Sustainable Mining Principles: Optimizing its application to enhance Small-scale Gold Mining in Developing Countries

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Abstract
The global gold mining industry has long faced environmental and social challenges, particularly in small-scale operations prevalent in developing countries. This study delves into the integration of sustainable principles within the context of small-scale gold mining, aiming to optimize practices for enhanced environmental stewardship and social responsibility. Focusing on developing countries, where small-scale mining plays a pivotal role in local economies, this research explores how the application of sustainable gold mining principles can be tailored to mitigate environmental impact, promote ethical labour practices, and contribute to community development.

The study employs a multidisciplinary approach, using a partisan-systematic research methodology that incorporated geological, environmental, and socio-economic perspectives to develop a comprehensive set of recommendations. Consequently, by addressing some unique challenges faced by small-scale operations, this research aims to provide actionable insights and guidelines for policymakers, mining communities, and industry stakeholders to foster a more sustainable and responsible trajectory for small-scale gold mining in developing countries. Through the optimization of sustainable practices, the research envisions a future where gold mining contributes positively to both the environment and the well-being of local communities, aligning with global efforts towards responsible resource extraction.

Keywords
Gold, Mining, Gold Mining, Small-scale Gold Mining, Sustainability, Sustainable, Sustainable Mining Principles, Mines Environmental Compliance, Mining Environment, Mines Inspectorate, Urban Challenges, Urban Environmental Challenges.

1. Introduction
The global gold mining industry has a rich history that spans centuries, shaping economies and cultures worldwide. Gold's allure, tied to its rarity and intrinsic value, has fuelled exploration and extraction endeavours across diverse geographies. From the gold rushes of the 19th century to the establishment of large-scale mining operations, the industry has undergone significant transformations (Bell & Donnelly, 2006). Ancient civilizations recognized gold's significance, viewing it not only as a symbol of wealth but also as a key element in cultural and religious practices. With the advent of industrialization, gold mining evolved into a complex and multifaceted sector (Bell & Donnelly, 2006; R. Klemm & Klemm, 2013). Today, the industry is characterized by a mix of large-scale industrial mining, small-scale mining, and artisanal-scale mining, with a significant portion of the small-scale and artisanal mining (ASM) concentrated in developing countries.

1.1 Background of the Global Gold Mining Industry
Gyoh (2020) highlights the importance of implementing adaptation principles. This mini review is built upon the presentation and arguments of one of the earliest groundbreaking ideas published in 1975 by Albert Fry, and this inspired the possibilities of adapting sustainable principles in developing mineral resources and exploring potential precious rocks.
Rocks exhibit distinct characteristics which are based on the unique minerals found within them, as a result of the discoveries that have occurred either accidentally or through intentional exploration (Ogan et al., 2016). These findings have resulted in the utilization of geological materials for the benefit of those who explore them. Consequently, these materials have been gathered, selected, sifted, excavated, extracted, or harnessed for practical applications, a process that may have originated in primitive ways or been conducted by early civilizations (Bell & Donnelly, 2006; R. Klemm & Klemm, 2013). This gathering, extraction, or utilization of geological resources is collectively termed as mining on a global scale (Klemm and Klemm, 2013). The initial segment of this literature review, therefore, assesses the art and science of mining itself, incorporating perspectives from various sources. It introduces the concept of mining over time, providing a global overview, and guides the review towards the specific focus on gold mining, emphasizing its introduction in the relevant country of interest.
The global gold mining industry has a storied past, marked by exploration, discovery, and the pursuit of this precious metal across diverse landscapes. Gold, with its shimmering allure and enduring value, has captivated humanity for millennia. Historically, gold mining has been intertwined with the rise and fall of civilizations, shaping economies and cultures in profound ways (D. Klemm et al., 2001).

Although researchers have argued that one of the defining moments in the history of gold mining was the 19th-century gold rushes, (Davies et al., 2020; Morse, 2003; Rawls et al., 1999), these frenzied periods of prospecting and extraction, such as the California Gold Rush and the Klondike Gold Rush, drew people from around the globe seeking fortune and opportunity (Morse, 2003). The quest for gold spurred technological advancements, with innovations like the rocker box and hydraulic mining techniques transforming the scale and efficiency of gold extraction.

However, as the industrial revolution unfolded, large-scale gold mining operations emerged. Deep shafts, heavy machinery, and chemical extraction processes became characteristic of the industry. The establishment of major gold mining companies further solidified the global reach and impact of gold mining; nevertheless, the education and implementation of sustainable small-scale gold mining (SSGM) principles appear to have been neglected over time, especially in developing countries where these SSGM practices have remained (Akindele et al., 2023; Ewepu, 2021; Garba et al., 2021; Ogunjobi, 2023), and in fact are on the increase due to the significance of this scale of mining in those countries (Delve, 2023).

1.2 Significance of Small-scale Gold Mining in Developing Countries

While large-scale mining operations often dominate discussions about the gold mining industry, it's essential to recognize the pivotal role played by small-scale and artisanal mining, particularly in developing countries. Unlike their industrial counterparts, small-scale gold mining operations are often characterized by simplicity, reliance on manual labour, and community-based structures (International Institute for Sustainable Development [IISD], 2023; Schindler et al., 2016).

In developing countries, where economic opportunities are scarce, small-scale gold mining serves as a lifeline for many communities (Clifford, 2022). Families and local cooperatives engage in gold mining to secure income and meet basic needs (Ezebilo, 2010). The informal nature of these operations, however, presents both challenges and opportunities. On one hand, it provides a source of livelihood for marginalized communities, fostering economic decentralization. On the other hand, the lack of formalization can lead to issues such as informal land tenure, unsafe working conditions, and limited access to resources and technology (S. K. Mensah et al., 2022; Owusu et al., 2019).

1.3 Overview of Environmental and Social Challenges

The pursuit of gold, whether through large-scale mining or small-scale operations, is not without consequences for the environment and society (Rawls et al., 1999). Large-scale mining operations, often characterized by expansive open-pit mines and significant resource extraction, can result in deforestation, habitat destruction, and alterations to natural watercourses. The use of toxic chemicals like cyanide and mercury in the extraction process poses considerable risks to ecosystems and water sources (Chu et al., 2001; Kondolf, 1994; Lam & Lau, 2000; Verbrugge et al., 2021).

In the context of small-scale gold mining in developing countries, unique challenges emerge. Limited access to technology and resources means that artisanal miners often employ rudimentary methods, such as manual panning and gravity concentration, leading to increased pressure on local ecosystems (Ewepu, 2021; Lawan, 2022; Okeke, 2018; Tukur et al., 2023). The lack of proper waste disposal mechanisms has also been reported to have resulted in soil erosion and water contamination (Akindele et al., 2023; Kazapoe et al., 2023).

Socially, the informal nature of many small-scale operations pose's challenges related to labour practices and community well-being (Metta et al., 2023). Child labour, unsafe working conditions, and inadequate health and safety measures are prevalent issues (Metta et al., 2023). Additionally, the absence of formalized structures can impede access to education, healthcare, and other essential services for mining communities (Hilson et al., 2018).

The health, safety, environmental and social challenges associated with gold mining underscore the urgency of developing and improving sustainable and responsible small-scale gold mining practices for developing countries, especially in nations like Nigeria and Zambia where there is an actual structure that can be built upon (Eniowo et al., 2022; Hilson, 2020). In the subsequent sections, we will explore how the integration of sustainable principles can address these challenges and optimize small-scale gold mining in developing countries.

2. Materials and Methods

A comprehensive research study was undertaken using a partisan-systematic approach, which focused on investigative evaluations. This study involved a meticulous examination and interpretation of sustainable mining principles extracted from research articles within a selected database. Initially, a total of 16,060 publications were identified through a Scopus search on the key theme "sustainable mining". Subsequently, to narrow the search results, the search was refined to 804 publications by extending the keywords to "sustainable gold mining". Furthermore, the search was narrowed down to 154 publications by including another keyword "small-scale". Thereafter, the search strategy was focused by applying filters to limit the papers from the 154 search results to the papers from only four strategic keywords ("Small Scale Gold Mining", "Artisanal and Small-scale Gold Mining", "Small-Scale Gold Mining", "Sustainable Mining") bringing the results to 36 papers. Further narrowing the scope thereafter, the search strategy was focused by applying filters to specify the timeframe of interest (2013 – 2023) leaving the results at only 27 quality papers on the subject area (see: Figure 1).

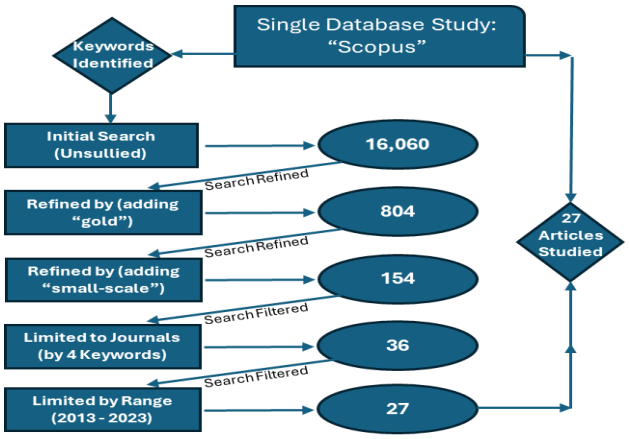

Figure 1: Search Strategy (Single Database Study)

The data was analysed into visuals using the VOS viewer software, and a couple of analysis stood out from the others. These were the *"co-authorship by countries"* analysis, and the *"co-occurrence by all keywords"* analysis. Thereafter the themes and keywords highlighted led to a rigorous review of the articles to which this study refers, which has also led to some of the outstanding arguments, ideas, and principles - discussed and recommended.

Table 1. Tabulated display of number of publications within the range of study

S/N	Year of Study	Number of Publications
01	2023	Results = 4
02	2022	Results = 14
03	2021	Results = 5
04	2020	Results = 1
05	2019	Results = 0
06	2018	Results = 2
07	2017	Results = 0
08	2016	Results = 0
09	2015	Results = 1
010	2014	Results = 0
011	2013	Results = 0

3. Results

3. 1 Co-Authors Bibliometric Analysis

Although the study has briefly introduced the subject of interest, with a review of the background, the significance of the niche, and an overview of certain challenges observed, the statistical analysis also provided interesting results from exploring and analyzing the large volumes of scientific data that the initial search generated (Donthu et al., 2021), and narrowing it down to the articles studied (see: Table 1). The study enabled us to unpack the evolutionary nuances of a small-scale gold mining, while shedding light on the emerging areas sustainable mining. Hence, after a refined and focused search, the data generated from Co-Authors crossed by Countries displayed brilliant network of connections that tells where the research interest in the last decade has been more prevalent.

Figure 2: Display of a Network between "Co-authors and Countries".

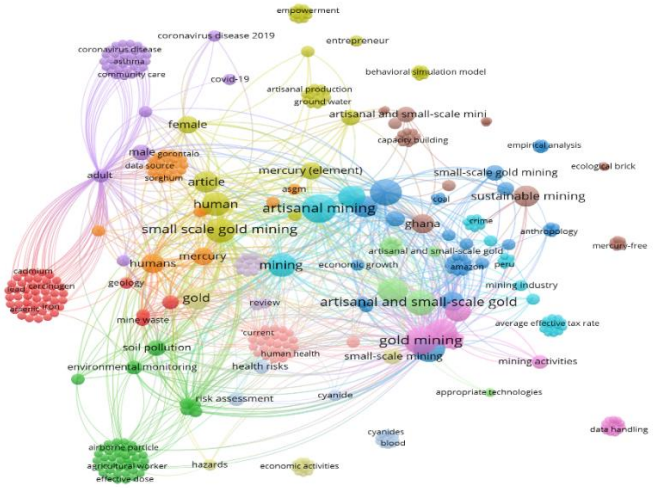

Figure 3: Display of the network between "Co-occurrence and All-Keywords" (Unsullied).

3. 2 "Co-occurrence" Bibliometric Analysis

The semantic network was analyzed and a graphic visualization that displayed the potential relationships between people and the major concepts represented within papers we studied were displayed as presented (see: Figure 3). The more captivating concepts in the semantic network or co-occurrence network were "sustainable mining, gold mining, artisanal mining, gold mine, mining, gold, mercury, human, environmental monitoring, sustainable development goal, risk assessment, hazard, Ghana, adult, male, female", etc. This gives a vivid picture of what is being discussed in relation to small-scale gold mining - when the semantic network was analysed - displaying how the buzzing keywords do connects. Hence, figure 4 suggests that a healthy discussion about small-scale gold mining and its impact is ongoing in the academic sphere globally.

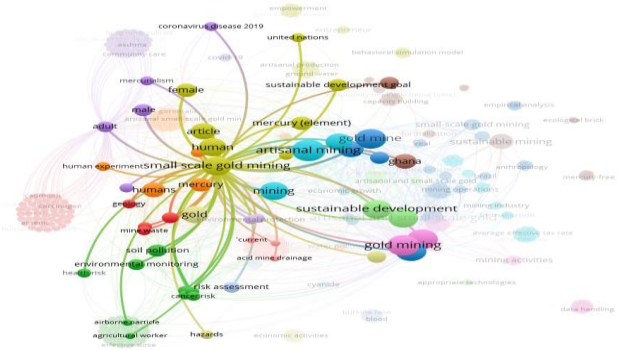

Figure 4: Display of the network between "Co-occurrence and All-Keywords" (With a Focus on Small-scale Gold Mining).

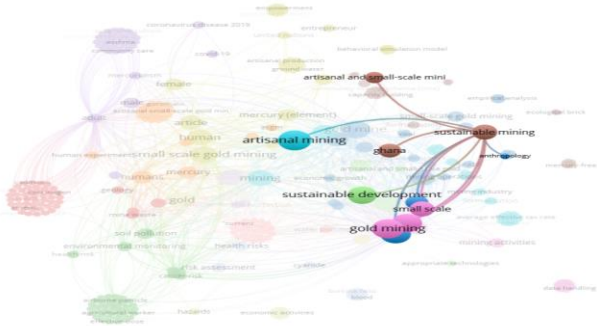

Figure 5: Display of the network between "Co-occurrence and All-Keywords" (With a Focus on Sustainable Mining).

Remarkably though, when the focus was moved to sustainable mining, only a hand full of semantic connections were observed (see: Figure 5). These included artisanal mining, gold mining, small scale, sustainable development, artisanal and small-scale gold mining, Ghana, and anthropology.

4. Discussion

Conducting a closer study of the generated connections and the lessons drawn from these selected studies, it was observed that in order for the "small-scale gold mining" sub-sector to begin to progress towards the implementation of "sustainable mining principles", the following themes would require proper attention, for "Optimization of their application to enhancing Small-scale Gold Mining in Developing Countries". These themes would include "Environmental Stewardship in Small-scale Gold Mining (Fisher et al., 2023; Sarpong et al., 2023), Ethical Labor Practices (M. K. Mensah et al., 2023; Metaragakusuma et al., 2023), Community Development (Massaro & de Theije, 2018; Obuobi et al., 2022), Comprehensive Framework for Sustainable Practices (Arthur-Holmes et al., 2022; Bebbington & Humphreys Bebbington, 2018; Leiva, 2022; Odell et al., 2018), and Policies Reframing, Advocacy and Executions (Policy Recommendations)" (Besada & Golla, 2023; Cheng et al., 2023; Kazapoe et al., 2023; Lawson & Chowdhury, 2022; Selin & Selin, 2022).

Table 2: Themes for "Optimizing Sustainable Mining Principles to enhance Small-scale Gold Mining in Developing Countries."

Themes	Features
Environmental Stewardship in Small-scale Gold Mining	• Mitigation of Environmental Impact • Adoption of Cleaner Technologies • Biodiversity Conservation
Ethical Labor Practices	• Addressing Issues of Child Labor and Unsafe Working Conditions • Fair Wages and Labor Rights • Community Engagement and Empowerment
Community Development	• Socio-economic Impact of Small-scale Gold Mining • Contribution to Local Economies • Infrastructure and Education Initiatives
Comprehensive Framework for Sustainable Practices	• Integration of Sustainable Principles • Customization for Small-scale Operations • Balancing Economic Viability and Environmental Responsibility
Policy Recommendations	• Reframing Guidelines for Policymakers • Regulatory Frameworks Supporting Sustainable Practices • Incentives for Adoption of Responsible Mining

4. 1 Environmental Stewardship in Small-scale Gold Mining

i. **Mitigation of Environmental Impact**: This involves implementing a range of measures to reduce the negative environmental consequences of small-scale gold mining. These may include using mercury-free processing methods, such as gravity separation or flotation; employing proper waste management practices to reduce contamination of soil and water sources; and implementing reclamation and rehabilitation plans to restore land affected by mining activities.

ii. **Adoption of Cleaner Technologies**: Small-scale miners can adopt cleaner and more sustainable technologies to reduce their environmental footprint. For example, they can use retorts or other mercury capture devices to reduce mercury emissions during gold amalgamation, or they can utilize solar-powered equipment to reduce reliance on fossil fuels and lower greenhouse gas emissions.

iii. **Biodiversity Conservation**: Protecting biodiversity is crucial in small-scale gold mining areas, where mining activities can lead to habitat destruction and loss of wildlife. Conservation efforts may involve establishing protected areas within mining concessions, implementing reforestation and habitat restoration projects, and conducting regular biodiversity assessments to identify and protect key species and ecosystems.

4. 2 Ethical Labour Practices

i. **Addressing Issues of Child Labor and Unsafe Working Conditions**: Governments and mining companies must enforce strict regulations to prohibit child labour and ensure safe working conditions for all miners. This may involve conducting regular inspections, providing safety training, and implementing occupational health and safety standards to prevent accidents and occupational hazards.

ii. **Fair Wages and Labor Rights**: Miners should receive fair compensation for their work and have access to basic labour rights, such as the right to organize and collective bargaining. This may require establishing minimum wage laws, ensuring timely payment of wages, and providing mechanisms for workers to address grievances and disputes.

iii. **Community Engagement and Empowerment**: Empowering local communities is essential for promoting ethical labour practices in small-scale gold mining. This may involve establishing community-based organizations or cooperatives to represent the interests of miners, providing training and capacity-building programs to enhance skills

and knowledge, and fostering partnerships between mining companies, governments, and communities to address common challenges and opportunities.

4. 3 Community Development

i. **Socio-economic Impact of Small-scale Gold Mining**: Understanding the socio-economic impact of small-scale gold mining is critical for designing effective community development initiatives. This may involve conducting socio-economic assessments to identify key challenges and opportunities, such as poverty reduction, income inequality, and social cohesion, and developing targeted interventions to address these issues.

ii. **Contribution to Local Economies**: Small-scale gold mining can make significant contributions to local economies by providing employment opportunities, generating income for local businesses, and stimulating economic growth. Governments and mining companies can support local economies by promoting local procurement, investing in infrastructure development, and facilitating access to finance and market opportunities for small-scale miners.

iii. **Infrastructure and Education Initiatives**: Investing in infrastructure and education is essential for promoting sustainable development in small-scale gold mining communities. This may involve building roads, schools, and healthcare facilities to improve access to basic services, providing scholarships and vocational training programs to enhance educational attainment and skills development, and supporting community-based initiatives to promote entrepreneurship and economic diversification.

4. 4 Comprehensive Framework for Sustainable Practices:

i. **Integration of Sustainable Principles**: Sustainable small-scale gold mining requires a holistic approach that integrates environmental, social, and economic considerations into all stages of the mining cycle. This may involve developing comprehensive sustainability frameworks or guidelines that outline best practices and standards for responsible mining operations, from exploration and extraction to processing and closure.

ii. **Customization for Small-scale Operations**: Recognizing the unique characteristics and challenges of small-scale gold mining operations is essential for designing effective sustainability interventions. This may involve tailoring support mechanisms, such as technical assistance, training, and financial incentives, to the specific needs and capacities of small-scale miners and communities.

iii. **Balancing Economic Viability and Environmental Responsibility**: Achieving a balance between economic viability and environmental responsibility is key to sustainable small-scale gold mining. This may require promoting alternative livelihoods and income-generating activities to reduce dependence on mining, incentivizing environmentally friendly practices and technologies, and establishing mechanisms for revenue sharing and benefit distribution to ensure that mining benefits are equitably distributed among all stakeholders.

4. 5 Policy Recommendations:

i. **Reframing Guidelines for Policymakers**: Governments can play a critical role in promoting sustainable small-scale gold mining by developing clear guidelines, regulations, and standards that prioritize environmental protection, social equity, and economic development. This may involve conducting stakeholder consultations, reviewing existing policies and regulations, and incorporating international best practices into national legal frameworks.

ii. **Regulatory Frameworks Supporting Sustainable Practices**: Strengthening regulatory frameworks is essential for ensuring compliance with environmental and labour standards in small-scale gold mining. This may involve enforcing stricter regulations, increasing penalties for non-compliance, and providing technical assistance and capacity-building support to regulatory agencies responsible for overseeing mining activities.

iii. **Incentives for Adoption of Responsible Mining**: Governments can provide incentives to encourage small-scale miners to adopt responsible mining practices and technologies.

Accordingly, by implementing these recommendations, stakeholders can work together to promote sustainable small-scale gold mining practices that contribute to economic development, environmental protection, and social well-being in mining communities.

5. Conclusions

Finally, our recommendations based on the results and the discussions of the study, would be that, governments, the private sector (mining firms, services firms, and other related firms), host communities, non-governmental organizations, and all stakeholders, should work towards implementing the "Sustainable Principles" out-lined table 2, by promoting the "Interconnectedness of Environmental, Social, and Economic Factors", the "Need for Collaborative Efforts", the "Importance of Tailored Solutions", the "Role of Policy and Regulation", "Long-Term Perspective and Continuous Improvement", and the "Recognition of the Value of Local Communities".

5.1 Interconnectedness of Environmental, Social, and Economic Factors

Sustainable small-scale gold mining requires a balanced approach that considers not only environmental protection but also social equity and economic development. These factors are interconnected, and addressing one without the others may lead to unintended consequences.

5.2 Need for Collaborative Efforts

Achieving sustainability in small-scale gold mining requires collaboration among multiple stakeholders, including governments, mining companies, local communities, NGOs, and international organizations. Effective partnerships and multi-stakeholder initiatives are essential for addressing complex challenges and finding mutually beneficial solutions.

5.3 Importance of Tailored Solutions

One-size-fits-all approaches are often ineffective in the context of small-scale gold mining, given the diversity of mining operations and the varying socio-economic contexts of mining communities. Tailored interventions that take into account the specific needs, capacities, and circumstances of small-scale miners and communities are crucial for promoting sustainable practices.

5.4 Role of Policy and Regulation

Clear and enforceable policies and regulations are fundamental for promoting sustainable small-scale gold mining. Governments have a critical role to play in setting standards, providing incentives, and ensuring compliance with environmental and labour laws. Regulatory frameworks should be designed to strike a balance between promoting responsible mining and enabling economic development.

5.7 Long-Term Perspective and Continuous Improvement

Sustainable small-scale gold mining is a long-term endeavour that requires ongoing monitoring, evaluation, and adaptation. Stakeholders should commit to continuous improvement, learning from both successes and failures, and incorporating new knowledge and innovations into their practices over time.

5.8 Recognition of the Value of Local Communities

It is a no-brainer to forget the importance of host or local communities. These communities are at the heart of small-scale gold mining, and their participation and empowerment are essential for achieving sustainability. Recognizing and respecting the rights and interests of communities, including their cultural heritage and traditional knowledge, is crucial for building trust, fostering collaboration, and ensuring the long-term well-being of mining-affected areas.

In conclusion, promoting sustainable small-scale gold mining requires a holistic and inclusive approach that addresses environmental, social, and economic dimensions, and would involve collaboration among diverse stakeholders, in such a way that would prioritize the well-being of local communities and ecosystems. Consequently, by working together and embracing innovation and best practices, stakeholders can contribute to a more sustainable and equitable future for small-scale gold mining in developing countries.

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