Environmental and socioeconomic footprint of Small-Scale Mining: Pathways for Cleaner Mineral Extraction in Sub-Saharan Africa

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***Abstract*—Artisanal and small-scale mining (ASM) plays a vital role in the livelihoods of millions across Sub-Saharan Africa. It contributes significantly to the global supply of precious metals and critical minerals. However, ASM is often associated with severe environmental degradation and unsafe working conditions. This paper presents an integrated assessment of the geochemical and socioeconomic footprint of small-scale mining, drawing on case studies from Nigeria and South Africa. Field investigations reveal a culture of disregard for environmental protection, resulting in cyanide and heavy metal contamination exceeding permissible regulatory limits. Socioeconomic impacts include the destruction of agricultural land, leading to food insecurity and unemployment, as well as pollution, which raises living costs and can impact public health. To address these challenges, the study proposes a framework for cleaner mineral extraction. These include formalisation of artisanal mining activities, enforcement of mine closure planning, and establishment of designated spaces for small-scale mining activities. The study contributes to ongoing debates on balancing mineral resource exploitation with environmental sustainability, offering policy pathways for transitioning ASM toward cleaner and more responsible mineral extraction in Sub-Saharan Africa.**

***Keywords*—environmental sustainability, formalisation, mine closure, mine planning.**

I. Introduction

Sub-Saharan Africa is blessed with mineral resources, possessing a large percentage of the world's reserves of critical minerals, gold, diamonds, and hydrocarbons, which are vital for the energy transition and economic development. The region holds nearly 30% of global critical mineral reserves, substantial amounts of cobalt and manganese, significant diamond and gold deposits, and important oil and gas reserves [1]. In Nigeria, for example, there is an abundance of mineral resources that spread across every state in the country. The country has an estimated US$700 billion worth of commercially viable reserves of minerals, including gold, barite, bitumen, iron ore, lead, zinc, and coal, among others. Similarly, South Africa has a vast mineral portfolio, estimated to be worth over $2.5 trillion, which includes precious metals, base metals, energy minerals, and industrial minerals, though the full extent of discoveries is still being explored with modern technology. The country holds the world's largest reserves of platinum, chrome, and manganese, and ranks among the top global producers of many other minerals, including gold and diamonds [2]. Yet, the mineral wealth in the sub-Saharan African region has failed to significantly improve the socioeconomic well-being of most of the population in these countries.

Even more striking than the extractive industry’s minimal socioeconomic benefits to the region is the significant environmental burden it has imposed on the local population. Specifically, [3] posit that not only has mineral wealth failed to benefit much of South Africa's population, but sections of society have actually been harmed through the process of mineral extraction. A typical cause of this problem is the poor closure of legacy mine sites, which are sometimes left for the state to address. [4] documents how alluvial gold mine sites are overtaken in some parts of Nigeria by a group of illegal miners who contaminate water bodies, pollute the soil and land, destroy natural habitat, while displacing communities and endangering the health of community dwellers and workers.

Artisanal and small-scale mining (ASM) has been recorded to bring about immense environmental, safety and health impacts. There is an extensive report of environmental challenges linked to the occupation. As an illustration, [5] documents how the dredging and sluicing operations during artisanal and small-scale gold mining (ASGM) operations cause severe environmental degradation and siltation. The increases in suspended sediments from the river siltation inhibit the penetration of light into the water and significantly affect the supply of nutrients. Suspended sediment also tends to contain high concentrations of heavy metals. One such metal is lead, which, unlike mercury, does not travel very far but can settle on the ground and contaminate the soil [6]. Lead dust can also leach into the ground during heavy rains and contaminate it. Thus, ASGM can potentially cause environmental pollution and destruction of natural habitats at mining and waste sites [6]. Although South Africa lacks a formal ASM framework, informal operations (‘zama-zamas’) mirror the challenges observed in Nigeria and other Sub-Saharan countries. Therefore, this paper presents an integrated assessment of the geochemical and socioeconomic footprint of small-scale mining, drawing on case studies from Nigeria and South Africa.

II. Methodology

This study adopts a mixed-method approach, which combines experimental data with qualitative insights. In addition, a

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comparative framework is employed to develop and analyse findings from the two study areas, Nigeria and South Africa, highlighting the shared environmental and socioeconomic footprints of small-scale mining. The study integrates geochemical data from small-scale mining sites in Nigeria with qualitative insights on informal ASM practices in South Africa to derive a comparative environmental–socioeconomic footprint framework. Specifically, the experimental approach helps to quantitatively examine the presence of contaminants in the soil samples from the study area, while the qualitative approach attempts to explore and gain a deep and nuanced understanding of artisanal and small-scale mining operations, the operational dynamics of the miners and the potential environmental implications of the operations. Soil samples were collected from selected locations being used for gold rewashing operations. Interviews were also conducted with the miners in the selected operations surveyed. This integrated approach employed in this study ensures a comprehensive understanding of the environmental and socioeconomic footprint of small-scale mining, capturing both site-specific realities and broader regional implications.

III. Results

The findings from the experimental study reveal the presence of contaminants in the soil samples collected from the gold rewashing sites, as seen in Table 1. The cyanide concentrations in washed soils are significantly higher than in ordinary soils across all sites, as shown in Table 1. The Cyanide concentrations exceed the MCL across all sites investigated [7]. Cyanide is often associated with alluvial gold extraction, and its persistence in soil can pose severe environmental and health risks, including groundwater contamination and toxicity to aquatic life. As an illustration, [8] asserts that the release of cyanide-bearing toxic waste from mining activities into the local river system causes the rapid death of aquatic organisms and animals living close to the river system.

TABLE 1: COMPARISON OF THE AVERAGE CONCENTRATION OF CYANIDE IN ORDINARY AND WASHED SOILS (Eniowo, 2025).

Site	Ordinary soil (mg/kg)	Washed soil (mg/kg)
1	0.7533	1.1160
2	0.7033	1.5188
3	1.0363	2.0000

The results of pH measurements of soil samples from the rewashing sites show a general decrease in pH in washed soils compared to ordinary soils across all sites, as shown in Table 2. Such reductions suggest increased soil acidity, likely due to the leaching of alkaline minerals during the washing process. Acidification of soil is known to impact microbial activity and plant growth, potentially leading to reduced agricultural productivity in the affected areas.

TABLE 2. COMPARISON OF AVERAGE PH VALUES BETWEEN ORDINARY AND WASHED SOILS (Eniowo, 2025)

Site	Ordinary soil	Washed soil
1	6.150	5.885
2	6.455	5.518
3	5.890	5.010

Similarly, the results of the tests for heavy metal contamination show that there is a significant increase in the concentration of these heavy metals in the washed soils from the mine sites compared with the ordinary soils close to the sites. The tests of heavy metal concentration of soil carried out on the samples establish the level of contamination from the operations. While the concentration of some contaminants, such as Cu and As, in most of these sites are within the maximum concentration limit (MCL) by WHO and US EPA, some heavy metals (Cr and Pb) exceed the MCL across all sites investigated. Specifically, there is a significant increase in the concentration of these heavy metals in the washed soils from the mine sites compared with the ordinary soils close to the sites.

IV. Discussion

The contamination levels recorded in the Nigerian study sites reveal the typical environmental footprint of poorly regulated artisanal and small-scale mining (ASM). Elevated concentrations of heavy metals such as chromium (Cr) and lead (Pb), as well as increased cyanide content in washed soils, indicate active leaching of toxic materials into the surrounding ecosystem. Declines in pH values further suggest degradation of soil fertility. While these findings are site-specific, they mirror environmental conditions in other informal mining areas across Sub-Saharan Africa, where limited oversight and rudimentary processing methods contribute to persistent ecological stress.

In South Africa, similar environmental and social interactions emerge through the activities of informal miners, popularly known as *zama-zamas* [9]. Operating mainly in abandoned or derelict shafts, these miners engage in small-scale extraction that parallels the Nigerian rewashing practices in both technique and impact. Acidic mine drainage, groundwater contamination, and the collapse of mine voids have been reported in provinces such as Gauteng and Mpumalanga, illustrating how unregulated mining can transform closed or inactive mines into environmental hazards [9]. The observed contamination profiles in Nigeria, therefore, provide a useful proxy for understanding the cumulative ecological footprint of South Africa’s informal mining economy.

The environmental degradation seen in these contexts is inseparable from socioeconomic realities. In both countries, poverty, unemployment, and social exclusion are major drivers of informal extraction. The rewashing miners in Nigeria and the *zama-zamas* in South Africa depend on these activities as primary sources of income, despite the evident health and safety risks. Field interviews from the Nigerian case show that miners earn between USD 10 and 80 daily, comparable to informal miners in South Africa who rely on unstable and unsafe incomes from reprocessing tailings or scavenging abandoned workings. This reinforces that environmental contamination is not merely a technical problem but a manifestation of deeper livelihood insecurity and inequality.

The environmental damage caused by artisanal and small-scale mining has immense socioeconomic implications, especially on agriculture, as seen in Figure 1. It creates long-term challenges that often outweigh immediate economic benefits. These negative effects include the destruction of agricultural land, leading to food insecurity and unemployment, as well as water pollution, which raises living costs and can impact public health. Social issues like increased school dropouts, social vices, and heightened health risks for both miners and local communities are also direct results of this environmental damage [10]. Addressing the environmental footprint of ASM, therefore, requires a dual approach: strengthening environmental governance while simultaneously formalising and supporting small-scale miners. Both cases demonstrate that without economic inclusion and proper mine closure planning, abandoned mine sites will continue to attract informal activities that perpetuate pollution. [11] succinctly explained that because most *Zama Zamas* activities happen at abandoned or decommissioned mine sites, it is essential to acknowledge the context of how these operations at some of these sites ensued. Therefore, closure planning needs to be part of the life of the mine and must be taken into consideration when the mine commences operation.

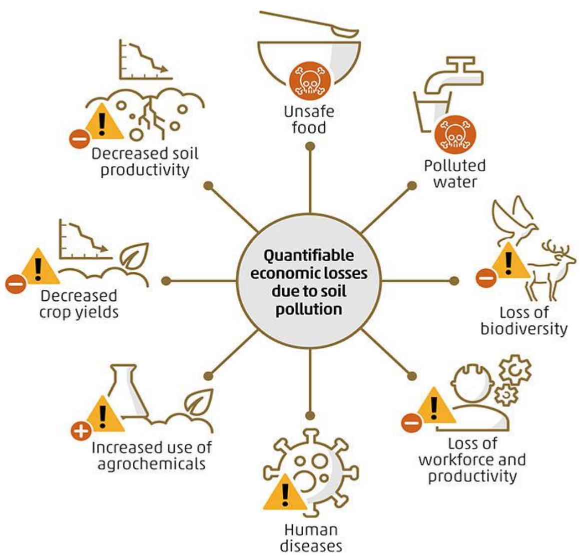

Figure 1. Impact of environmental degradation on livelihoods [12]

Integrating environmental rehabilitation with social protection measures, such as cooperative licensing, training in safer technologies, and alternative livelihood schemes, can mitigate contamination while improving community resilience. The intersection of contamination data and socioeconomic realities ultimately illustrates that cleaner mineral extraction in Sub-Saharan Africa will depend as much on social reform as on technical remediation. The socioeconomic dimensions of artisanal and small-scale operations mean that the occupation cannot simply be criminalised. The resultant social effect of such a move may be worse than the environmental concerns attributed to the occupation. The needs of the local miners must be addressed by any potential regulatory or policy intervention in the operations. Therefore, legitimate small-scale miners should be granted the necessary permits to operate legally, which aligns with current perspectives on artisanal and small-scale mining within sub-Saharan Africa [13], [14], [15].

V. Conclusion

This paper examines the environmental and socioeconomic implications of artisanal and small-scale mining (ASM) in Sub-Saharan Africa using Nigeria and South Africa as analytical lenses. The study found that ASM activities negatively impact the environment, which can affect other sources of livelihoods. However, the study observed that although the activities of the miners in this industry pose certain negative impacts, the local miners engaged in this occupation possess fundamental skills in the extraction and processing of mineral resources, and they contribute significantly to the national and regional production of critical minerals. The study therefore provides recommendations on a viable approach to tackling the environmental challenges linked to the occupation. In this regard, the study proposed an integration of the enforcement of environmental protection standards with social protection measures for ASM operators. In line with the findings of this research, further studies should pilot and evaluate formalisation schemes (such as cooperatives, licensing systems, or public–private partnerships) tailored to fit the socio-economic realities of small-scale miners across Sub-Saharan Africa.

Appendix

The supplementary dataset supporting the findings of this study can be found in Eniowo, O. D. (2025). https://doi.org/10.1016/j.wdp.2025.100682. This work extends the analysis of the previous study to compare socio-economic implications across new regions.

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