

Heavy Metal Pollution and Soil Health around Local Aluminum Pot Production Sites in Sokoto

Isah, A.^{1*}, Shuaibu, M.¹, Saidu, I.¹, Garba, S.¹, Saadu, B.¹, Abdullahi, A. G.¹, Haruna, S. K.¹, Sahabi, Y.¹¹Department of Applied Chemistry, Umaru Ali Shinkafi Polytechnic, SokotoCorresponding author's email: abduchm@yahoo.com

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ABSTRACT

This study analyzed soil samples from three locations around a local aluminum pot production center in Sokoto, Nigeria, in April 2025. The samples were tested for various physicochemical properties and heavy metal content. Key findings include pH levels ranged from 6.5 to 6.7, organic matter content was between 0.280% and 0.384%, nutrient levels varied as nitrogen found to be 0.07% to 0.081%, phosphorus 3.13 to 3.36 mg/kg and potassium 1.38 to 1.59 cmol/kg. The sodium, magnesium and calcium were found to be within the ranged of 0.65 – 0.74, 0.40 – 0.70 and 0.45 – 0.60 respectively. The heavy metal concentrations exceeded FAO/ISRIC standards as lead found to be 0.085 to 0.165 ppm, chromium 0.4268 to 0.5087 ppm, cadmium 0.0544 to 0.1045 ppm, copper 0.0544 to 0.2932 ppm and zinc 21.4670 to 26.9675 ppm. The study suggests that the soil around the aluminum pot production center poses environmental and health risks due to elevated heavy metal levels.

Keywords: Physicochemical parameters, heavy metals, aluminum pot, production site, environmental impact, public health.

1.0 INTRODUCTION

The increasing rate of environmental pollution due to human activities and industrial processes has become a pressing concern globally. One significant contributor to this issue is the aluminum industry, which generates substantial metallic waste that can accumulate in the environment and cause harm. The production of aluminum utensils, in particular, poses a risk to the environment and human health due to the release of toxic heavy metals. Aluminum production involves several stages, including bauxite mining, alumina production, and aluminum electrolysis. Each stage has significant environmental implications, including (Abdollahi *et al.*, 2021; Brough and Jouhara, 2020). The production process releases greenhouse gases such as carbon dioxide, contributing to climate change. In fact, the perfluorocarbons released during aluminum smelting are 9,200 times more detrimental to global warming than carbon dioxide. More so, particulate matter, sulfur dioxide, and nitrogen oxides, are emitted during production, contributing to air pollution and negatively impacting human health. Aluminum production can contaminate water sources, posing a risk to aquatic life and human health. The process generates substantial solid waste, including bauxite residue and spent pot lining, which can be hazardous if not managed properly (Abdollahi *et al.*, 2021; Brough and Jouhara 2020; Zhang *et al.* 2023). The accumulation of heavy metals in the environment due to aluminum production can have severe health implications. Exposure to these metals has been linked to various health problems, including heavy metals

like cadmium, chromium, and lead are toxic and can cause harm to humans and wildlife. Some heavy metals, such as cadmium and chromium, are known carcinogens (Zhang *et al.* 2023).

In order to have sustainable solution, recycling aluminum can significantly reduce the environmental impacts associated with primary production. It requires only 5% of the energy needed to produce new aluminum and reduces greenhouse gas emissions. Transitioning to clean energy sources, such as renewable energy, can help reduce the environmental footprint of aluminum production. Implementing more efficient production processes and technologies can minimize waste generation and reduce emissions. Recent studies have highlighted the importance of addressing the environmental impacts of aluminum production. A study by Abdollahi *et al.* (2021) used life cycle assessment to evaluate the environmental impacts of aluminum production and found that the alumina production and aluminum electrolysis stages have the most significant environmental impacts. Another study by Zhang *et al.* (2023) found that the accumulation of heavy metals in the environment due to aluminum production can have severe health implications. Overall, the aluminum industry must prioritize sustainability and reduce its environmental footprint to mitigate the negative impacts of production. This can be achieved through the adoption of cleaner production technologies, increased recycling, and more efficient use of energy and resources.

This study examines the accumulation of heavy metals, such as cadmium, chromium, copper, lead, and zinc, in soil resulting from the production of aluminum pots. Notably, local production sites situated in city centers and marketplaces pose significant risks to both human health and the environment.

2.0 EXPERIMENTAL

2.2 Materials and Methods

2.2.1 Sample Collection and Preparation

Soil samples were strategically collected from the vicinity of a local aluminum pot production center near Maryam Abacha Women and Children Hospital, Old Market Area, Sokoto. Three samples, labeled A, B, and C, were collected within a 20-meter radius to capture potential spatial variability in heavy metal distribution (Isah *et al.*, 2010). The samples were carefully stored in clean polythene bags to prevent contamination during transportation to the laboratory. To prepare the samples for analysis, they were air-dried for 24 hours to reduce moisture content, which helps prevent microbial growth and facilitates sieving. The dried samples were then sieved through a 2mm mesh standard sieve to obtain uniform particle sizes, ensuring consistency and reliability in subsequent laboratory analyses. This meticulous sampling and preparation protocol aimed to ensure the accuracy and representativeness of the soil samples for further investigation.

2.2.2 Soil Analysis

A thorough soil analysis was conducted to assess the chemical properties of the soil. The analysis included measurements of Soil pH that determine the acidity or alkalinity of the soil, which affects nutrient availability, microbial activity, and plant growth. Soil pH influences the solubility and availability of essential nutrients. Cation Exchange Capacity (CEC), this evaluates the soil's ability to retain and exchange cations, which impacts nutrient availability, soil fertility, and overall plant health. Organic Matter Content assesses the soil's nutrient status, carbon sequestration potential, and overall soil health. Organic matter influences soil structure, water-holding capacity, and microbial activity. Nitrogen and Phosphorus Content use to determine the soil's nutrient status and potential for plant growth. These macronutrients are essential for plant development and productivity. Calcium (Ca) and Magnesium (Mg) Content was analyzed using Ethylenediaminetetraacetic Acid (EDTA) titration, a reliable method for determining Ca and Mg concentrations in soil. Sodium (Na⁺) and Potassium (K⁺) Content was Investigated using Flame Emission Spectrophotometry (FES), a sensitive technique that measures the emission spectra of alkali metals. The concentrations of zinc (Zn), chromium (Cr), cadmium

(Cd), copper (Cu), and lead (Pb) were determined using Atomic Absorption Spectrometry (AAS) with a model 210 VGP spectrometer. AAS is a precise and accurate method for detecting heavy metals in soil.

3.0 RESULTS AND DISCUSSION

The results of the soil analysis are presented in Table 1, which reveals the chemical properties and nutrient status of the soil samples. The pH values of the soil samples A, B, and C were found to be 6.70, 6.74, and 6.54, respectively, indicating a slightly acidic to neutral soil environment. According to Kumar *et al.* (2020), soil pH plays a crucial role in determining nutrient availability and microbial activity. The organic matter content of the soil samples varied significantly, with sample B having the highest value (0.384%), followed by sample A (0.342%) and sample C (0.280%). This is consistent with the findings of Lal (2019), who emphasized the importance of organic matter in soil fertility, structure, and overall health. Organic matter influences soil's water-holding capacity, aeration, and nutrient cycling (Brady and Weil, 2019; Kumar *et al.* 2020). The nutrient levels in the soil samples also varied. Sample A had the highest phosphorus content (0.084%), followed by Sample C (0.081%) and Sample B (0.070%). According to Fageria (2019), these values are within the optimal range for crop growth. The nitrogen content was found to be 0.07% for sample A, 0.07% for sample B, and 0.082% for sample C. Adequate nitrogen levels are essential for plant growth and development (Fageria, 2019). The CEC values of the soil samples were also determined, with sample B having the highest value (4.76), followed by Sample A (4.72) and Sample C (4.54). According to Brady and Weil (2019), CEC plays a significant role in soil fertility and structure, influencing nutrient availability and retention. The results of this study have implications for soil management and fertility. The slightly acidic to neutral soil pH and optimal nutrient levels suggest that the soil is suitable for crop growth. However, the varying levels of organic matter and CEC among the soil samples highlight the need for targeted soil management strategies to optimize soil fertility and structure (Brady and Weil, 2019; Fageria, 2019).

Table 1: pH, %organic matter, %phosphorus, %nitrogen and cation exchange capacity results of the Soil

| Sample | A | B | C |
|--------------------------|-------|-------|-------|
| pH | 6.70 | 6.74 | 6.54 |
| % Organic Matter | 0.342 | 0.384 | 0.280 |
| % Phosphorus | 3.26 | 3.36 | 3.13 |
| %Nitrogen | 0.08 | 0.07 | 0.082 |
| Cation Exchange Capacity | 4.74 | 4.76 | 4.54 |

Table 2 presents the concentrations of essential nutrients in the soil samples which carried out in accordance with the literature found elsewhere (Mehlich, 2020; Sparks, 2022; Tan, 2019). The results show that all the samples had K concentrations below the FAO/ISRIC limit (0.012 Cmol/Kg), indicating low K levels. This finding is consistent with the research of Lal (2019), who reported that potassium deficiency is a common issue in many soils. According to Brady and Weil (2019), potassium plays a crucial role in plant growth and development, and its deficiency can lead to reduced crop yields. The sodium concentrations in all the samples were within the FAO/ISRIC limits (0.0435 - 0.0652 Cmol/Kg), indicating moderate Na levels. This is in agreement with the findings of Fageria (2019), who reported that sodium is an essential nutrient for plant growth, but excessive levels can be detrimental. According to Kumar *et al.* (2020), sodium plays a role in plant water balance and nutrient uptake. The calcium concentrations in all the samples were within the FAO/ISRIC limits (0.02 - 0.04 Cmol/Kg), indicating moderate Ca levels. Calcium is an essential

nutrient for plant growth, and its deficiency can lead to reduced crop yields. According to Weil and Brady (2019), calcium plays a crucial role in plant cell wall development and root growth. The concentrations of magnesium in all the samples were within the WHO/FAO limits (0.004 - 0.016 Cmol/Kg), indicating moderate Mg levels. This finding is in conformity with the research of Brady and Weil (2019), who reported that magnesium is an essential nutrient for plant growth and development. According to Fageria (2019), magnesium plays a role in photosynthesis and nutrient uptake. The results of this study have implications for soil management and fertility. The low K levels in the soil samples suggest that potassium-based fertilizers may be necessary to optimize crop yields. The moderate levels of Na, Ca, and Mg suggest that these nutrients are not limiting factors for plant growth. However, regular soil testing is necessary to monitor nutrient levels and adjust soil management strategies accordingly (Brady and Weil; 2019; Fageria, 2019; Kumar *et al.*, 2020).

Table 2: Results for K, Na, Ca, and Mg in the soil samples

| Conc. (Cmol/Kg)/ Sample | A | B | C | FAO/ ISRIC (Cmol/Kg) |
|-------------------------|--------|--------|--------|----------------------|
| K | 0.0014 | 0.0016 | 0.0014 | 0.012 |
| Na | 0.0007 | 0.0007 | 0.0007 | 0.0435-0.0652 |
| Ca | 0.0006 | 0.0005 | 0.0006 | 0.02-0.04 |
| Mg | 0.0006 | 0.0007 | 0.0004 | 0.004-0.016 |

The analysis of heavy metal concentrations in the soil samples revealed concerning levels of zinc (Zn), chromium (Cr), and lead (Pb). Specifically, Zn all samples exceeded the WHO limit of 0.0002 Cmol/Kg, with Sample B having the highest concentration of 0.02697 Cmol/Kg. Elevated Zn levels can be phytotoxic, affecting soil fertility and crop yields. Sample C had Cr levels below the FAO/ISRIC limit of 0.00002 Cmol/Kg, while Samples A and B slightly exceeded this limit. Cr contamination can lead to reduced soil productivity and enzyme activity. Concentrations of Cd and Cu metals were below the FAO/ISRIC limits of 0.00005 Cmol/Kg and 0.00200 Cmol/Kg, respectively. The Pb concentrations in all the samples exceeded the FAO/ISRIC limit of 0.00001 Cmol/Kg, with Sample B having the highest concentration of 0.00017 Cmol/Kg. Pb is particularly hazardous, causing abnormalities in metabolic functions and reducing soil productivity. These findings are consistent with studies highlighting the risks

of heavy metal contamination in soils. For instance, research has shown that heavy metals like Pb, Cd, and Zn can accumulate in soil, posing ecological risks and affecting plant growth. Another study emphasized the impact of heavy metal pollution on soil health, including reduced enzyme activity and microbial biomass (Kabata-Pendias, 2019; Rajendran *et al.*, 2020).

Continuous monitoring of heavy metal concentrations in soil is crucial to mitigate potential ecological risks. Implementing remediation techniques, such as phytoremediation or adsorption, can help reduce heavy metal levels in contaminated soils. Sustainable Practices: Promoting sustainable agricultural practices, like using organic amendments and minimizing chemical inputs, can help minimize heavy metal accumulation in soils (Yan *et al.*, 2020). By adopting these strategies, we can mitigate the risks associated with heavy metal contamination and protect soil health for future generations (Gong *et al.*, 2018).

Table 3: Results for Heavy Metals Analysis of the Soil Samples

| Conc. (Cmol/Kg)/Sample | A (ppm) | B (ppm) | C (ppm) | FAO/ISRIC (Limits) |
|------------------------|-------------|-------------|-------------|--------------------|
| Zn | 0.021 47 | 0.026 97 | 0.026 54 | 0.0002 |

| | | | | |
|----|------------|-------------|-------------|---------|
| Cr | 0.000 5 | 0.000 47 | 0.000 02 | 0.00002 |
| Cd | 0.000 1 | 0.000 07 | 0.000 05 | 0.00005 |
| Cu | 0.000 3 | 0.000 22 | 0.000 04 | 0.00200 |
| Pb | 0.000 1 | 0.000 17 | 0.000 13 | 0.00001 |

4.0 CONCLUSION

The analysis of soil samples from the vicinity of local aluminum pot production centers revealed alarming levels of heavy metal contamination, despite exhibiting good physico-chemical properties. The study found that zinc had the highest concentration, exceeding the WHO limit, followed by lead, which also surpassed the FAO/ISRIC limit. Chromium levels were slightly above the limit in some samples, while cadmium levels were within the safe limit. Copper levels were within the safe limits set by the Food and Agriculture Organization (FAO) and International Soil Reference and Information Centre (ISRIC). The study concludes that the soil around local aluminum pot production centers poses significant environmental and health risks due to heavy metal contamination, which can lead to soil degradation, reduced crop yields, and potential human health hazards. Proper waste management practices, regular monitoring, and regulatory measures are necessary to mitigate these risks and protect human health and the environment. Furthermore, the implementation of sustainable practices, such as using cleaner production technologies and promoting environmental awareness, can help minimize the impact of heavy metal contamination.

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