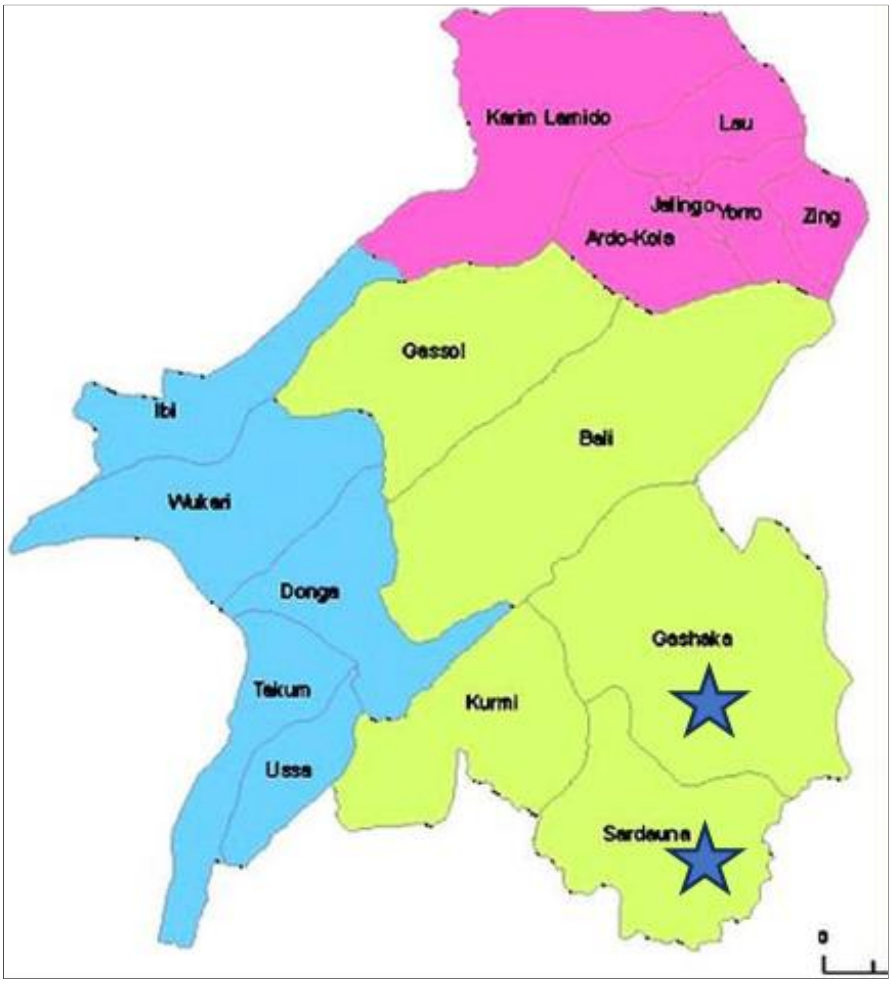
The combination of steep terrain, high rainfall, and mining activity enhances the mobility and dispersion of metal contaminants into surrounding surface and groundwater systems, raising ecotoxicological concerns for both ecological and human populations (Adekola *et al*., 2016) [1]. This study aims to assess the concentrations of selected heavy metals in water sources within Mayo-Sinna, benchmark these values against international and national water quality guidelines, and evaluate their potential ecotoxicological risks using the Hazard Quotient (HQ) framework.

2. Method

2.1 Study Area

Mayo-Sinna is situated in Nguroje, a settlement within the Sardauna Local Government Area (LGA) of Taraba State, located in the Central Zone of northeastern Nigeria. The area lies on the Mambilla Plateau and is characterized by rugged terrain, undulating hills, and highland climatic conditions. Nguroje town, which hosts Mayo-Sinna, is situated at approximately:

Latitude: 6.9572° N, Longitude: 11.2631° E, Elevation: Over 1,800 meters above sea level. The region experiences high annual rainfall (over 1,800 mm), cool temperatures ranging between 15°C to 25°C, and well-drained soils. These climatic conditions, combined with intense mining activities and the natural geomorphology, contribute to the mobilization and leaching of heavy metals from mine tailings into surface and groundwater systems. Mayo-Sinna and its surrounding watersheds drain into local streams that ultimately feed into larger river systems within the Benue Basin. The proximity of informal mining pits and ore processing areas to these water sources raises serious environmental and public health concerns.



Study Location in the Sardauna

Fig 1: Map of the Study Area (Taraba State Government)

2.2 Sample Collection and Analysis

Water samples were collected from streams and wells within and around mining sites in Mayo-Sinna in 2024. Control samples were also collected from areas with no mining influence. All samples were analyzed at an accredited laboratory using standard atomic absorption spectrophotometry (AAS) techniques.

2.3 Risk Assessment Method: Hazard Quotient (HQ)

To evaluate ecotoxicity, HQ values were calculated:

$$HQ = \frac{EDI}{\mathrm{RfD}}$$

Where: HQ is the Hazard Quotient; EDI is the Estimated Daily Intake; RfD is the Reference Daily Dose

Regulatory threshold (minimum of WHO or NSDWQ values) HQ > 1 indicates a potential ecological risk and HQ < 1 indicates no significant ecological risk

3. Results

Table 1: Heavy Metal Concentrations

Parameter	Mayo-Sinna (ppm)	Control (ppm)	WHO/NSDWQ (ppm)	HQ (Mayo-Sinna)
Cadmium (Cd)	0.0013	0.0010	0.0030	0.43
Lead (Pb)	0.0220	0.0500	0.0100	**2.20**
Cobalt (Co)	0.0038	0.1000	0.0500	0.076
Copper (Cu)	0.0178	1.5000	1.0000	0.018
Chromium (Cr)	0.0083	0.0300	0.0500	0.166
Zinc (Zn)	0.0418	2.7300	3.0000	0.014
Nickel (Ni)	0.0118	0.0500	0.0700	0.169
Manganese (Mn)	0.2179	0.3600	0.4000	0.545
Iron (Fe)	1.1233	0.2200	0.3000	**3.744**

High-risk metals: Lead (HQ = 2.20), Iron (HQ = 3.744)
Low-risk metals: All other elements exhibited HQ values well below 1 (Table 1).

Table 2: Heavy Metal Concentrations – Comparative Analysis

Metal	Mayo-Sinna (ppm)	HQ (Mayo-Sinna)	Risk Status	Other ASM Sites in Nigeria (Range, ppm)	Comparison
Cadmium (Cd)	0.0013	0.43	No risk	0.001–0.045(Gashaka,Zamfara,Bagega)	Low in Mayo-Sinna
Lead (Pb)	0.0220	2.20	High Risk	0.010–1.300(Bagega,Shikira,Gidan-Kara)	Moderate to High, above WHO
Cobalt (Co)	0.0038	0.076	No risk	0.01–0.18 (Bali, Jos Plateau)	Very Low
Copper (Cu)	0.0178	0.018	No risk	0.05–2.20(Langalanga,Maijankasa, Niger)	Much lower in Mayo-Sinna
Chromium (Cr)	0.0083	0.166	No risk	0.02–0.60 (Gembu, Kano mines)	Low
Zinc (Zn)	0.0418	0.014	No risk	0.30–5.00(Gashaka,Lafia, Nasarawa)	Extremely Low
Nickel (Ni)	0.0118	0.169	No risk	0.02–0.55 (Maibokati, Nasarawa)	Low
Manganese (Mn)	0.2179	0.545	Slight concern	0.10–0.90 (Bali, Zamfara)	Within the average range
Iron (Fe)	1.1233	3.744	High Risk	0.20–1.80 (Langalanga, Plateau, Kogi)	Among the highest recorded

The concentration of Lead of 0.0220 ppm in Mayo-Sinna exceeds the WHO guideline (0.0100 ppm) by 120% (HQ = 2.20). At 1.1233 ppm, iron concentration is 274.4% above the WHO/NSDWQ limit (0.3 ppm), indicating severe contamination (HQ = 3.744). Though within acceptable limits (HQ = 0.545), the Mn value is moderately elevated and close to the WHO threshold. Cadmium, Copper, Chromium, Zinc, Nickel, and Cobalt all fall below WHO/NSDWQ standards (HQs < 1.0), with zinc and copper levels especially low compared to other sites like Nasarawa and Plateau, where smelting and ore roasting occur (Table 2).

4. Discussion

The elevated Hazard Quotient (HQ) values for lead and iron in Mayo-Sinna (Nguroje) indicate significant contamination, with lead exceeding the permissible limit by 120% and iron by approximately 274.4%. These high exceedances are strongly suggestive of substantial environmental impact, most likely resulting from ongoing artisanal and small-scale mining (ASM) activities in the area.

Lead is particularly toxic and has been widely documented as a potent neurotoxin, especially harmful to children and aquatic organisms at even trace concentrations (USEPA, 2006). Similarly, while iron is a naturally occurring element and essential micronutrient, excessive concentrations can lead to bioaccumulation and oxidative stress in aquatic biota, altering physiological functions and degrading water quality. Although the HQs for other metals such as cadmium (Cd), cobalt (Co), copper (Cu), chromium (Cr), zinc (Zn), nickel (Ni), and manganese (Mn) were below the critical threshold of 1, their presence still reflects measurable anthropogenic influence, especially when compared to control samples. These findings align with those of Awofolu *et al*. (2005) [2], who reported detectable but sub-threshold levels of similar metals in groundwater around informal industrial zones in South Africa. Notably, while individual concentrations may not pose an immediate ecological threat, the potential for synergistic or cumulative toxicity cannot be ignored, particularly in ecosystems exposed to complex mixtures of metals over long durations.

Comparative studies within Nigeria substantiate these findings. For instance, Onoja *et al*. (2019) [10] found that water sources in Bukkuyum (Zamfara State), a region affected by lead-zinc mining—contained significantly elevated concentrations of Pb and Fe, with corresponding HQ values above 1, posing high risks to both human and aquatic health. Similarly, Ezeh and Chukwu (2011) [6] observed chronic contamination in water bodies surrounding the Ishiagu mining area in Ebonyi State, where Pb and Fe levels exceeded both WHO and Nigerian water quality standards. These parallels underscore the widespread ecotoxicological footprint of ASM practices in Nigeria.

Outside Nigeria, similar ecological risk trends have been documented. For example, in Ghana, Bortey-Sam *et al*. (2015) [4] reported hazardous levels of Pb and Fe in water samples from mining-impacted areas in the Tarkwa region, with HQ values for Pb reaching as high as 3.2. In Latin America, Rodríguez *et al*. (2018) [11] reported comparable findings from abandoned gold mining sites in Peru, where chronic exposure to Fe, Pb, and Cd in surface water posed high ecological risks. These studies reinforce the global dimension of the issue, indicating that the problems observed in Mayo-Sinna are part of a broader pattern of environmental degradation associated with poorly regulated small-scale mining operations.

The recurring elevation of Pb and Fe across multiple sites—both domestic and international—suggests that these two metals serve as critical indicators of mining-related ecotoxicity. Moreover, the persistence of sub-threshold levels of other metals emphasizes the importance of holistic environmental monitoring that goes beyond individual metal concentrations and considers interactive toxicological effects.

5. Conclusion
This study confirms that water sources in Mayo-Sinna are contaminated with heavy metals, with Pb and Fe exceeding ecotoxic thresholds. These findings have serious implications for environmental sustainability and public health in mining communities.

6. Recommendations
1. Immediate monitoring and restriction of water use from contaminated sources.
2. Enforcement of environmental regulations for mining operations.
3. Community sensitization and public health interventions, especially for children.
4. Implementation of water treatment and remediation techniques, such as constructed wetlands or biosorption systems.

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