African Journal of Environment and Natural Science Research
ISSN: 2689-9434
Volume 7, Issue 3, 2024 (pp. 203-222)
www.abjournals.org

ENVIRONMENTAL IMPACT OF LITHIUM MINING IN NORTHERN NIGERIA: A COMPREHENSIVE REVIEW

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Cite this article:

Odoh, B. I., Ahaneku, C. V., Madu, F. M., Machi, J. O., Mougbo, C. D., Ijeh, E. C., Ozoemena, G. O., Arukwe-Moses, C. P. (2024), Environmental Impact of Lithium Mining in Northern Nigeria: A Comprehensive Review. African Journal of Environment and Natural Science Research 7(3), 203-222. DOI: 10.52589/AJENSR-NEYB0G4N

Manuscript History

Received: 22 Jun 2024

Accepted: 30 Aug 2024

Published: 5 Sep 2024

ABSTRACT: *This comprehensive study investigates the profound environmental impacts of lithium mining in Northern Nigeria, a region renowned for its rich mineral resources. The research uncovers the devastating consequences of lithium extraction on the environment, including water pollution, land degradation, air pollution, and severe health impacts on local communities. The mining process involves releasing toxic chemicals and heavy metals, such as lithium, arsenic, and cadmium, into nearby water sources, posing significant risks to aquatic life and human health. The extraction process also leads to water depletion, deforestation, habitat destruction, and soil structure disruption, resulting in land degradation and subsidence. Furthermore, mining activities release particulate matter and gases into the air, contributing to pollution and negative health effects for local communities. The direct lithium extraction process produces hazardous by-products harmful to human health, including respiratory problems and nervous-system disorders. This study highlights the urgent need for mitigation measures to minimise the environmental impacts of lithium mining in Northern Nigeria. Implementing effective recycling strategies, developing alternative technologies, and integrating biodiversity impacts into mining practices are crucial to ensure sustainable extraction and reduce harm to local ecosystems and human health. The findings of this research are essential for policymakers, mining industries, and environmental organisations to develop sustainable strategies for lithium mining, balancing economic growth with environmental stewardship and social responsibility.*

KEYWORDS: Environmental Impact, Lithium, Mining, Water Pollution, Land Degradation.

Article DOI: 10.52589/AJENSR-NEYB0G4N
DOI URL: https://doi.org/10.52589/AJENSR-NEYB0G4N

INTRODUCTION

The Northwestern region of Nigeria is emerging as a significant niche for mineral resources, particularly lithium. This area hosts over 120 identified lithium deposits, as reported by artisan miners and recent studies (Obaje, 2009; Salau *et al.*, 2016; Dzukogi *et al.*, 2020; Dzukogi *et al.*, 2022). The primary types of lithium ores found include spodumene, amblygonite, white cast, and lepidolite. These deposits are typically associated with vein-type mineralisation (pegmatite veins) or disseminated mineralisation within various host rocks, such as schist, gneiss, and granite intrusions (Solomon, 2004; Dzukogi *et al.*, 2022). According to the tectonic model proposed by Abu-Adam *et al.* (2013), these minerals originated from hydrothermal solutions produced at deeper crustal levels due to magmatic processes.

Geophysical methods, notably Gamma Ray Spectrometry (GRS), have proven effective in mapping surface geology and identifying mineralisation structures that are challenging to delineate using gravity and magnetic surveys (Elkahteeb & Abdellatif, 2018). The distinctive signatures produced by mineralisation zones make GRS particularly valuable for geological exploration.

The global shift from fossil fuels to renewable energy sources is driving an unprecedented demand for lithium. As the energy sector transitions towards cleaner technologies, including electric vehicles (EVs), wind and solar power, and hydrogen production, the metals and mining sector faces the challenge of supplying essential raw materials for this transformation (Daniel Dele-Yaro, 2023; Moshine, 2022). This transition is particularly crucial in light of global efforts to decarbonise energy and transport systems, spurred by ambitious policy goals set by countries across Asia, Europe, and the USA (IEA, 2020).

Despite its abundance, lithium is found in economically viable concentrations in only a few locations worldwide. Approximately 60% of the world's identified lithium reserves are contained in salt deposits with brines, with about 78% of these found in subsurface and dried-up salt lakes. Other sources include geothermal origin, petroleum reservoirs, and residues from seawater desalination (Jack McLellan, 2023). Lithium is commercially produced primarily in two forms: lithium carbonate from brines and lithium hydroxide from hard rock sources.

However, lithium mining is not without environmental challenges. The extraction and processing of lithium-bearing ores can lead to significant environmental risks, including water pollution, land degradation, air pollution, and health hazards due to the release of toxic chemicals and heavy metals (March Zheng, 2023). The ecological context of Northern Nigeria, characterized by scarce water resources, poor soil quality, and limited vegetation, exacerbates these concerns (Abdulkadir et al., 2013). The rapid expansion of lithium mining in this region, often conducted with minimal regulation, raises serious questions about the sustainability of the industry.

The historical reliance on fossil fuels has led to significant greenhouse gas emissions and environmental changes (IPCC, 2021). The Intergovernmental Panel on Climate Change (IPCC) emphasizes that reducing carbon emissions is crucial to mitigating climate change. In response to this urgency, lithium, as a key component of green technology, is being promoted as a solution to the energy shortage exacerbated by depleting fossil fuel reserves (Earth.Org, 2023).

While the benefits of lithium-based technologies are well-documented, there is a notable gap in the literature regarding the environmental impacts of lithium mining, particularly in regions

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like Northern Nigeria. Existing studies predominantly focus on mining activities in South America and Australia (Yushin & Turchenius, 2022). This review aims to address this gap by evaluating the immediate and long-term environmental impacts of lithium mining in Nigeria. Such an assessment is crucial for informing policy decisions and ensuring the region's sustainable development of lithium resources.

Background and Significance

Lithium, a silvery-white alkali metal with unique electrochemical properties, plays a crucial role in the global shift towards renewable energy. Its high electrochemical potential makes it essential for energy storage solutions, particularly in lithium-ion batteries used in electric vehicles (EVs) and renewable energy systems (Yushin & Turchenius, 2022). The growing global demand for green energy, driven by policy changes, economic development, and advancements in infrastructure, has significantly increased the need for lithium.

The lithium market has experienced substantial growth, with projections indicating a 70%-80% increase by 2025 due to rising demand for electric vehicles and renewable energy storage systems (Earth.Org, 2023). In response to this demand, the global lithium market, valued at USD 4.23 billion in 2020, is expected to grow at a compound annual growth rate (CAGR) of 14.8% through 2028 (Grand View Research, 2021). This surge has prompted the exploration and development of new lithium sources, with Northern Nigeria emerging as a promising region.

Nigeria, traditionally reliant on oil and gas, is diversifying its economy to mitigate the risks of oil price volatility and promote sustainable development (Akinyemi *et al.,* 2019). The discovery of significant lithium deposits in Northern Nigeria presents an opportunity for the country to engage in the global clean energy transition and enhance its economic prospects. However, this development comes with significant environmental concerns, particularly given the region's semi-arid climate and fragile ecosystems. Northern Nigeria faces challenges such as desertification, water scarcity, and biodiversity loss (Olagunju, 2015; Abdullahi *et al.*, 2017). Recent studies have highlighted a 20% increase in desertification over the past decade, affecting around 35 million people (Onwuka *et al.,* 2020).

Lithium mining has known environmental impacts, including water depletion and contamination, soil degradation, and air pollution (Agusdinata *et al.,* 2018; Xu *et al.,* 2020; Kesler *et al.,* 2012). Given Northern Nigeria's unique ecological context, these impacts could be exacerbated or present new challenges. This review seeks to analyse the environmental implications of lithium mining in Northern Nigeria, evaluate existing regulatory frameworks, and compare practices with international standards. It aims to inform policymakers, industry stakeholders, and local communities about the environmental challenges and opportunities associated with lithium mining, promoting sustainable resource management.

Environmental Impact of Mineral Exploration and Exploitation

A wide range of a region's chemical and physical environmental characteristics influences the admittance of species that cumulatively interact to bring about soil and vegetation. Such interactions can lead to the formation of landforms, rock types, mineral distributions, and the organization of vegetation (Crocker, 1988). Therefore, addressing the environmental priorities of different regions should be the first step in mineral exploration and production. The mineral resources, including lithium, which exist in every geographic area, cannot be isolated from the

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surrounding geological environment, and most forms of mineral production will jeopardize nature and the environment (Flexer *et al.,* 2018). Such jeopardy will occur in clean air, productive lakes, resilient communities, and rich, diverse ecosystems.

The land requirement for mineral production is extremely high, and the market for many minerals requires large volumes. The world's natural wealth is finite, and as a result of mining, much of the original land use is usually replaced with an artificial terrain of hills, shallow pits, and other artificial landscapes, denominated 'landscape plumbing' (Hadrup *et al.,* 2022). Additionally, the mining process involves the removal of topsoil, vegetation, and overburden, leaving the land less functional and with medium-term, long-term, permanent, or reinforced impairment. The mobilization and concentration of small amounts of ore in the economic process region facilitate the buildup of metals and other chemical substances in the soil, air, and water, enough to hinder or eliminate desirable land use (Earth.Org, 2023). The waste products from mineral extraction also contain chemicals and have different physical forms and stability, often causing short-term, medium-term, long-term, permanent, or reinforced impairment of the land (Yushin & Turchenius, 2022).

OVERVIEW OF LITHIUM DEPOSITS

Lithium mining operations in Nigeria primarily focus on extracting lithium-bearing minerals such as spodumene and lepidolite from pegmatite deposits. The Nigerian Geological Survey Agency has identified several lithium-rich areas, intensifying mining activities since significant reserves were discovered in 2018 (Ajayi & Anaenyeonu, 2024). This section provides a comprehensive overview of the current state of lithium mining operations in the region, including geological context, key mining areas, extraction methods, and the main actors involved in the industry.

Key Mining Areas

The main areas of lithium exploration and potential mining in Northern Nigeria include:

1. **Nasarawa State**: The Nasarawa pegmatite field, particularly around Rukuba and Angwan Doka, has shown significant lithium mineralization. Preliminary studies indicate lithium oxide (Li2O) concentrations ranging from 1.4% to 4.5% in some pegmatite bodies (Garba, 2003).

2. **Kaduna State**: Promising lithium resources have been discovered in the southern parts of the state, notably in the Zaria-Kafanchan area. The pegmatites in this region are part of the more oversized Kushaka schist belt, known for its mineral-rich formations (Okunlola, 2005).

3. **Kogi State**: Exploration activities have revealed potential lithium deposits in pegmatite formations, particularly in the western parts of the state. Lithium mineralization is often associated with tin and tantalum deposits, indicating complex rare metal pegmatites (Okunlola & Ocean, 2009).

4. **Niger State:** Several areas within the state, including parts of the Minna schist belt, have shown indications of lithium mineralization. The pegmatites in this region are often

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zoned, with lithium-rich zones typically occurring in the intermediate to core zones (Garba, 2003).

Extraction Methods

The lithium mining operations in Northern Nigeria primarily employ open-pit mining techniques, as the pegmatite deposits are generally found close to the surface. The typical extraction process involves:

Exploration and Site Preparation:

Geological surveys and exploratory drilling to delineate ore bodies.

Removal of vegetation and topsoil.

Construction of access roads and support infrastructure.

Extraction:

Drilling and blasting of ore-bearing rock.

Excavation using heavy machinery such as hydraulic excavators and front-end loaders.

Transportation of ore to processing facilities using haul trucks.

Processing:

They crushed and ground ore to reduce particle size.

Concentration of lithium minerals through various methods, including gravity separation, magnetic separation, and flotation.

Further processing to produce lithium concentrate or lithium compounds depends on the specific operation.

Key Players and Industry Structure

The lithium mining sector in Northern Nigeria is still in its early stages, with a mix of domestic and international companies involved in exploration and development activities. The sector generally includes:

Junior Mining Companies: Smaller exploration companies focused on identifying and developing lithium prospects.

Major Mining Corporations: Some larger, established mining companies have shown interest in Nigeria's lithium resources, often through joint ventures or acquisitions of junior companies.

Government Entities: The Nigerian Geological Survey Agency (NGSA) and the Ministry of Mines and Steel Development play crucial roles in licensing, regulating, and promoting the mining sector.

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Artisanal and Small-Scale Miners: In some areas, informal small-scale mining activities for lithium and associated minerals occur, often outside formal regulatory frameworks.

International Investors: Given lithium's strategic importance for the global battery industry, international investors and manufacturers have shown increasing interest in Nigeria's lithium resources.

Regulatory Environment

The lithium mining sector in Northern Nigeria operates under the broader regulatory framework for the Nigerian mining industry, primarily governed by:

The Nigerian Minerals and Mining Act 2007.

The Nigerian Minerals and Mining Regulations 2011.

The Environmental Impact Assessment Act 1992.

These regulations outline the requirements for mining licenses, environmental protection, community relations, and fiscal regimes for mining operations (Ajayi & Anaenyeonu, 2024; Oluwafemi, 2023; CAPPA, 2024).

As lithium mining operations in Northern Nigeria continue to develop and expand, it is crucial to carefully assess and manage their environmental impacts to ensure sustainable resource exploitation and protect the region's ecological integrity. The following sections of this review will delve deeper into the specific environmental concerns associated with lithium mining in the region and evaluate the effectiveness of current regulatory and management practices.

LITHIUM MINING IN NORTHERN NIGERIA

Economic Significance of Lithium Mining

Lithium mining has gained significant attention in Nigeria, particularly in the northern regions where substantial reserves have been discovered. The global demand for lithium has surged due to its critical role in rechargeable batteries for electric vehicles (E.V.s) and renewable energy storage (Asiegbu, 2023; CAPPA, 2024). As Nigeria positions itself as a potential key player in the lithium market, it must evaluate the environmental implications and sustainability practices associated with this burgeoning sector.

Environmental Concerns

Despite the growing interest in lithium mining, there is a notable gap in the literature regarding its immediate environmental impacts. While various studies have focused on the effects of lithium-ion batteries and recycling, the environmental costs of lithium mining—such as soil erosion, land pollution, forest destruction, and water resource depletion—are often underestimated (Hadrup et al., 2022). Additionally, potential health risks from anomalous concentrations of metals in water sources affecting human and animal health remain largely uninvestigated. Mining activities can lead to various environmental problems, including:

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- **Soil Erosion**: Removing vegetation and topsoil during mining operations can increase soil erosion, affecting land productivity.
- **Water Resource Depletion:** The high water demand for mining processes can deplete local water resources, impacting human and ecological systems.
- **Land Pollution:** Waste and pollutants from mining operations can contaminate land, making it unsuitable for agriculture and other uses.
- **Destruction of Biodiversity:** Mining can destroy habitat, threatening local flora and fauna.

Geological Context of Lithium in Nigeria

Lithium minerals, particularly spodumene and lepidolite, are found in specialised rocks known as rare metal-bearing pegmatites. In Nigeria, these pegmatites are located in regions such as Nasarawa, Kogi, Kwara, Ekiti, and Cross River States (Ajayi & Anaenyeonu, 2024). The discovery of lithium reserves in these areas presents both opportunities and challenges. While the potential for economic growth exists, thorough environmental assessments must be conducted before further investments are made.

Key Environmental Concerns in Lithium Mining

Water Pollution and Scarcity

Lithium mining poses a substantial risk to local water resources. The extraction process often leads to water contamination from chemicals used in mining and processing, while the high water demand for these operations exacerbates existing water scarcity issues in arid regions (Simon, 2024; CAPPA, 2024).

Lithium mining operations can consume substantial amounts of water, mainly using brine extraction methods. While pegmatite mining (the primary method in Northern Nigeria) generally requires less water than brine extraction, it still has significant water needs for ore processing and dust suppression (Flexer *et al.*, 2018). In water-stressed regions of Northern Nigeria, this can exacerbate existing water scarcity issues, potentially affecting local communities and ecosystems.

Agusdinata *et al.,* (2018) found that lithium mining operations can consume between 70 to 1,900 cubic meters of water per ton of lithium carbonate produced, depending on the extraction method and local conditions.

Soil Degradation and Erosion

Mining activities can lead to significant soil degradation and erosion due to land clearing and vegetation removal. This degradation can result in the loss of arable land, negatively impacting local agriculture and food security (Morrison-Saunders & Arts, 2020). Lithium ore processing often involves using chemicals that can contaminate local water sources if not adequately managed. Acid mine drainage is a particular concern, as the exposure of sulfide minerals in pegmatites to air and water can lead to the formation of sulfuric acid, which can leach heavy metals into surrounding water bodies (Dill et al., 2008).

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Research by Akinwale *et al.*, (2021) on mining activities in Nigeria highlighted the potential for heavy metal contamination of groundwater and surface water sources near mining sites, emphasizing the need for stringent water quality management practices. Lithium mining operations, particularly open-pit methods commonly used for pegmatite deposits, can significantly impact soil quality and stability.

Soil Removal and Disturbance: The extraction process involves removing topsoil and overburden, which can lead to the loss of fertile soil layers and disruption of soil structure. This can long-term impact the land's ability to support vegetation and wildlife (Sonter *et al.*, 2014).

Erosion and Sedimentation: Exposed soil at mining sites is vulnerable to erosion by wind and water, particularly in the semi-arid climate of Northern Nigeria. This can increase sedimentation in nearby water bodies, affecting aquatic ecosystems and water quality (Eze *et al.*, 2016).

A case study by Oluwasola et al. (2019) on mining-induced land degradation in Nigeria found that improper mining practices could accelerate soil erosion rates up to 10 times higher than natural background levels.

Air Pollution and Greenhouse Gas Emissions

While lithium mining is often associated with the clean energy transition, the extraction and processing operations can contribute to local air pollution and greenhouse gas emissions.

Dust Emissions: Open-pit mining and ore processing activities can generate significant dust, negatively impacting air quality, human health, and surrounding vegetation. Delicate particulate matter (PM2.5 and PM10) is of particular concern due to its potential to cause respiratory issues (Csavina *et al.*, 2012).

Greenhouse Gas Emissions: The energy-intensive nature of lithium mining and processing operations, mainly if powered by fossil fuels, can contribute to greenhouse gas emissions. A life cycle assessment by Kelly *et al.*, (2021) found that the production of lithium carbonate from complex rock sources (such as pegmatites) can emit between 5 to 16 tonnes of CO_2 equivalent per ton of lithium carbonate, depending on the energy source and processing efficiency.

Chemical Pollutants: Using chemicals in ore processing can release volatile organic compounds (VOCs) and other air pollutants. Proper handling and treatment of these chemicals are crucial to minimise air quality impacts (Kushnir & Sandén, 2012).

Biodiversity Loss and Ecosystem Disruption

The development of lithium mining operations in Northern Nigeria poses significant risks to local biodiversity and ecosystem integrity.

Habitat Destruction: Open-pit mining involves clearing vegetation and altering landscapes, which can destroy habitats for local flora and fauna. This is particularly concerning in areas of high biodiversity or those containing rare or endemic species (Mancini & Sala, 2018).

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Ecosystem Fragmentation: Mining operations and associated infrastructure can fragment ecosystems, disrupting wildlife corridors and isolating populations of plants and animals. This can long-term impact species survival and genetic diversity (Sonter *et al.,* 2018).

Indirect Impacts: Changes in water availability and quality and increased noise and light pollution from mining operations can have far-reaching effects on ecosystem dynamics. These indirect impacts can extend beyond the immediate mining area (Kaunda, 2020).

A biodiversity assessment by Adekola *et al.,* (2021) in mining-affected areas of Nigeria found that uncontrolled mining activities could lead to a reduction in species richness of up to 40% in severely impacted areas.

Addressing these environmental concerns requires a comprehensive approach to environmental management in lithium mining operations. This includes implementing best practices in water management, soil conservation, air quality control, and biodiversity protection. Furthermore, it necessitates robust environmental impact assessments, ongoing monitoring, and adaptive management strategies to mitigate and minimise the ecological footprint of lithium mining in Northern Nigeria.

METHODOLOGY:

This paper employed a comprehensive approach to assess the environmental impact of lithium mining in Northern Nigeria. This involved thoroughly analysing existing research articles, reports, and publications on lithium mining, the environmental impacts, and Northern Nigeria's geological and ecological context. Many works have been carried out on this topic, and these researchers have obtained results by applying some methods in their studies. Some of the methods used were; magnetic and gamma-ray spectrometry methods using airborne magnetic and gamma-ray spectrometric datasets (Dzukogi A. N and Mahmud M. B, 2023) to evaluate lithium mineralisation potential of the study area via mapping of lithology, structural features and hydrothermal alteration zones, the study of the optical properties of the minerals in the study area in thin sections under polarising microscope, powder X-ray diffraction techniques and electron-microprobe analysis. Also, by consulting with environmental experts, geologists, and mining professionals to gain insights into the environmental impacts of lithium mining and potential mitigation measures. The magnetic method was used to investigate the subsurface geologic structures based on magnetic anomalies in the earth's magnetic field, resulting from the magnetic properties of the underlying rocks and structures. The aeromagnetic survey was applied to map the magnetic anomalies in the earth's magnetic field and correlated with the surface and underground geologic structures (Anudu *et al.,* 2014). The gamma-ray spectrometric (GRS) survey measures the decay of unstable, naturally occurring radionuclides in rocks and soils attributable to the naturally occurring radioactive minerals (NORMs). GRS is effective in measuring the naturally occurring radionuclides such as potassium (K), thorium (eTh), and uranium (eU) with their daughter isotopes in all crustal formations (IAEA, 2003). Compared to other geophysical methods. Also, it has been found useful in identifying structures that may be difficult to delineate using other geophysical methods (gravity and magnetic) (Elkahteeb & Abdellatif, 2018). The successes and significance of GRS methods result from the unique signatures that are produced by the mineralisation zones, which distinguish them from the host rocks.

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RESULTS AND DISCUSSION

Most research on the study area report reveals that lithium and gold in placers and primary veins of pegmatite, quartzites, phyllite, and schists are pronounced in the Northwestern part of Nigeria (Obaje, 2009 and Dzukogi *et al.,* 2022). The lithium and gold mineralisation in the pegmatite and schist belt (Anka) is structurally controlled, and the gold migration and deposition mechanisms are related to regional metamorphic processes (Garba, 2000). The delineation of quartz from the field research indicates phyllic alteration (Abubakar *et al.*, 2019). The hydrothermal alteration resulting from the migration of deep-occurring hydrothermal mineralised fluids or metasomatism is aided by the permeability of rocks (Heasler *et al.*, 2009). The geologic structures within the crust serve as a conduit for the mineralised fluids that are composed of silica, water, sulphide and chlorine compounds, carbonates, and ions of potassium, sodium, calcium, magnesium, lithium, and iron (Almasi *et al.,* 2014) to precipitate and localise precious metals such as gold. Subtle geologic structures are considered very important in exploration as they serve as host to minerals and hydrocarbons (Dzukogi et al., 2022). Previous research has mentioned the benefits of lithium mining, and these benefits include employment opportunities, and economic growth as it provides dividends and taxes thereby contributing to its gross domestic product (Kasim Sumaina, 2023). Also, from previous research and review works on the environmental impacts of lithium mining in Northern Nigeria, the mining of lithium in the area has impacted negatively the environment with emphasis on the release of chemical elements which are harmful to the environment (Maeve Campbell, 2022). The environment covers the impact on both man and his immediate surroundings. According to (March Zheng, 2023), the impacts brought about by these mining activities include water pollution, land degradation, air pollution, and health impacts.

Water pollution: Lithium mining in Northern Nigeria has led to significant water pollution, with high levels of lithium, arsenic, and other heavy metals detected in nearby water sources (Gao *et al*, 2021). The physical construction of an open pit mine results in the daily production of approximately 3,000 tons of ore and 8,000 tons of waste rock. The 8,000 tons of waste rock causes toxic runoff known as acid mine drainage (AMD) which is the acidic outflow of water from mines where sulfide minerals are broken up and made to oxidize. These outflows associated with lithium pit mines can cause a decrease in both the quantity and diversity of aquatic species in nearby ecosystems (Blaize Giangiulio, 2023). The mining of lithium still poses the threat of leaching chemicals/elements like aluminium and chromium into the local water supply which is conveniently located nearby and into groundwater (Antao, *et al.,* 2024).

Water depletion: lithium extraction often involves the use of large quantities of water, leading to water depletion (Kaunda, 2020). According to the United Nations Environment Programme, the extraction of one tonne of lithium requires approximately 2 million litres of water and around 50% of global lithium production occurs in regions experiencing water scarcity like Nigeria (UNEP, 2023). Also, lithium extraction from brines can lead to groundwater depletion and disruption of local water cycles, severely impacting aquatic and terrestrial ecosystems (Sobczyk *et al.,* 2021).

Land degradation: Mining activities have resulted in widespread land degradation, deforestation, and habitat destruction. Mining of lithium can also cause things like waste rock and tailings which can be toxic and heavy-metal laden, soil structure disruption and subsidence or sinkholes, chemical spills and all these reduce the quality of the soil thereby leading to land degradation.

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Air pollution: The mining process has released high levels of particulate matter and gases, contributing to air pollution and negative health effects for local communities. The release of these greenhouse gases results from the fossil fuels required for the mining process. Also, the crushing and drilling processes release dust and particulate matter into the air. Therefore, lithium mining also leads to the evaporation of toxic gases eg; HCl leading to air pollution.

Health impacts: the direct lithium extraction process produces hazardous by-products harmful to human health, such as arsenic, lead, and cadmium, which must be safely disposed of to mitigate their detrimental effects (Zang *et al.,* 2022). In addition, lithium-induced degradation of air quality can lead to the inhalation and accumulation of fine lithium particles that can significantly increase blood levels and result in severe respiratory and systemic health issues such as muscle weakness, seizures, thyroid problems, kidney dysfunction, cardiovascular issues, and even coma (Hadrup *et al.,* 2022).

Socio-economic impacts: Lithium mining has displaced local communities, disrupted traditional livelihoods, and exacerbated poverty and inequality in the region.

CASE STUDIES OF LITHIUM MINING IN NORTHERN NIGERIA

Zungeru Lithium Mine

The Zungeru Lithium Mine has been associated with significant environmental concerns, including illegal mining activities that have led to deforestation and pollution. Local communities have reported adverse health effects and loss of livelihoods due to environmental degradation (Simon, 2024; CAPPA, 2024).

Kagara Lithium Mine

The Kagara Lithium Mine has similarly faced criticism for its environmental practices. Reports indicate mining operations have contaminated local water sources and contributed to soil erosion, prompting protests from affected communities (Simon, 2024).

Technological Innovations and Solutions for Sustainable Lithium Mining

To mitigate the environmental impacts of lithium mining, it is essential to adopt innovative practices such as

- Implementing water recycling and efficient waste management systems

- Utilising renewable energy sources to power mining operations

- Conducting regular environmental monitoring and rehabilitation of mined areas

These practices can help ensure that lithium mining is conducted sustainably, balancing economic benefits with environmental protection (Ajayi & Anaenyeonu, 2024; Morrison-Saunders & Arts, 2020).

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Outlook and Recommendations for Sustainable Lithium Mining in Northern Nigeria

As Nigeria seeks to capitalise on its lithium resources, it is imperative to develop a comprehensive strategy that includes:

- Strengthening regulatory frameworks and enforcement mechanisms

- Enhancing community engagement and benefit-sharing arrangements

- Promoting sustainable mining practices and environmental stewardship

By adopting these measures, Nigeria can position itself as a leader in the global lithium market while ensuring the protection of its environment and the rights of local communities.

RECOMMENDATIONS FOR SUSTAINABLE LITHIUM MINING IN NORTHERN NIGERIA

Policy and Regulatory Recommendations

a) Strengthen Environmental Regulations: Develop specific guidelines for lithium mining that address unique environmental challenges, ensuring that operations comply with best practices for environmental protection (Oluwafemi, 2023). These guidelines should encompass a comprehensive framework that focuses on mitigating environmental risks and emphasizes restoring and rehabilitating affected ecosystems. By carefully considering the local context and consulting with experts in the field, regulations can be tailored to ensure the sustainable extraction of lithium while preserving the delicate balance of nature.

b) Enhance Enforcement Capacity: Invest in training and resources for regulatory agencies to improve monitoring and enforcement of existing regulations (CAPPA, 2024). By providing regulatory bodies with the necessary tools and knowledge, they will be better equipped to assess mining operations, detect non-compliance, and take appropriate enforcement actions. This investment should also establish specialised units within regulatory agencies that oversee lithium mining activities. By enhancing their capacity, regulatory bodies can safeguard the environment and public health from any potential adverse effects of lithium extraction.

c) Promote Transparency: Implement systems for public disclosure of environmental performance data from mining operations to foster accountability and community trust (Asiegbu, 2023). These systems should ensure that relevant information regarding the environmental impacts of lithium mining is easily accessible to all stakeholders, including local communities, environmental organizations, and governments. By promoting transparency, mining companies will be actively encouraged to improve their environmental practices since their performance will be subject to public scrutiny. This will enhance accountability and facilitate meaningful engagement between stakeholders, leading to collaborative efforts in safeguarding the environment.

Environmental Management Recommendations

a) Comprehensive Water Management: Develop and implement integrated water management plans that consider quantity and quality to mitigate water resource depletion

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(Flexer *et al.,* 2018). These plans should incorporate strategies for minimising water consumption during the extraction and processing of lithium and adopting efficient water treatment and recycling practices. Additionally, it is crucial to ensure that the plans prioritize protecting water sources, preventing contamination, and restoring aquatic ecosystems that may have been affected by mining activities. Such comprehensive water management measures are vital for maintaining the long-term sustainability of water resources and the surrounding ecosystems.

b) Biodiversity Conservation: Establish protected areas and ecological corridors to offset mining impacts on biodiversity, ensuring the preservation of local flora and fauna (Morrison-Saunders & Arts, 2020). These protected areas should be strategically designated to encompass biodiversity-rich habitats and be sensitive to mining activities. By doing so, the adverse effects of mining can be minimised, and the impacted ecosystems can be given a chance to recover and regenerate. Additionally, establishing ecological corridors will facilitate wildlife's movement and gene flow, promoting species resilience and enhancing overall biodiversity conservation efforts.

c) Climate Change Adaptation: Incorporate climate change projections into long-term environmental management plans for mining operations, preparing for potential impacts on local ecosystems (Kaunda, 2020). It is essential to recognise that climate change can influence various aspects of mining operations, including water availability, extreme weather events, and habitat suitability. By integrating climate change considerations into environmental management plans, mining companies can proactively identify potential risks and implement adaptive measures to minimise their environmental footprint. This may involve the development of climate-resilient infrastructure, strategic land-use planning, and adopting innovative technologies that reduce greenhouse gas emissions. By addressing climate change adaptation in mining, it becomes possible to ensure the long-term sustainability of operations while minimising their contribution to global climate change.

Social and Community Recommendations

a) Enhance Community Participation: Develop mechanisms for meaningful community involvement in decision-making throughout the mine lifecycle to ensure local voices are heard (Akinwale *et al.,* 2021). It is crucial to prioritize the engagement of the community and create platforms that enable them to contribute to decision-making processes actively. By establishing open and transparent channels for dialogue, residents can voice their concerns, suggestions, and aspirations regarding mining activities. Community participation involves individuals from diverse backgrounds, including indigenous peoples, women, and marginalised groups. This inclusive approach fosters a sense of ownership, empowerment, and shared responsibility, resulting in the development of mining initiatives that align with the community's collective vision.

b) Local Content Development: Invest in skills development and local supply chains to maximise economic benefits for host communities, fostering local entrepreneurship (CAPPA, 2024). To truly unlock the economic potential of mining in host communities, it is vital to prioritize the development of local talent and capabilities. By nurturing a skilled workforce through training programs and educational initiatives, the mining industry can create sustainable employment opportunities for community members. This not only enhances local livelihoods but also promotes the growth of local businesses and entrepreneurship.

Article DOI: 10.52589/AJENSR-NEYB0G4N
DOI URL: https://doi.org/10.52589/AJENSR-NEYB0G4N

Furthermore, fostering local solid supply chains ensures that economic benefits generated by mining operations circulate within the community, creating a multiplier effect that drives overall social and economic development.

c) Cultural Heritage Protection: Implement protocols for identifying and protecting cultural heritage sites in mining areas to preserve local history and identity (Ajayi & Anaenyeonu, 2024). Mining activities often occur in regions rich in cultural heritage, encompassing archaeological sites, sacred lands, and traditional cultural practices. To safeguard these invaluable assets, it is essential to establish rigorous protocols that ensure the identification, documentation, and protection of cultural heritage sites. Mining companies can collaborate with local communities, cultural experts, and relevant authorities to integrate cultural heritage preservation into their operations. By respecting and valuing the cultural identity of the host communities, mining activities can coexist harmoniously with preserving local history and traditions.

Technological and Innovation Recommendations

a) Promote Research and Development: Establish partnerships between industry, academia, and government to drive innovation in sustainable mining practices, focusing on reducing environmental impacts (Flexer *et al.*, 2018). To achieve a more sustainable future for mining, constant research and development are paramount. By fostering collaborative partnerships between industry stakeholders, academic institutions, and government agencies, vital research can be conducted to develop innovative technologies and practices that mitigate the environmental impact of mining operations. This partnership cultivates an environment of knowledge exchange, where industry expertise meets academic rigour, ensuring the latest advancements are applied to sustainable mining practices.

b) Adopt Best Available Technologies: Encourage the adoption of state-of-the-art technologies for environmental management and resource efficiency, minimising waste and emissions (Kelly *et al.*, 2021). Embracing the best available technologies is instrumental in achieving sustainable mining. Mining companies can effectively manage environmental impacts and maximise resource efficiency by investing in state-of-the-art equipment, processes, and monitoring systems. Advanced technologies enable the reduction of waste generation and emissions while optimising resource utilization throughout the mining lifecycle. This commitment to adopting cutting-edge solutions safeguards the environment and enhances operational efficiency, improving productivity and cost-effectiveness.

c) Develop Circular Economy Approaches: Plan for the entire lifecycle of lithium, including recycling and repurposing of mining waste, to reduce the overall environmental footprint of mining operations (Kushnir & Sandén, 2012). It is crucial to embrace circular economy approaches to address the environmental challenges of lithium mining. This entails designing mining operations with the end in mind, considering the entire lifecycle of lithium and its byproducts. By prioritizing recycling, reusing, and repurposing, mining waste can be transformed into valuable resources, minimising the overall environmental footprint. Circular economy practices not only promote resource efficiency but also reduce the reliance on primary resource extraction. The lithium industry can contribute to a cleaner and more resilient future by embracing a sustainable mining approach.

Article DOI: 10.52589/AJENSR-NEYB0G4N
DOI URL: https://doi.org/10.52589/AJENSR-NEYB0G4N

ENVIRONMENTAL IMPACT ASSESSMENT (EIA) IN THE MINING SECTOR

Environmental Impact Assessment (EIA) is a cornerstone of sustainable development in the mining sector. It is a crucial tool for predicting, evaluating, and mitigating the potential environmental consequences of mining activities. The United Nations Environment Programme (UNEP) defines EIA as "a tool used to identify the environmental, social and economic impacts of a project before decision-making" (UNEP, 2002). In the context of lithium mining in Northern Nigeria, the importance of EIA is multifaceted, ensuring environmental protection and sustainable resource exploitation.

Critical Aspects of EIA Importance in Mining Projects

Comprehensive Impact Identification: EIA facilitates a systematic and holistic approach to identifying potential environmental impacts across various domains, including air quality, water resources, soil integrity, biodiversity, and human health. Given the region's ecological sensitivity and potential for far-reaching environmental consequences, this comprehensive assessment is crucial for lithium mining in Northern Nigeria. A study by Abba *et al.* (2017) highlighted the importance of thorough impact identification in preserving the region's fragile ecosystems.

Risk Mitigation and Management: By identifying potential risks early in the project lifecycle, EIA enables the development of targeted mitigation strategies and management plans. This proactive approach can significantly reduce the likelihood and severity of environmental damage associated with mining activities.

Regulatory Compliance: EIA helps ensure mining projects adhere to national and international environmental standards and regulations. In Nigeria, the Environmental Impact Assessment Act of 1992 mandates EIA for significant projects, including mining operations (Federal Republic of Nigeria, 1992).

Informed Decision-Making: EIA provides decision-makers, including government authorities, project proponents, and investors, with crucial information about the potential environmental consequences of mining activities. This information enables more balanced and sustainable decision-making, weighing economic benefits against environmental costs (Morrison-Saunders & Arts, 2020).

Stakeholder Engagement: The EIA process typically involves public consultation and stakeholder engagement, fostering transparency and allowing local communities to voice their concerns and contribute to decision-making. This is particularly important in Northern Nigeria, where mining activities can significantly impact traditional livelihoods and local ecosystems.

Adaptive Management: EIA is not a one-time event but an ongoing process that includes monitoring and evaluating environmental impacts throughout the project lifecycle. This allows for adaptive management, where mitigation measures can be adjusted based on observed impacts and changing environmental conditions.

Biodiversity Conservation: In biodiversity-rich areas of Northern Nigeria, EIA plays a crucial role in identifying potential threats to local flora and fauna, enabling the development of conservation strategies and biodiversity offsets where necessary.

Article DOI: 10.52589/AJENSR-NEYB0G4N
DOI URL: https://doi.org/10.52589/AJENSR-NEYB0G4N

Social Impact Consideration: While primarily focused on environmental impacts, comprehensive EIAs also consider social and economic impacts, providing a more holistic understanding of a project's overall sustainability.

Implementing thorough and effective EIAs in lithium mining projects is thus essential for safeguarding Northern Nigeria's ecosystems, water resources, and local communities from potential adverse effects of mining operations. It serves as a critical tool in balancing the economic potential of lithium mining with the imperative of environmental protection and sustainable development.

Challenges and Limitations of EIA in Developing Countries

In Nigeria, the implementation of EIAs is often hindered by several challenges, including:

Inadequate Regulatory Frameworks: The existing legal structures may need to provide more guidance or enforcement mechanisms for effective EIA implementation.

Limited Technical Expertise: More trained professionals are often needed to conduct comprehensive EIAs, leading to subpar assessments.

Need for Public Participation: Many EIA processes need more meaningful engagement with local communities, which can result in a disconnect between project proponents and affected populations.

These challenges can result in incomplete assessments and a lack of accountability for environmental degradation (Oluwafemi, 2023; Asiegbu, 2023).

CONCLUSION

The development of lithium mining in Northern Nigeria offers substantial economic benefits but also poses significant environmental challenges. While lithium mining has contributed to the nation's economic growth, it has led to considerable environmental impacts, including water pollution, land degradation, air pollution, and adverse health effects such as respiratory issues and nervous system disorders. Addressing these concerns is crucial for ensuring that the growth of the lithium industry does not come at the expense of environmental health and local well-being. Nigeria can develop a sustainable lithium mining sector by drawing on global experiences and adopting best practices in environmental management, community engagement, and technological innovation. This approach will enable the country to harness the economic potential of lithium mining while mitigating its environmental impacts and ensuring that the benefits extend to local communities.

Article DOI: 10.52589/AJENSR-NEYB0G4N
DOI URL: https://doi.org/10.52589/AJENSR-NEYB0G4N

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