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Geo-Accumulation Index Assessment of Heavy Metal Contamination in Soil Samples from Mayo-Sinna, Sardauna LGA, Central Taraba State, Nigeria

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Abstract

Soil contamination by heavy metals presents a persistent threat to environmental quality and human health, particularly in agriculturally active and ecologically sensitive regions. This study applies the Geo-accumulation Index (Igeo) to evaluate the extent of heavy metal pollution in surface soils collected from Mayo-Sinna, located in Sardauna Local Government Area, Central Taraba State, Nigeria. A total of nine metals including Cadmium (Cd), Lead (Pb), Cobalt (Co), Copper (Cu), Chromium (Cr), Zinc (Zn), Nickel (Ni), Manganese (Mn), and Iron (Fe) were quantified using standard analytical techniques. The Igeo classification revealed that seven of the nine metals fall within Class 0 (Igeo ≤ 0), indicating an uncontaminated status. Lead (Pb) exhibited a mild enrichment, classified as Class 1 (uncontaminated to moderately contaminated), while Iron (Fe) was classified as Class 2, indicating moderate contamination. The elevated Fe level suggests possible lithogenic or localized anthropogenic sources. These findings highlight the generally low levels of heavy metal pollution in the region but underscore the need for periodic monitoring to preempt environmental degradation and safeguard agricultural productivity.

Keywords: *Geo-accumulation, Assessment, Heavy Metals, soil contamination, Taraba State, Nigeria.*

1. INTRODUCTION

The accumulation of heavy metals in soils has become a critical environmental issue globally due to their inherent toxicity, persistence in ecosystems, and non-biodegradable nature (Alloway, 2013). These elements, even at trace levels, can pose significant ecological risks and public health concerns through bioaccumulation and trophic transfer. Anthropogenic sources such as mining, intensive agriculture, industrial emissions, and improper waste disposal are recognized as the primary contributors to the elevation of heavy metal concentrations in terrestrial environments (Kabata-Pendias & Mukherjee, 2007).

To quantitatively assess the extent of contamination and identify potential ecological risks, several indices have been developed. Among these, the Geo-accumulation Index (Igeo), originally proposed by Müller (1969), remains one of the most robust and widely utilized tools. The Igeo enables the assessment of anthropogenic enrichment by comparing present-day metal concentrations with pre-industrial background values, adjusted with a constant factor to account for natural variability.

Despite the increasing environmental pressures associated with land use change and intensifying agricultural practices, data on the heavy metal status of soils in Mayo-Sinna, a key agrarian locality within Sardauna Local Government Area (LGA) of Central Taraba State, Nigeria, remain scarce. Given the region's ecological significance and socio-economic reliance on agriculture, a baseline assessment is imperative. This study, therefore, employs the Igeo index to evaluate the extent and nature of heavy metal contamination in surface soils from Mayo-Sinna. The results are expected to inform future monitoring frameworks and guide sustainable land and environmental management strategies in the area.

2. Materials and Methods

2.1 Study Area

The study was conducted in Mayo-Sinna, located within Sardauna Local Government Area (LGA) in the Central Zone of Taraba State, Nigeria. The region is characterized by a montane highland ecosystem, marked by elevated terrain, moderate to high rainfall, and predominantly agrarian land use. Agricultural intensification, deforestation, and expanding human settlement in recent decades have led to increasing anthropogenic pressures on the soil environment.

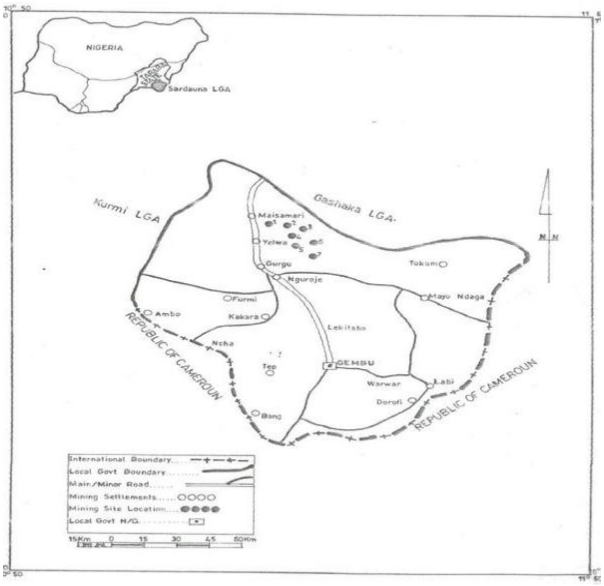

Figure 1: Map of the Study Area

2.2 Soil Sampling and Analytical Procedures

Composite surface soil samples were systematically collected from multiple geo-referenced sites across Mayo-Sinna at a depth of 0–20 cm, consistent with standard environmental soil sampling protocols. Samples were air-dried at ambient temperature, homogenized, and passed through a 2 mm mesh sieve to remove debris and ensure uniformity. The concentrations of nine heavy metals—Cadmium (Cd), Lead (Pb), Cobalt (Co), Copper (Cu), Chromium (Cr), Zinc (Zn), Nickel (Ni), Manganese (Mn), and Iron (Fe) were determined using Flame Atomic Absorption Spectrophotometry (AAS) following acid digestion, in accordance with standard methods recommended by the American Public Health Association (APHA, 2017).

2.3 Geo-accumulation Index (Igeo)

The extent of heavy metal contamination was evaluated using the Geo-accumulation Index (Igeo), originally formulated by Müller (1969). The index is defined by the following equation:

$Igeo = \log_2(Cn/[1.5 \times Bn])$

- Cn = Measured concentration of the metal in the soil sample
- Bn = Geochemical background concentration of the metal

The constant 1.5 is a correction factor to accommodate natural background fluctuations due to lithogenic variability. This index helps to quantify the degree of heavy metal pollution by comparing current concentrations to natural baseline levels.

2.4. Classification of Contamination Levels

The Igeo values were interpreted based on the classification scheme proposed by Müller (1969), as follows:

- Class 0: Igeo $\leq$ 0 (Uncontaminated)
- Class 1: 0 < Igeo $\leq$ 1 (Uncontaminated to moderately contaminated)
- Class 2: 1 < Igeo $\leq$ 2 (Moderately contaminated)
- Class 3: 2 < Igeo $\leq$ 3 (Moderately to heavily contaminated)
- Class 4: 3 < Igeo $\leq$ 4 (Heavily contaminated)
- Class 5: 4 < Igeo $\leq$ 5 (Heavily to extremely contaminated)
- Class 6: Igeo > 5 (Extremely contaminated)

This classification enables the differentiation of natural versus anthropogenic contributions to metal concentrations in soils and aids in prioritizing remediation efforts.

3. Results

Table 1: Geo-accumulation Index (Igeo) of Heavy Metals in Mayo-Sinna Soil Samples

S/N	Heavy Metal	Igeo Value	Igeo Class	Pollution Level
1	Cadmium (Cd)	0.0000	0	Uncontaminated
2	Lead (Pb)	0.5327	1	Uncontaminated to moderately contaminated
3	Cobalt (Co)	0.0000	0	Uncontaminated
4	Copper (Cu)	0.0000	0	Uncontaminated
5	Chromium (Cr)	0.0000	0	Uncontaminated
6	Zinc (Zn)	-5.6977	0	Uncontaminated
7	Nickel (Ni)	-1.3316	0	Uncontaminated
8	Manganese (Mn)	-0.1520	0	Uncontaminated
9	Iron (Fe)	2.0911	2	Moderately contaminated

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Table 1 of the study presents the Geo-accumulation Index (Igeo) values for nine heavy metals including Cadmium (Cd), Lead (Pb), Cobalt (Co), Copper (Cu), Chromium (Cr), Zinc (Zn), Nickel (Ni), Manganese (Mn), and Iron (Fe) in surface soil samples from Mayo-Sinna, Taraba State, Nigeria, categorized according to Müller's classification scheme. The results show that seven out of the nine metals, including Cd, Co, Cu, Cr, Zn, Ni, and Mn, fall within Igeo Class 0, indicating they are uncontaminated and thus reflect either natural background levels or minimal anthropogenic input. Notably, Zinc (-5.6977), Nickel (-1.3316), and Manganese (-0.1520) showed negative Igeo values, further affirming their low contamination potential and likely lithogenic origin. Cadmium, Cobalt, Copper, and Chromium all recorded exact Igeo values of 0.0000, suggesting ambient, background-level presence. Lead (Pb), with an Igeo value of 0.5327, is classified under Class 1 uncontaminated to moderately contaminated, suggesting some degree of enrichment potentially linked to localized human activities such as vehicular emissions or agrochemical use. The most striking result is for Iron (Fe), which exhibited an Igeo value of 2.0911, placing it in Class 2 moderately contaminated, indicating a notable anthropogenic contribution, possibly from the erosion of iron-rich parent material, application of iron-containing fertilizers, or nearby industrial input.

4. Discussion

The findings from this study reveal that the soil environment in Mayo-Sinna is largely uncontaminated, with minimal anthropogenic influence on the concentrations of most heavy metals. The majority of metals, including Zinc (Zn), Nickel (Ni), and Manganese (Mn), exhibited significantly negative Igeo values, indicating that these elements either occur naturally in abundance in the region or have experienced minimal anthropogenic input. This aligns with the general understanding that these metals are typically abundant in the Earth's crust and may not be significantly influenced by human activities in areas without intensive industrial or agricultural practices (Kabata-Pendias, 2011).

Cadmium (Cd), Cobalt (Co), Copper (Cu), and Chromium (Cr) all recorded Igeo values of zero, which is indicative of background levels typical for regions with limited anthropogenic disturbance. These results are consistent with studies conducted in other rural and agricultural regions of Nigeria and sub-Saharan Africa, where these metals are generally found at low concentrations in soils due to the absence of significant industrial or mining activities (Nwajei *et al*., 2012; Adefemi & Awokunmi, 2009). For example, a study by Nwajei *et al*. (2012) in the Niger Delta similarly found that these metals did not exceed natural background levels, supporting the notion that agricultural practices in the region do not significantly alter their concentrations.

In contrast, Lead (Pb) presented an Igeo value of 0.5327, placing it within the "uncontaminated to moderately contaminated" category. This mild elevation may reflect localized anthropogenic activities, such as vehicular emissions or the use of lead-based pesticides, which are common sources of Pb contamination in rural and semi-urban areas (Cui *et al*., 2005). Similar findings have been reported in agricultural zones of Nigeria, where lead concentrations in soil were found to be influenced by factors such as the use of lead-containing products in farming and local traffic emissions (Adefemi & Awokunmi, 2009).

The most notable finding from this study is the moderate contamination of Iron (Fe), which had an Igeo value of 2.0911, categorizing it as moderately contaminated. While iron is a ubiquitous element in soil, this elevated concentration is suggestive of anthropogenic influences such as erosion of iron-rich parent material, the use of iron-containing fertilizers, or potential local industrial activities (Kabata-Pendias, 2011). In contrast to many rural areas where iron levels remain at natural background concentrations, several studies have noted elevated Fe levels in regions impacted by intensive agricultural practices or localized industrial pollution (Mishra *et al*., 2017; Eze *et al*., 2020). For instance, Eze *et al*. (2020) reported similar moderate enrichment of iron in soils from urbanized regions of southeastern Nigeria, where both industrial runoff and agricultural amendments contributed to elevated Fe concentrations.

The overall low contamination levels observed in Mayo-Sinna's soils are consistent with similar studies conducted in rural agroecological zones of Nigeria and sub-Saharan Africa, where natural soil characteristics and limited industrialization result in minimal metal contamination (Nwajei *et al*., 2012). However, the moderate contamination of Iron observed in this study underscores the potential influence of local agricultural practices, such as the use of iron-based fertilizers, or geological factors that could lead to the accumulation of iron in the soil (Adefemi & Awokunmi, 2009). Given that lead also showed slight enrichment, continuous monitoring is recommended to assess potential risks from emerging anthropogenic sources, especially as urbanization and agricultural practices evolve in the region.

These findings highlight the importance of considering both natural and anthropogenic sources of heavy metal contamination in soil environments. While Mayo-Sinna's soils are generally free from significant contamination, localized human activities, especially in agricultural and urban areas, may contribute to future increases in metal concentrations. Therefore, this study provides a valuable baseline for future research and environmental management practices aimed at mitigating the risks of heavy metal contamination in the region.

5. Conclusion

This study has demonstrated that soils in Mayo-Sinna are largely free from significant heavy metal contamination, with the exception of moderate iron contamination and slight lead accumulation. Continuous environmental monitoring is recommended to detect future changes in metal concentrations. Preventive measures should also be implemented to minimize anthropogenic input into the soil system.

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