



Science Forum (Journal of Pure and Applied Sciences)



Journal Homepage: <https://atbuscienceforum.com.ng/index.php/jpas>

Green Mining: A Review and Recommendation for Reducing Environmental Risks in Nigeria

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Abstract

Nigeria's mining sector has contributed appreciably to national economic growth through revenue generation, employment creation, and enhanced access to strategic and precious mineral resources. Notwithstanding these benefits, conventional mining practices in the country are typically associated with significant environmental externalities. These include extensive land degradation manifested as habitat destruction and landscape alteration, accelerated soil erosion, contamination of surface and groundwater systems through the release of toxic effluents and heavy metals, and large-scale deforestation resulting from unregulated extraction activities. Such impacts collectively threaten ecosystem integrity, biodiversity sustainability, and long-term land productivity. This review critically evaluates the concept of *green mining* as a sustainable framework for mitigating the environmental risks associated with mineral resource exploitation in Nigeria. *Green mining* is examined as an integrated approach that emphasizes environmentally responsible extraction, efficient resource utilization, minimization of ecological footprints, and the adoption of cleaner production technologies throughout the mining value chain. The study synthesizes existing literature on green mining principles, including waste minimization, energy efficiency, water conservation, land reclamation, and the incorporation of environmentally benign processing techniques. Furthermore, the review provides context-specific recommendations for operationalizing green mining practices within the Nigerian mining sector. These include the enforcement of stricter environmental regulations, integration of environmental impact assessment (EIA) protocols into all stages of mining operations, deployment of modern low-impact extraction technologies, and promotion of mine closure and land rehabilitation strategies. Emphasis is also placed on institutional strengthening, stakeholder engagement, and capacity building to ensure compliance and sustainability. Overall, the study underscores the imperative for transitioning from conventional mining systems to environmentally sustainable frameworks, positioning green mining as a viable pathway for balancing economic development with ecological preservation in Nigeria.

Keywords

Green mining,
Environmental sustainability,
Nigeria mining sector,
Mines, Hazards,
Toxic Compounds

1.0 Introduction

Mineral resources constitute a fundamental component of modern industrial economies, serving as critical raw materials for manufacturing, infrastructure development, and energy production across continents (Pekka, 2017). The extraction and utilization of these resources remain indispensable to human development, as mining provides the primary means of harnessing naturally occurring geological materials. In many resource-endowed nations, including Nigeria, mineral resources represent a significant source of national income, foreign exchange earnings, and employment opportunities. However, these resources must undergo sequential stages of exploration, extraction, and processing before attaining economic utility (Adekoya, 2003).

Despite the economic importance of mining, its environmental implications are profound. As noted by Khobragade (2020), anthropogenic activities driven by the need for survival and socio-economic advancement are the principal drivers of environmental degradation. Mining operations, in particular, leave long-lasting ecological footprints. In many parts of Nigeria, abandoned mine sites are characterized by water-filled pits, extensive overburden dumps, and accumulations of tailings. These features not only degrade the landscape but also pose significant environmental and public health risks, including potential radiation exposure, land defoliation, contamination of surrounding ecosystems, and hazards to both human and animal populations.

The mineral development cycle—comprising exploration, mining, and mineral processing—has been widely associated with diverse

environmental risks. These include radiation hazards, ecosystem disruption, biodiversity loss, air and water pollution, soil contamination, geotechnical instability of rock masses, and overall landscape degradation (Aigbedion and Iyayi, 2007). Such impacts underscore the urgent need for sustainable approaches to mineral resource exploitation. In response to these challenges, the concept of *green mining* has emerged as a strategic framework aimed at minimizing the environmental and social impacts of mining activities while maximizing economic and community benefits.

Green mining (GM) refers to the adoption of environmentally responsible technologies and practices in mineral extraction and processing, with a focus on sustainability, resource efficiency, and ecological preservation (Sonter et al., 2018). This study, therefore, examines the mining sector in Nigeria, evaluates the associated environmental risks, reviews the current state of knowledge, identifies critical gaps, and proposes feasible mitigation strategies for sustainable mining development.

1.1 Environmental Risks in Nigerian Mining

Conventional mining practices in Nigeria are often associated with significant environmental degradation. These impacts include deforestation, destruction of natural habitats, contamination of surface and groundwater systems, and increased greenhouse gas emissions. Such outcomes not only compromise ecosystem integrity but also threaten human health and long-term environmental sustainability.

Green mining seeks to address these challenges by promoting operational frameworks that reduce the ecological

footprint of mining activities while ensuring occupational safety, worker well-being, and broader societal protection. It emphasizes the integration of environmental management systems, cleaner production technologies, and sustainable resource utilization throughout the mining lifecycle.

Environmental degradation in mining environments arises from various extraction and processing methods, including:

(1) open-pit mining, which leads to large-scale land disturbance and vegetation loss;

(2) underground mining, associated with subsidence and groundwater disruption;

(3) in situ leach (ISL) mining, which poses risks of aquifer contamination;

(4) heap leaching, often linked to chemical leakage and soil pollution; and

(5) brine mining, which can alter hydrological systems and salinity balances. A

comprehensive understanding of these mining methods and their associated environmental risks is essential for developing effective mitigation strategies and advancing sustainable mining practices in Nigeria.



Fig 1: Dangerous Collapsed Open Mining Pits in Jos, Nigeria (After Tunji, 2022).

Azubuiké et al. (2023), opined that mining activities play a significant role in Nigeria's economy, contributing to revenue generation and employment opportunities. However, these activities also pose various environmental risks, which need to be carefully managed to ensure sustainable development and minimize negative impacts.

This section discusses the various environmental risks associated with traditional

mining practices in Nigeria. It covers issues such as land degradation, water contamination, air pollution, and biodiversity loss. Azubuiké et al. (2023), again maintained that uncontrolled mining could result in the discharge of hazardous materials into the land, air, and water. To lessen the harm from mining-related sources, it has been suggested that governments deploy cutting-edge technologies and strict controls on businesses.



Fig 2: Artisanal Lotto Mine Practice in Nigeria (Diaro, 2021)

With the increasing globalization of the mining industry and the expansion of operations into jurisdictions with varying degrees of environmental regulation, it has become imperative that robust safeguards—such as those prescribed by the Strategic Minerals Association (SMA)—are fully implemented prior to the commencement of mining activities. These safeguards are critical for ensuring that environmental protection measures are standardized and enforced irrespective of local regulatory disparities, thereby minimizing ecological degradation and associated health risks.

Mining operations are inherently linked to a range of environmental challenges, primarily due to the disturbance of geological materials and the mobilization of potentially hazardous substances. Among the principal contaminants generated during mining activities are

radionuclides, particulate matter (dust), greenhouse gas emissions (notably carbon outputs), and a variety of heavy metals such as lead, arsenic, cadmium, and mercury. These contaminants can be released into the atmosphere, hydrosphere, and lithosphere, leading to widespread environmental pollution and long-term ecological consequences.

For example, mechanical processes such as drilling, blasting, and crushing of rock materials generate fine particulate dust that can act as a vector for toxic metal dispersion. As noted by Paul and Campbell (2011), such dust often contains heavy metals that are strongly associated with adverse human health outcomes. A notable case is the mineral riebeckite, an amphibole that exhibits structural similarities to asbestos. When fragmented, riebeckite can produce fibrous particles capable of becoming airborne and

subsequently inhaled. Once deposited in lung tissue, these fibers may induce chronic respiratory diseases, including pneumoconiosis and silicosis—commonly referred to as “black lung” disease.

These health risks underscore the necessity for stringent environmental monitoring, dust

suppression systems, and occupational health controls in mining operations. The integration of such measures within a green mining framework is essential for reducing exposure pathways and safeguarding both environmental quality and human health.

Table 1: Risks during Mining and associated Toxic Compounds and Compartments

Risk	Affected Compartments	Relevant toxic Compounds
Overtopping of tailing dams	Groundwater, surface water, soil	Water Emissions In most cases Radionuclides, mainly Thorium and Uranium Heavy metals Acids Fluorides
Collapse of tailings dam by poor construction	Groundwater, surface water, soil	
Collapse of tailings dam by seismic events	Groundwater, surface water, soil	
Pipe leakage	Groundwater, surface water, soil	
Ground of tailings pond not leak-proof	Groundwater	Air Emissions In most cases Radionuclides, mainly Thorium and Uranium Heavy metals HF, HCL, SO ₄ , etc.
Waste rock stockpiles exposed to rainwater	Groundwater, surface water, soil	
Dust from waste rock and tailings	Air, soil	
No site rehabilitation after cease of mining operation	Land-use, long-termed contaminated land	
Processing without flue gas filter	Air, soil	
Processing without waste water treatment	Surface water	

An additional example of harmful dust produced is flue dust, a byproduct of mining fluorine. According to the Chinese Society of Rare Earths (Schuler et al, 2011), every ton of rare earth element (REE) produced produces 8.5kg of fluorine and 13kg of flue dust, which contains heavy metals. According to the Chinese Society of Rare Earths, every ton of

REE produced generates 8.5kg of fluorine and 13kg of flue dust, waste materials which contain heavy metals (Schuler et al, 2011).

1.1 Green Mining Principles

Green mining which is the implementation of environmentally friendly practices and technologies in the mining industry aims to

reduce the ecological impact of mining operations, minimize resource consumption, and promote sustainable practices throughout the mining life cycle (Sonter et al., 2018). Achieving green mining in Nigeria, or any region, involves implementing environmentally friendly practices and technologies throughout the mining process.

By integrating principles of sustainability, energy efficiency, and responsible resource management, green mining strives to balance economic growth with environmental stewardship. The following are the key principles that Nigeria can follow to implement green mining:

1. **Environmental Stewardship:** Green mining prioritizes the protection and preservation of ecosystems, biodiversity, and water resources. It aims to minimize the disturbance of habitats, prevent soil erosion, and mitigate the release of harmful substances into the environment.
2. **Energy Efficiency:** Green mining focuses on optimizing energy consumption and reducing greenhouse gas emissions associated with mining activities. This involves implementing energy-efficient technologies, utilizing renewable energy sources, and adopting strategies to minimize energy waste.
3. **Waste Reduction and Recycling:** Green mining aims to minimize waste generation and promote the recycling and reuse of materials. This includes employing efficient extraction techniques to reduce the amount of waste produced, implementing waste management strategies, and recycling or repurposing mining byproducts.

4. **Water Conservation:** Green mining emphasizes responsible water usage and management. It strives to minimize water consumption during mining operations, implement water treatment and recycling systems, and prevent water pollution by adopting appropriate containment and treatment measures.
5. **Community Engagement and Social Responsibility:** Green mining encourages meaningful engagement with local communities and indigenous groups, respecting their rights and interests. It promotes responsible mining practices that prioritize the well-being of local communities, including job creation, skills development, and infrastructure investments.

1.2 Promoting Green Mining in Nigeria

Mining plays a crucial role in our modern society (Githiria and Onifade, 2020) especially in Nigeria, providing the essential raw materials needed for various industries. Traditional mining techniques, however, have a major negative impact on the environment, including habitat destruction, water pollution, and greenhouse gas emissions. A growing awareness of the urgent need to switch to environmentally friendly and sustainable mining methods has emerged in recent years. To promote green mining, these are the points to observe

1. **Environmental Impact Assessment:** Conduct a comprehensive environmental impact assessment before starting any mining operation. This assessment should evaluate the potential environmental consequences of the mining activities and identify

- measures to mitigate and minimize those impacts.
2. **Sustainable Mining Practices:** Implement sustainable mining practices that minimize the ecological footprint of mining operations. This includes reducing the use of water, energy, and chemicals, as well as optimizing the extraction and processing methods to minimize waste generation.
 3. **Reforestation and Biodiversity Conservation:** Develop reforestation programs to restore and rehabilitate the ecosystems affected by mining activities. Planting native tree species can help restore biodiversity and improve soil quality. Protecting and conserving areas with high ecological value is also crucial to preserve local biodiversity.
 4. **Efficient Water Management:** Implement water management strategies to minimize water consumption and prevent contamination of water sources. Use closed-loop systems for water recycling and treatment to reduce the impact on local water bodies.
 5. **Adoption of Clean Energy:** Promote the use of clean and renewable energy sources to power mining operations. Installing solar panels, wind turbines, or other renewable energy systems can help reduce greenhouse gas emissions and dependency on fossil fuels.
 6. **Waste Management:** Develop comprehensive waste management plans to minimize the generation of mining waste and ensure proper disposal of hazardous materials.
 7. **Stakeholder Engagement:** Engage with local communities, government agencies, and environmental organizations to ensure transparency and incorporate their perspectives in the decision-making process. Foster dialogue and collaboration to address concerns and implement sustainable mining practices that benefit the local communities.
 8. **Compliance with Regulations:** Adhere to environmental regulations and standards set by the government and regulatory bodies. Ensure that mining operations meet all requirements related to air quality, water quality, land reclamation, and other environmental parameters.
 9. **Continuous Monitoring and Reporting:** Establish monitoring systems to regularly assess the environmental impacts of mining activities. Monitor air and water quality, soil erosion, and biodiversity to identify potential issues and take corrective actions promptly. Transparent reporting of environmental performance helps build trust and accountability.
 10. **Research and Innovation:** Encourage research and development of innovative technologies and practices that can further improve the sustainability of mining operations. Explore alternatives to conventional mining methods, such as bioleaching or phytomining, which can reduce the use of harmful chemicals.

1.3 Best Practices for Green Mining

This section examines successful green mining initiatives from around the world and presents relevant case studies that can serve as inspiration for Nigeria. It explores innovative techniques for waste management, energy efficiency, water conservation, and land rehabilitation.

Many sustainable ways have been developed to mitigate the effects of mining. In Europe and Australia, for example, the 3RS technique (Reduce, Recycle, and Reuse) is used. Total mined waste can be reused without reprocessing, saving energy and water, whilst recycling aids in the production of new products. Toxic metals such as arsenic, cadmium, and thorium, according to

Struthers, can be removed using a constantly stirred tank reactor (Venkata et al., 2021).

1.3.1 Hybrid Diesel/Electric Equipment

This is used in underground mining to reduce pollution and greenhouse gas emissions, enhance energy efficiency, and promote sustainable development. Hybrid diesel-electric trucks, trucks outfitted with electricity-generating gen-sets, trolley assist systems (which might reduce diesel usage by roughly 350 litres per hour), electric drills and sophisticated electric batteries are among the alternatives now being explored. According to the survey, using hybrid diesel-electric equipment in underground mines cut 32% of greenhouse gas emissions in Canada.



Fig 3: White Hybrid Diesel/Electric Hitachi Dump Truck used to cut Greenhouse Gas Emissions (Moore, 2014)

1.4.2. Biomining

Biomining, also known as bioleaching or bioremediation, is a process that uses microorganisms to extract valuable metals from ores and other mineral sources (Balasubramanian, 2016). It is a form of mining that relies on the biological activity of living organisms to carry out the extraction process.

In traditional mining methods, such as open-pit or underground mining, metals are extracted by physically removing and processing large amounts of ore. Biomining, on the other hand, harnesses the metabolic capabilities of certain microorganisms, such as bacteria or fungi, to dissolve and recover metals from low-grade ores or mineral concentrates.

The inclusion of microbes removes metal from rocks, which is an environmentally favourable technology. Copper may be recovered from rocks by adding bacteria to bioleaching ores in acid (Venkata et al., 2021).

1.4.3. Gangue Backfilling Mining Technology

Land subsidence and gangue discharge are two primary environmental problems associated with mining in Nigeria. This is used in coal mining to assist reduce waste and manage roof deformation as seen in Fig 3. Mining under the roof can have a significant impact on the working force, thus controlling and supporting the roof control of the coal seam Mining technology for gangue backfilling is used.

The application of backfilling technology leads to many problems as it affects the mining face. Various backfilling solutions have been developed; however, their application has not been very successful. In China, the University of Mining and Technology conducted research and produced a novel mechanization system in 2006. Gangue backfilling system that improved the gangue-filling impact in the Gob area.



Fig 4: Backfilling a chamber at the 637-level former potash mine Ronnenberg, Germany (Helmholtz Zentrum München, 2010)

1.4.4. Biosurfactants

Another good green mining practice that will be good for Nigeria is biosurfactants. *Bacillus subtilis* can create biosurfactants, which are used to remove heavy metals from pollution by precipitation-dissolution, ion exchange, and counter-ion binding. Sphorolipids are essential in the removal of iron, arsenic, and copper from mining tailings (Venkata et al., 2021).

Sonic drilling is an innovative green mining technique that uses mechanical oscillation drills to drill faster than conventional drilling.

It mines diamonds, gold, and lithium without the use of drilling fluids, which helps to lessen environmental effects.

1.4.5. Dust Suppression Technique

A dust suppression technology was proposed to investigate the compound dust suppressant with four functions of wetting, coagulation, moisture absorption, and moisture retention, and improve the hydrophilicity and dust suppression efficiency of burnt rock in order to solve the serious dust pollution problem in the mining and loading process of burnt rock open-pit coal mines (Zhao et al., 2021).



Fig 5. Dust Suppression: A Misting Ring Encloses the Material Stream in a Curtain of Atomized Dust (ECWeigh, 2023)

By pre-wetting the regions in mining zones, this strategy aids in dust removal. The spraying dust performance technique was enhanced by developing a negative pressure secondary dust suppression approach that successfully absorbs the dust air flow and

covers all of the areas between the coal walls and the hydraulic supports column.

1.4.6. Liquid Emulsion Technology

Acid mine drainage is one of the biggest environmental issues, and numerous

approaches (biosorption, ion exchange solvent, chemical precipitation) have been used to address the issue, however, these methods have many drawbacks. In the central portion of Chile, the liquid emulsion technique is employed to recover copper from acid mine drainage. A dispersed system composed of at least two immiscible liquid phases is referred to as an emulsion. The distributed liquid, which is typically in the form of droplets, is known as the dispersed, discontinuous, or internal phase. The continuous or exterior phase is the liquid that surrounds these droplets (McClements, 2015).

1.4 Policy and Regulatory Framework

An effective policy and regulatory framework are crucial for promoting green mining practices. This section discusses the importance of developing comprehensive regulations and guidelines that incentivize sustainable mining practices. It also emphasizes the need for effective enforcement mechanisms and stakeholder engagement. Capacity building and technology transfer from advanced countries is also important in achieving this. Therefore, in implementing green mining practices, they are essential. This section explores strategies for training mining personnel in sustainable techniques and facilitating the transfer of environmentally friendly technologies to Nigeria.

1.5 Community Engagement and Social Responsibility

Engaging local communities and addressing their concerns is vital for the success of green mining initiatives. This section emphasizes the importance of community participation, consultation, and benefit-sharing, as well as

promoting responsible mining practices and corporate social responsibility.

1.6 Recommendations for Green Mining Exploitation in Nigeria

Green mining is an approach to mining that aims to minimize the environmental impact of mining activities, promote sustainable practices, and ensure the efficient use of resources. Here are some recommendations for green mining in Nigeria:

- 1 **Sustainable Mining Practices:** Encourage mining companies to adopt sustainable practices such as reducing water and energy consumption, minimizing waste generation, and promoting recycling and reuse of materials.
- 2 **Environmental Impact Assessment:** Implement a robust environmental impact assessment process for mining projects to ensure that potential environmental risks and impacts are thoroughly evaluated and appropriate mitigation measures are put in place.
- 3 **Reclamation and Rehabilitation:** Enforce regulations that require mining companies to reclaim and rehabilitate mining sites after the completion of mining activities. This includes restoring vegetation, controlling erosion, and mitigating any other environmental damage caused by mining.
- 4 **Biodiversity Conservation:** Protect and preserve biodiversity in mining areas by identifying and conserving ecologically sensitive areas, establishing buffer zones, and implementing measures to minimize habitat destruction and fragmentation.
- 5 **Community Engagement and Benefit Sharing:** Encourage mining companies to engage with local communities and involve them in decision-making processes.

Promote fair benefit-sharing mechanisms that ensure communities receive tangible benefits from mining activities, such as employment opportunities, infrastructure development, and investments in education and healthcare.

- 6 **Technology and Innovation:** Promote the adoption of cleaner and more efficient mining technologies, such as advanced drilling and blasting techniques, automated equipment with lower emissions, and improved waste management systems. Encourage research and development in sustainable mining practices.
- 7 **Regulatory Framework:** Strengthen the regulatory framework for mining activities, including stricter enforcement of environmental regulations, monitoring and reporting requirements, and penalties for non-compliance. Encourage transparency and accountability in the mining sector.
- 8 **Capacity Building and Training:** Invest in training programs and capacity-building initiatives to enhance the skills and knowledge of mining professionals in sustainable mining practices, environmental management, and responsible mining techniques.
- 9 **Collaboration and Partnerships:** Foster collaboration between government agencies, mining companies, local communities, and civil society organizations to promote sustainable mining practices, share best practices, and address common challenges together.
- 10 **Renewable Energy Integration:** Encourage the use of renewable energy sources, such as solar or wind power, to meet the energy needs of mining operations. This can help

reduce greenhouse gas emissions and dependence on fossil fuels.

1.7 Conclusions

By implementing the recommendations outlined in this review, Nigeria can move towards a more sustainable and environmentally responsible mining sector, mitigating the negative impacts of mining while maximizing its economic potential. Green mining practices can help safeguard Nigeria's natural resources for future generations and contribute to the country's overall sustainable development goals.

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