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## Estimation of Heavy Metals in Soil of Okaba Coalfields and Environs Ankpa, Kogi State, Nigeria

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### Abstract

This study investigates the concentrations of heavy metals in soils from the Okaba Coalfields and environs, Ankpa, Kogi State, Nigeria, to assess potential environmental and public health risks. Soil samples were collected from ten distinct locations and prepared through oven-drying, grinding, sieving, and acid digestion using concentrated nitric acid. The resulting digests were analyzed using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) to quantify levels of chromium (Cr), zinc (Zn), copper (Cu), cadmium (Cd), lead (Pb), nickel (Ni), and arsenic (As). The mean concentrations recorded were 113.92 mg/kg for Cr, 53.87 mg/kg for Zn, 37.78 mg/kg for Cu, 1.01 mg/kg for Cd, 91.82 mg/kg for Pb, 39.99 mg/kg for Ni, and 22.32 mg/kg for As—values that generally exceed the World Health Organization (WHO) permissible limits. These elevated heavy metal levels pose significant health risks, including respiratory, renal, neurological, and developmental effects, particularly among vulnerable populations such as children. The findings underscore an urgent need for regular environmental monitoring, stricter regulation of industrial emissions and waste disposal practices, and targeted remediation efforts to mitigate the adverse impacts on human health and the ecosystem in the Okaba region.

**Keywords:** Heavy Metals, Soil Contamination, ICP-MS, Environmental Pollution, Public Health Risk

## Introduction

Heavy metals are broadly defined as inorganic metallic elements and metalloids with densities exceeding  $5 \text{ g/cm}^3$ , which pose significant health and environmental risks when present beyond permissible concentrations. Common heavy metals frequently studied due to their environmental and health impacts include titanium, vanadium, chromium, manganese, iron, cobalt, nickel, copper, zinc, arsenic, molybdenum, silver, cadmium, tin, platinum, gold, mercury, and lead (Briffa, et al., 2020, Ojiego et al., 2022). The escalation of heavy metal pollution in the environment has been attributed to factors such as intensified agricultural activities, expansion of metal-based industries, and inadequate waste disposal systems (Briffa et al., 2020; Onwukeme and Eze, 2021, Ojiego et al., 2022). Recognized as a major adverse consequence of global industrialization, heavy metals are particularly concerning due to their unique physicochemical characteristics, including their persistence in the environment and high toxicity levels (Njoke and Nwani, 2022, Ojiego et al., 2022). In addition to their toxicity and non-degradable nature, heavy metals predominantly accumulate in soil, which serves as the primary medium of contamination, especially in areas influenced by anthropogenic activities.

The environmental implications of coal mining have garnered significant attention due to the associated release of heavy metals into surrounding ecosystems. In Nigeria, particularly within Kogi State, coal mining activities have been linked to elevated concentrations of heavy metals in soils, posing risks to both environmental and human health. The Okaba Coalfield in Kogi State has been a focal point for coal mining activities, which, while economically beneficial, present significant environmental challenges, particularly concerning soil contamination by heavy metals (Obiora et al., 2016).

Soil acts as a major sink for heavy metals that leach from dumpsites, altering its physical, chemical, and biological properties—a serious challenge for sustainable agriculture (FAO, 2015). For example, when non-essential heavy metals like cadmium (Cd), mercury (Hg), and lead (Pb) infiltrate the soil, they are absorbed by plant roots and other organisms, leading to declines in soil productivity, diversity, and overall life abundance (Syed et al., 2018, Agbesie et al., 2020, Ojiego et al., 2022). Additionally, heavy metal pollution disrupts the normal functions of microbes, plants, animals, and even human systems within agricultural ecosystems (Elemga et al., 2022). Some of these metals also migrate from the soil into surface and groundwater, contaminating drinking water sources (Karimian et al., 2021, Mavakala et al., 2022, Ojiego et al., 2022 ), thereby posing serious health risks. Both short-term and long-term exposures in humans have been linked to chronic toxic effects, including cancer, skin disorders, birth defects, and impairments in kidney, nervous, gastrointestinal, circulatory, immune, and vascular functions, as well as in the process of apoptosis (Elemga et al., 2022). The overall toxicity of these non-essential heavy metals in the environment is thus a major concern.

Recent studies have highlighted the prevalence of heavy metals such as vanadium (V), manganese (Mn), arsenic (As), uranium (U), chromium (Cr), cobalt (Co), strontium (Sr), antimony (Sb), barium (Ba), and thorium (Th) in coal samples from mining sites within Kogi State, including Okaba (Ewa et al., 2023). These contaminants can adversely affect soil health, agricultural productivity, and human well-being. Research focusing on the Odagbo area of Kogi State evaluated the impact of coal mining on soil quality. The findings revealed elevated

concentrations of heavy metals, underscoring the environmental implications of mining activities in the region (Ameh et al., 2022). Similarly, an assessment of heavy metal contamination in soils around the Oke-Ere mining area in Yagba West, Kogi State, identified potential health risks associated with these pollutants (Olatunji & Abimbola, 2019). Seasonal studies around the Okaba coal mine have shown variations in toxic metal pollution levels in soil and sediment. Higher concentrations of metals such as zinc (Zn), lead (Pb), and copper (Cu) were observed during the dry season compared to the wet season, suggesting that climatic factors influence the dispersion and concentration of these contaminants (Ameh et al., 2022). Given the potential for heavy metals to bioaccumulate in the food chain, their presence in agricultural soils is particularly concerning.

A study by Ameh et al. (2022) investigated the seasonal variations of toxic metal pollution in soil and sediment around the Okaba coal mine area in Kogi State. The research revealed that concentrations of metals such as zinc (Zn), lead (Pb), and copper (Cu) were higher during the dry season compared to the wet season, suggesting that climatic factors significantly influence metal dispersion and concentration levels. The study emphasized the need for continuous monitoring to understand the temporal dynamics of heavy metal pollution in mining areas.

Similarly, a recent assessment by Ewa et al. (2023) focused on the heavy metal contamination of coal deposits in selected mining sites within Kogi State, including Okobo, Odagbo, Ofugo, and Opoko-Obido in Ankpa, Kogi State. Utilizing Instrumental Neutron Activation Analysis, the study identified varying concentrations of metals such as vanadium (V), manganese (Mn), arsenic (As), uranium (U), chromium (Cr), cobalt (Co), strontium (Sr), antimony (Sb), barium (Ba), and thorium (Th) in the coal samples. The findings underscored the potential environmental hazards associated with coal mining in these regions. Further research by Olatunji and Abimbola (2019) examined heavy metal pollution in soil samples obtained from communities around a cement factory in Obajana, Kogi State. The study assessed the levels of heavy metals in soils of three communities within forty kilometers from the cement factory. The findings revealed varying concentrations of heavy metals, highlighting the influence of industrial activities on soil quality in the region.

This study aims at a comprehensive assessment of heavy metal concentrations in soils from the Okaba coalfield in Kogi State, Nigeria. Understanding the spatial and temporal distribution of these contaminants is essential for developing effective mitigation strategies to protect environmental and public health.

## **2.0. Study Area**

Okaba (7°24'28"N, 7°48'06"E) and Okobo (7°22'14"N, 7°37'31"E) are located in the Enjema district of Ankpa Local Government Area in southeastern Kogi State, Nigeria. This region lies within the Middle Benue Trough, a significant geological formation characterized by rift basins extending from the Niger Delta to the Chad Basin. The Benue Trough is notable for its complex stratigraphy, tectonic history, and abundant natural resources (Benkhelil, 1989).

The geology of Okaba and Okobo features sedimentary rocks from the Cretaceous period, forming part of the Anambra Basin within the Middle Benue Trough. This area is rich in

bituminous coal, a valuable resource for industrial applications such as power generation and metallurgy (Mbogu & Inoni, 2018). The sedimentary formations in this region also include sandstone, shale, limestone, and coal seams, reflecting depositional environments that alternated between marine and continental settings (Obaje, 2009).

Beyond coal, the sedimentary rocks in Okaba and Okobo may host other economic minerals, such as limestone for cement production and shale, which has applications in construction and as a potential source of shale gas (Ezeigbo & Ozoko, 1987). The region's coal reserves, part of the larger Anambra Coal Basin, have been a focal point of mining activities for decades, making it an area of interest for assessing environmental and health impacts associated with mining.



(a)



(b)

Figure 1: Photograph of farmland and coal mining site in Okaba

## Materials and Methods

### Sample Collection and Preparation

Soil samples were collected from ten different locations within the study area using clean, non-contaminating tools such as a hand trowel, placed in clean containers washed with acid to prevent heavy metal contamination. The samples were oven-dried at 45°C to avoid loss of volatile species and ground into a fine powder to ensure homogeneity. The ground soil was sieved using a <math><2\text{ mm}</math> sieve to remove coarse fragments and achieve uniformity in particle size. A measured volume of concentrated nitric acid ( $\text{HNO}_3$ ) was added to acidify and oxidize organic matter in a 1:1 ratio. The mixture was left for 25 minutes at room temperature to pre-wet and pre-digest the sample before heating.

The acid-soil mixture was transferred to a digestion vessel equipped with a reflux condenser to minimize the loss of volatile components and was gradually heated to a temperature near boiling (95–100 °C) for one hour and twenty minutes until the solution was cleared of particulate matter. Once digestion was complete, the vessel was removed from the heat source, allowed to cool to room temperature, and filtered through a fine (0.45  $\mu\text{m}$ ) filter paper to remove undigested

particulates, yielding a clear, homogeneous solution. The filtered digest was then transferred into a volumetric flask and diluted to a known final volume with deionized water. The final diluted solutions were analyzed for trace metals using Inductively Coupled Plasma Mass Spectrometry (ICP-MS).

### Sample Analysis

The sample analysis was carried out using ICP-MS. The diluted soil digest sample was loaded into the auto sampler rack, ensuring thorough mixing. The signal intensities were measured, converted into concentration values using calibration curves, and the data were stored for further analysis.

### Results and Discussion

Table 1: Concentration of Heavy Metals in Soil of Okaba

Sample location	Cr (mgkg <sup>-1</sup> )	Zn (mgkg <sup>-1</sup> )	Cu (mgkg <sup>-1</sup> )	Cd (mgkg <sup>-1</sup> )	Pb (mgkg <sup>-1</sup> )	Ni (mgkg <sup>-1</sup> )	As (mgkg <sup>-1</sup> )
<b>A</b>	124.00	48.56	38.92	0.80	79.20	38.32	22.39
<b>B</b>	116.24	49.92	33.24	1.24	86.52	35.02	20.44
<b>C</b>	99.67	54.39	37.66	0.96	92.36	56.23	25.32
<b>D</b>	96.38	60.24	39.89	0.92	90.24	38.92	20.43
<b>E</b>	132.38	48.50	34.56	1.45	81.98	40.38	19.20
<b>F</b>	121.94	54.01	40.44	0.96	98.62	39.81	18.22
<b>G</b>	109.58	58.26	44.32	0.87	100.01	36.23	26.32
<b>H</b>	114.36	62.56	36.02	0.79	115.64	37.94	24.14
<b>I</b>	122.98	51.24	35.98	1.11	89.27	34.69	23.38
<b>J</b>	101.63	50.98	36.79	1.02	84.36	42.32	23.41
<b>Mean</b>	<b>113.92</b>	<b>53.87</b>	<b>37.78</b>	<b>1.01</b>	<b>91.82</b>	<b>39.99</b>	<b>22.32</b>
<b>WHO</b>	<b>100</b>	<b>50</b>	<b>36</b>	<b>0.8</b>	<b>85</b>	<b>35</b>	<b>20</b>

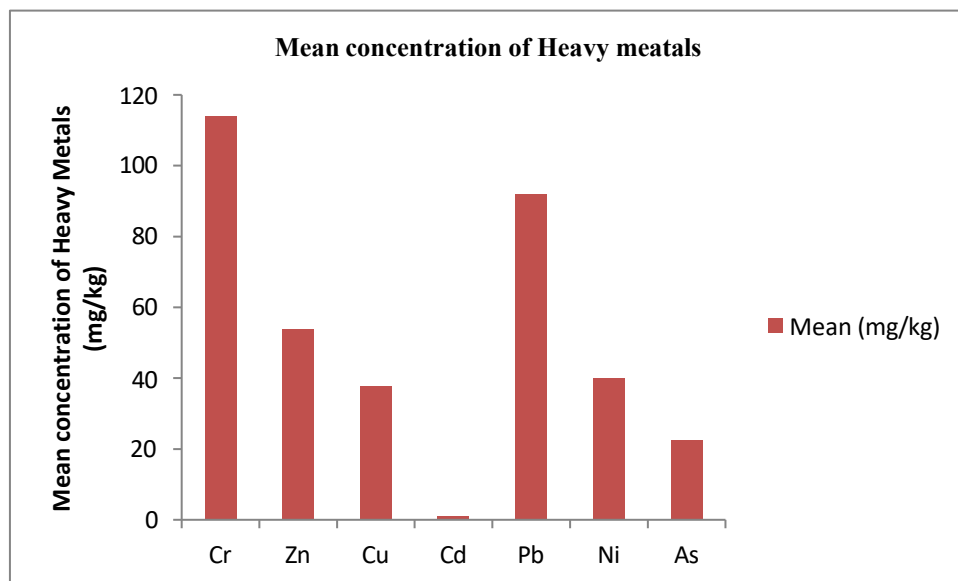


Figure 2: Mean concentration of heavy metals in soil of Okaba

The concentration of heavy metals in ten (10) soil samples from the Okaba community, Ankpa, Kogi State, Nigeria, is reported. Table 1 and Figure 1 reveal the presence of all tested heavy metals at varying concentrations in the sampled soil. This aligns with recent findings from previous studies on heavy metal concentrations near dumpsites (Onwukeme & Eze, 2021; Musa et al., 2020; Nyiramigisha & Komariah, 2021). The National Environmental Standards and Regulations Enforcement Agency (NESREA), in collaboration with the Food and Agriculture Organization (FAO) and the World Health Organization (WHO), has established permissible limits for Cr, Zn, Cu, Cd, Pb, Ni, and As as 100 mg/kg, 50 mg/kg, 50 mg/kg, 0.8 mg/kg, 85 mg/kg, 35 mg/kg, and 20 mg/kg, respectively (NESREA, 2021, FAO/WHO, 2021). The concentrations range as follows: Chromium (Cr): 96.38 to 132.38 mg/kg, with a mean concentration of 113.92 mg/kg, Zinc (Zn): 48.50 to 62.56 mg/kg, with an average of 53.87 mg/kg, Copper (Cu): 33.24 to 44.32 mg/kg, with an average of 37.78 mg/kg, Cadmium (Cd): 0.79 to 1.45 mg/kg, with an average of 1.01 mg/kg, Lead (Pb): 79.20 to 115.64 mg/kg, with an average of 91.82 mg/kg, Nickel (Ni): 34.69 to 56.23 mg/kg, with an average of 39.99 mg/kg and Arsenic (As): 18.22 to 26.32 mg/kg, with an average of 22.32 mg/kg.

The mean concentration of chromium exceeds the WHO permissible limit of 100 mg/kg, with some samples significantly surpassing this threshold (e.g., sample E: 132.38 mg/kg). Chromium, especially in its hexavalent form, is highly toxic and prolonged exposure can cause skin irritation, lung and kidney damage, and an increased risk of cancer. Residents of Okaba may face serious health risks, including respiratory issues and skin problems.

Zinc concentrations slightly exceed the WHO limit of 50 mg/kg, with several samples above this level (e.g., sample H: 62.56 mg/kg). While zinc is an essential nutrient, excessive exposure can lead to toxicity, affecting the gastrointestinal and immune systems. Chronic exposure may also

cause kidney or liver damage, and residents may experience symptoms such as nausea, vomiting, and stomach cramps.

Copper levels exceed the WHO limit of 36 mg/kg in several samples (e.g., sample G: 44.32 mg/kg). Though copper is an essential micronutrient, high concentrations can cause toxicity, resulting in liver and kidney damage. Symptoms of copper poisoning include nausea, vomiting, and gastrointestinal distress, while chronic exposure may lead to organ damage, posing a health risk to the residents of Okaba.

Cadmium concentrations exceed the WHO limit of 0.8 mg/kg in all samples, with a mean concentration of 1.01 mg/kg. Cadmium is highly toxic, even at low levels, and can accumulate in the kidneys and liver, causing kidney damage, bone disease, and an increased risk of cancer. Prolonged exposure puts residents at significant health risk.

Lead levels surpass the WHO permissible limit of 85 mg/kg in most samples, with concentrations ranging from 79.20 mg/kg to 115.64 mg/kg. Lead is a potent neurotoxin, particularly harmful to children, affecting brain development and causing cognitive and behavioral issues. It can also lead to kidney damage, high blood pressure, and reproductive problems. The elevated lead concentrations put Okaba residents, especially children, at a high risk of lead poisoning.

Nickel levels slightly exceed the WHO limit of 35 mg/kg. While nickel is essential in small amounts, excessive exposure can cause skin allergies, lung problems, and, in severe cases, cancer. The higher concentrations in the samples may negatively impact residents' health, particularly those exposed through skin contact or inhalation.

Arsenic levels exceed the WHO limit of 20 mg/kg recommended for Nigeria in most samples, with concentrations ranging from 18.22 mg/kg to 26.32 mg/kg. Arsenic is highly toxic and is linked to skin, lung, and bladder cancers. Chronic exposure can cause severe health problems, including neurological damage and cardiovascular diseases. The elevated arsenic levels pose a serious health threat to Okaba residents.

The findings of this study indicate that multiple heavy metal concentrations exceed WHO permissible limits, posing significant health risks to the residents of Okaba. Long-term exposure to these metals could lead to various serious health conditions, including: Respiratory and skin problems from chromium and nickel exposure, gastrointestinal distress and organ damage due to high zinc and copper levels, kidney and liver damage from cadmium and arsenic exposure. Neurological issues, particularly in children, due to lead exposure. According to the literature, cadmium (Cd) and lead (Pb) are heavy metals with minimal benefits for the growth and nutrition of plants and animals (Hayat et al., 2018; Zhang et al., 2012; Ojiego, 2022). When ingested directly or indirectly through contaminated food, air, dust, or water, they can cause Cd poisoning (Hayat et al., 2018) and Pb poisoning, particularly in children exposed to lead-laden dust particles (Zhang et al., 2012). Chromium (Cr), particularly in its hexavalent form (Cr VI), is more toxic than trivalent chromium (Cr III) and has been linked to cancer and other health issues when released into the environment through industrial emissions or waste (Coetzee et al.,

2020). These findings highlight the urgent need for environmental monitoring and intervention to mitigate the health risks associated with heavy metal contamination in Okaba.

## **Conclusion**

The results of this study highlight concerning levels of heavy metals in the Okaba study area, with concentrations of chromium, zinc, copper, cadmium, lead, nickel, and arsenic exceeding the World Health Organization (WHO) permissible limits. The mean concentrations of these metals especially chromium, cadmium, lead, and arsenic significantly surpass safe thresholds, indicating a potential public health hazard. Long-term exposure to these metals is known to cause various adverse health effects, including organ damage, neurological disorders, and even cancer. The elevated levels of these contaminants suggest potential environmental pollution, likely stemming from mining activities, agricultural practices, or improper waste management, all of which have contributed to environmental contamination.

The findings emphasize the urgent need for action to address the growing pollution in Okaba. The excessive concentrations of metals like lead and arsenic are particularly alarming, as they pose serious risks to human health, especially for vulnerable groups such as children and the elderly. In light of these results, immediate steps are necessary to mitigate further exposure to these harmful pollutants and safeguard the health of residents. Continuous monitoring of heavy metal concentrations in the environment, particularly in soil, should be implemented in Okaba to track changes in contamination levels and allow for timely intervention when concentrations exceed safe limits. Authorities should enforce stricter regulations on industrial emissions, mining activities, and waste disposal to prevent further contamination by heavy metals.

**Conflicts of Interest:** The authors declare no conflict of interest on the manuscript

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