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THEME

**NIGERIA'S MINERAL RESOURCES: A SOURCE OF
ECONOMIC RECOVERY EMPLOYING INNOVATIVE TECHNOLOGY**

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Content



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Editorial Address

Department of Mineral and Petroleum Resources Engineering,
College of Engineering,
Kaduna Polytechnic, P. M. B. 2021, Kaduna.
Tel: 08030495371, 08023636689
Email: nigerianminingjournal@gmail.com
Website: www.nsme.org.ng



**Nigerian Society of Mining
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14th - 18th October

**Book of Proceedings
Edo 2024
International Conference**

**COMMUNIQUE ISSUED AT THE 23RD ANNUAL GENERAL MEETING
(AGM)/INTERNATIONAL CONFERENCE OF THE NIGERIAN SOCIETY OF MINING
ENGINEERS (NSME) HELD AT THE EDO STATE UNIVERSITY, UZAIRUE, EDO STATE
FROM 14TH - 18TH OCTOBER, 2024**

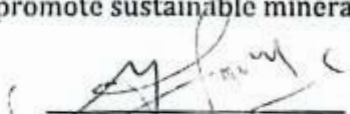
The Nigerian Society of Mining Engineers (NSME) held her 23rd AGM/International Conference from 14th to 18th October, 2024, under the chairmanship of her President, Engr. Dr. Umar A. Hassan, FNSME, with the theme titled: 'Nigeria's Mineral Resources: A Source of Economic Recovery Employing Innovative Technology'.

Preamble:

The theme was chosen because of the following inherent benefits to the development of the national economy. These benefits include increased efficiency of mineral production, enhanced operational safety, environmental sustainability, increased revenue, value addition and global competitiveness.

The pre - AGM panel discussions which attracted mining leaders of thought and participants from academia, industry and government, intensively deliberated on the theme of the conference and came up with the following resolutions:

1. The conference recognizes the significant progress made by the Federal Government in repositioning Nigeria as a mining destination, however, challenges such as insecurity, inadequate infrastructure and high cost of capital remain the depressing factor for fast tracking mining industry development. Government is called upon to intensify its efforts in tackling the above mentioned problems and to ease access to funding at single digit interest rate for the local investors in the mineral sector.
2. There is an urgent need for collaborative efforts between Government (Federal and State), mining companies and host communities to bring about peaceful co-existence in the industry in order to facilitate rapid development in the mineral sector.
3. The Nigerian mining industry is encouraged to embrace Artificial Intelligence (AI) to improve its activities. The need for Federal Government to develop strategic framework for the deployment of AI that suit her environment cannot be overemphasized.
4. The need to continue to create enabling environment, provision of adequate geoscientific data, mining related infrastructure, inexpensive electric power, institutional manpower and skilled workforce to attract foreign direct investment for achieving sustainable development in the mining sector cannot be overstressed.
5. Operators in the mining sector are called upon to adopt green mining in order to promote sustainable mineral development.


Engr. Dr. Umar A. Hassan, FNSME
President


Engr. Prof. D. G. Thomas, FNSME
Secretary General



Lead Paper: Applications of Artificial Intelligence to Mining Activities in Nigeria

¹Afeni T. B., ²Oyeladun, O. A.W. and ¹Adeyemi, A.J.

¹Department of Mining Engineering, Federal University of Technology Akure

²Department of Metallurgical Engineering Technology, Kaduna Polytechnic, Kaduna

Abstract

The mining industry in Nigeria would undergo a swift transformation as a result of the application of artificial intelligence (AI) to mining operations. This will require deep knowledge of artificial intelligence (AI), machine learning (ML), deep learning (DL), computer vision (CV), natural language processing (NLP), automation, which will help in revolutionizing the mining industry in Nigeria. The use of AI algorithms to process mineral exploration, core logging, ore grade control, drilling and blasting operation, geometallurgy, extractive metallurgy, automation and robotics, health and safety monitoring, maintenance of equipment, mine planning, data mining and so on will create a lot innovation in mining sector of the economy. The reality unfolding globally in mining industries paint a more optimistic picture than the fear of widespread job losses. The integration of AI in mining is not about turning miners into tech specialists or eliminating jobs. Rather, it is about giving them the tools and insights to work smarter, safer, and more efficiently. Thus, the future of Nigeria mining industry lies in both human and AI.

Keywords: Artificial intelligence (AI), Machine Learning (ML), Deep Learning (DL), Computer Vision (CV), Natural Language Processing (NLP), Automation

Introduction

Artificial intelligence (AI) is a set of technologies that aids computers to perform a variety of advanced functions, including the ability to see, understand and translate spoken and written language, analyze data, make recommendations, and much more. The ideal characteristic of artificial intelligence is its ability to rationalize and take action to achieve a specific goal. Artificial Intelligence is revolutionizing the mining industry by the way daily operations are handled. These intelligent systems are capable of analyzing large quantities of data and providing digital solutions for companies, with the technology helping to increase speed and safety in mining operations. AI encompasses developing computer systems capable of performing tasks that typically require human intelligence. These include but not limited to: learning, reasoning, problem-solving, perception, linguistic understanding and creativity (Bashir, 2019; Godoy, 2024).

2.0. Areas of Application of Artificial Intelligence in Mining

There are broad range of methodologies, technologies, and subfields that are combined in

AI. Machine Learning (ML) and other AI algorithms are now commonly in use predictive maintenance, exploration and resource estimation, autonomous vehicles, environmental monitoring, ore sorting and grade control, robotic and automation, decision support systems and safety management. In Nigeria mining industry, AI can be help in addressing specific challenges such as: improving operational efficiency, enhancing sustainability and increasing competitiveness. ML is a subset of AI that deals with the area of computational science that focuses on analyzing and interpreting patterns and structures in data to enable learning, reasoning and decision-making outside human interaction. Recent advancements in Deep Learning (DL), Computer Vision (CV) and Natural Language Processing (NLP) have allowed the development of AI models that can not only improve efficiency and safety but also pave the way for innovative practices that will redefine the sector (Corrigan and Ikonnikova, 2024).

This paper sheds more light into the current applications of AI in mining, highlighting innovations that, while not yet universally adopted, have the potential to reshape the

industry in the areas of improvement in mine production and reduction in mining cost. AI is revolutionizing the mining industry by enhancing operational efficiency, improving safety, predictive maintenance and condition monitoring, identification of risk and reducing environmental impacts. Some of the transformative applications currently being deployed are highlighted below:

2.1. Mineral Exploration

The use of AI algorithms to process large amounts of geological data is becoming the order of the day because the technology is outperforming traditional methods in speed and accuracy. Machine Learning (ML) algorithms are being used to generate exploration targets, assess their potential values and optimize exploration strategies. This approach not only increases the chances of discovering new deposits but also minimizes the environmental impact of exploration activities (Adeyemi et al., 2024).

2.2. Core Logging

Artificial intelligence (AI) has allowed for groundbreaking technology that results in more reliable data, improved core logging efficiencies and better decision-making. It removes the need for mundane tasks and gives geologists time to better interpret their data, allowing them to see the bigger picture. AI-based core logging is a revolutionary tool aimed at enhancing geologists' understanding of their orebodies and streamlining decision-making within the mining industry. A Canadian based startup (GeologicAI, formerly known as Enersoft) is transforming this process by combining multi-sensor hardware and AI-based software solutions to produce the most comprehensive datasets in the mining industry. By integrating geologic, hydrologic, and other information on surface environment and characteristics, artificial intelligence could help in the analysis of impacts and thereby, management of water and land (Ochieng et al., 2010; Worlanyo and Jiangfeng 2021).

2.3. Ore Grade Control

AI has significantly impacted ore grade control in mining operations by providing advanced algorithms that improve the accuracy and efficiency of predicting ore grades. Through the utilization of machine learning techniques, AI can analyze vast amounts of data to identify patterns and trends that may not be readily apparent to human operators. AI plays a crucial role in real-time monitoring of ore grades, allowing for

immediate adjustments to be made based on the data collected. By enabling mining professionals to access up-to-date information on ore quality, AI helps in minimizing uncertainties and reducing potential risks in ore extraction processes. Overall, the adoption of AI in ore grade control has revolutionized how mining companies operate, paving the way for increased productivity and cost-effectiveness in the industry (Saldana et al., 2022; Flores et al., 2020; Zhang et al., 2022).

2.4. Mineral Processing

The applications of artificial intelligence tools can be used in the area of mineral processing and leaching (Saldana et al., 2022; Flores et al., 2020; Zhang et al., 2022). Also, it can be considered for use in color-sorting and in identifying various physical, mineralogical, and chemical properties. Due to the capability of artificial intelligence to handle large arrays of data, it emerges as a valuable tool for near-infrared sensor data analysis (Bashir et al., 2019). Tools to improve the efficiency of the comminution process and reduce energy cost, as crushing and grinding are the most energy intensive and least energy efficient parts of the mineral processing cycle' (Hyder et al., 2019).

2.5. Drilling and Blasting Operations

AI has made available automated drillers that can drill hole to predetermined level with little or no error. Also, integrating blast displacement and mineable ore blocks via ML has increased commodity recovery and increased NPV at producing mines. The Geologist/Mining Engineer can prove through analytic that ore blocks are selective mining unit (SMU) compliant and dig orientation minimizes dilution, better mining decisions are made.

2.6. Geometallurgy

One of AI's earliest uses in mining is ML. It involves analyzing complex relationships between ore attributes and processing plant performance. These relationships are then used to improve decision-making and optimize processing operations. More recently, some companies are using ML-based systems to adjust processing plant parameters in real-time, based on characteristics of the ore being mined. This leads to better recovery and throughput, enhanced supply chain efficiencies, and reduced energy consumption (Zhang et al., 2022).

2.7. Extractive Metallurgy

AI is playing a significant role in charging furnaces in pyrometallurgy, leaching in hydrometallurgy and electrorefining and electroplating in electrometallurgy. Crucial decisions are made using ML. Researches are going on in order to develop new sensors or instruments for acquiring the critical variables of different processes in extractive metallurgy.

2.8. Automation and Robotics

The mining industry is increasingly employing autonomous vehicles, robots and drones. These technologies, are AI-based, they can operate in hazardous environments, performing tasks such as topographic surveys, drilling and transporting materials without human intervention. This not only improves safety, by reducing human exposure to hazardous conditions and areas, but also enhances operational efficiency.

2.9. Health and Safety Monitoring

AI-trained wearable devices are being used to monitor the health and safety of mine workers in real-time, detecting signs of fatigue, exposure to harmful substances, or physical stress. These systems can alert workers and managers to potential health and safety risks, thus, significantly improving workplace safety (Afeni and Ibitolu, 2018; Toteu, 2020).

2.8. Maintenance of Equipment

Application of AI in mining for predictive maintenance is now a common practice. By using ML algorithms to analyze equipment data, mining companies have been able to predict failures before they occur, minimizing downtime and extending the lifespan of fixed and mobile assets. This approach not only cuts costs but also improves safety by lowering the risk of equipment-related incidents.

2.9. Mine Planning

AI was applied in the early 2000s to develop the first stochastic mine planning method for open pit scheduling. Since then, a more sophisticated solutions have been developed that are able to optimize whole mining complexes, from mine to market. The method can take a myriad of uncertainties into account. This method, in broad terms, uses a combination of stochastic optimization and AI techniques to obtain the optimal solution for the mine scheduling problem.

2.10. Data Mining

Commercial and company-owned AI platforms

have been used to digest vast quantities of technical reports, financial disclosures, and press releases as well as mining news and technical articles. This creates an extensive knowledge base that can be consulted using natural language and advanced analytic. The most common users of such platforms are investors, analysts, deal makers, and exploration teams.

3.0. Possible Benefits of Artificial Intelligence in Nigeria Mining Industry

The applications of artificial intelligence in Nigeria mining industry are bright, with potentials set to further transform the mining industry, making it safer, more efficient, and sustainable. These applications can be increasingly more effective and productive in many previous and new aspects of the mining industry.

3.1 Resource Modeling

Resource modeling is a process of processing data, to analyze and refine the expected outcome. Autonomous systems are guided by algorithms-based artificial intelligence on an efficient set of instructions. This will enable mining engineers to spend considerably more time stress-testing models and refining estimates, resulting in higher confidence estimates and models that can be updated seamlessly as additional information becomes available.

3.2 Digital Twins

Recently, a lot of artificial intelligence metrics have been created to run digital twins of mining assets. These digital models will allow us to model and simulate the behavior and performance of entire mining complexes. Embedded with stochastic planning capabilities, these digital twins will help us optimize operations, predict failures, and test different scenarios for improved decision-making. Importantly, it will break the infamous mine planning cycle, that mines go through every year, and allow for near-real-time updates that respond to the ever-changing conditions of a mining operation.

3.3 Mine Design

Mine design is a laborious and time-consuming task, which requires considering multiple parameters such as resource models, mining methods, equipment selection, infrastructure, capital costs, operating costs, and many others. Artificial intelligence models can enable more efficient design creation and allow for the

evaluation of hundreds or thousands of scenarios with ease. This ability is key in determining the more efficient and cost-effective mine design for a given mineral deposit in a timely fashion.

3.4 Environmental Monitoring and Sustainability

Artificial intelligence has lot of opportunities to explore for systems advancement in environmental monitoring and sustainability. It can be used to monitor the impact of mining activities on ecosystems, predict environmental risks, and develop strategies to mitigate negative effects. These applications will help to achieve sustainable mining practices and adhere to increasingly stringent environmental regulations.

3.5 Automation and Robotics

Automation and robotics are transforming the mining industry in various ways, enhancing efficiency, safety, and productivity. Robotics can be designed to work alongside humans. This artificial intelligence-driven robotics could undertake tasks that are unsafe or unsuitable for humans, while humans focus on supervisory and decision-making roles, creating a synergistic team of personnel.

4.0. Conclusion

The future of Nigeria mining industry is in human and AI. The reality unfolding globally in mining industries paint a more optimistic picture than the fear of widespread job losses. The integration of AI in mining isn't about turning miners into tech specialists or eliminating jobs. It's about giving them the tools and insights to work smarter, safer, and more efficiently. Embracing AI is not merely an option but a critical step forward for the Nigeria mining industry. This will ensure its growth, sustainability, and resilience in the years to come.

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Lead Paper: Use of Green Mining for Sustainable Exploitation of Nigeria's Mineral Resources

E. O. A. Damisa

Mining Engineering Programme

Department of Metallurgical and Materials Engineering, Ahmadu Bello University, Zaria

Abstract

Green mining refers to technologies, best practices and processes that reduce environmental impacts while ensuring efficient mineral resource extraction. Nigeria, endowed with significant mineral resources, faces significant environmental degradation due to traditional mining practices over the decades. Green mining technology offers a sustainable alternative, enabling environmentally responsible mineral extraction while promoting economic development. It is believed that Nigeria's mineral sector holds tremendous potential to diversify the national economy beyond oil dependence. However, mining practices, particularly in artisanal and small-scale operations, contribute heavily to land degradation, water pollution and deforestation. To align with global sustainable development goals (SDGs), particularly SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action), Nigeria must transition to green mining practices. This paper explores the application of green mining technologies in Nigeria, assesses current practices, evaluates environmental and socio-economic impacts and proposes strategies for implementation. Key technologies such as bioremediation, water treatment, renewable energy use and automated monitoring systems are examined in the Nigerian context.

Key words: Green Mining, Climate Change, Sustainable Development Goals, Energy Transition

Introduction

As the world begins to demand greater environmental accountability, mining operations in many countries around world are implementing technologies that reduce the environmental footprint throughout the lifecycle of the mining enterprise. Green mining, also known as environmentally sustainable mining, aims to reduce the environmental footprint and promote responsible resource extraction. The environment is not just a backdrop to economic activity; it's the foundation of life itself encompassing land, water and air – basic supporting ingredients of life. Rivers provide water for agriculture; forests on land sustain biodiversity and clean air sustains life and keeps humans healthy. Neglecting these resources for short-term gains is like removing the ladder after climbing up. Neglecting the environment therefore is shortsightedness and foolhardy.

Modern mining practices and technologies can minimize environmental damage while maximizing economic benefits at the same time. On one side lies the promise of boundless economic growth, driven by its vast mineral resources; on the other hand, there is a pressing need to protect our environment from irreversible damage which can

result from irresponsible mining activities. However, with the right strategies, Nigeria can harmonise economic advancement with environmental preservation by adopting green mining practices—a true win-win scenario that benefits both the present and future generations.

Historical background on use of energy

Nearly all energy used before the 19th century, was renewable. The oldest known use of renewable energy, in the form of traditional [biomass](#) to [fuel fires](#), dates from more than a million years ago. The use of biomass for fire did not become commonplace until many hundreds of thousands of years later (Kris, 2013). Probably the second oldest usage of renewable energy is harnessing the wind in order to drive ships over water. This practice can be traced back some 7000 years, to ships in the Persian Gulf and on the Nile. From [hot springs](#), geothermal energy has been used for bathing since [Paleolithic](#) times and for space heating since ancient Roman times (Geothermal Energy, 2017). Moving into the time of recorded history, the primary sources of traditional

renewable energy were human [labour](#), [animal power](#), [water power](#), wind in grain crushing [windmills](#) and [firewood](#) a traditional biomass. In the 1970s environmentalists promoted the development of renewable energy both as a replacement for the eventual [depletion of oil](#), as well as for an escape from dependence on oil and the first electricity-generating [wind turbines](#) appeared.

Role of green mining in addressing climate change
The terms “green” and “mining” haven’t traditionally sat comfortably together but things are starting to change. As a developing country, robust mining can provide revenues to fund critical infrastructure, create millions of jobs and boost GDP growth. But these benefits from mining must not come at the expense of our land, water and air. If we destroy the environment in pursuit of wealth or development, we lose far more than we gain. As we progress through the 21st century, the importance of green energy in shaping our modern world cannot be overstated. Many countries and mining companies have acknowledged the challenge and have stated their commitment to the values of sustainability. Nigeria should do the same because Nigeria is not immune from the negative impact of mining on the environment, especially emission of greenhouse gases (CO₂, CH₄, N₂O etc).
Overview of Environmental Impacts of Traditional Mining in Nigeria

Traditional mining practices have long been associated with significant environmental impacts in Nigeria, including: Blasting and excavation, resulting in land disturbance and ground vibration; Habitat destruction and deforestation; Land degradation and Soil erosion; Air and water

pollution; Waste generation and the release of chemicals and heavy metals into the environment. Some of mining activities that have caused pollution are discussed below.

Sedimentation and Erosion

Mining that involves removing overburden and scraping away rocks to get the mineral buried near the surface, leads to the destruction of agricultural lands and erosion of soil. Plants, trees and topsoil are scraped away from the mining area and destroy wildlife habitats and landscapes. When these mining sites experience heavy rain, the loosened topsoil is washed away, carrying sediments that may pollute the streams, lakes and rivers. Excessive residue can harm aquatic organisms and watershed vegetation downstream. [Moreover, it can also cause disfiguration of streams and river channels, which results in flooding.](#)

Water Pollution

Water is essential to life on our planet. A prerequisite of sustainable development must be to ensure uncontaminated streams, rivers, lakes and oceans. The mining and processing of mined materials generally require water. Water is also the primary vehicle by which mining-related contaminants can inadvertently be transported into the environment and worsen the quality of water resources. Mining water pollution has severe consequences for wildlife and human life. Protecting endangered species and maintaining clean water sources are crucial for sustaining biodiversity, ensuring human health and well-being. Prevention of water quality degradation is an important step in ensuring environmental sustainability in mining areas.



Figure 1: Polluted section of the Osun river from artisanal gold mining activities, Osogbo (Source: Eromo Egbejule and Festus Iyora. Published On 2 Sep 2022)



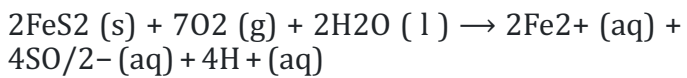
Figure 2: Polluted water bodies at mining sites, near Abakaliki, Ebonyi state.
(Source: SOFRECO/Beak consultants, MMSD, 2019)

(i) Acid Mine Drainage (AMD)

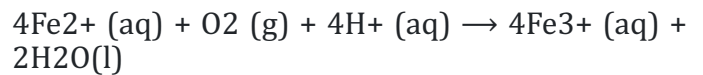
When sulphide-containing rocks are exposed to air and water, they can react to form sulphuric acid, which can leach into groundwater and surface water, polluting it with heavy metals and acid.

Chemistry of AMD

Although a host of chemical processes contribute to acid mine drainage, pyrite oxidation is by far the greatest contributor. A general equation for this process is:



The oxidation of the sulphide to sulphate solubilizes the ferrous iron ([iron\(II\)](#)), which is subsequently oxidized to ferric iron ([iron\(III\)](#)):



Either of these reactions can occur spontaneously or can be catalyzed by microorganisms that derive energy from the oxidation reaction. The ferric cations produced can also oxidize additional pyrite and reduce into ferrous ions:

The net effect of these reactions is to release H^+ , which lowers the pH and maintains the solubility of the ferric ion.



Figure 3: Left: River pollution by acid mine drainage. Right: Polluted river after cleaning

An analysis of water quality in Onyema and Okpala mine districts in Enugu, Southeast, Nigeria was reported by mean values of heavy metals namely; Cadmium, Arsenic, Lead, Chromium were respectively reported as

0.33mg/l, 0.06mg/l, 0.53mg/l and 0.06mg/l with mean pH values of 5.4 all of which exceeded the WHO permissible limits of 0.0-5.0mg/l for all the metals identified.. It was also reported that total dissolved solids (TDS) values ranging

between 21.80 and 520 mg/l were below WHO permissible limits of 0.00-1500 mg/l but however injurious to the aquatic life in the catchment (Ojonimi, 2020).

(ii). Heavy Metal Contamination

Mining operations release heavy metals like arsenic, lead, mercury and zinc into the environment, which can contaminate water sources and leach into the soil.

(iii). Tailings and Waste Rock

Mining processes generate vast amounts of waste, including tailings (material left over after ore processing) and waste rock. These materials can

contain toxic substances and heavy metals that can leach into soil and groundwater.

(iv). Processing chemicals pollution

Mining companies generally use chemical compounds such as sulphuric acid or cyanide to separate their respective target minerals from the ore. Contamination occurs when these chemicals are leached, leaked, or spilled from the mining area into the nearby bodies of water; contaminating water sources and harming aquatic life. These chemicals are highly toxic and could lead to loss of life on wildlife species and [severe health concerns on the human body](#).



Figure 4: Reprocessing of gold using cyanide at Uke gold mining site
(Source: SOFRECO/Beak consultants, MMSD, 2019)

Air Pollution

(i). Dust and Particulates

Mining activities, such as blasting, hauling and smelting, generate dust and particulates that can be released into the atmosphere, impacting air quality and potentially affecting human health.

(ii) Gases

Blasting operations release gases like carbon dioxide, nitrogen oxides, and sulfur dioxide into the atmosphere.

(iii). Smelting Emissions

Smelting, the process of extracting metals from ore, releases toxins like lead, mercury and sulphur dioxide into the atmosphere.

Soil Pollution

(i) Heavy Metal Contamination: Mining activities can contaminate soil with heavy metals, making it unsuitable for agriculture and impacting plant and animal life.

(ii) Tailings and Waste Rock: Tailings and waste rock can be deposited on land, contaminating the soil with toxic substances and heavy metals.



Figure 5: Primary processing of gold at Uke mining site, Nasarawa state
(Source: SOFRECO/Beak consultants, MMSD, 2019)

Habitat Destruction and Biodiversity Loss:

(i) Deforestation: Mining operations often require clearing large areas of land, leading to deforestation and habitat destruction.

Fire-setting



Fire-setting activities

Fire-setting is a method of [traditional mining](#) used most commonly from [prehistoric times](#) up to the [Middle Ages](#). Fires were set against a rock face to heat the rock, which was then doused with water or any other kind of liquid, causing the rock to fracture by [thermal shock](#).



Magnet quarry, Kaduna (Source: Lawal, 2024)

Although fire-setting was frequently used before [modern times](#), it has been used sporadically since then. The artisanal miners set fire on the rock mass to weaken its strength. Water is then sprayed on the rock to cool it. The effect of heating and cooling (expansion and contraction) leads to cracking of the rockmass. The already weakened rockmass is then broken into smaller pieces using hammer and chisel. This practice is common in some areas in the country especially where big operators have ceased working or places where blasting operations cannot be carried out (e.g., Malali in Kaduna).

Waste from the mining process

An ore is a mineralized rock containing valued metal(s) such as gold or copper. Mining involves the excavation of large quantities of waste rock in order to extract the desired mineral. The ore is then crushed into finely ground particles for separation of valuable minerals from non-valuable components that are discarded as tailings or waste. Similar wastes are also generated from other minerals other than ores, for instance coal resources, non-metallic or industrial minerals.

Transition to sustainable development

Nigeria is a signatory to many of the protocols or agreements on globalization, social and environmental concerns. Green energy is important for the environment because it can replace the negative effects of fossil fuels

(emission of greenhouse gases e.g. CO₂, CH₄. Clean energy are those types which do not release pollutants into the air and renewable energy comes from sources that are constantly being replenished, such as hydropower, wind power or solar energy. Sustainable development is progress and transformation that meets the needs of the present without compromising the ability of future generations to meet their own needs. It is critical that no one is left behind. The transition to sustainable development is primarily grounded in a series of international agreements and goals that are then implemented at the level of the individual states and communities involved. Among these, the best known are: The United Nations Framework Convention on Climate Change and its protocols, which set commitments to reduce greenhouse gas (CO₂, CH₄, N₂O etc.) emissions; The Convention on Biological Diversity (CBD), which promotes the conservation of biodiversity; and especially the UN [Sustainable Development Goals \(SDGs\)](#), which cover a wide range of sustainability issues. Built around these goals is the UN 2030 Agenda, a plan of action for people, planet and prosperity, signed into law by the UN General Assembly on September 25, 2015. The Agenda includes 17 goals, valid for everyone around the world, articulated along the three dimensions of sustainable development: economic, social and environmental.



Figure 6: Sustainable Development Goals

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Energy transition refers to the global energy sector's shift from fossil-based systems of energy production and consumption — including oil, natural gas and coal — to renewable energy sources. In 2021, Nigeria's Energy Transition Plan (ETP) was created with COP26 support, prompting Nigeria's net-zero commitment by 2060. The plan has government approval and presents a \$23 billion opportunity for supporting financiers and partners. The plan maps a pathway to reduce Nigeria's dependence on hydrocarbon sources, emphasizing renewable energy. The plan aims for net-zero emissions by 2060 and proposes gas commercialization until 2030, then a gradual fossil fuel phase-out. The plan aims to reduce Nigeria's greenhouse gas emissions and improve air quality. It estimates that the transition could reduce Nigeria's greenhouse gas emissions by up to 45% by 2030 and up to 90% by 2050. The plan is expected to create significant economic opportunities and job creation across various sectors of the economy, including renewable energy, energy efficiency and electric vehicles. This is a possibility that 5 million new jobs could be created by 2030. Estimates are that US\$1.9 trillion will be invested in the sector by a full transition in 2060. This includes initiatives to support developing sectors like electric mobility, green hydrogen and capacity-building for the creation of new markets. There is a need for policy and regulatory change mainly aimed at creating a conducive environment for businesses to invest in energy transition. There is also a need for significant capacity building and skill development to support roll-out and growth of new technologies.

Development of Nigeria's mineral resources
Nigeria is blessed with abundant mineral

resources including: Precious metals (Gold, Silver etc.), Metallic Minerals (Cassiterite, Tantalite, Iron ores, Columbite, Lead/Zinc Sulphides, Chromite, Copper ores, Molybdenite, Manganese, Wolframite, Bismuthine etc.), Industrial Minerals & Dimension stones/Construction minerals (Clays, Barytes, Gypsum, Feldspar, Limestone/Marble, Kaolin, Talc, Mica, Diatomite, Sand, Phosphate, Soda ash, Granite etc.) Gemstones (Amethyst, Aquamarine, Tourmaline, Garnet, Zircon, Sapphire etc), Fossil Fuels (Coal, Tar sands), Green Energy Minerals/Metals (Lithium, Tin, Cobalt, Nickel, Graphite, Copper, Aluminium, Manganese, Neodymium, Zinc, Rare Earth Elements etc).

The grundnorm, that is, the fundamental rule or principle that underpins the Nigerian mining law and serves as the basis for all other laws in the development of minerals in the country is the Nigerian Minerals and Mining Act (NMMA), 2007. The NMMA is the most important law on which all other laws, such as, the Regulations, and policies are based.

Green Mining Technology Technologies

The concept of "green mining" is no longer a futuristic fantasy—it's happening worldwide. From renewable energy-powered operations to advanced waste recycling systems, mining companies have access to a suite of eco-friendly tools. One of the core principles of green mining is the transition to renewable energy sources for mining operations. Instead of relying on fossil fuels, which contribute to climate change, green mines are adopting solar, wind and hydropower technologies to power their operations. In general, mining techniques become much more environmentally sensitive when efficiency is improved because less waste is produced. The current "green" mining techniques need to become more widespread and there will be a

focus on researching new environmentally friendly techniques.

(i) In-situ mining and bioleaching

Green mining embraces innovative techniques, like in-situ recovery and bioleaching, which minimize surface disruption and reduce environmental footprint. These methods are particularly useful for extracting minerals from ore bodies that are hard to access through traditional means.

(ii) Bioremediation

Use of microorganisms to detoxify polluted soils and water in mining areas. This can be applied post-mining to restore ecosystems affected by heavy metals.

(iii) Use of electric vehicles

The use of advanced equipment, such as electric vehicles and energy-efficient machinery. The deployment of electric haul trucks and processing units is a key component of green mining technology, offering a practical solution for reducing greenhouse gas emissions associated with mineral extraction and processing. Traditional diesel-powered mining machinery contributes significantly to CO₂ emissions, air pollution, and operational costs. Replacing these with electric-powered alternatives enhances environmental sustainability and improves operational efficiency.

(iv) Renewable energy sources like solar and wind power are also being integrated into mining operations to reduce reliance on fossil fuels. In addition, solar and wind power have the advantage is that electric mining equipment can be powered by renewable energy, especially solar. Nigeria's abundant solar radiation makes it ideal for charging battery-electric mining vehicles. These renewable energy sources can also power processing machinery at artisanal mining sites by creating mini-grids to support mining clusters with clean and stable electricity. This integration would significantly reduce the use of diesel, which is both expensive and environmentally harmful. These will align with Nigeria's Energy Transition Plan (ETP) aiming for net-zero emissions by 2060.

Challenges to Implementation

Despite the advantages, several barriers must be addressed:

High Capital Costs: Importing electric mining equipment can be cost-prohibitive for small and medium mining enterprises.

Infrastructure Deficiency: Lack of charging infrastructure, spare parts, and trained

technicians limits large-scale adoption.

Policy Gaps: There is currently no national incentive for mining firms to adopt electric equipment or switch to renewable energy.

Resistance to Change: Many operators are unfamiliar with the benefits or technical requirements of electrification.

Water Management, Conservation and Treatment

Green mining emphasizes water conservation and efficient management practices. Mining operations can significantly impact local water resources, leading to water scarcity and pollution. Mines can implement strategies to minimize water consumption by recycling and reusing water wherever possible. Furthermore, advanced water treatment technologies are being employed to ensure that any discharged water is clean and safe for the environment.

Sustainable Materials Handling

Efficient materials handling is essential for minimizing waste and reducing the environmental impact of mining. Innovations help increase resource recovery rates. For example, bulk ore sorting separates valuable minerals from waste early in the process.

Selective Mining and in-situ mining

Selective mining involves extracting only high-grade materials, leaving lower-grade ores in place. This approach reduces waste generation and decreases the amount of material that needs to be processed, minimizing the overall environmental impact. Therefore, do selective mining first and follow it by doing in-situ mining

Ecosystem Restoration

Traditional mining often leads to the destruction of natural habitats and biodiversity loss. Green mining seeks to restore ecosystems impacted by mining activities. After the closure of mining operations, reclamation efforts are undertaken to rehabilitate the land and support the return of native flora and fauna.

Reprocessing of tailings

Sometimes amounts of the metals being mined end up in the wastes. Reprocessing these wastes can result in more usable material.

Dust suppression techniques

During the mining process, large amounts of dust are released into the atmosphere. This can be minimized by pre-wetting the areas to be blasted with high volume sprinklers. Dust in the air, can also be removed through mist cannons (very high-volume water sprinklers).

Liquid membrane emulsion technology

This is a separation technique that can be used to extract usable metal from highly toxic or acidic waste water produced by a mine. This technology can even deal with dilute solutions

Choice of ventilation system and diesel engines

Ten percent of mining costs come from electricity consumption. Better ventilation systems and diesel engines can maximize efficiency in mining operations.

Community Engagement and Social Responsibility

Green Mining recognizes the importance of engaging with local communities and respecting their rights. It involves the creation of sustainable livelihoods, fostering economic opportunities, and investing in social development projects. This approach not only improves the quality of life for nearby communities but also ensures the long-term success of the mining operation by gaining community support.

Charging towards the future

The green mining technology is still in the early stages, with many of these technologies still in concept stages and as with most emerging technologies, the only foreseeable way that large-scale transition can occur will require government incentives and a potentially a move towards a price on carbon and/or other pollutants. The path to a better tomorrow is rarely easy, but Nigeria has what it takes to walk it. By prioritizing both economic growth and environmental preservation, we can secure a legacy of prosperity and sustainability for future generations. The time to act is now. Let's build a future where Nigeria's mining industry sets the gold standard for the world.

Green mining can offer many benefits in the exploitation of Nigeria's mineral resources. These include:

(i) **Environmental Conservation:** Green mining practices minimize the negative environmental impacts of mining, such as deforestation, water pollution, and soil degradation. This is achieved through sustainable mining technologies, reclamation strategies, and waste management techniques.

(ii) **Job Creation and Economic Growth:** The mining industry provides employment opportunities and stimulates local economies, contributing to economic growth and development. Green mining can ensure that these benefits are sustained while minimizing harm to the environment.

(iii) **Improved Community Engagement:** Green mining encourages mining companies to engage with local communities, ensuring they benefit from mining activities through job creation, infrastructure development and social programmes.

(iv) **Reduced Carbon Footprint:** The adoption of green technologies, such as solar and wind energy, can significantly reduce the carbon footprint of mining operations. For example, the Gold Fields Tarkwa Mine in Ghana has installed a 40 MW solar power plant to reduce dependence on fossil fuels.

(v) **Increased Investment Attraction:** African countries are attracting investments in green mining initiatives, local empowerment and environmental protection. The World Bank's Africa Mining Project has invested over \$300 million to support sustainable mining practices (Future of Mining, 2025).

(vi) **Water Conservation:** Green mining practices prioritize water conservation and efficient use, reducing the risk of water contamination and ensuring that local communities have access to clean water.

(vii) **Land Rehabilitation:** Mining companies are encouraged to restore land to its original state or repurpose it for sustainable uses after mineral extraction. This includes replanting trees, rebuilding topsoil and ensuring that water resources are clean and available for local communities.

Overall, green mining offers a more sustainable and responsible approach to mineral exploitation, balancing economic benefits with environmental and social responsibility.

Challenges and Opportunities

Regulatory Frameworks: Strengthening regulatory frameworks can encourage the adoption of green mining technologies.

Research and Development: Investing in R&D can help develop context-specific green mining technologies for Nigeria's mining industry.

Training and Capacity Building: Providing training and capacity-building programs can enhance the skills of mining professionals in green mining technologies.

Conclusion

To ensure that Nigeria's mining sector remains a driver of economic growth without compromising environmental sustainability, there is a need for continued investment in green mining technologies and practices. Nigeria must collaborate with global partners, share knowledge

and build capacity to develop a sustainable mining sector that contributes to both the green energy transition and the country's development goals.

Ultimately, the path to sustainable mining in Nigeria lies in the careful balance between harnessing the country's mineral wealth and protecting the environment. Through innovative solutions, regulatory reforms and increased community involvement, the giant of Africa can lead the way in sustainable mining for the green energy future. By prioritizing environmental protection and sustainable practices, Nigeria can ensure that it's mineral resources benefit not only the global green energy transition but also it's own communities for generations to come.

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Lead Paper: Enhancing Nigeria's Revenue through Formalization of Artisanal Mining in Nigeria

Engr. Dr. Luqman Kareem Salati, FNSME

Department of Metallurgical Engineering Technology, Kaduna Polytechnic, Kaduna

1.0 Introduction

Artisanal mining (AM) can be defined as mining activities carried out by individuals, groups, families or cooperatives with minimal or no mechanisation. AM can be legal or illegal. It is generally characterised by lack of long-term planning and the mining activities are largely uncoordinated because the people involved lack the technical know-how, use inappropriate methods, tools and equipment, and have no regard for the environment. Consequently, mineral production is inefficient and has attendant environmental, health and safety problems, as well as total disorganisation in the minefields. In 2011 alone, artisanal gold mining caused the deaths of more than 400 children, while several thousands more were severely poisoned through their exposure to lead dust in Zamfara State, North-western Nigeria. A major reason for the deplorable state of AM and its attendant challenges in Nigeria is the lack of proper management, which is the lack of planning, organising, coordinating and controlling. There is no clear government policy on the acquisition of artisanal concessions and how mining should be carried out; there are no guidelines on the methods and equipment that could be used for mining and processing; and there is weak policy on the sale of minerals by artisanal miners. In recent times, the issue of streamlining AM to make it safe, efficient, more environmentally friendly, profitable and thereby contribute more to the national economy has become a major concern to the government of Nigeria. Artisanal mining is a significant part of Nigeria's economy, providing livelihoods for countless individuals and contributing to local development. However, the majority of this sector operates informally, limiting its potential to generate substantial revenue for the government. By formalizing artisanal mining, Nigeria can harness this potential, fostering economic growth and sustainability.



Fig. 1: An AM site in Otukpa, Benue State

2.0 General Characteristics of Artisanal Mining

Generally, the characteristics of AM can be categorised in the following ways: selectivity of deposits and mobility of mine sites; lack of investment capital; manually oriented personnel; informality of activities; low level of technology and improvised extraction methods; lack of management skills and poor entrepreneurial attitude; employment opportunities at the community level; and negative impacts, among others.

i. **Selectivity of Deposits and Mobility of Mine Sites:** Artisanal miners are highly selective in their

choice of deposits and prefer to extract small but high grade mineral deposits. The available mineral deposits are either large-and-low-grade or small-and-high-grade. However, because the former require heavy earth moving equipment and high capital outlay, miners in the AM sector prefer the latter through selective mining. They also target old tailing dumps which require no blasting, incompetent alluvial deposits and abandoned large scale gold mines for selective scavenging. Miners found in such sites include those laid off upon mine closure. AM operated sites are highly mobile and easily depleted within a short period through miners' progressive migration leading to extensive land devastation, pollution and land use conflicts. The mobility of the mine sites is thus a reflection of the diverse nature of the AM sector in which miners' activities are difficult to monitor due to their crafty operating techniques. The types of mines worked by the AM operators also indicate the extent of their mobility. Such mines include permanent artisanal gold mining, seasonal artisanal mining, rush-type artisanal mining and shock-push artisanal mining.

ii. **Lack of Investment Capital:** A major factor militating against the rapid development of AM sector is the lack of capital. High technical and

financial risks make funding of AM business difficult, especially considering the heavy capital requirements of mining investment. Miners in the sector also have difficulty in obtaining foreign exchange to secure vital equipment needed for their operations. Credit facilities are mostly not available to them to finance their operations and facilitate their trade. They, however, rely mostly on government's assistance for funding and technical support. Such incentive packages usually include working tools and equipment, as well as operating capital. The credit scheme is part of the government efforts to regularise and control the activities of miners in the AM sector, thereby gradually integrating them into formal mining sector.

iii. **Manually Oriented Personnel:** In AM, labour is the second most important production factor after the mineral deposit. AM is characterised by high manual labour workforce and low productivity. Though miners work in large number, their use of basic tools has limited production capacity compared with mechanised equipment with larger capacity. Thus, the hunting-gathering approach employed by the miners to extract mineral reserves using unplanned methods and rudimentary tools is highly indicative of their manual orientation.

iv. **Informality of Activities:** AM is generally characterised by informal activities in terms of structure, work organisation and use of equipment. Thus, it is often seen as a synonym for informal or illegal mining. Such informality is mostly reflected in their chaotic and un-organised mining activities, lack of qualified and technical personnel and inefficient business transactions. Lack of operating licences gives miners the opportunity to engage in illegal gold mining, while also partaking in other complimentary activities such as subsistence farming. Thus, informality and illegality largely drive most AM activities to a large extent, thereby leaving the miners vulnerable at the mercy of middlemen who finance their businesses and extort them in turn. Despite the circumstances surrounding their economic predicament, and large population, the miners take advantage of their open access and proximity to suitable deposits to start AM activities. However, legalisation and formalisation of AM activities and subsequent follow-ups through government support and implementation have recorded enormous achievements in some countries. Hence, once the twin-problem of illegality and informality is addressed, other challenges in the AM sector will be easier to tackle.

v. **Low Level of Technology and Extraction Methods:** A major feature of AM is the low level of mechanisation. Its technological level is characterised by unskilled manual labour using

any available tools and machinery, and individual ingenuity. The use of basic and obsolete tool is a common feature in AM activities since the local operators have access only to intermediate technology. Hence, their mining activities are rudimentary in nature. The miners usually extract any form of gold deposits technically accessible and near the surface including alluvial and reefs. Their extraction technique is characterised by the use of basic tools such as shovels, hammers, picks, pickaxes, buckets, calabashes, wood ladders, ropes, metal pieces, plastic bags, sawn gas bottles, etc. The AM sector employs mercury as a major processing (amalgamation) technology compared to mercury free processing methods which are more environmentally friendly. Miners in the sector employ traditional extraction techniques which are reflective of the type of simple tools and equipment they use in working their deposits. Hence, they rarely exploit deposits on logical basis with a pre-planned sequence of mining and processing procedures. Hard rock deposits are sometimes mined through manual digging using chisels and hammers, and in few cases, through drilling and blasting.

vi. **Lack of Management Skills and Poor Entrepreneurial Attitude:** Another dominant feature of AM is lack of management skills required to guide management decisions in both technical and administrative aspects of its activities. The managerial and entrepreneurial challenges associated with AM are obstacles to the improvement and sustainability of the sector, creating inefficiency in decision making process. While miners' decisions on mineral reserve estimation and grade control are rather determined by historical than empirical evidences, gold recovery studies and economic analysis required for any successful mineral project are virtually lacking in AM activities. Consequently, capital investment in AM business does not yield the expected returns, thereby leading to premature closure of many projects in the sector. Therefore, the poor entrepreneurial attitude which dominates AM activities both at individual and group levels deprives the operators the full benefits of their business transactions.

vii. **Employment Opportunities at Community Level:** AM provides alternative employment opportunities for large number of people within and outside the gold mining communities, alongside farming and other traditional occupations in the rural areas. AM is not simply a low capital venture alone but also an important mineral supply chain and secondary economy. The sector also provides indirect employment to local vendors and support service providers. Most of whom are found at AM sites and the surrounding communities.

viii. **Negative Impacts:** AM is usually associated with a lot of negative impacts despite its positive contributions. Due to the low level of technology used in the AM sector, occupational health and safety hazards represent major environmental impacts. Dry processing methods of lead-rich gold ores create toxic lead dust that contaminates soils and waters, and poisons children and miners through ingestion and inhalation, leading to the death of children and miners. The environmental pollution caused by mercury emissions in AM activities has been significantly higher than any other source. Thus, amalgamation process is the single largest potential release of mercury in the world. Mercury use in AM results in severe miners' exposure, releasing toxic gases to the environment and posing risks to people in the nearby communities who eat fish contaminated with mercury. Women of child-bearing ages and children are the most vulnerable. It also results in extensive environmental degradation and ecosystem contamination, which may go on for decades after the stoppage of mining; hence, negative impacts of AM have long-standing consequences on the miners and residents in the host communities.

Other negative effects of AM activities include the following:

- a) Poor health and hygiene due to poor sanitation and exposure to harsh weather conditions;
- b) Child labour on mining sites caused by the use of children in AM related hard labour, leading to child prostitution, physical injury and various illnesses;
- c) Land use degradation and land use conflicts leading to destruction of farmlands, forests, ecosystem, as well as injuries and deaths;
- d) Migration and increased population due to the influx of prospective miners into mining communities thereby stressing infrastructural facilities, and also resulting into sexual promiscuity, prostitution and spread of diseases such as syphilis, gonorrhoea and HIV and AIDS, etc; and
- e) Social insecurity at the AM sites caused by drug addiction, delinquency swindling and crime.

Other peculiar characteristics of AM sector include:

- i. Remote mine sites;
- ii. Traditional administrative authority and set u.
- iii. Widespread attachment to superstitious beliefs and fetish practices;
- iv. Lack of knowledge about legal requirements;
- v. Limited access to mining titles;
- vi. High tax burden; and
- vii. Seasonal switching or alternation of mining with farming.

3.0 Artisanal Mining Practices in Nigeria

AM in Nigeria involves the manual exploitation of mineral deposits without any prior exploration. Thus, the sector is poorly managed and remains underdeveloped. The management of AM in Nigeria is characterised by the following practices:

- i. Mining activities are undertaken by individuals or groups, relying heavily on manual labours, simple implements and inefficient methods, without prior exploration thereby making mineral estimation and grade control difficult.
- ii. AM serves as pathfinders to the occurrence of minerals and can be used effectively to indicate prospecting areas.
- iii. Mining sites are chaotic and fraught with a lot of cultural practices, and social vices.
- iv. Miners involved in AM activities are mostly unskilled and operate illegally without licences.
- v. The use of mercury for gold extraction is common in most gold mining sites.
- vi. People involved in AM activities are poor, peasants, artisans and children, mostly in the rural communities.
- vii. Mineral trading is inefficient and largely unregulated, but large number of people are involved in it.
- viii. The available ministry officials are not sufficient to effectively monitor mining sites, indicating weak enforcement of laws.
- ix. AM activities are carried out alongside other support services which turn the mining communities to busy commercial centres.
- x. The presence of people from different parts of the country is noticed at AM sites, including aliens from neighbouring countries, as well as Chinese nationals; and
- xi. Large pit-holes are noticeable all over AM sites, indicating serious environmental degradation due to inadequate mining tools and methods.

Measures put in place in the past to effectively manage miners' activities in the AM sector in Nigeria included the implementation of the 'Safer Mining Programme' and training of miners on the use of 'Igoli' and wet milling machines (crushers) in some processing centres within Zamfara State, North-western Nigeria. These followed the outbreak of lead poisoning in the area due to sporadic and illegal AM activities in the area in 2011, leading to the death of many children. Recently, the present administration has put in measures to tackle illegal mining in Nigeria including the constitution of Mines Squad named 'Mines Marshals' comprising specially trained para-military personnel whose functions are to protect the mining sites and curtail illegal mining.

4.0 The Role of Artisanal Mining in Nigeria

For decades, AM had represented an important livelihood activity for the Nigerian rural population. It involves various stages of sporadic mineral exploitation and division of manual labour. AM in rural communities is often marked by involvement of mostly young, uneducated and unskilled miners whose low economic status and desire to earn a means of livelihood and escape poverty keep them in vicious circle of illegal mining activities. In spite of direct employment opportunities of AM activities to a significant number of local miners and a boost to their socio-economic life, there is little or no economic contribution to the national treasury since the capacity of government regulatory agencies to effectively monitor and control miners' activities is mostly hampered by inadequate logistics and funding.

The contribution of the mining industry to Nigeria's economy is generally low despite its huge economic potentials which can guarantee the nation's economic prosperity. The Nigerian mining sector only contributes less than 1 % to Nigeria's Gross Domestic Product (GDP), a far cry from projected revenue base of a sector believed to be more generative than petroleum industry. Thus, the sector has been ignored as an insignificant contributor to the national economy, thereby leaving its enormous potentials to illegal and sporadic exploitation by unlicensed artisans who lack the required technical skills and equipment to exploit mineral deposits as well as the capital means to generate business opportunities. Consequently, the sector's contribution to the national economy is insignificant due in spite of massive illegal smuggling of unprocessed mineral ore to neighbouring West African countries.

Nigeria's AM industry has never had it so good with the exit of adverse effects of the Indigenisation Decree of 1972 which edged out the multinationals and expatriate professionals who were in control of the mining industry. The aftermath of this event placed the bulk of mining operations on the shoulders of indigenous small-scale miners who lacked the skill, finances and equipment to sustain profitable mining business. This ultimately ushered in illegal miners whose indiscriminate activities have caused enormous damages to nation's economic landscape and hidden treasures. The already dwindling gold production between 1940's and 1960's in Nigeria as a result of falling gold prices in the international market became worsened with government's policy somersault of 1972 which ushered in unprecedented artisanal mining activities as reflected in Figure 3.

Although lack of statistical data on AM production

remains a major obstacle in the mining industry, the United States Geological Survey, in 2013, released Nigeria's gold production between 2002 and 2009 in Table 1. From the Table, the dwindling gold production country shows the pathetic level of revenue loss through the smuggling of unprocessed solid minerals out of the country; the peak gold production of 200 kg in 2008 and 2009 is an indication to this reality. Amoka and Ogunbajo in 2003, also estimated the weekly royalty loss for selected minerals in Table 2, which ran into millions of naira per week considering an increase in miners' activities and increasing market value of some minerals. It is better imagined today how much this would have translated to in terms of billions of naira.

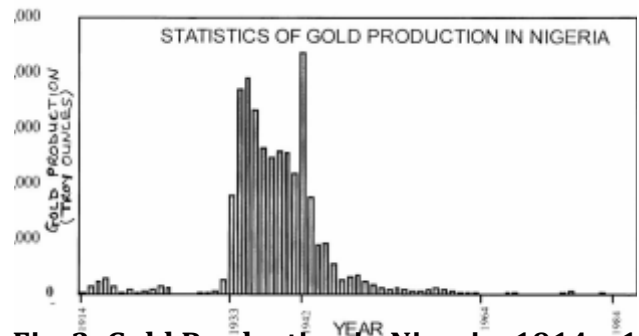


Fig. 3: Gold Production in Nigeria: 1914 – 1984

Table 1: Gold Production in Nigeria 2002 - 2009

Year	Production	Unit of Measure	% Change
2002	40	Kilograms	NA
2003	50	Kilograms	25.00
2004	30	Kilograms	-40.00
2005	30	Kilograms	0.00
2006	40	Kilograms	33.33
2007	180	Kilograms	350.00
2009	200	Kilograms	0.00

(Source: United States Geological Survey Minerals Resources Programme)

Table 2: Estimated Royalty Loss for Selected Nigerian Minerals

Mineral	Royalty (Naira/Tonne)	Estimated Production (Tonnes/Day/Week)	Estimated Loss N/Week)
Sand	N20/t	250t/d	30,000
Laterite	N25/t	250t/d	37,500
Baryte	N150/t	250t/d	225,000
Aquamarine	N25/t	10kg/wk	250,000
Tourmaline (green)	N10/t	10kg/wk	100,000
Tourmaline (pink, blue)	N45/t	10kg/wk	450,000

(Source: Amoka and Ogunbajo, 2003)

It was widely reported that, in 2012 alone, Nigeria lost about 50 billion dollars through illegal smuggling of unprocessed gold ore to neighbouring West African countries. The Nigerian Senate also disclosed in 2015 that about 4 trillion naira was lost to illegal mining in the country. Although the computation adopted by the government officials and empirical evidences of the figures arrived at could not be verified, it can be logically feasible that an estimated assessment of the situation in the AM industry by experienced stakeholders would give an estimation close to figures obtained.

The huge economic damage to which this important sub-sector has been subjected is quite unfortunate and regrettable because of enormous royalty and mining tax losses, wasteful mining practices and minerals ore smuggling. A case in point is great economic loss accompanying the poorly managed AM business in Zamfara State and other AM zones through which the nation is deprived of huge revenue due to mineral ore smuggling to neighbouring countries. This scenario is better imagined as illustrated in Figure 4. The activities culminating in eventual theft and smuggling of gold from ASM sites take the following routes:

- i. Ore is collected from gold mines near Sunke.
- ii. The ore is bagged and brought by motorcycle to villages like Dareta or Sunke, where villagers manually grind and wash the ore. Gold is mostly extracted by the villagers using mercury amalgamation after which the resulting gold is sold to traders in Gusau, the capital of Zamfara State, where further processing takes place.
- iii. The processed gold is then transported to the Benin border and later transferred to dealers in Cotonou.
- iv. The dealers then sell the gold to wholesalers from Europe and the Middle East, who in turn introduce it to the worldwide market.



Fig. 4: Trade Route of Artisanally Mined Gold (Source: Bloomberg, 2013)



Fig. 5: AM Business Site in Bagega, Zamfara State

Figure 5 shows miners crushing rocks in an AM site in Zamfara State.

5.0 Strategies of the Formalisation Process

Formalization offers an opportunity to tap into significant economic benefits. Implementing a structured licensing system can allow the government to collect taxes and fees, enhancing national revenue. Additionally, formalizing operations can improve job security and wages for miners, stimulating local economies. By connecting miners to better markets, the economic impact can be further amplified.

5.1 Unlocking the Business and Investment Potentials of Artisanal Mining in Nigeria

To say that AM in Nigeria has enormous business and investment opportunities would be an understatement considering its proven economic potentials spread across the country and human capital endowments capable of huge revenue generation to the economy. To plug all the economic leakages associated with indiscriminate AM in Nigeria, Salati in 2015 proposed an Integrated Management Model for effective management of Artisanal and Small-scale Gold Mining (ASGM) in Northern Nigeria which had recorded huge economic loss due to lack of management of the ASM sub-sector. The major thrusts of the proposed model include stoppage of smuggling of unprocessed gold out of Nigeria through which billions of naira had been lost in the past; a boost in revenue generation to government through the collection of royalty and mining taxes; and generation of employment opportunities to millions of Nigerians, especially in the rural areas.

5.1.1 Direct Revenue Generation

In spite of lack of reliable statistical data to generate empirical evidences for AM productions across Nigeria, estimations from field studies and extrapolation of reported figures indicate that huge revenue can be generated from collection of royalty and mining taxes on gold mining alone. Therefore, revenue generation from payment of

royalty for all the varieties of minerals mined informally across the country could stand at approximately over a trillion naira annually. In the same vein, significant revenue would have been saved by immediate stoppage of illegal mining and smuggling of unprocessed minerals, given the level of reported cases of such economic leakage across the country.

5.1.2 Direct Employment Generation and Wealth Creation

A study on the effective management of the Nigerian AM industry by Salati in 2015 came up with the following employment and wealth creation projections for local miners in the rural areas and youth:

- a) Over 2 million young persons could be employed by the ASM industry.
- b) About 387, 000 Local miners could be empowered in the rural areas.
- c) About 584 jobs could be created for technical and non – technical officers at the proposed State Mines Inspectorate, Cadastral and Registration Centres.
- d) About 12, 024 jobs could be created for technical and non – technical officers at the proposed Local Government Mines Inspectorate, Cadastral and Registration Units.
- e) Over 2, 500 workers are estimated to be accommodated by the proposed semi-mechanised ASM companies across the country; and
- f) About 1 million indirect employments and support services could be created from ASM across Nigeria.

5.2 Establishing a Regulatory Framework

To achieve formalization, a clear regulatory framework is essential. Key elements include:

- i. **Licensing:** Creating an accessible licensing process encourages miners to operate legally and responsibly.
- ii. **Training Programs:** Educating miners on safe practices, efficient techniques, and business management can empower them and improve their operations.

5.3 Strengthening and Enforcement of the Law

The review of Minerals and Mining Act, 2007 with a view to strengthening the existing provisions on the punishment meant to discourage defaulting or illegal miners is a necessity. More importantly necessary is enforcement of law against offenders to equally serve as a deterrent to others.

5.4 Enhancing Market Access

Improving market access is crucial for the success of artisanal miners. Establishing cooperatives can enable them to negotiate better prices for their products. Furthermore, developing a certification system for artisanal minerals can enhance buyer confidence, encouraging ethical sourcing and potentially leading to higher sales prices.

5.5 Prioritizing Environmental Sustainability

The environmental impact of mining cannot be overlooked. By promoting sustainable practices within the formalization framework, Nigeria can mitigate ecological damage. Initiatives for land restoration after mining activities can help ensure that resources are preserved for future generations.

5.6 Community Engagement and Infrastructure Development

Engaging local communities in the formalization process is vital. Their insights can shape regulations and initiatives to better meet local needs. Additionally, investing in infrastructure—such as roads, schools, and healthcare—can improve the quality of life in mining communities and enhance overall productivity.

5.7 Collaborative Efforts among Stakeholders

Successful formalization requires collaboration among various stakeholders, including the government, private sector, NGOs, and international organizations. These partnerships can facilitate resource sharing and expertise, enhancing the effectiveness of formalization efforts. Establishing mechanisms for monitoring and enforcement will ensure compliance with regulations, promoting safer and more sustainable mining practices.

5.8 Access to Financial Resources

Providing artisanal miners with access to finance is crucial for facilitating their transition to formal operations. Microfinance options can enable miners to invest in better tools and technology, while grants and subsidies can support the adoption of formal practices.

6.0 Enhancing the Structure of Artisanal Mining Formalization

6.1 Decentralisation

Decentralisation of government functions down to the community level will discourage miners' illegality and facilitate legalisation and formalisation of AM sector. The comparison of AM policies of other countries such as Ghana, Tanzania, Uganda, Peru and Ecuador is done with a view to identifying organisational features that

can improve Nigeria's mining sector as shown in Table 3.

Table 3 Comparison of Government Policies on Artisanal Mining in Selected Countries

Country	Status	Size	Cadastral System	Estimated Contribution to National Economy	Areas to be Improved Upon	Other Areas of Impressive Policies	Policy Compliance Level
Ecuador	AM	Moderate	Decentralised	65 - 75 % (2002 - 2005)	Large scale mining sector.	Formalisation; mercury reduction.	Growing and encouraging.
Ghana	AM	Large	Semi-centralised	28 % (2011)	Environmental challenge.	Decentralisation drive; mineral buying centres.	Gradual and encouraging.
Uganda	AM	Moderate	Semi-centralised	Low < 5 %	Socio-environmental issues.	Legalisation drive.	Low but growing.
Peru	AM	Moderate	Decentralised	12.63 % (2000)	Mercury-induced pollution.	Formalisation; cleaner processing technologies.	Growing and encouraging.
Tanzania	AM	Large	Decentralised	10 % (2011)	Environmental issues.	Formalisation; Miner education and empowerment.	Growing and encouraging.
Nigeria	AM	Large	Centralised	Insignificantly low < 5 %	Entire Mining sector.	Private investment drive; computerised Mine cadastral.	Low and discouraging.

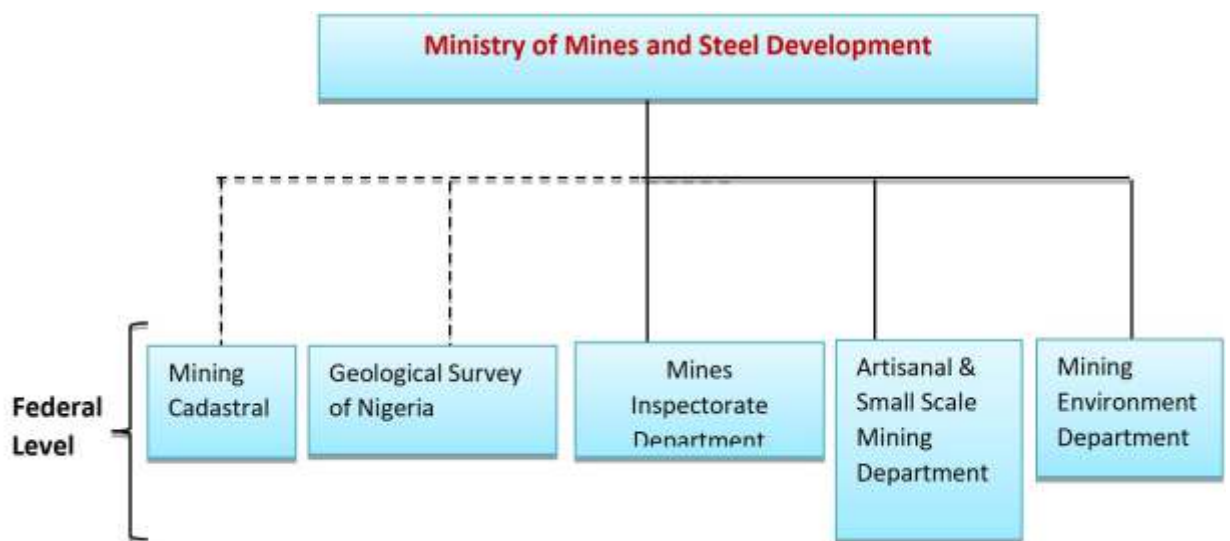


Fig. 6 Organisational Structure of MMSD in Nigeria

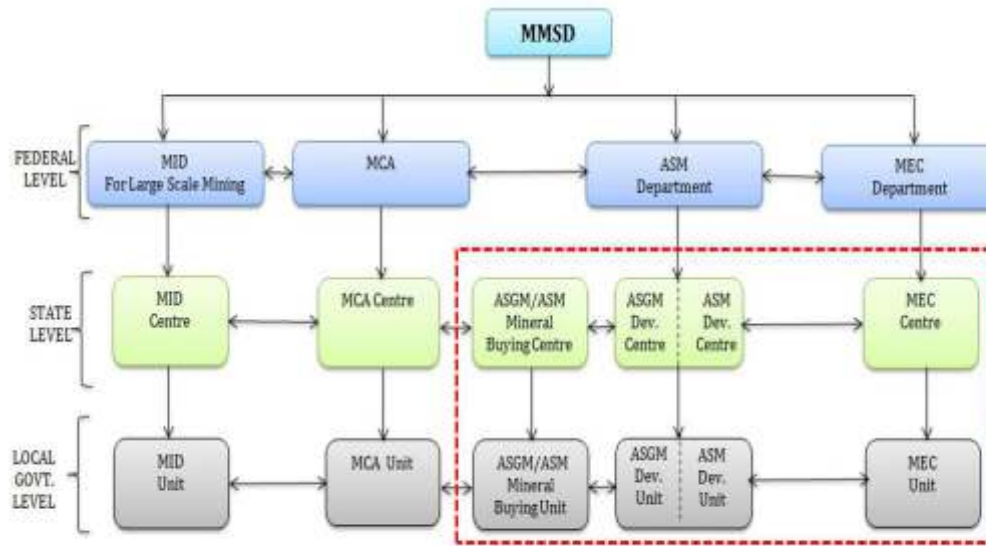


Fig. 7 Proposed IMM for ASGM in Northern Nigeria

Table 4: Identified Strategies for Policy Implementation on Artisanal Mining

Threat	Strategy
Illegality Non-compliance	Decentralisation of MCA functions to the Local Government Level; making cadastral application a 'one-stop-shop'; creation of AM Development Centres and units at the State and Local Government levels; employment of adequate technical workforce in the mining sector and provision of adequate logistic for the smooth enforcement of their assignments.
Ignorance	Massive education on AM.
Smuggling Criminality Population explosion	Creation of AM Development Units at local levels; empowering the local authorities (<i>e.g.</i> Emirate Council) to monitor AM in their domains; provision of more rural infrastructures.
Rural underdevelopment Environmental Degradation Child Labour Health and safety hazards	Ensuring effective collaboration between AM Development Centres/Units and the local authorities; fostering collaboration between AM Development Centres/Units and the Mining Environment Centres/Units; punishment for non-compliance with environmental guidelines through the collaboration of Mining Environment Centres/Units and law enforcement agencies.

7.0 Conclusion

The formalization of artisanal mining in Nigeria presents a significant opportunity to enhance national revenue and promote sustainable economic development. By addressing regulatory, economic, and environmental challenges through a collaborative approach, Nigeria can unlock the full potential of its artisanal mining sector. This initiative promises not only economic benefits but also improved livelihoods for local communities, paving the way for a more prosperous future for all. Hence, just like the proverbial saying goes: "The baby should not be thrown away with the

bath water." Artisanal mining in Nigeria should not be discarded despite its inherent challenges, but should be nurtured with effective management, collaborative efforts, and good policy formulation and implementation.

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Lead Paper: Strategies and Regulatory Measures for combating insecurity in the Nigerian Mining Sector

Engr. H.T. Bolarinwa, FNSE, FNSME, FNIMMME, MNMGS

1. Introduction

The Nigerian mining sector is crucial to the nation's economy, providing essential raw materials and significantly contributing to revenue generation, employment, and industrial development. With a wealth of natural resources such as gold, limestone, tin, and coal, the industry holds the potential to be a major economic driver. However, it faces significant challenges, primarily insecurity, which threatens to undermine its growth and stability. Insecurity in the mining sector manifests as illegal mining, theft, vandalism, and violent attacks by armed groups, disrupting operations and deterring investment. These security challenges lead to lost of revenues, job and hinder community development. Current regulatory measures have proven inadequate in addressing the root causes of insecurity. This paper aims to explore effective strategies and regulatory measures to combat these issues, enhancing security and fostering a stable environment for investment and sustainable growth in the mining industry.

2. Overview of Insecurity in the Mining Sector

2.1 Types of Insecurity

- a) **Illegal Mining Operations:** which is unauthorized extraction of minerals undermining legitimate businesses.
- b) **Theft and Vandalism:** theft equipment and resources, leading to operational disruptions.
- c) **Violent Attacks:** armed groups targeting mining sites, posing threats to workers and communities.

2.2 Impact on Mining Operations and Communities

- a) **Operational Disruption:** Insecurity leads to halted mining activities and increased costs.
- b) **Economic Consequences:** Loss of revenue for companies and government; diminished local economies.
- c) **Community Well-being:** Threats to safety and livelihoods, resulting in job losses and reduced development.

2.3 Strategies to Combat Insecurity

- i. **Community Engagement:** foster partnerships between mining companies and local communities to promote mutual benefits and shared responsibilities. Engaging community leaders can help to build trust and improve communication regarding security concerns.
- ii. **Private Security Investment:** encourage mining companies to invest in private

security measures tailored to their specific risks. This can include hiring trained security personnel and utilizing surveillance technologies to protect sites and personnel.

- iii. **Technology Adoption:** implement advanced technologies such as drone surveillance, geolocation systems, and data analytics to monitor mining activities and enhance security measures. These technologies can help identify and respond to threats more effectively.

2.3.1 Regulatory Measures to Combat Insecurity

- a. **Updates to the Nigerian Minerals and Mining Act:** revise and strengthen existing laws to address contemporary security challenges, ensuring they encompass measures against illegal mining and related crimes.
- b. **Strengthening Law Enforcement:** increase collaboration between mining companies and law enforcement agencies to improve responsiveness and effectiveness in addressing security issues in mining areas.
- c. **Enhanced Border Controls:** implement stricter border controls to prevent the illegal entry of arms and materials used for illegal mining, thereby reducing the operational capabilities of criminal groups.
- d. **Creation of Dedicated Security Regulations for Mining:** Security-specific regulations should be introduced to ensure that mining

- companies follow standardized protocols regarding surveillance, personnel safety, and protection of mineral resources.
3. Creation of a National Mining Security Task Force
 - a) Composition and Mandate: to form a dedicated task force comprising representatives from various government agencies, mining companies, and local community leaders to oversee security measures in the mining sector.
 - b) Importance of the Mining Marshal Initiative: I appreciate the Federal Government's establishment through the Honorable Minister, Dr. Dele Alake of the Mining Marshal from the Nigeria Security and Civil Defence Corps (NSCDC) to combat illegal mining. This initiative has been effective in enhancing security and reducing illegal activities since its inception.
 - c) Strengthening the Role of Mining Inspectorates: Mining inspectors must be empowered to monitor mining activities more effectively, ensuring that security protocols are adhered to. Inspections should be regular and rigorous, with a focus on compliance with environmental, safety, and security standards. Mining inspectorates must also work closely with law enforcement agencies to track and dismantle illegal mining operations.
 4. Other Strategies to Combat Insecurity
 - i. Regulation of Artisanal and Small-Scale Mining (ASM): The government should streamline and formalize the operations of ASM by issuing licenses, creating mining cooperatives, and providing training on safe and secure mining practices.
 - ii. Collaboration with State and Local Government.
 - iii. Improving Mineral Tracking Systems.
 - iv. Strengthening Inter-Agency Collaboration and Intelligence Sharing.
 - v. Implementing a Comprehensive Licensing and Monitoring System.
 - vi. Increase Funding for Mining Security.
 5. Case Study: Mining Security in Zamfara State
 - a. Background and Insecurity: Zamfara State has faced severe insecurity issues due to rampant illegal mining, armed banditry, and violent conflicts among mining factions, disrupting mining activities and endangering lives (Adekunle, 2019).
 - b. Government Response: the government has implemented several measures, including deploying military and police forces to affected areas, enforcing the ban on illegal mining, and collaborating with local communities to enhance security (Okonkwo, 2022).
 - c. Outcomes and Ongoing Challenges: while there have been some successes in reducing illegal activities and improving safety, challenges remain, such as resistance from illegal miners, limited resources for enforcement, and the need for sustained community engagement to ensure long-term security.
 6. Conclusion and Recommendations
 - 6.1 Conclusion
 - a. The Nigerian mining sector faces significant security challenges, including illegal mining, theft, and violent attacks, which threaten its potential for growth and development.
 - b. Addressing insecurity requires a collaborative effort involving government agencies, mining companies, and local communities to implement effective strategies and regulatory measures.
 - c. Additionally, urgent action is needed to enhance security, promote sustainable mining practices, and ensure the long-term viability of the sector, fostering a safe environment for investment and community development.
 - 6.2 Recommendations
 - i. Strengthen Regulatory Framework: revise existing laws and regulations to enhance penalties for illegal mining and related crimes, ensuring that law enforcement agencies have the necessary authority and resources to act effectively.
 - ii. Promote Sustainable Mining Practices: encourage the adoption of sustainable mining practices that prioritize environmental protection and community well-being, fostering a culture of responsibility within the industry.
 - iii. Increase Investment in Security Infrastructure: allocate resources for improving security infrastructure, including surveillance systems and communication tools, to ensure effective monitoring and rapid response to security threats.
 - iv. Enhance Training and Capacity Building: provide training for law enforcement and mining personnel on security best practices,

conflict resolution, and community engagement to build a more informed and responsive workforce.

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Lead Paper: Foreign Direct Investment as Impetus for Achieving Sustainable Development in Nigeria's Mining Industry

Dr. M.N.S Usaini

Kaduna State Mining Company Limited, Kaduna

1. Introduction

The Nigerian mining industry has substantial potential, given the nation's rich endowment of minerals, including gold, lithium, limestone, lead, zinc, and tin. However, to achieve sustainable development within the industry, significant investment and modernization are needed. Foreign Direct Investment (FDI) can play a pivotal role in bridging the financing gap, enhancing technology transfer, and building capacity in the sector. This report explores how FDI can catalyze sustainable development in Nigeria's mining industry by examining the current landscape, the benefits of FDI, potential challenges, and recommendations for fostering a more attractive environment for foreign investors.

2. The State of Nigeria's Mining Industry

The Nigerian mining sector remains underdeveloped despite the abundance of natural resources. Contributing less than 1% to the national GDP, the industry is plagued by poor infrastructure, outdated technology, and inadequate capital. Challenges such as regulatory uncertainty, insecurity, and weak enforcement of mining laws further deter potential investors. However, there is increasing recognition of the role the sector can play in economic diversification, job creation, and sustainable growth. Recent reforms and strategic policy frameworks like the "Roadmap for the Growth and Development of the Nigerian Mining Industry" aim to revitalize the sector.

3. Foreign Direct Investment as a Catalyst for Sustainable Development

3.1 Capital Injection and Infrastructure Development

FDI introduces essential capital that can enhance exploration activities, develop infrastructure, and improve overall industry efficiency. For example, investments in transport and power infrastructure can facilitate access to remote mining locations and reduce operational costs, which can in turn benefit local economies.

3.2 Technology Transfer and Skill Development

Foreign investors often bring advanced mining technologies and best practices that can significantly increase efficiency and safety in the mining industry. The adoption of technologies such as automated drilling, geospatial data analysis, and mineral processing innovations can boost productivity and reduce environmental impact. Additionally, skill development initiatives associated with FDI can improve the capabilities of the local workforce, ensuring sustainable knowledge transfer.

3.3 Job Creation and Economic Diversification

The mining industry has the potential to create thousands of direct and indirect jobs in Nigeria. By attracting FDI, new projects can stimulate job creation across various stages of the mining value chain, from exploration and extraction to processing and logistics. A diversified economy less reliant on oil will be better equipped to achieve sustainable development goals.

3.4 Case Studies of FDI Impact on Mining in Africa

To illustrate the potential benefits of FDI, this section examines FDI's impact on the mining sectors in Ghana, Mali, Burkina Faso, South Africa, and the Democratic

Republic of Congo (DRC).

FDI in Ghana, Mali, Burkina Faso, South Africa, and the DRC: Notable mining companies such as AngloGold Ashanti (Ghana), IAMGOLD (Mali), and Glencore (DRC) highlight the significant presence of foreign investors in these countries. These companies are publicly listed on major stock exchanges and attract capital from international investors.

Contributions to GDP: The mining sectors in these countries contribute significantly to their GDPs, underscoring the role of FDI in economic growth. For instance, in Ghana, mining contributes around 7% to the GDP, largely due to foreign investments.

Positive Outcomes and Lessons Learned: These countries have benefited from job creation, technology transfer, and, in some cases, improved sustainability practices. Public-private partnerships and CSR initiatives have also strengthened community relations and mitigated environmental impacts.

4. Challenges to Attracting FDI in Nigeria's Mining Sector

4.1 Regulatory and Political Uncertainty

Nigeria's mining regulations have undergone multiple changes in recent years, leading to uncertainty among potential foreign investors. A clear, consistent regulatory framework is essential for FDI attraction. Moreover, political instability, including insecurity in mining regions, poses a significant risk to investments.

4.2 Inadequate Infrastructure and Power Supply

Inadequate infrastructure, particularly in transportation and electricity, increases operational costs and reduces competitiveness. The absence of reliable power sources in many mining areas hampers productivity and deters investment.

4.3 Environmental Concerns and Community Relations

Mining activities can have adverse environmental impacts, such as deforestation, water pollution, and soil degradation. Moreover, strained relationships with local communities due

to land rights and environmental issues can pose significant obstacles. Foreign investors need to navigate these challenges carefully to ensure sustainable development and social acceptance.

5. Strategies for Maximizing FDI in the Mining Sector

5.1 Policy Reforms and Regulatory Stability

To attract FDI, Nigeria needs to streamline mining regulations, ensure consistent policy enforcement, and provide tax incentives and exemptions for foreign investors. Policies that protect property rights and reduce bureaucratic red tape will also foster a more attractive investment climate.

5.2 Public-Private Partnerships (PPP)

PPP models can encourage foreign investment by sharing risks and leveraging government resources. Collaborative ventures between the government, foreign investors, and local companies can improve infrastructure, enhance technical capacity, and promote economic diversification.

5.3 Sustainability Initiatives and Corporate Social Responsibility (CSR)

Integrating sustainability initiatives and CSR practices into mining operations can mitigate environmental impacts and improve relations with local communities. Environmental regulations that encourage green mining practices, combined with FDI, can ensure long-term resource sustainability and social acceptance.

6. Conclusion and Recommendations

FDI is crucial to unlocking Nigeria's mining potential and achieving sustainable development. By addressing the sector's challenges—such as regulatory instability, infrastructure deficits, and environmental concerns—Nigeria can attract the capital, technology, and expertise needed to drive growth, create jobs, and diversify the economy.

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**Air Quality Assessment at Offunene Ceramics Company Ltd and immediate
Environs, Lokoja North Central Nigeria.**

N. Ballin¹ B.S. Jatau², and S.E. Obrike¹

¹ Department of Geology and Mining Nasarawa State University, Keffi, Nigeria.

² Hensard University Toru-Orua, Bayelsa State, Nigeria

Corresponding email: sj.blason@gmail.com

Abstract

The air quality assessment to ascertain the atmospheric conditions was undertaken at offunene Ceramics Company and Environs. The study area is underlain mostly by Granitic gneiss and fine-grained biotite gneiss rock as revealed from geological transversing. Twelve (12) air quality points were taken at proximity to the various locations around the Offunene Ceramics Company, Lokoja, Kogi State, Nigeria to ascertain the atmospheric conditions. The atmospheric analysis revealed Volatile Organic Compound (VOC) and carbon monoxide (CO) concentrations above the maximum permissible limits. From the results of atmospheric analysis, the study Area can generally be objectionable in terms of air quality due to the high concentration of VOC and CO. It is suggested that remediation and mitigation measures be emplaced to reduce the objectionable air quality.

Keywords: Air, Volatile organic compound, carbon monoxide, concentration, objectionable

1.Introduction

Delete this and start typing from here (12 pt) Resource enhancement and its disposal is greatly affecting natural cycle; our society consumes and exploits the environment in a frantic way, which is considered by many to overshoot the carrying capacity of the earth. Environmental pollution is greatly increasing, and it is the most significant problem throughout the world. As the world is witnessing the rapid urbanization and industrialization, the need for energy and waste discharges are in an increasing trend. The waste discharge in any form (solid, liquid or gas) can cause a severe health problem, greenhouse gas emissions, water pollution and acid rain. To cater the needs of the growing population, various industries have started and are currently manufacturing different products. These industries procure raw materials, process them and produce the finished products. Manufacturing the finished products, the industries produce various by-products, and the challenge is the disposal of these wastes, wrong disposal automatically result in environmental pollution. Environmental pollution basically is the unwanted disposal of mass materials, wastes or energy product material into the earth's natural resources pool such as water, land, air that results in long- or short-term detriment to the atmosphere and its ecological health to negatively impacts the living beings and their life both

quantitatively and qualitatively globally (Poonam, 2022). Environmental pollution basically is the unwanted disposal of mass materials, wastes or energy product material into the earth's natural resources pool such as water, land, air that results in long- or short-term detriment to the atmosphere and its ecological health to negatively impacts the living beings and their life both quantitatively and qualitatively globally (Poonam, 2022). Pollutions can also be produced by various industries such as cement industry, fertilizer industry, dye, iron and steel, pesticides, oil refineries, textiles, tanneries, thermal power plant and the ceramic industry (Hanif, 2005)

Ceramic products are widely used as building material, the clean and attractive appearances are the special characters of ceramic product. Hence, the ceramic products are regarded as the highest percent of building materials. The ceramic tiles production across the globe reached 18.3 billion square meters in 2021, this figure represents a growth rate of 7% in comparison to the previous year (Ceramic world, 2023). Hence, the demand for the ceramic products is increasing every year and to cater for the need, the industries are being set up around the world strictly for ceramic production. The production of any ceramic products like tiles, plates, cups etc. Involves various processes from mining to the finish product, during these processes transportation of goods is important, energy is required a lot from exploitation to the finish product. Due to the production process, lots of waste

can be generated and this can lead to generation of different pollutant, which will affect the entire ecosystem, when the ecosystem is affected, it may deface the world. A few studies have investigated the environmental impact due to the ceramic industry. Such as impact due to specific parameters like sintering, smoke and CO emission (Almeida, 2016). This study involves environmental impact assessment (EIA) of Offunene Ceramics Companies on groundwater, surface water and particulate matter at Offunene Area, was investigated using conventional geologic, hydrogeologic and atmospheric methods. The Study area covers 30sqkm and Lies Between Latitudes 7°25'5" N and 7°27'45" N and Longitudes 6°39'40"E and 6°43'10"E (Figure1).

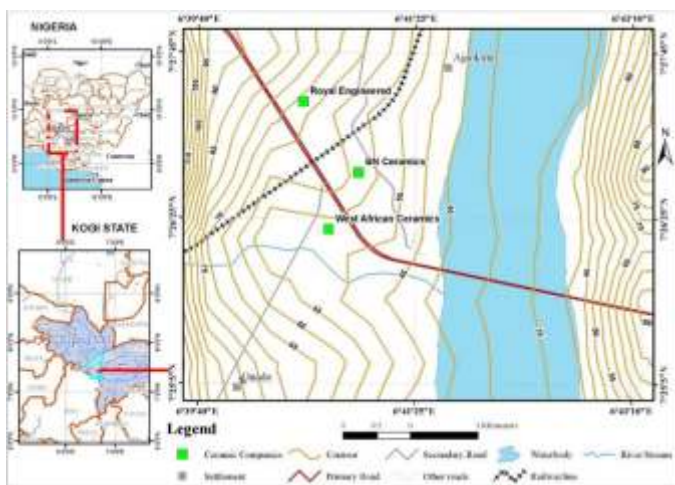


Figure 1: Map of Nigeria showing Kogi State and the study area.

2.0 LITERATURE REVIEW

Muthiah (2018) discussed the environmental impacts caused by ceramic industries, they collected the details of the ceramic tiles and compiled based on manufacturing process, environmental impacts and assessment methodology. They found out that manufacturing of ceramic tiles produces its own amount of harmful and hazardous gases in the environment depending on the raw material used, this assessment was done using air quality monitoring to know the concentration of gases that have effect on global warming, ozone depletion, acidification and eutrophication. Assessment of particulate matter (PM) pollution episode in a ceramic cluster with As, Cd, Ni, and Pb was done by (Vicente, 2017), also Control fugitive particulate emissions in the ceramic industry (Monfort, 2006) particulate matter and statistical tools for air pollution assessment; multivariate and spatial analysis studies in Madrid 2019, they all carried out air quality with mostly reference to particular matter and correlated it to their law standard. They assess

the air quality with other parameters like NO, NO₂, O₃ and used statistical method to correlate their relationship and used the concentration to produce a geostatistical analysis, a spatial interpolation method using contour map to show the concentration. Particulate matter F, Co₂, NO₂, VOC, SO₂ was analyzed by (Giacomo, 2020), they wrote about the sustainability in Italian ceramic tile production, evaluating its impact to the environment, they monitored the air quality with respect to Particulate matter F, Co₂, NO₂, VOC, SO₂ and also used graphical representation of the data found. It is important to note why particulate matter (PM) is necessary, this is because they serve as drivers for constituent.

3 Materials and Methods Used

The research methods involve reconnaissance, field studies, laboratory studies, data processing, analysis and interpretations. Results generated obtained by geological traversing, and laboratory studies were analyses and interpreted and used to discuss the Environmental Impacts within the study area.

4 Results and Discussion

The study area underlain by Basement Complex composed of gneissic rocks, the rocks unit encountered were granitic gneiss and fine-grained biotite gneiss rock. Mineralogically, the rocks contain some amount of quartz, biotite mica in hand specimen. The rock type across the field of study was deduced to be gneiss with similar elemental composition (Figure2)

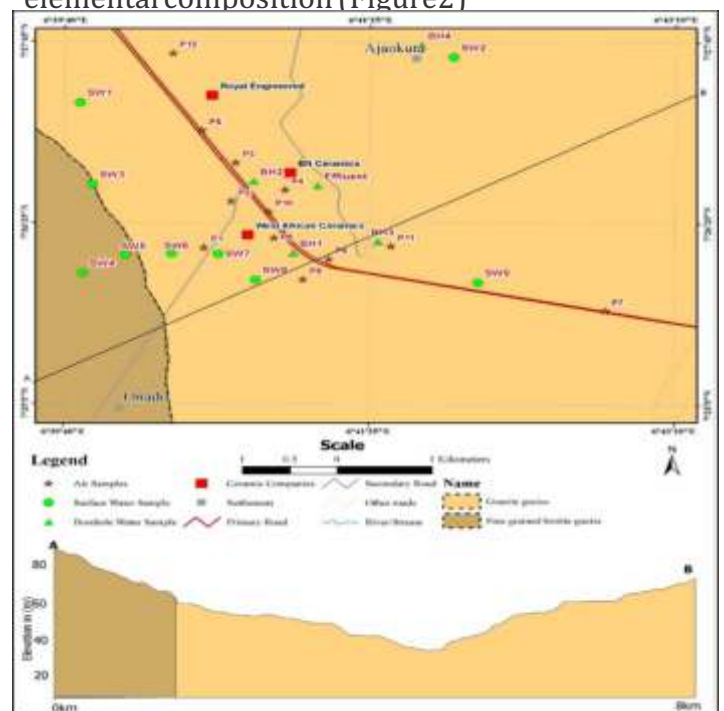


Figure 2: Geologic map of the study area

The air quality results are showed in Table1

Table 1: AIR QUALITY RESULT

PARAMETERS	UNIT	FMEnv Limit	PT 1	PT 2	PT 3	PT 4	PT 5	PT 6	PT 7	PT 8	PT 9	PT 10	PT 11	PT 12
GAS MONITORS														
NO ₂	mg/m ³	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00
SO ₂	mg/m ³	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.14
H ₂ S	mg/m ³	NS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NH ₃	mg/m ³	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CH ₄	mg/m ³	NS	302	292	113	281	287	336	317	321	318	295	0.00	0.00
VOC	mg/m ³	0.01	12.0	0.0	0.0	0.0	2.0	5.0	5.0	6.0	0.0	4.0	2.4	1.0
CO	mg/m ³	10.00	39.0	40.0	40.0	41.0	41.0	36.0	37.0	37.0	35.0	36.0	0.00	0.00
O ₂	%	NS	21.5	21.5	21.5	21.5	21.50	20.9	20.9	20.9	20.9	21.5	21.4	21.5
CO ₂	mg/m ³	5000.0	1099	1062	410	1024	1045	1224	1154	1170	1157	1073	449	432

AIR PARTICLES							
PARAMETERS	UNIT	FMEnv	POINT 1	POINT 2	POINT 3	POINT 4	POINT 5
PM 0.3	µm	0 – 250,000	120,487.00	101,345.00	165,197.00	94,427.00	123,907.00
PM 0.5	µm	0 – 87,500	27,700.00	26,472.00	45,357.00	26,819.00	32,404.00
PM 1.0	µm	0 – 20,800	3,383.00	3,434.00	6,149.00	3,265.00	4,041.00
PM 2.5	µm	0 – 1,362	399.00	437.00	688.00	399.00	433.00
PM 5.0	µm	0 – 483	73.00	51.00	81.00	62.00	54.00
PM 10.0	µm	0 – 170	20.00	17.00	23.00	23.00	12

PARAMETERS	UNIT	FMEnv	PT 6	PT 7	PT 8	PT 9	PT 10	PT 11	PT 12
PM 0.3	µm	0 – 250,000	163,880	85,205	102,815	88,780	115,422	98,456	101,234
PM 0.5	µm	0 – 87,500	44,088	22,843	26,115	24,382	30,036	28,345	30,425
PM 1.0	µm	0 – 20,800	5,601	3,111	3,199	2,906	3,965	3,457	3,248
PM 2.5	µm	0 – 1,362	663	333	369	288	367	387	342
PM 5.0	µm	0 – 483	94	46	46	41	40	37	47
PM 10.0	µm	0 – 170	29	15	11	15	16	16	19

ENVIRONMENTAL PARAMETERS														
PARAMETERS	UNIT	FM Env	PT 1	PT 2	PT 3	PT 4	PT 5	PT 6	PT 7	PT 8	PT 9	PT 10	PT 11	PT 12
Temperature	°C	40	28.9	34.2	29.5	30.6	29.6	27.0	27.1	29.7	31.0	29.1	29.7	29.6
Relative Humidity	%	100	73.7	74.1	74.2	71.4	73.0	85.8	84.2	77.5	74.0	76.4	72.8	74.6
Wet Bulb	°C	NS	26.3	27.6	26.1	26.7	26.1	25.3	25.2	26.7	27.4	26.0	26.8	26.9
Dew point	°C	NS	24.8	26.2	24.6	25.0	24.6	24.4	24.2	25.4	26.0	24.6	24.5	25.7
Heat index	°C	NS	33.3	44.0	35.0	37.0	35.0	30.0	30.0	36.0	39.0	34.0	35.0	35.1
Noise	dB	85-90	75.9	65.9	71.4	76.8	64.3	72.1	61.2	63.3	51.3	54.2	62.7	58.9
Wind Speed	m/s	NS	1.4	1.2	1.7	0.8	1.3	1.4	0.8	1.0	0.6	1.2	1.5	1.3

4.1 AIR QUALITY

From the assessment of the air quality, the parameters ascertain were found to be mostly within limit with the exception of volatile organic compound (VOC) and carbon monoxide (CO). From the air assessment, due to the wind pressure, there is high diffusion of the particulate matter.

4.1.1 Volatile Organic Matter (VOC)

Volatile organic compounds (VOCs) are a group of chemicals that can vaporize into air. VOCs are in thousands of daily use products, including paint, varnish, wax, and various cleaning, degreasing, and cosmetic products. Exposure to VOC vapors can cause a variety of health effects

The concentration of VOC particularly is high for every sampling point in the environment, and this could be because of the raw materials used in the production of the ceramic tiles. The raw materials used in the ceramic production is 68% made of clay, (Valerie, 2005) In the ceramic industry, burning of pore-forming agents in clay materials during firing leads to the emission of pollutant volatile organic compounds (VOC). Natural organics present in clays, called humic substances, ensure good deflocculation and plasticity of the clay, necessary for forming by extrusion.

Having high concentration of VOC can lead to severe environmental problem like leaching of VOC into groundwater and migrate to drinking-water

supply wells. Once in groundwater, they can generate toxic vapors that move through soils and can get into buildings and degrade indoor air quality, a process called [vapor intrusion](#) (Minnesota Pollution Control, 2023).

The concentration of VOC from the study area ranges from $1.0\text{mg}/\text{m}^3$ - $12\text{mg}/\text{m}^3$, the acceptable VOC range in FMEnv is $0.01\text{mg}/\text{m}^3$.

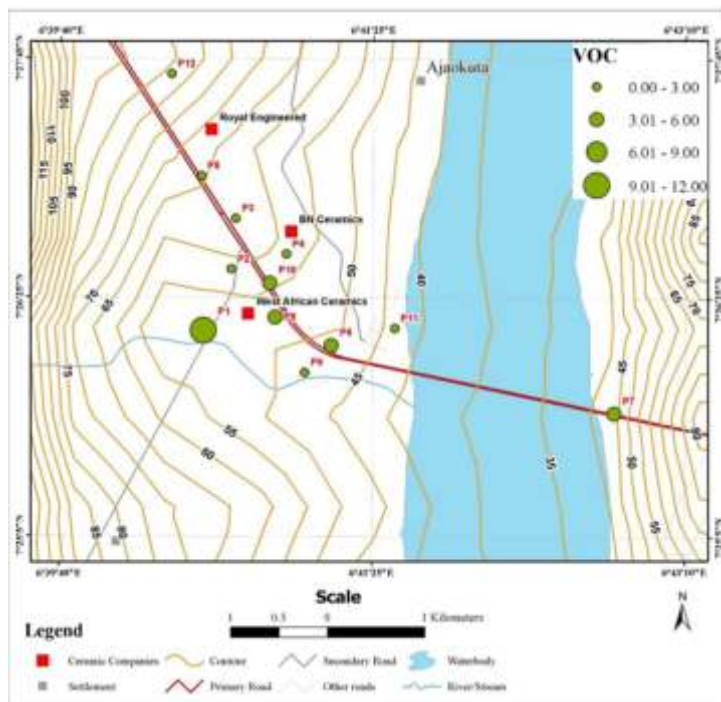


Figure 3: Geospatial VOC concentration for air quality

4.1.2 Carbon monoxide

The concentration of CO from the study area ranges from $35.00\text{mg}/\text{m}^3$ - $41.00\text{mg}/\text{m}^3$, the acceptable CO range in FMEnv is $10.00\text{mg}/\text{m}^3$. Carbon monoxide can be a dangerous, poisonous substance if people are exposed to it in high quantities, this makes it harmful. Carbon monoxide is a major component of motor vehicle exhaust fumes, and is emitted into the atmosphere by cars, trucks, Vehicle exhaust fumes and bushfires are the highest emitters of carbon monoxide.

When carbon monoxide is emitted into the atmosphere it affects the amount of greenhouse gases, which are linked to climate change and global warming, this means that land and sea temperature increases changing to ecosystems, increasing storm activity and causing other extreme weather events, therefore CO is a gas that indirectly contribute to the formation other gases that control global warming amongst others (Australian Government, 2022).

5 Conclusions

Result of the air quality index indicated presence of

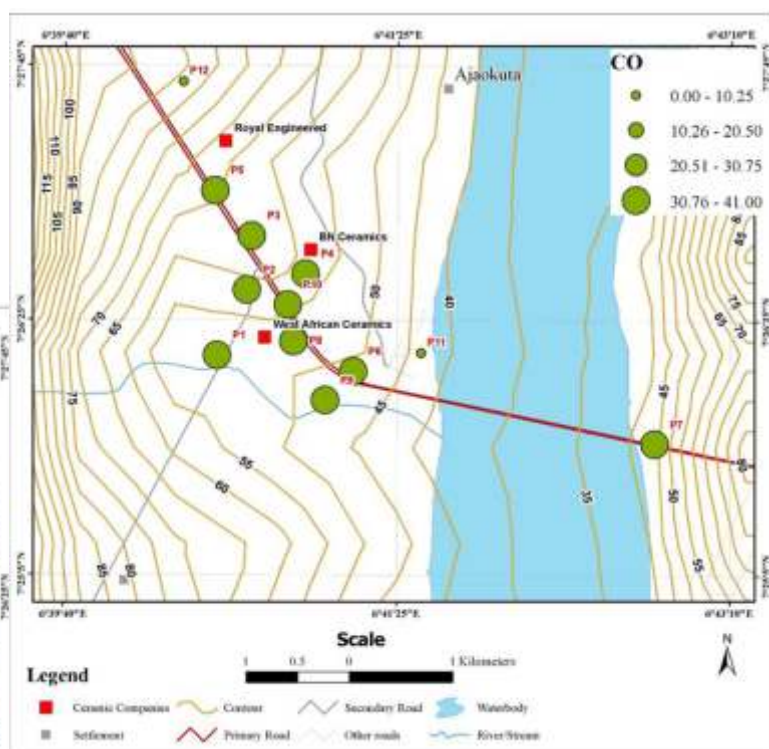


Figure 4: Geospatial CO concentration for air quality

possible environmental pollution with the presence of gaseous pollutant like VOC and CO which may be attributed to the ceramic companies present from the sampling points locations. The air quality source of pollution is anthropogenic. It has been identified that ceramic industries release toxic substance into the atmosphere, the major effect on the inhabitant is basically climate change, ecosystem quality degradation and emission of hazardous gases in the atmosphere. But this act is unavoidable because of the increasingly high demand of the product every year, however there is the need to mitigate and provide remediation measures on a serious ground following these findings. Based on the study carried out in the area, the following recommendations are being suggested. Environmental monitoring plan (EMP) should be enforced in all the manufacturing industries in the study area, to mitigate the adverse effect of environmental pollution and data gathering, since most of the air pollution is coming from the product used in the ceramic production, more studies need to be done on how the raw materials react for example the use of calcium silicate instead of calcium carbonate land soda ash, this eliminates the carbon dioxide from carbonate and therefore reduces the amount of particulate matter. There is need to set up parliament with core values of reducing atmospheric pollution to minimize harmful effect on human health with particular attention on sensitive population. It is also important that researchers and the environmental scientists invent new methods,

technologies, materials to manufacture the tiles without delivering any harmful substance to the environment at the same time fulfilling the demand of the global market.

i.

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Evaluation of the Impacts of Limestone Mining on Landcovers in Okpella, Edo State, Nigeria

¹Ayodele, G., ²Owolabi, A. O., ²Ogunro, A.T., ¹Osiyoku, D.A., ³Osaghae, S.O. and ⁴Raphael, E.O.

¹Department of Mineral and Petroleum Resources Engineering Technology, School of Engineering Technology, Auchi Polytechnic, Auchi, Edo State.

²Department of Mining Engineering, Federal University of Technology, Akure, Ondo State.

³Department of Geological Technology, School of Applied Science and Technology, Auchi Polytechnic, Auchi, Edo State.

⁴Department of Petroleum and Gas Processing, School of Engineering Technology, Auchi Polytechnic, Auchi, Edo State.

Corresponding author: stevenayodele03@gmail.com.

ABSTRACT

This research evaluated the impacts of limestone mining on landcovers in Okpella, Edo State, Nigeria. Landuse / landcover (LULC) analysis was also done in the study area for 2011, 2016 and 2021. Spatial distribution of vegetation analysis was carried out within the study area. Normalized Difference Vegetation Index (NDVI) showed mean values of 0.36557, 0.32961 and 0.41674 for years 2011, 2016 and 2021 respectively. NDVI showed that the studied area is dominated by shrubs, grassland and moderately healthy vegetation before the mining began in 2014. Modified Normalized Difference Water Index (MNDWI) was used to determine the visual representation of the spatial and temporal water variations within the study area. MNDWI showed that the surface water is a stressed landcover in the area which aroused from anthropogenic activities including mining operation that is known to require the use of great amount of water for mineral recovery and processing. Normalized Difference Moisture Index (NDMI) also showed that the mean value 0.01415, -0.32949 and -0.15331 for years 2011, 2016 and 2021 respectively. NDMI depicted low water stress in the study area. Soil Moisture Index (SMI) showed moderate moisture content (0.73682, 0.58690 and 0.58897) for years 2011, 2016 and 2021 respectively in the soil. Land Surface Temperature (LST) showed that LST values (28.623°C to 32.525°C) has continued to rise, though the water bodies have the lowest LST for the three studied years but the bare land and built-up areas have highest values of LST. This increase was due to moderate vegetation level and very low surface water as observed from the NDVI, NDMI and MNDWI analyses.

Keywords: Vegetation; moisture content; limestone; water bodies; land surface temperature.

INTRODUCTION

Human-driven changes in the terrestrial surface of the earth hold wide-ranging significance for the structure and function of ecosystems to the earth system, with equally far-reaching consequences for human well-being (Steffen *et al.*, 2004). The land use pattern of any terrain reflects the complex physical process acting upon the surface of the Earth (Anees *et al.*, 2014). Zhang *et al.*, (2017) opined that landscape changes are directly correlated with land use change and the human factor to a certain extent.

Mining process has undeniably brought affluence and employment prospects in mining areas, but concurrently has led to widespread environmental degradation and the erosion of traditional values in society (Oluku, and Asikhia, 2021). Turner and Ruscher (2004) affirmed that modern techniques of mining using heavy

equipment can produce dramatic alterations in land cover, both ecologically and hydrologically. Chen *et al.*, (2018) also observed that open-pit areas are not only affected vegetation, soil, and terrain, but has created big pits, transit sites, solid waste, and changed in land use /land cover (LULC). The direct negative effects of mining activities can be an unsightly landscape, loss of cultivated land, loss of forest and pasture land, and the overall loss of production (Osazuwa *et al.*, 2016).

Limestone mining creates large disturbances that significantly impact soil, vegetation and fauna and result in habitat fragmentation and loss (Sort and Alcañiz 1996). Mishra *et al.*, (2020) noted that aerial imagery and remote sensing data are used to capture on-going changes in landscape structure. Environmental monitoring using remote sensing is becoming an increasingly

important tool in the study of various aspects of ecosystems at local, regional, and global scales (Latifovic *et al.*, 2005). Hilson (2002) observed that mining, especially continuous surface mining has a significant effect on the landscape, not only during the active mineral extraction period but also during post mining operation.

The research aims at employing conventional and geospatial methods to evaluate mining impacts on the natural landcovers in the study area. The specific objectives are to determine the quality of surface and groundwater resources; analyze soil quality in active mining area; evaluate the impacts of mining activities on vegetation, water and soil using landcover dynamics and to determine the correlation between trends in changes in the landcover, water and soil quality in the study area.

Limestone Mining in Okpella

Limestone is a carbonate sedimentary rock, consisting of calcium carbonate and in some cases magnesium carbonate as a secondary component (Ganapathi and Phukan, 2020). In Nigeria, limestone is one of the most important minerals extracted owing to its use for cement production. The most widely adopted method of limestone mining is through opencast pits with bench formation (Ganapathi and Phukan, 2020). Olotu *et al.*, (2022) investigated the effect of limestone extraction in Okpella and its environs. Environmental degradation due to limestone exploitation has seriously affected crop yield in Okpella as a result of sealing up the plant leaf and reducing the photosynthesis rate Olotu *et al.*, (2022). The evidential detrimental effect of limestone mining on the vegetation in Okpella area was noted by Osazuwa *et al.*, (2016).

Landcovers in Mining Terrain

Land cover refers to the surface cover on the ground, whether vegetation, urban infrastructure, water, bare soil or other (Natural Resources Canada, 2021). They are the natural or basic elements of the environment that link and impacts many parts of the local, regional and global levels of the environment.

Water Quality and Mining

Mining can deplete surface and groundwater supplies viz-a-viz lowering of water table, percolation due to subsidence, reduction in moisture content in soil and atmosphere, disturbance of hydrological cycle, just to mention but a few. Water is considered polluted when it is altered in composition or condition directly or indirectly as a result of activities of man so that it becomes unsuitable or less suitable for any or all the functions or purposes for which it would be suitable in its natural state. Changes in water quality resulting from mining activities include

increase of water turbidity, concentrations of major ions and trace elements. In tropical countries like ours, the high temperature partially accounts for the water dissolving more materials.

Soil Quality, Vegetation Vitality and Mining

Soils are precious natural resources widely used as environmental indicators and their chemical analysis provide significant information on the assessment of anthropogenic activities of an area (Amadi *et al.*, 2017). Soils are dynamic and diverse natural systems that lie at the interface between earth, air, water, and life (Needelman, 2013). Li *et al.*, (2005) observed that soil quality is not only one of the most important environmental factors in developing sustainable ecosystem, but concerning the yields and safety of agricultural produces.

The Role of RS and GIS in Environmental Studies

Charou *et al.*, (2010) observed that integrating remote sensing (RS) and Geographical Information System (GIS) technology has enabled environmentalists and natural resources managers to acquire multi-temporal data and detect periodical changes.

Landcover Indices

a. Normalized Difference Vegetation Index (NDVI)

NDVI is a numerical indicator that uses the visible and near-infrared bands of the electromagnetic spectrum, and is adopted to analyse remote sensing measurements and assess whether the target being observed contains live green vegetation or not (Rouse *et al.*, 1973).

b. Modified Normalized Difference Water Index (MNDWI)

MNDWI is more suitable for enhancing and extracting water information for a water region with a background dominated by built-up land areas because of its advantage in reducing and even removing built-up land noise over the NDWI (Xu, 2006). The value of MNDWI ranges from -1 to +1.

c. Normalized Difference Moisture Index (NDMI)

It is a reliable indicator of water stress in crops (EOS Data Analytics, 2023). NDMI is used to determine vegetation water content (USGS, 2023). NDMI values range from -1 to +1.

d. Soil Moisture Index (SMI)

Soil moisture is simply the water stored in the soil, and it depends on rainfall, temperature, soil characteristics, and other variables (Richaud, 2019).

e. Land Surface Temperature (LST)

Land surface temperature (LST) represents the temperature value of an object on the surface of the earth (Erthalia *et al.*, 2019).

MATERIALS AND METHODS

Geology and Description of the Study Area

According to Ogunyele *et al.*, (2018), Okpella lies within the basement complex and the cretaceous to recent sediment of South Western Nigeria, the area falls within the Anambra and Afikpo basin

which formed the sedimentary cycle. The area is the eastern extension of the Upper Proterozoic Igarra Schist Belt, South-western Nigerian Basement Complex. Okpella is located between latitude N07° 16' and N07° 22' and longitude E06° 18' and E06° 23' in the North-eastern part of Edo State, Nigeria (see Figure 1).

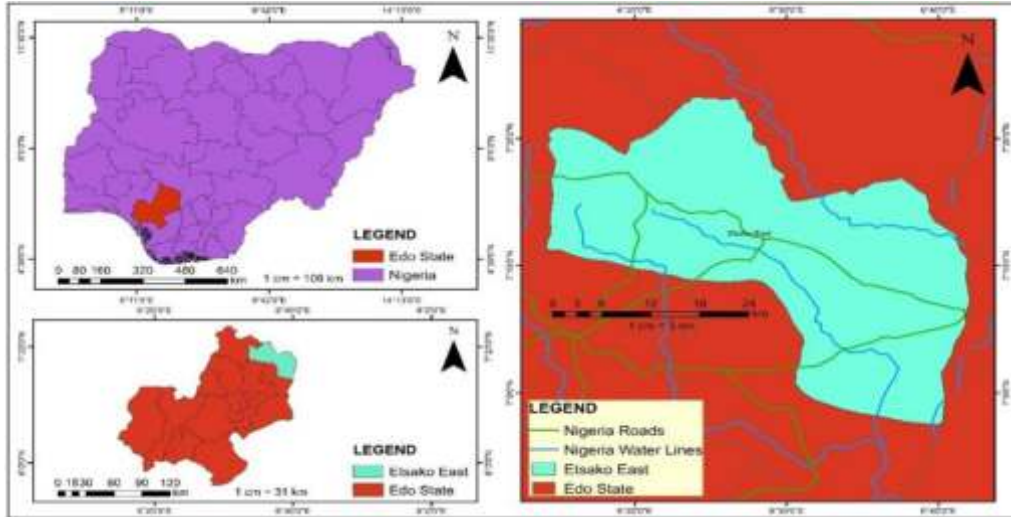


Figure 1: Map of the Study Area (ArcGIS, 2023).

Landsat Imagery Processing and Analysis

Normalized Difference Vegetation Index (NDVI) Estimation

NDVI is estimated as developed by Rouse *et al.*, (1973) using Equation 1.

$$NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}} \quad (1)$$

Where ρ_{NIR} is the surface reflectance of band 4 and ρ_{RED} is the surface reflectance of band 3 in Landsat 7 ETM+. In Landsat 8 OLI, ρ_{NIR} is the surface reflectance of band 5 while ρ_{RED} is the surface reflectance of band 4.

Modified Normalized Difference Water Index (MNDWI) Estimation

The MNDWI developed by Xu (2006) employed the GREEN band and the short-wave infrared (SWIR) band. MNDWI can be calculated by using Equation 2.

$$MNDWI = \frac{\rho_{GREEN} - \rho_{SWIR}}{\rho_{GREEN} + \rho_{SWIR}} \quad (2)$$

Where ρ_{GREEN} is the surface reflectance of band 2 and ρ_{SWIR} (short wave infrared) is the surface reflectance of band 5 in Landsat 7 ETM+. In Landsat 8 OLI, ρ_{GREEN} is the surface reflectance of band 3 while ρ_{SWIR} is the surface reflectance of band 6.

Normalized Difference Moisture Index (NDMI) Estimation

NDMI is calculated using the near infrared (NIR) and the short-wave infrared (SWIR) reflectance (EOS Data Analytics, 2023). NDMI can be calculated by using Equation 3.

$$NDMI = \frac{\rho_{NIR} - \rho_{SWIR}}{\rho_{NIR} + \rho_{SWIR}} \quad (3)$$

Where ρ_{NIR} is the surface reflectance of band 4 in Landsat 7 ETM+ and ρ_{SWIR} (short wave infrared) is the surface reflectance of band 5 in Landsat 7 ETM+. In Landsat 8 OLI, ρ_{NIR} is the surface reflectance of band 5 while ρ_{SWIR} is the surface reflectance of band 6.

Soil Moisture Index (SMI) Estimation

Two determinant of SMI estimation are the NDVI and the LST. According to Weng, *et al.*, (2004); Zeng *et al.*, (2004); Parida *et al.*, (2008); Wang and Qu (2009); Potic *et al.*, (2017), SMI is estimated in equation 4.

$$SMI = \frac{LST_{MAX} - LST}{LST_{MAX} - LST_{MIN}} \quad (4)$$

Where LST_{MAX} and LST_{MIN} are the maximum and minimum surface temperature in °C for a given NDVI while LST is Land Surface Temperature, the surface temperature of a pixel for a given NDVI derived using remotely sensed data (Potic *et al.*, (2017).

Land Surface Temperature (LST) Retrieval

LST was retrieved from thermal band 6 Enhanced Thematic Mapper Plus (ETM+) and thermal band 10 Thermal Infrared Sensor (TIRS), along with the spectral bands for NDVI retrieval.

RESULTS AND DISCUSSIONS

Spatial Distribution of Vegetation

a. Normalized Difference Vegetation Index (NDVI)

An explanatory visual representation of the spatial distribution of vegetation analysis within Okpella using NDVI is presented in Table 1 and Figure 2. The spatial pattern of the NDVI distribution shows that vegetated areas have values between 0.2 to 0.5, while values between 0.1 and 0.2 represent bare soil built-up areas. It can be deduced from the NDVI values that

vegetation has increased gradually for almost ten (10) years in the study area. This shows that the study area is dominated by shrubs and grassland or has a moderately healthy vegetation before mining began in 2014 and has not been affected by mining operation since greenery shows improved condition even after mining commenced. This corroborates the findings of Orewere *et al.*, (2019).

Table 1: Descriptive Statistics of NDVI

Year	Minimum	Maximum	Mean	Standard Deviation
2011	-0.00008	0.59474	0.36557	0.06143
2016	-0.71300	0.76728	0.32961	0.09221
2021	-0.66038	0.79108	0.41674	0.14585

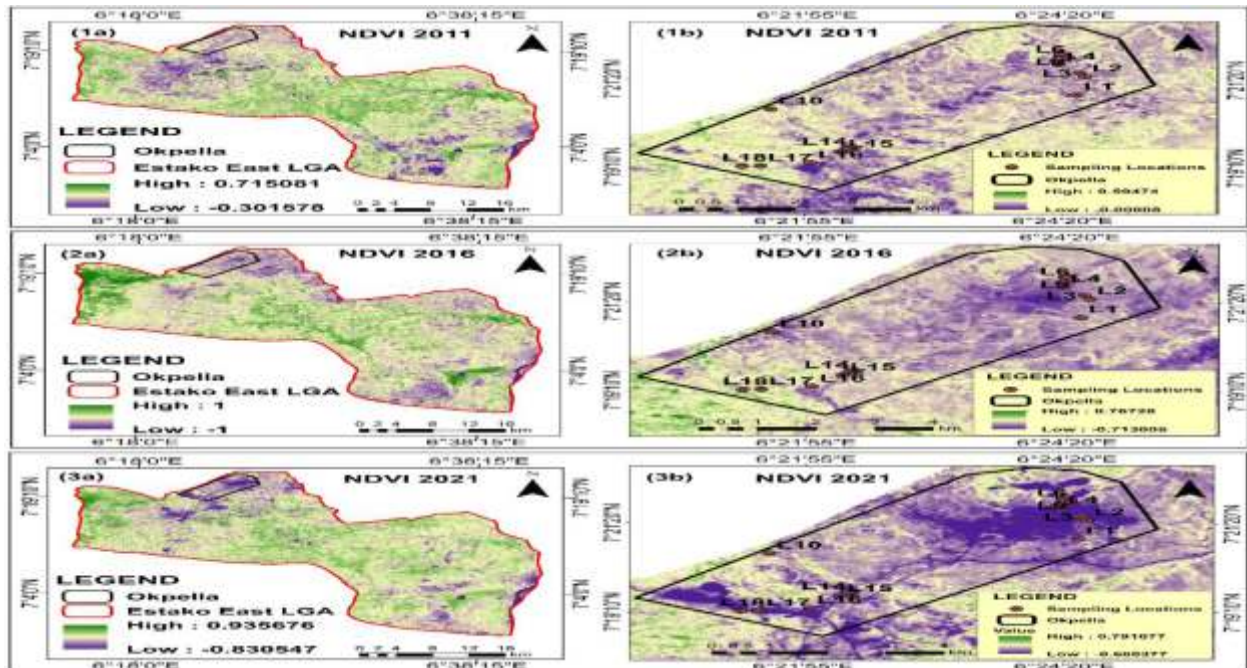


Figure 2: Spatial Distribution Map of NDVI in 2011, 2016 and 2021

b. Modified Normalized Difference Water Index (MNDWI)

The visual representation of the spatial and temporal water variations within Okpella using MNDWI are shown in Table 2, Figure 3. Surface water in the study area decreased in 2016 compared to 2011, and increased insignificantly in 2021. The negative mean values obtained in the study area show that Okpella area is one of the most stress towns in Etsako East Local Government Area of Edo State regarding surface water availability.

c. Normalized Difference Moisture Index (NDMI)

The spatial and temporal vegetation moisture variations within Okpella area using NDMI are

shown in Table 3, Figure 4. The mean values of the year studied (0.01415, -0.32949 and -0.15331) depict a low water stress in the vegetation in the study area. Vegetation ranges from a very low canopy cover to average canopy cover.

Table 2: Descriptive Statistics of MNDWI

Year	Minimum	Maximum	Mean	Standard Deviation
2011	-0.85365	0.47893	-0.32040	0.06405
2016	-0.52078	-0.34460	-0.75125	0.04231
2021	-0.90350	0.52655	-0.64796	0.08152

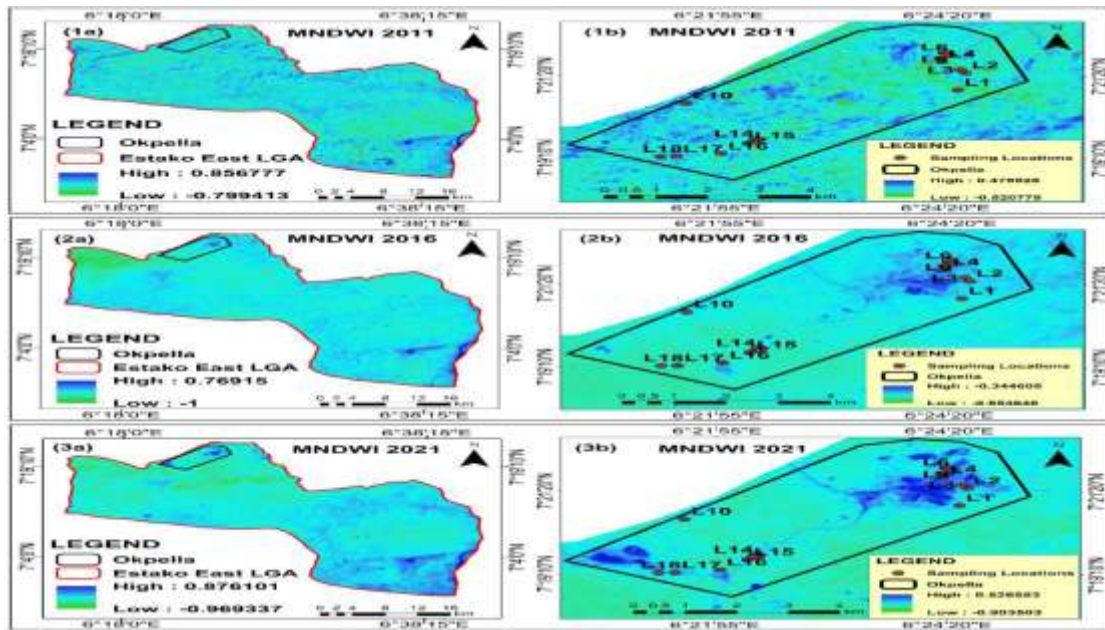


Figure 3: Spatial Distribution Map of MNDWI in 2011, 2016 and 2021

Table 3: Descriptive Statistics of NDMI

Year	Minimum	Maximum	Mean	Standard deviation
2011	-0.29619	0.41873	0.01415	0.07888
2016	-0.82784	0.10741	-0.32949	0.06265
2021	-0.65404	0.26319	-0.15331	0.08447

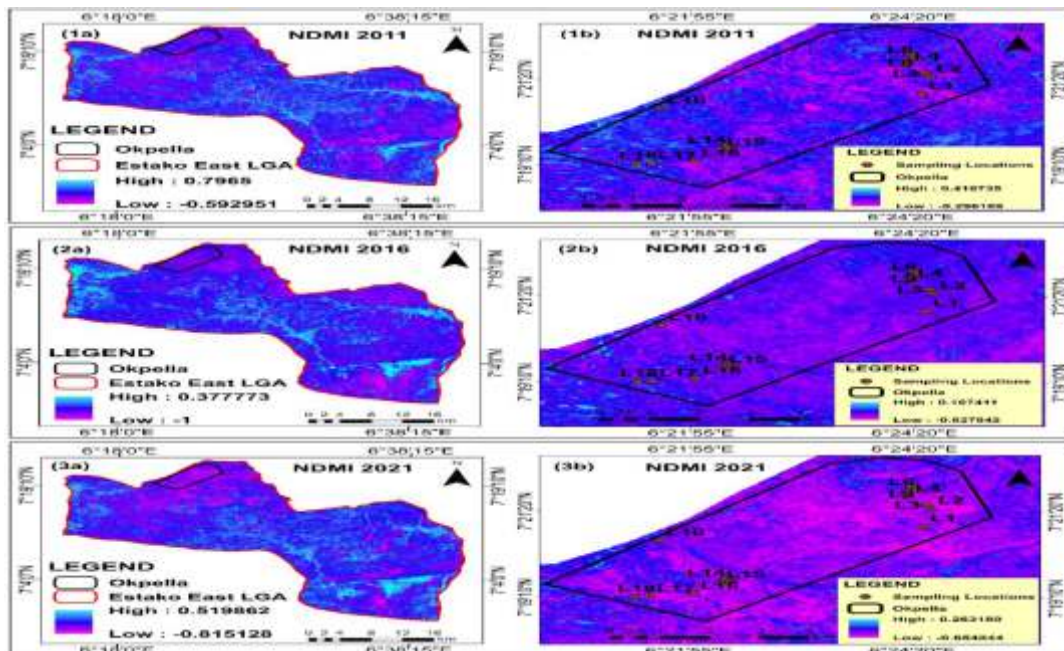


Figure 4: Spatial Distribution Map of NDMI in 2011, 2016 and 2021.

Spatial Distribution of Soil Water

a. Soil Moisture Index (SMI)

Table 4, Figure 5 provide an informative visual depiction of the spatial pattern of the soil

moisture within Okpella. The mean value of the moisture available in soil in 2011, 2016 and 2021 (0.73682, 0.58690 and 0.58897) shows that soil moisture declined greatly in 2016 and

made an insignificant increase in 2021, thus depicting that the moisture needed by soil for vegetation growth and crop production declined in Okpella mining area, but still remain at an average scale with SMI varying from 0 to 1.

Table 4: Descriptive Statistics of SMI

Year	Minimum	Maximum	Mean	Standard deviation
2011	0.47828	0.91733	0.73682	0.06428
2016	0.34479	0.79410	0.58690	0.05759
2021	0.25564	0.84897	0.58897	0.08063

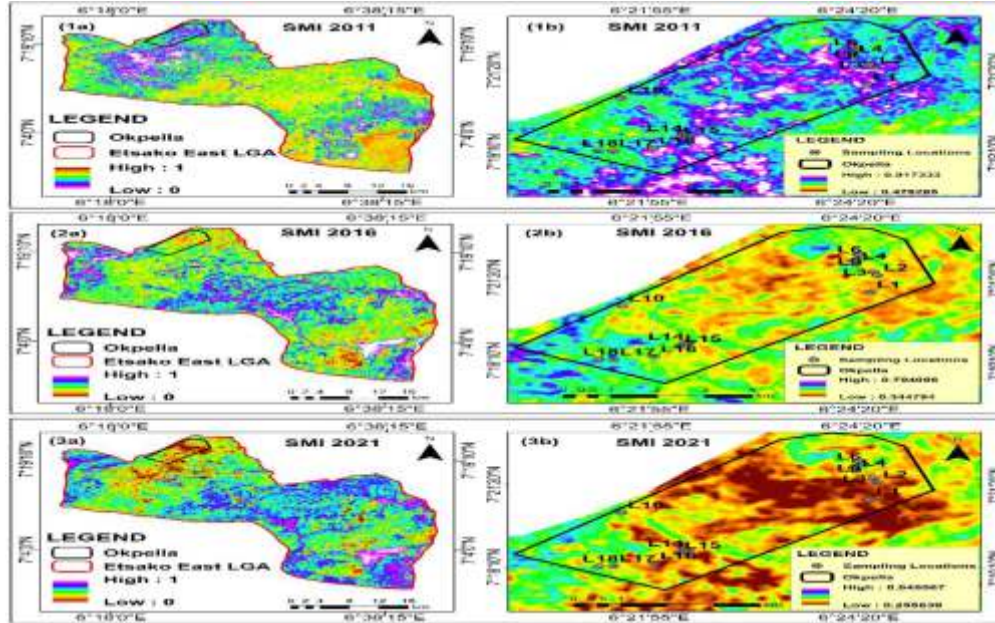


Figure 5: Spatial Distribution Map of SMI in 2011, 2016 and 2021

3.3 Spatial Distribution of Surface Temperature

a. Land Surface Temperature (LST)

The spatial distribution of surface temperature for the three investigated years in Okpella area is depicted in Table 5, Figure 6. The mean values of the surface temperature of Okpella show that the study area has continued to experience rise in land surface temperature.

Table 5: Descriptive Statistics of LST

Year	Minimum (°C)	Maximum (°C)	Mean (°C)	Standard deviation
2011	23.918	35.360	28.623	1.675
2016	25.750	34.724	29.889	1.150
2021	27.455	39.020	32.523	1.572

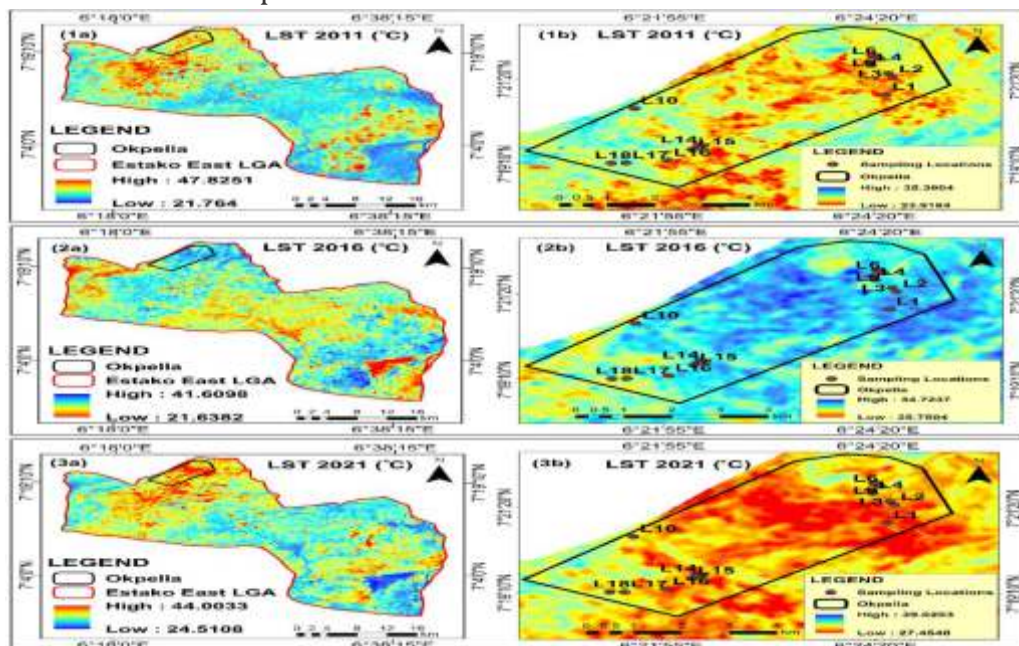


Figure 6: Spatial Distribution Map of LST in 2011, 2016 and 2021

Geospatial Analysis

Geospatial analysis revealed that vegetation abundance decreased after mining began, though it increased in 2021 when compared to 2011, prior to mining activity in the study area. Moreover, vegetation remains dominated by grasslands and shrubs in a moderately healthy state. The moisture available in the soil for vegetation growth and crop cultivation has declined in the study area since mining began in 2014, though the area still has moderate soil moisture. The highest soil moisture content in ten (10) years, which was recorded in 2011 before mining began, was not reached, despite a slight rise in moisture availability in the study region during the preceding five (5) years.

Conclusion

The findings demonstrated that Okpella is not densely populated with forests; rather, it is dominated by grasslands and shrubs. Nevertheless, the amount of vegetation has increased from what was discovered during the pre-mining era (2011). In addition to the mining and extractive industries, other variables that may directly or indirectly contribute to the loss of forests include population growth, climate change (mainly brought on by greenhouse gas emissions), an increase in agricultural and animal production, infrastructure development, illicit logging, and inadequate forest management. It is important to note that these variables are often interconnected, and multiple factors must have simultaneously contributed to forest degradation in the study area before mining began. Soil moisture and vegetation levels were decreased when after mining began in 2014 (2016 and 2021) compared to the pre-mining year (2011), though values remained average. Undoubtedly, decline in soil moisture has contributed to rising LST since a lack of soil moisture limits evaporative cooling and increases the heating impact. The land surface temperature has continued to increase as a result of the direct consequence and reaction of flora (discovered to be grasses and shrubs) and water to mining activities in Okpella, as well as other factors such as population growth, increase in built-up, urban health island (UHI) effect increase in bare lands and exposed rocks etc.

The results of the study provided valuable insights into the previous and current environmental conditions in the Okpella mining area. The findings contribute to the understanding of environmental impacts associated with mining activities, facilitating informed decision-making and sustainable management practises in the region.

Sequel to the findings of this study, comprehensive rehabilitation plans that focus on restoring vegetation in the mined areas must be developed and implemented. Secondly, soil conservation and

management practices to improve soil fertility and structure must be prioritized. Thirdly, native plant species that are adapted to Okpella local conditions and can thrive in the limestone-rich soil, thereby contributing to the overall biodiversity and ecological balance must be planted. Also, regularly monitoring of the progress of vegetation recovery and conducting maintenance activities must be employed. Environmental experts and relevant authorities that can help to develop a tailored plan to address the implications of heavy metal contamination in the soil must be involved. Lastly, more research may be done in the study region to better understand the forces causing land cover stress utilizing higher spatial resolution satellite data such as WorldView-2, WorldView-3, WorldView-4, GeoEye-1, Quick Bird, Ikonos, SPOT-6 and SPOT-7.

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Maintenance of Laboratory Equipment: Evaluation and Reactivation of Laboratory Electromagnetic Separator.

O. A. W. Oyeladun¹, S. Tolu² and I. Isa²

¹Metallurgical Engineering Technology, Kaduna Polytechnic, Kaduna

²Mineral and Petroleum Resources Engineering, Kaduna Polytechnic, Kaduna

Corresponding Author email: oawoyeladun@gmail.com

Abstract

Maintenance of laboratory equipment should be the priority of a Mineral Engineer. The evaluation and reactivation of Mineral Petroleum Resources Engineering (MPRE), Kaduna Polytechnic laboratory Electromagnetic separator was carried out to establish the state of the machine's component. The faulty components were identified and reactivation of the machine was carried out based on identified faults. The test-run of the reactivated machine using a magnetite ore was done. The test result revealed that ratio of concentration is 1:4. The cost of repair was N65,000:00. It is recommended that the maintenance of the machine should be carried out frequently to avoid further damage.

Keywords: evaluation, reactivation, machine component, laboratory Electromagnetic separator.

INTRODUCTION

Mineral concentration employs the differences in some specific physical or physiochemical properties to enhance separation. These properties as well as corresponding method upon which depend include specific gravity, magnetic susceptibility electrical conductivity, radioactive property and surface properties. Hence, gravity concentration, magnetic and electrostatic separation sorting and floatation. Magnetic separation can also be used in electromagnetic cranes that separate magnetic material from scraps and unwanted substances. This explains its use for shipment equipment's and waste management. Unwanted metals can be removed from goods with this technique (Wills and Napier-Munn, 2006).

Low magnetic field gradients are field gradients that are smaller than one hundred tesla per meter. Mono disperse magnetite (Fe_3O_4) and Nano-crystals (NCs) are used for this technique. Magnetic filters are fitted on the boiler's pipework to collect magnetite from the circulating water before it has a chance to build up and lower the efficiency of the heating system. The water circulating around the heating system picks up bits of sludge (or magnetite) which can build up. The magnetic filter attracts all these bits of debris with a strong magnet as the water flows around it, preventing a build-up of sludge in the pipework or in the boiler. Weak magnetic separation is used to create cleaner iron-rich products that can be

reused (Li et al., 2018). These products have low levels of impurities and a high iron load. This technique is used as a recycling technology. It is coupled with steelmaking slag fines as well as a selection of particle size screening (Marin and Marin, 2014)

Magnetic Separators are designed specifically to remove fine iron powders introduced to the base material during the grinding process. This is a process in which magnetically susceptible material is extracted from a mixture using a magnetic force. This separation technique can be useful in mining iron as it is attracted to a magnet. It is suitable for belts with a speed less than or equals to 4.5m/s. With this electromagnetic separator, materials are refined and iron impurities are collected. The working principle of magnetic separator is that when the slurry into the magnetic field, one of the strong magnetic minerals are adsorbed on the cylinder surface, if the magnetic and non-magnetic minerals is to get rid of discharge, with the cylinder rotating strong magnetic minerals, was brought the magnetic field, with the rinse water into the concentrate tank to complete the sorting operation. The applications areas of electromagnetic separators are as follows: power plants, mines, building material factories, other factories in metallurgical and food industries. The coil of our electromagnetic separator is specially processed with good oxidation and last resistance, with ensuring the heat transferring, capacity and insulation performance of the coil.

The Design variables affecting the sorting performance of the induction roller magnetic separator are divided into design variables and operational variables. The pole shape and rotor diameter are the main design variables, and the pole pitch, rotor speed, applied current, feed rate, and split position are the primary operational variables. In addition to these parameters, the characteristics of the feedstock, i.e. the particle size, the mineral magnetic susceptibility, density and shape of the particles, also is essential in the induction of separating the magnetic roll separator. The mineral machine specific conditions being treated in addition to the physical properties (i.e., magnetic susceptibility, density and size) of the particles is also affected by an external force. In addition, some of the effects of important variables discussed previously mentioned in the discussion section. Sunil Kumar Tripathy determines the effect of test variables on grade by changing variables during mineral sorting experiments such as hematite, the effect of optimizing the magnetic field strength, roll speed and the feed rate of the three process variables, the modeling and design Box.

Several equipment in Department of Mineral and Petroleum Resources Engineering are malfunctioning or nonfunctioning. This has hampered the performance of practical by students of department. The electromagnetic separator is one of them; hence reactivating the machine will be advantageous for both lecturers and students.

2.1 MAGNETIC CONCENTRATION

Magnetic concentration, a key method in mineral processing, involves exploiting the magnetic properties of minerals for separation. This technique is particularly effective for ores containing minerals with contrasting magnetic susceptibilities. Magnetic concentration utilizes the response of minerals to magnetic fields, allowing for the extraction of valuable components from raw ore (Weiss, 1985; Marin and Marin, 2014).

2.1.1 Principle of Magnetic

The principles of magnetic separators involve the use of magnetic fields to selectively separate minerals based on their magnetic properties which include:

- **Magnetic Susceptibility:** Different minerals exhibit varying degrees of magnetic susceptibility. Ferromagnetic and paramagnetic minerals are attracted to a magnetic field, while diamagnetic minerals are repelled (Wills and Napier-Munn, 2006).
- **Magnetic Field generation:** magnetic separators

create a magnetic field using magnets or electromagnets. This field induces magnetic forces on minerals, influencing their behaviour and facilitating (Wills and Napier-Munn, 2006).

- **Magnetic Separators:** These are employed such as drum-type magnetic separators, rare earth roll magnetic. These devices create the necessary magnetic field for effective separation based on the specific properties (Weiss, 1985).
- **Particle trajectory:** when exposed to a magnetic field, mineral experience magnetic forces that affect their trajectory. This leads to the segregation of minerals based on their magnetic properties (Weiss, 1985).
- **Selective Separation:** Magnetic concentration relies on the selective response of minerals to the magnetic field. Adjusting parameters such as magnetic field strength allows for the targeted concentration or removal of specific minerals from the ore.
- **Intensity and Gradient:** The intensity of the magnetic field and its gradient are critical. High-intensity magnetic fields are often employed to enhance the separation of strongly magnetic minerals, contributing to the efficiency of the concentration process.
- **Matrix and Carrier Materials:** Some magnetic separators use a matrix or carrier material to enhance the overall magnetic properties of the system. This aids in capturing and retaining magnetic particles during the separation process.
- **Particle Size and Liberation:** The efficiency of magnetic (Wills and Napier-Munn, 2006).

2.1.2. Types of magnetic separation

The types of magnetic separator are;

- **Drum Magnetic Separators:** these use a rotating drum to generate a magnetic field, minerals are attracted to the drum surface and are carried along its rotation for separation and its Commonly used for coarse-grained and strongly magnetic minerals (Dwari and Rao, 2007; Chen and Jan, 2016).
- **Induced Roll Magnetic Separators:** these employ an induced magnetic roll to attract and separate minerals with varying magnetic susceptibilities and Suitable for separating paramagnetic and weakly magnetic minerals (Dwari and Rao, 2007; Chen and Jan, 2016).
- **High-Gradient Magnetic Separators (HGMS):** These utilize strong magnetic fields and gradients to enhance the capture of fine magnetic particles. it is Effective for separating small, weakly magnetic particles (Dwari and Rao, 2007; Chen and Jan, 2016).

- **Magnetic Roll Separators:** Is used to separate minerals based on their magnetic properties and Suitable for separating weakly magnetic minerals and removing magnetic impurities (Dwari and Rao, 2007; Chen and Jan, 2016).
- **Overband Magnetic Separators:** It Uses a suspended or stationary magnet above a conveyor belt to attract and remove ferrous metals and commonly used for removing tramp iron from conveyed materials (Dwari and Rao, 2007; Chen and Jan, 2016).

2.2. ELECTROMAGNETIC CONCENTRATOR

An electromagnetic concentrator is a device designed to manipulate and control electromagnetic waves, concentrating their energy or directing them towards a specific area. This concept is analogous to optical lenses that focus light. In the realm of electromagnetic waves, concentrators are often used in applications such as antennas, energy harvesting, and imaging. One notable example is the concept of a "meta material super lens," which can be considered a type of electromagnetic concentrator. This super lens is made of metamaterials with unique properties not found in natural materials. Metamaterials are engineered structures that exhibit electromagnetic properties not commonly found in nature, enabling unprecedented control over the behavior of electromagnetic waves (Dwari and Rao, 2007; Chen and Jan, 2016).

There are various types including;

- i. **Direct Lenses:** these use materials with different refractive indices to focus electromagnetic waves
- ii. **Metallic lenses:** constructed from metamaterials, these lenses manipulate electromagnetic waves through sub wave length structures.
- iii. **Parabolic Reflectors:** curved surfaces concentrate incoming waves at a focal point, commonly used in satellite dishes.
- iv. **Horn Antennas:** these flared structures efficiently couple electromagnetic waves between free space and a transmission line.
- v. **Fresnel Lenses:** thin, Flat lenses with concentric grooves that focus light, often used in solar concentrators.
- vi. **Materials:** Engineered materials with unique electromagnetic properties, enabling control over wave propagation.
- vii. **Conical structures:** Tapered shapes that can concentrate waves towards a specific point.

2.3 DESIGN OF ELECTROMAGNETIC CONCENTRATOR

Designing an electromagnetic concentrator

involves the use of metamaterials and specific geometric configurations to control the propagation of electromagnetic waves. The detailed design specifications may vary based on the specific application and desired outcomes (Dwari and Rao, 2007; Chen and Jan, 2016).

2.5.1 Basic Design Principles:

- i. **Metamaterial Selection:** Metamaterials are typically engineered composites with specific arrangements of sub wavelength structures to achieve desired electromagnetic properties.
- ii. **Geometric Configuration:** The shape and arrangement of the metamaterial structures play a crucial role. Common configurations include split-ring resonators, fishnet structures, or other periodic arrangements, depending on the frequency range of interest.
- iii. **Simulation and Optimization:** Utilize electromagnetic simulation tools such as Finite Element Method (FEM) or Finite Difference Time Domain (FDTD) to model and optimize the performance of the concentrator.
- iv. **Tuning Mechanisms:** Incorporate tunable elements if adaptability is required. This could involve using materials with variable properties or integrating tunable components like varactors.
- v. **Experimental Validation:** Fabricate a prototype based on the simulation results. Use experimental methods such as near-field scanning or far-field measurements to validate the concentrator's performance.

2.4 ACTIVATION OF MACHINE

The term "activation of electromagnetic machine" is quite broad and could refer to various processes, such as starting an electric motor or energizing an electromagnetic device. The specific context would determine the details (Li et al., 2018).

2.4.1 General Steps for Activating an Electromagnetic Machine:

- i. **Power Supply:** Ensure a stable and appropriate power supply for the electromagnetic machine. This could involve connecting to an electrical grid, a battery, or another power source.
- ii. **Switching Mechanism:** it is suitable switching mechanism to initiate the flow of electric current through the coils or windings of the electromagnetic machine. This could be a manual switch, an automated control system, or a programmable logic controller (PLC).
- iii. **Magnetic Field Generation:** When current flows through the coils, it generates a magnetic field. This field interacts with the machine's

components, inducing motion or performing the intended function.

- iv. **Control Systems:** In more complex systems, activation may involve control systems that manage the startup process, monitor performance, and ensure safety.

2.4.2. Design Consideration and Assessment

Electromagnetic separators are devices designed to separate magnetic materials from non-magnetic materials in various industrial applications. They utilize the principles of magnetism and electromagnetism to achieve this separation. The key components of an electromagnetic separator typically include (Dwari and Rao, 2007; Chen and Jan, 2016, Arol and Aydogan, 2004):

- i. **Magnetic Coils or Electromagnets:** These are the primary components that generate the magnetic field needed for the separation. Electromagnetic separators use coils of wire carrying an electric current to produce a magnetic field. When the current flows through the coils, it induces magnetism, and the generated magnetic field attracts or repels magnetic materials.
- ii. **Power Supply:** To energize the electromagnetic coils, a power supply is required. The power supply provides the necessary electrical current to create the magnetic field in the coils. The strength of the magnetic field can be controlled by adjusting the current flowing through the coils.
- iii. **Control System:** A control system is used to manage the operation of the electromagnetic separator. It enables users to turn the magnetic field on or off, adjust the strength of the magnetic field, and control other operational parameters. The control system may include switches, knobs, or electronic controls.
- iv. **Feed System:** In many applications, material to be separated is transported on a feed system. The magnetic field attracts the magnetic particles from the material as it moves along the conveyor, effectively separating them from the non-magnetic components.
- v. **Collection System:** Once the separation process occurs, the separated materials need to be collected. Discharge chutes or collection systems are designed to capture and redirect the separated magnetic and non-magnetic materials to their respective outlets.

Electromagnetic separators find applications in industries such as mining, recycling, and bulk material handling, where the separation of magnetic and non-magnetic materials is essential

for processing and quality control. The design and specific components of an electromagnetic separator may vary based on the intended use and the characteristics of the materials being processed

MATERIALS AND METHODS

3.1 IDENTIFICATION OF COMPONENTS AND THEIR CHALLENGES

The specification variables (design and operating) considered for assessment include magnetic field strength, coiling configuration and geometry, efficiency of operation, material characteristics, gap width control system features, materials, flow and distribution.

3.2 Reactivation of Electromagnetic Separator

Reactivating the electromagnetic separator involves restarting or bringing the equipment back into operation after a period of inactivity. Several considerations are done during this reactivation process to ensure a smooth and efficient restart.

The electromagnetic separator was reactivated as a function of the identified problems or deficiencies. The emphasis was laid on the copular adjusted due to the timing and on electrical system taking into consideration, coiling, magnetic field calibration, material handling system and control system verification according to assessment.

3.2.1 Magnetic Field Strength: The strength of the magnetic field generated by the electromagnetic coils is a critical variable. It influences the separator's ability to attract and separate magnetic materials from the feed. The magnetic field strength was adjusted, allowing for optimization based on the characteristics of the materials being processed.

3.2.2 Coil Configuration and Geometry: The arrangement and geometry of the electromagnetic coils play a crucial role in shaping the magnetic field. We considered factors such as the shape, size, and positioning of the coils to achieve the desired magnetic field distribution for effective separation.

3.2.3 Frequency of Operation: In some electromagnetic separators, alternating currents are used, and the frequency of the electromagnetic field can impact the separation efficiency. The choice of frequency depends on the material properties and the separation requirements.

3.2.4 Material Characteristics: The properties of the materials being processed, such as particle size, magnetic susceptibility, and conductivity, are critical variables. Different materials may require adjustments to the magnetic field strength, frequency, or other parameters to achieve optimal separation.

3.2.5 Gap Width: The distance or gap between the electromagnetic coils and the material being processed can impact the strength and reach of the magnetic field. The gap width is a variable that were considered to optimize the separation process.

3.2.6 Control System Features: The design of the control system includes variables such as the ability to adjust the magnetic field strength, turn the electromagnetic field on or off, and implement automation features. These controls provide flexibility in adapting the separator to different materials and operational conditions.

3.2.7 Material Flow and Distribution: The way in which the material is fed into the separator and how the magnetic and non-magnetic fractions are collected can impact the overall efficiency of the separation process. We considered the material flow path and distribution to minimize losses and ensure effective separation.

3.2.8 Environmental Conditions: The operating environment was considered, that is factors like temperature, humidity, and dust, which can affect the performance and longevity of electromagnetic separators.

3.2.9 Size and Capacity: The physical dimensions of the separator and its processing capacity are design variables influenced by the specific application and result required.

Optimizing these variables ensures that the electromagnetic separator meets the desired performance criteria for efficient and effective separation of materials in a given industrial process.

Evaluation of Reactivated Machine

The reactivated electromagnetic separated was assessed for performance on the basis of separation efficiency. A thorough visual inspection of the entire electromagnetic separator was conducted and check for any signs of damage wear or corrosion that may have occurred during the inactive period. Inspection of the electrical components, wiring and connections for any sign of damage was also carried out. The coil configuration and setting were checked and adjust as needed considering the specific characteristics of the magnetic ores. The control system functionality including switches, knobs and electronic control were tested.

Test Run of the Machine

The equipment was test ran using magnetite ore. 400g ore was loaded into the machine and was allowed to run for 15 minutes. After which, products were collected and weighed and recorded.

RESULT AND DISCUSSION

The electromagnetic separator activation takes into consideration the following components.



Figure 1: Magnetic coil



Figure 2: Control system



Figure 3: The Feed system



Figure 4: Collection System



Figure 5: The copular



Figure 6: The wiring of Electromagnetic Separator



Figure 7: Electromagnetic Disk Rotator



Figure 8: The Activated Electromagnetic Separator

The activated laboratory electromagnetic separator considers the production of concentrate and tailings from a given feeds. Out of the 400g of feed (Magnetite) that was subjected to the process, 288g was recovered as the concentrate while 112g as tailings. It is evidence from the appearance of the concentrate product that the reason for such quantity reporting as concentrate is traceable to the fact that it contains considerable amount of extraneous materials that are attached to the targeted materials. This implies the concentrate product resumed series of cleaning product.

Ratio of Concentration

$$\text{Ratio of concentration (R.C)} = \frac{F}{C}$$

Where F= Feed and C= concentrate

$$\text{R.C} = \frac{400}{288} = 1.4$$

Discussion

Figure 1 to Figure 8 present the components and electromagnetic separator activated. The figures

include Magnetic coil, Control system, Feed system, collection System, Disk Rotatory. The activated laboratory electromagnetic separator considers the production of concentrate and tailings from a given feeds.

Out of the 400g of feed (Magnetite) that was subjected to the process, 288g was recovered as the concentrate while 112g as tailings. It is evidence from the appearance of the concentrate product that the reason for such quantity reporting as concentrate is traceable to the fact that it contains considerable number of extraneous materials that are attached to the targeted materials. This implies the concentrate product resumed series of cleaning product. The ratio of concentration of the magnetite used was discovered to be 1.4. This is high, because the ore was rich in magnetite.

The cost of repair was valued at sixty – five thousand naira (N65, 000:00) only.

CONCLUSION AND RECOMMENDATION

Conclusion

The evaluation and reactivation of MPRE Kaduna Polytechnic laboratory Electromagnetic separator was carried out and following conclusions were dra:

- the laboratory electromagnetic separator has been activated
- the machine was tested and run using a magnetite ore.
- the test result revealed that ratio of concentration is 1.4.wn:

Recommendation

The following recommendation should be observed:

- the maintenance of the machine should be carried frequently to avoid further damage;
- further tests should be carried out to calibrate

the machine;

- iii. the security should be tightened in laboratory to prevent vandalized of equipment.

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EFFICIENT BENEFICIATION OF BURA BAUCHI STATE IRON ORE USING JIGGING

U.H, Abubakar, Isa, I and Umar A.

Department of Mineral and Petroleum Resources Engineering, Kaduna, Kaduna Polytechnic.

Email: isaibrahim@kadunapolytechnic.edu.ng

Abstract

A comprehensive metallurgical evaluation was conducted to assess the effectiveness of jigging in upgrading low-grade iron ore deposits from Bura, Bauchi State. The iron ore feed, characterized by high silica and alumina content, was crushed and classified into various size fractions to evaluate the impact of particle size on jigging performance. Gravity separation tests, including sink and float analysis, were performed to determine the optimal operating conditions for maximum iron recovery and separation efficiency. The samples were then processed through a laboratory Denver mineral jig and Harz jig, with operating parameters such as particle size, water velocity, stroke amplitude, frequency, and pulp density optimized to achieve an optimal iron ore recovery of 78.6% with a concentrate grade of 63.7% Fe, consistent with theoretical predictions from sink and float studies. The recovery of iron values and separation efficiency were evaluated through mineralogical analysis and quantification of Fe content in the jig concentrate and tailings using wet chemical and X-ray fluorescence (XRF) techniques. Optimization of the jigging process yielded a maximum iron ore recovery of 78.6% with a concentrate grade of 63.7% Fe, achieved at a medium stroke, average water velocity, and particle size of less than 5 mm. These results align closely with theoretical predictions derived from sink and float studies, demonstrating the efficacy of jigging in beneficiating low-grade iron ore.

Keywords: Low-grade iron ore, Beneficiation, Jigging, Gravity separation, Mineral processing, Metallurgical evaluation, Separation efficiency and Iron recovery.

1.0 INTRODUCTION

Large numbers of iron ore mines are in operation in Bura, Bauchi State, Nigeria, to meet the internal and export demand of iron ore for iron and steel making. During the process of mining, relatively lower grade iron ore containing 56-58% Fe is also being generated and stockpiled separately due to less market and industrial value. The accumulation of these lower grade lumps and fines are increasing day by day due to increase in the regular production of iron ore for steel industries. Simple washing of these low grade ores by scrubbing could not upgrade the iron content as evidenced from some laboratory studies. However, the utility of these ores in sinter or pellet making have urged many laboratories in Nigeria to undertake systematic studies for recovering iron values from these low-grade ores.

Lot of developments in iron ore processing have been taken place in recent years in many iron ore producing countries of the world. The emphasis was on development of a cost-effective flow sheet to beneficiate the low-grade iron ores to produce concentrates suitable for blast furnace, sinter or pellet making. Some of the development features in the processing side

are jigging, innovations in spiral concentrator, autogenous grinding, column flotation, high gradient magnetic separators (HGMS), fine screening, etc. (Rong & Lyman, 1992; Xia & Peng, 2007).

Jigging is a gravity-separation technique, where bulk materials are separated into light fraction, medium-density fraction, and heavy-density fraction. It is one of the oldest methods of gravity concentration technique. Even today, it is the widespread technology in coal preparation because of its high separation precision, cost-effectiveness, and high throughput rate (Tsunekawa et al., 2001). It is a technique where particles of mixed bed, size, shape, and specific gravity are separated from each other by the force of gravity with stratification. In this process, the close size range feed with correct water balance and pulp density is very much essential.

The jigging technology uses water as the separation medium and can be applied to minerals, ores, slags, as well as any other material that has difference in density between the wanted and unwanted materials. It is highly effective in the cases where the difference in cut density is more than 4.1 g/cc. During the last one

decade, jigging has become one of the most cost-effective methods of obtaining minerals from solid waste materials (Tsunekawa et al., 2005).

The mechanical separation of plastics such as polystyrene (PS), acrylonitrile butadiene styrene (ABS), and polyethylene terephthalate (PET) used in copy machines were carried out using a TACUB jig. Under the suitable conditions, grades of 99.8% PS, 99.3% ABS, and 98.6% PET were recovered as the products (Olubambi & Potgieter, 2005). The effective separation of iron ore concentrate from Itakpe iron ore was achieved by jigging operation. The performance of the jig was greatly influenced by the operating variable of the jig and the particle size of the feed (Sripriya & Murty, 2005).

The recovery of metal values from ferrochrome slag by jigging has been carried out in a commercial plant at Bamnival, India (Yang et al., 2003). In another investigation, the Yang Jig technology offers the recovery of metals from slag, especially from ferroalloys. A commercial Jig plant has been installed in South Africa to recover metal concentrate of 97% grade with 76% metal recovery (Mukherjee & Mishra, 2006).

The upgrading of ferrous ores by jigging has been an emerging trend in South Africa as well as in other countries such as Australia and Brazil. Studies carried out at the Sishen iron ore mine in South Africa have proved that the separation of fine ferrous ores was achieved by Bateman Jig. The new enhanced jig minimizes the back mixing of fine concentrate with reject before discharge. It has been stated that the flow of water inside the jig has a strong bearing on the rate of stratification of particles. Besides that amplitude, frequency of pulsation, and feed characteristics are the most important process parameters in jigging (Mukherjee & Mishra, 2006).

2.0 Materials and Methods

A low-grade iron ore sample from Bura, Bauchi State, Nigeria was obtained for detailed studies. The as-received hematite samples were thoroughly mixed, and a representative sample was drawn by coning and quartering method for various characterization, mineralogical, and beneficiation studies. This ensured that the sample was representative of the entire ore body.

Size analysis of the representative sample was conducted using the wet sieving method. This involved separating the sample into different size fractions to determine the particle size distribution. Chemical analysis of the bulk sample and different size fractions was determined using wet chemical and X-Ray Florescence Technique (XRF). This provided information on the chemical composition of the ore.

Sink and float studies of different size fractions were conducted at three specific gravities (2.8, 3.1, and 3.3) using heavy organic liquid to separate

liberated light gangue minerals. This process helped to identify the density-based separation of minerals. All sink and float products were thoroughly washed with acetone, dried, weighed, and subjected to complete chemical analysis to determine their composition.

Jigging studies were conducted using a Denver mineral jig fitted with a screen. The effects of water velocity and particle size on jigging were investigated using different sizes of iron ore (-5+1mm, -4+1mm, and -1+0.21mm). The jigging process helped to separate the iron ore into different grades based on density. Large-scale continuous jigging studies were conducted in a Harz jig using -5+1 mm size material at a feed rate of 190-200 kg/hr to simulate industrial-scale operations.

The study aimed to achieve better grade and recovery with respect to iron values at various sizes. All products from the sink and float and jigging studies were analyzed to calculate product grades. The research contributes to the understanding of iron ore beneficiation in Nigeria, supporting the development of the country's iron and steel industry. The findings can be used to optimize beneficiation processes and improve the quality of iron ore produced in Nigeria.

3.0 Result and Discussion

3.1 Characterization

The iron ore sample was analyzed chemically, revealing a low-grade iron content of 56.5% Fe, with significant impurities of SiO₂ (5.6%), Al₂O₃ (6.2%), P₂O₅ (0.32%), and a high loss on ignition (LOI) of 7.10%. This composition makes the sample unsuitable for direct use in blast furnaces or sponge iron production without prior physical beneficiation.

Particle size analysis was conducted, and the results showed that gangue materials, being fine-grained and friable, are predominantly concentrated in finer sizes. However, iron values in all fractions fell below 60% Fe. The 80% passing size of the material was approximately 10 mm, with 19.0% of particles below 210 micron size. Notably, this fine fraction is typically discarded as tailings in Indian iron ore washing plants due to its small particle size and high silica and alumina content.

The characterization studies highlight the need for physical beneficiation techniques to upgrade the iron ore sample and enhance its suitability for industrial applications.

3.2 Mineralogical Studies

The iron ore samples exhibited varied textures, including hard massive, laminated, porous, biscuity, and powdery forms. Mineralogical analysis revealed the presence of kaolinite, gibbsite, and fine-grained goethite (ochreous/earth goethite) as surface coatings on

iron ore lumps.

Ore microscopic studies identified diverse hematite grain types, including microplaty, lacy, vermicular, and specular hematite. Martite grains displayed euhedral and subhedral shapes, with complete transformation from precursor magnetite grains. Recrystallization resulted in granular martite grains (25-35 μm). Dense aggregates of martite and microplaty hematite grains (max. length 25 μm) contained minor voids (<5%).

Vitreous and ochreous goethites were abundant, filling voids and fractures partially or completely. Hematite inclusions of varying sizes and shapes occurred within goethite. Goethite manifested as massive masses, crusts, colloform bands, and fibrous grains. Vitreous goethite appeared grey to dark grey, while ochreous/earthy goethite was

black to dark grey, comprising ultra-fine crystallites.

Aluminous minerals, kaolinite and gibbsite, were fine-grained and intimately associated with ochreous goethite.

Table 1: Chemical analysis of the iron ore sample

Constituents	Percent
Fe ₂ O ₃	80.79
Fe	56.5
Al ₂ O ₃	6.2
SiO ₂	5.6
P ₂ O ₅	0.32
LOI	7.1

Table 2: Size and iron analysis of the sample

Size, mm	Weight, %	Fe, %	Fe ₂ O ₃ , %	SiO ₂ , %	Al ₂ O ₃ , %	P ₂ O ₅ , %	LOI, %
-30+18	18.7	57.1	81.62	3.57	4.24	0.24	9.17
-18+5	23.7	59.7	85.3	3.85	4.23	0.22	6.2
-5+1	27.3	58.5	83.65	4.2	4.5	0.24	8.4
-1+0.21	11.3	57.9	82.8	4.5	4.0	0.26	8.2
-0.21	19.0	48.2	68.92	9.3	11.62	0.37	9.4

The iron ore sample exhibits a heterogeneous composition across various size fractions. The largest fraction (-30+18 mm) accounts for 18.7% of the sample, while the finest fraction (-0.21 mm) accounts for 19.0%. Iron content and Fe₂O₃ decrease with decreasing particle size, ranging from 59.7% and 85.3% in the -18+5 mm fraction to 48.2% and 68.92% in the -0.21 mm fraction, respectively. Conversely, silica and alumina increase with decreasing particle size, reaching 9.3% and 11.62% in the finest fraction. Phosphorus content remains relatively consistent, while Loss on Ignition (LOI) varies across fractions. These findings indicate a higher concentration of impurities in finer fractions, emphasizing the need for optimized beneficiation processes to upgrade the iron ore sample. Understanding the size distribution and chemical composition is crucial for effective processing and utilization of the iron ore resource.

3.3 Sink and Float Studies

Sink and float studies were conducted on different size fractions at specific gravities of 2.8, 3.1, and 3.3 to evaluate the liberation characteristics of iron and gangue particles. At 2.8 sp. gravity, minimal floats were observed, indicating limited free silica or alumina minerals, with a total float of 11.1% and 41.8% Fe. Increasing the sp. gravity to 3.1 resulted in a higher float percentage (22.2%)

with 46.0% Fe, and 66.1% of the heavy material was obtained at 3.3. Further increasing the sp. gravity to 3.3 slightly enhanced the float fraction, yielding 61.8% at 64.21% Fe. Mineralogical analysis revealed that the float samples consisted of porous laterites, lateritised iron ores, quartz, and shale particles, with identified minerals including goethite, hematite, quartz, kaolinite, and gibbsite, indicating the presence of both iron and gangue minerals.

Table 3: Summary of sink and float studies

Specific gravity	Weight, %	Fe, %
2.8 Float	11.1	41.8
3.1 Float	22.2	46.0
3.3 Float	26.4	47.6
3.3 Sink	61.8	64.5

Jigging, a effective gravity concentration technique, was employed to beneficiate the iron ore. The impact of water velocity on particle separation was investigated using three closed-sized feed samples: -5+1 mm, -4+1 mm, and -1+0.21 mm.

Separation efficiencies were calculated for various amplitudes and sizes. The separation efficiency (SE) is calculated as:

$$E = (C - F) / (69.9 - F)$$

where:

$$E = \text{Enrichment} = (C - F) / (69.9 - F)$$

$$R = \text{Recovery} = (C \times (F - T)) / (F \times (C - T))$$

with:

C = Iron concentration in jig concentrates

F = Iron concentration in feed

T = Iron concentration in tailings

69.9 = Theoretically maximum iron percent obtainable

The separation efficiency calculation assesses the effectiveness of the jigging process in concentrating iron ore.

3.4 Effect of Water Velocity

This paper shows the impact of water velocity on separation efficiency for -5+1 mm, -4+1 mm, and -1+0.21 mm particles at constant stroke length. Finer sizes (-1+0.21 mm) achieve higher separation efficiency due to better particle liberation. Optimal water velocity for iron-gangue separation is 4-5 cm/sec, beyond which further increases have minimal effect.

It also illustrates the effect of water velocity on -5+1 mm particles at varying amplitudes. Higher amplitudes enhance separation efficiency, and coarse particles require higher amplitudes for lifting.

Optimal water velocity and amplitude are crucial for effective iron ore separation, with finer particles benefiting from lower velocities and coarser particles requiring higher amplitudes.

3.5 Jigging Studies

Large-scale jigging studies were conducted on a composite -5+1 mm iron ore sample using a Denver Harz Jig, with a controlled feed rate of 150-200 kg/hr and water rate of 10 liters/minute. The objective was to evaluate the effectiveness of the jigging technique in separating iron ore fines. After attaining steady-state conditions, simultaneous samples of feed, concentrate, and tailings were collected for analysis. The results revealed a significant upgrade in iron content, achieving a high-quality concentrate with 63.71% Fe and a yield of 73%. Notably, the jig tailings contained a relatively high iron content of 47%, allowing for easy rejection without requiring further treatment. The jigging technique demonstrated its efficacy in processing iron ore fines, producing a superior concentrate while minimizing waste. Detailed chemical analysis of the large-scale jig concentrate and tailings, presented in Tables 4 and 5, further highlights the effectiveness of this separation process.

Table 4: Continuous large scale Jigging studies

Experiment Nos.	Jig concentrate, Fe%	Jig tailings, Fe%
1	63.1	40.91
2	63.4	46.49
3	64.6	45.43
4	63.4	44.53
5	63.1	46.5
6	63.8	46.5
7	63.8	45.43
8	64.1	46.49
9	64.6	45.4
10	63.1	43.45

Particle size -5 +1 mm, self bed, water rate: 10litres/minute

Jigging studies were conducted on a composite -5+1 mm iron ore sample using a Denver Harz Jig, with a controlled feed rate of 150-200 kg/hr and water rate of 10 liters/minute. The objective was to evaluate the effectiveness of the jigging technique in separating iron ore fines. After attaining steady-state conditions, simultaneous samples of feed, concentrate, and tailings were collected for analysis. The results revealed a significant upgrade in iron content, achieving a high-quality concentrate with 63.71% Fe and a yield of 73%. Notably, the jig tailings contained a relatively high iron content of 47%, allowing for easy rejection without requiring further treatment. The jigging technique demonstrated its efficacy in processing iron ore fines, producing a superior concentrate while minimizing waste. Detailed chemical analysis of the large-scale jig concentrate and tailings, presented in Tables 4 and 5, further highlights the effectiveness of this separation process.

Constituents	Jig Concentrate (%)	Jig Tailings (%)
Fe ₂ O ₃ (Hematite)	90.24	67.35
Fe (Total Iron)	63.11	47.1
Al ₂ O ₃ (Alumina)	3.15	13.78
SiO ₂ (Silica)	2.41	6.97
P ₂ O ₅ (Phosphorus)	0.075	0.263
LOI (Loss on Ignition)	4.0	11.6

3.6 Mineralogy of Jig Concentrate and Tailings

Mineralogical studies on jig concentrate and tailing samples revealed significant differences in their composition. The jig concentrate contained substantially more total hematite, with percentages of 49.37%, 48.95%, and 39.7% in three different size fractions. In contrast, the jig tailings had much lower hematite content, ranging from 7.46% to 12.55% in the same size fractions. Conversely, the tailings contained higher amounts of goethite and exhibited porous particles, primarily consisting of laterites, including some aluminous varieties. These findings indicate effective separation of hematite from goethite and other minerals, resulting in a high-grade hematite concentrate.

The mineralogical data reveals that the jigging process effectively separates hematite from other minerals, particularly in finer size fractions. Concentrates contain significantly higher total hematite (49.37%, 48.9%, and 39.7%) compared to tailings (7.46%, 8.42%, and 12.55%) across all size fractions. Free hematite is predominantly found in tailings, while concentrates contain more free earthy goethite and locked hematite-vitreous goethite/earthy goethite particles. Vitreous goethite is less effectively separated, with higher amounts in tailings, especially in finer size fractions. Weight percentage increases in concentrates with decreasing size fraction, indicating improved separation efficiency. Overall, the jigging process demonstrates effectiveness in hematite separation, but further optimization is needed for vitreous goethite and earthy goethite separation.

Conclusion and Recommendations

This comprehensive metallurgical evaluation conclusively demonstrates the effectiveness of jigging in upgrading low-grade iron ore deposits from Bura, Bauchi State, achieving a remarkable 78.6% iron ore recovery and 63.7% Fe high-grade concentrate through optimized operating parameters. Finer particle sizes exhibited better liberation of iron particles, enhancing separation efficiency, corroborated by mineralogical studies showing higher hematite concentrations in jig concentrates. Large-scale investigations confirmed the feasibility of producing 63.71% Fe concentrates with 73% yield, closely matching theoretical

predictions. The resultant products are suitable for steel plant sinter feed material. This research significantly contributes to developing effective beneficiation strategies for low-grade iron ore deposits, highlighting jigging's potential for enhancing iron ore recovery and grade, with optimized operating conditions applicable to similar deposits for improved resource utilization and sustainability in the steel industry.

Implement jigging as a beneficiation technique for low-grade iron ore deposits to achieve significant improvements in iron ore recovery and grade. Regularly monitor and optimize particle size, water velocity, stroke amplitude, frequency, and pulp density to ensure maximum separation efficiency and achieve optimal results.

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Assessment of Occupational Health and Safety of Artisanal Granite Quarrying Activities in
Kangimi Community, Igabi Local Government Area, Kaduna State
¹A. Aminu and ²A.D. Bida

¹Natere Gure, Lere Local Government Area, Kaduna State

²Department of Mineral and Petroleum Resources Engineering, Kaduna Polytechnic
Corresponding Author Email address: anduchiaminu@gmail.com

Abstract

This research assessed the occupational health and safety of artisanal granite quarrying (AGQ) activities in Kangimi community in Igabi local government area of Kaduna State. The study employed field observation, structured questionnaires and oral interviews at quarries located in Malalin Kangimi, Sabon Garin Kangimi and the main Community. Both Malalin Kangimi and Sabon Garin Kangimi quarries use fire and manual tools to carry out quarrying activities. Observations and interview show that the quarry workers shun the use of personal protective equipment. It was also discovered that first-aid facilities were not provided to handle emergency cases despite the fact that about 20 persons were recorded to have experienced physical injuries. Thus, the findings revealed that majority of AGQ workers in Kangimi community are not sufficiently equipped with knowledge of safety measures to comprehensively maintain high level of health and safety. It is therefore recommended that AGQ workers should be informed, instructed, trained and supervised on safety and critical aspects of their jobs, and educate them on the benefits of compliance with the use of personal protective equipment. Government should equally intensify efforts through the appropriate agencies to monitor AGQ activities towards effective compliance with the extant laws.

Keywords: Occupational Health and Safety; Artisanal Granite Quarry; Physical Injuries; Personal Protective Equipment.

1 Introduction

According to world Health Organization (WHO, 1995) "occupational health deals with all aspects of health and safety in the workplace with strong focus on primary prevention of hazards" and also defined health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity." Safety in the other hand has been defined as the state of being free from threats induced by natural factors or random human errors. The main aim of occupational health and safety is promotion and maintenance of the highest degree of physical, mental and well-being of all employees in an organization.

Mineral exploitation in Nigeria dates back to the geological expedition by colonial masters in the early part of the 20th century. Artisanal quarrying in Nigeria involves informal and labour-intensive mining activities with limited capital, involving unskilled workforce of ten or more persons using rudimentary tools and techniques to extract stones or minerals (Azubike, 2011).

More so the various impacts produced by these operations are on the air, water, soil, earth surface, floral and fauna, and human beings. According to National Industrial and Sand Association (2012), dusts generated from granite quarrying contain 71 percent silica. Inhaling such dust results in

silicosis which is capable of disabling an exposed person and subsequently lead to death. A part from silicosis, quarry workers are to suffer from pneumoconiosis. Occupational accidents and injuries are a substantial factor in the overall health profile of society. Some sectors remain particularly dangerous due to inherent features of the work environment, the technology, and equipment or the absence of adequate policies and protection for the workers (Aloh et al., 2017).

Therefore, any entity that wants to succeed in the quarrying sector must consider safety issues as an integral part of the entire process. When quarrying activities are safely carried out, a lot of gains are accruable to the employers and their employees. Social responsibility in providing a safe work environment is in order to avoid civil and criminal litigations which may arise when accidents occur. Moreover, organizations that have a positive safety culture where all stakeholders are safety conscious usually stand to gain a lot economically as accidents are usually expensive to mitigate. Therefore, safety consciousness provides the knowledge, skills, attitude, mindset and procedure that are required to ensure that people conduct themselves as safe as possible. On that note, all minerals and quarrying activities within Nigeria are subject to laws, regulations and guidelines of the country. No one can legally undertake any

quarrying activity without the knowledge and approval of the federal government. So, it is important to understand the role of government in shaping safety consciousness during quarrying activities (Benard, 2018).

1.1 Previous works on Occupational Health and Safety of Stone Quarries.

From researchers point of view, that most works done by manual labour take more time and effort to produce the same outcomes than in developed nations that have undergone some kind of modernisation and mechanisation. A current study report that more than half of quarry workers worked from 7 to 8 hours. This high number of work hours may be attributed to increased workload and this led to high exposure of workers to workplace hazards. Ekong et al., (2020).

A report by Tandesse and Israel (2016), demonstrated that the leading and third most common reasons for injuries among workers are lack of safety awareness and personal protective usage. This is true according to a report by Doloksaribu (2015), who stated that knowledge about workplace accidents affects perceptions of controlling accident risk. Salawu O.G et al., (2020) who also clearly identified in his study conducted on artisanal granite quarrying workers in Kaduna metropolis that majority of the respondents did not use safety wears and 40% use improvised safety wears such as eye glasses as safety goggles and water hose as hand gloves. Similar to study done by Ahadzi et al., (2020) on 524 stone quarries in Ghana and found out that the majority of quarry workers did not wear personal protective equipment at work. This is also similar to Ekong et al., (2020) that only 15.4% often used it. Another researcher studied 156 quarry workers and found that majority of them were not aware of workplace hazards, while 4.49% were aware of hazards Oranusi et al., (2014).

The impact of granite stone quarrying on the health of workers in abeokuta Ogun state, Nigeria where it was observed that 26% of the workers suffered from cough, 20% suffered from common cold cattarrh and 15% from sinusitis, 40% suffered from eye irritation. Olusegun et al (2009).

2 Materials and Methods Used

2.1 Administration of Questionnaire, Observations, Interviews

A well-structured questionnaire was produced and used as one of the instruments for data collection in this research. The instrument was divided into three sections. Section A, sought to obtain demographic information of the respondents. Section B sought to determine years of experience, quarry products in the sites, level of

job training received and work hours. Section C assessed the knowledge and workers awareness of the hazards they are exposed to at work, assessed the occupational accidents and illnesses experienced by the respondent quarry workers at work, assessed safety awareness, level of compliance to the use of personal protective equipment (PPE). In the course of this study, field observations were made to identify the artisanal quarrying methods, and potential health risks associated with quarrying activities in the study area. A number of quarry workers were interviewed directly to know how they carryout quarrying activities and the status of their health which helped in assessing health and safety practices in the study area.

2.2 Data Analysis

The tools that were used in data analysis include descriptive statistics such as frequency and percentage. Microsoft excel was used for charts to analyse information of the respondents on quarrying activities.

3 Results and Discussion

3.1 Results from Questionnaires

In this study, thirty(30) copies of questionnaires were produced and administered to individual quarry workers in Sabon Garin Kangimi quarry, Malalin Kangimi quarry and the community respectively, but only 23 were retrieved. The detail is shown in Table 1 below.

Table 1. Questionnaire Response Rate

Respondents	Copies Retrieved
Sabon garin Kangimi quarry	5 questionnaires
Malalin Kangimi quarry	8 questionnaires
Kangimi community	10 questionnaires

Unretrieved questionnaires: $30 - 23 = 7$ questionnaires

The responses rate from the questionnaires that were retrieved is shown below;

Response Rate = $\frac{\text{Number retrieved}}{\text{Total questionnaires}} \times 100$

Response Rate = $\frac{23}{30} \times 100 = 76\%$

Therefore response rate from the questionnaires is 76% out of thirty (30) questionnaires.

3.2 Level of Hazard Awarenesses

Table 2 shows the level of awareness on hazard

of the respondents.

Table 2: Level of Awareness of Hazard.

Awareness	Frequency	Percentage (%)
Yes	22	95
No	1	5
Total	23	100

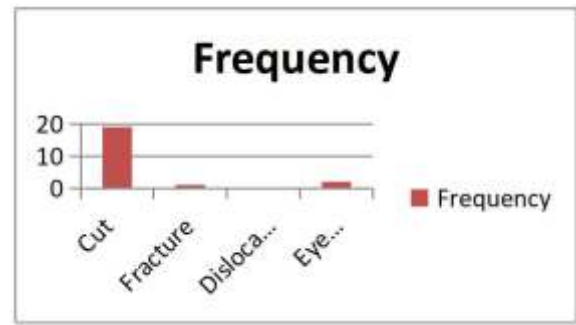
From the result above, it shows that 95% of the respondents were aware of the presence of hazards in granite quarrying activities while 5% were not aware. The insufficient training on how to protect oneself from hazards is the main problem faced by artisanal granite quarrying workers in Kangimi community. The type of training received is practical training on how to break and crush stones as one continue to work a number of times in the quarries and get used to the work by time.

Table 3: Occupational Hazard associated with Artisanal Granite Quarrying in the Study Area

Hazard	Frequency	Percentage (%)
Physical injury	18	82
Noise pollution	1	3
Dust inhalation/ Smoke	1	3
Excessive heat	1	5
Fatigue/ stress	2	7
Total	23	100

Table 4 shows physical injuries associated with artisanal granite quarrying activities in the study area

Injuries	Frequency	Percentage
Cut	19	86
Fracture	1	5
Dislocation	-	0
Eye Injury	3	9
Total	23	100



From the chart and table above, it shows that 86% of the workers suffer from cuts injuries that leads to serious bleeding during rock breaking and 9% suffer from eye injuries. The cuts or wounds and eye injuries are incurred from sharp edges of the stones during lifting or breaking with sledge hammer which causes rock particles to forcefully fly whenever a blow is delivered on the rock.

Table 5: Illnesses Common to the Respondent Quarry Workers in the Study Area.

Illnesses/ Diseases	Frequency	Percentage (%)
Catarrh	21	95
Skin disease	-	0
Impaired hearing	-	0
Cancer	2	5
Total	23	100

From Table 5, 95% quarry workers in Kangimi community suffer from Catarrh due to quarry dust. And 5% experienced cancer as a result of wound which later developed to cancer.

Discussion

From the observations and interviews conducted, it was observed that the artisanal quarrying workers in Kangimi community were not kitted in terms of personal protective equipment (PPE) despite being aware of the hazards associated with artisanal granite quarrying activities. Only few quarry workers were seen using improvised protective equipment such as water hose in place of protective gloves and eye glass instead of safety goggles, though some of them claimed that it is due to high cost of the protective equipment and that some of the equipment are not durable, such as safety gloves don't last long because of the nature of the work. Thus, water hose is used to protect fingers during crushing to avoid crushing the

fingers. However, this does not go in line with Nigerian Mineral and Mining Act, 2007 and Nigerian Mineral and Mining Regulations, 2011. It was rather found that majority of the quarry workers did not have any formal training on quarrying activities which could be one of the reasons safety measures are over looked. In the aspect of first aid, none of the two quarries has first aid facilities, instead they all rely on self medication whenever injury occur. This does not correspond with the reports by Tandesse and Israel (2016) and Oranusi et al., (2014) who demonstrated that the majority of the quarry workers were not aware of workplace hazards.

4 Conclusions

In conclusion, this study confirmed that the artisanal granite quarrying workers in Kangimi community make use of simple tools such as hammers, wedges, chisels, shovels and fire for quarrying activities as against other form of quarrying and do not use personal protective equipment to comprehensively mitigate the occupational health and safety hazards. Also, the quarries lack first-aid facilities to address emergency cases during accident despite high cases of physical injuries (20 persons) being record.

Recommendation

- i. Workers should be informed, instructed, trained and supervised on safety and critical aspects of their jobs and they should be made aware of the benefits of compliance with the use of personal protective equipment.
- ii. Government should intensify efforts through the appropriate agencies to monitor artisanal granite quarrying activities to make sure they comply with Nigerian Mineral and Mining Regulations.
- iii. Artisanal granite quarrying tools should be redesigned or modified for safety and in order to reduce occupational stress.

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Evaluation of the Impacts of Limestone Mining on Soil and Water Quality in Okpella, Edo State, Nigeria

¹Ayodele, G., ²Owolabi, A. O., ²Ogunro, A.T., ¹Osiyoku, D.A., ³Osaghae, S.O. and ⁴Raphael, E.O.

¹*Department of Mineral and Petroleum Resources Engineering Technology, School of Engineering Technology, Auchi Polytechnic, Auchi, Edo State.*

²*Department of Mining Engineering, Federal University of Technology, Akure, Ondo State.*

³*Department of Geological Technology, School of Applied Science and Technology, Auchi Polytechnic, Auchi, Edo State.*

⁴*Department of Petroleum and Gas Processing, School of Engineering Technology, Auchi Polytechnic, Auchi, Edo State.*

Corresponding author: stevenayodele03@gmail.com

ABSTRACT

This research evaluated the impacts of limestone mining on soil and water quality in Okpella, Edo State, Nigeria. Samples of water and soil were collected from the quarry and processing plant of BUA Cement Company and from residential areas in close proximity to the company. Control samples were also collected from residential area within Okpella. Physico-chemical analysis was carried out on soil and water samples to evaluate the impacts of limestone mining on the quality of water and soil in the study area. The water samples collected from the mine site were alkaline with a mean pH value of 8.6. The mean electrical conductivity of water from the mine was 674 μ S/cm. This value is due to the high amount of dissolved salt in the water samples. The concentration of heavy metals like iron, manganese, copper and chromium were slightly above WHO and NSDWQ Standards while zinc, nickel and lead were within the maximum permissible limits. Also, the soil samples taken around the mine were of high concentration of phosphate, sulphur, potassium and calcium as compared to the elemental composition of the control samples. Concentration of heavy metals such as iron, zinc, copper, nickel and cobalt were higher than the maximum allowable limits of FAO/WHO while manganese, lead and chromium concentrations were within the limits. Soil and water bodies are essential natural resources that play crucial roles in maintaining the sustainability of an environment. Therefore, environmental experts and relevant authorities that can help to develop a tailored plan to address the implications of heavy metal contamination in the soil and water bodies of the host community of BUA Cement Company must be involved.

Keywords: Heavy metals; quarry; concentration; water; soil.

INTRODUCTION

Mining process has undeniably brought affluence and employment prospects in mining areas, but concurrently has led to widespread environmental degradation and the erosion of traditional values in society (Oluku, and Asikhia, 2021). Mining creates large disturbances that significantly impact soil, vegetation and fauna and result in habitat fragmentation and loss (Owolabi, 2020; Ogunro and Owolabi, 2022).

Limestone is a carbonate sedimentary rock, consisting of calcium carbonate and in some cases magnesium carbonate as a secondary component (Ganapathi and Phukan, 2020). Limestone is a

highly prized industrial rock raw material. It is a raw material that pivots cement production in several countries. In Nigeria, limestone is one of the most commonly extracted minerals because of its use in cement production. The most widely adopted method of limestone mining is through opencast with bench formation (Ganapathi and Phukan, 2020). Olotu *et al.*, (2022) investigated the effect of limestone extraction in Okpella and its environs. Environmental degradation due to limestone exploitation has seriously affected crop yield in Okpella as a result of sealing up the plant leaf and reducing the photosynthesis rate (Olotu *et al.*, 2022). The detrimental effect of limestone

mining on the vegetation in Okpella area was noted by Osazuwa *et al.*, (2016).

Water Quality and Mining

Water is considered polluted when it is altered in composition or condition directly or indirectly as a result of activities of man so that it becomes unsuitable or less suitable for any or all the functions or purposes for which it would be suitable in its natural state (Owolabi and Opafunso, 2017). Changes in water quality resulting from mining activities include increase of water turbidity, concentrations of major ions and trace elements. In tropical countries like ours, the high temperature partially accounts for the water dissolving more materials.

Soil Quality

Soils are precious natural resources widely used as environmental indicators and their chemical analysis provide significant information on the assessment of anthropogenic activities of an area (Amadi *et al.*, 2017). Soils are dynamic and diverse natural systems that lie at the interface between

earth, air, water, and life (Needelman, 2013). Li *et al.*, (2005) observed that soil quality is not only one of the most important environmental factors in developing sustainable ecosystem, but concerning the yields and safety of agricultural produce.

MATERIALS AND METHODS

Geology and Description of the Study Area

According to Ogunyele *et al.*, (2018), Okpella lies within the basement complex and the cretaceous to recent sediment of South Western Nigeria, the area falls within the Anambra and Afikpo basin which formed the sedimentary cycle. The area is the eastern extension of the Upper Proterozoic Igarra Schist Belt, South-western Nigerian Basement Complex. Okpella is located between latitude N07° 16' and N07° 22' and longitude E06° 18' and E06° 23' in the North-eastern part of Edo State, Nigeria (see Figure 1 and Plate 1).

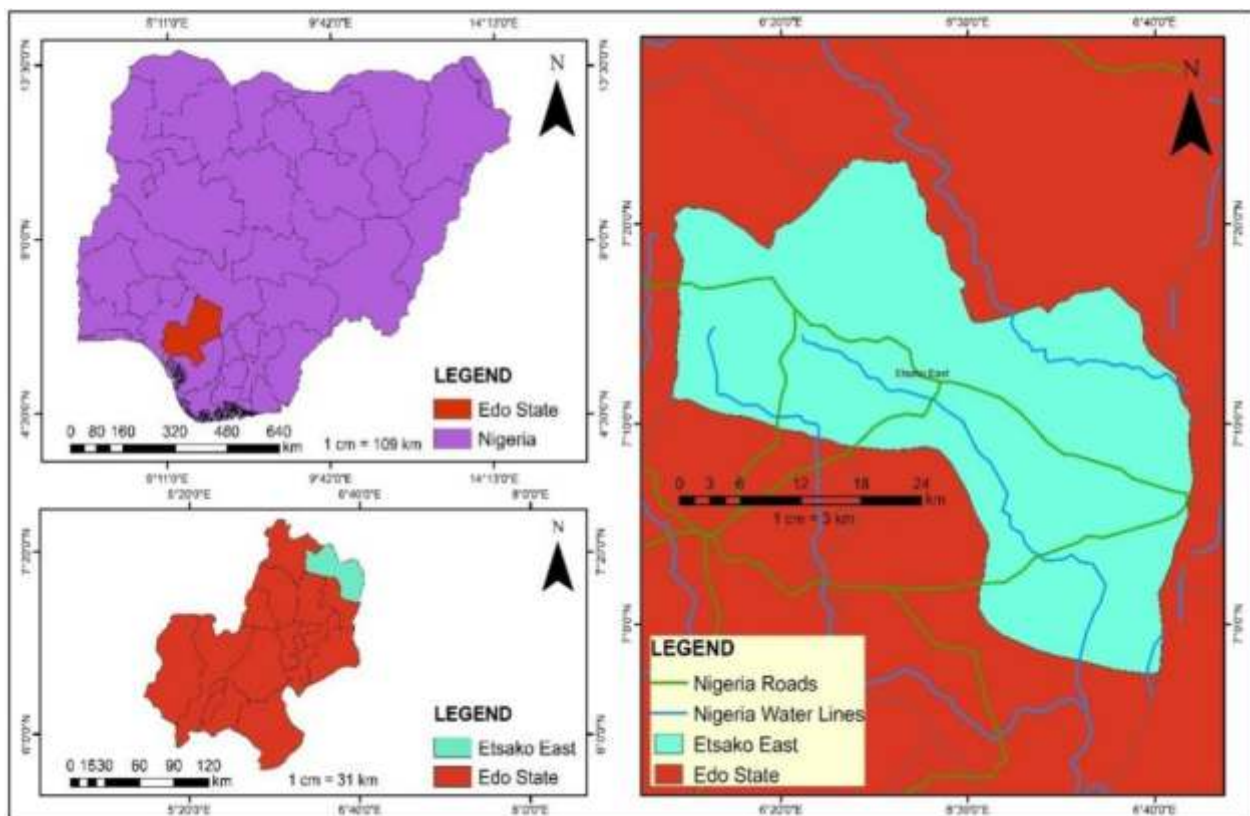


Figure 1: Map of the Study Area (Arc GIS, 2023)



Plate 1: Aerial Photography of Okpella Cement Processing Plant and Mines showing the sample collection points

Data Collection and Sampling

Collection of representative soil and water samples in the study area. Eighteen (18) water samples (surface and groundwater) and twelve (12) soil samples were collected from the quarries and immediate environments using random sampling method in accordance to standard sampling procedure.

In-Situ and Laboratory Analysis

The pH multi-meter was used to measure the physical parameter of the water sample. Electrical Conductivity was determined by switching the pH meter to EC mode and Total Dissolved Solid (TDS) determination by switching the pH meter to TDS mode. Heavy metal concentrations of the samples were determined in the laboratory

Water

At the mine sites pH values ranged from 8.4 to 8.7, with a mean value of 8.6 while the pH values in Okpella town varied from 6.5 to 8.4, with a mean value of 7.0 (Table 1), implying that majority of surface and underground waters at the mine site and Okpella are alkaline. The EC of water samples taken from the mine site ranged from 574 $\mu\text{S}/\text{cm}$ to 765 $\mu\text{S}/\text{cm}$, with a mean value of 674 $\mu\text{S}/\text{cm}$, while the EC of Okpella town ranged from 172 $\mu\text{S}/\text{cm}$ to 573 $\mu\text{S}/\text{cm}$, with a mean value of 348 $\mu\text{S}/\text{cm}$ (Table 1). This clearly shows that waters in mine sites are good conductor of electricity than the waters at the Okpella town.

Salinity of the water samples taken from the mine site ranged from 260 mg/l to 360 mg/l, with a mean value of 310 mg/l while the waters samples obtained from Okpella town ranged from 130 mg/l to 260 mg/l with a mean value of 170 mg/l (Table 1). The water in mine site is more saline compared to the water obtained from the Okpella town. Salts increase the ability of a solution to conduct an electrical current, so a high EC value indicates a high salinity level.

No colour was detected in all the water samples considered, indicating that the water samples have good colour. However, the inability to detect colour in the water samples may not denote that the water is pure; rather it may imply that colouration could be present in amounts below the detection limit (DL). Turbidity distribution in the study area range from 1.5 NTU to 3.6 NTU, with a mean of 2.55 NTU (Table 1). Turbidity values were not detected in all the samples collected from the mine while only four (4) samples taken from the Okpella community were detected. Turbidity values are generally low and meet the maximum permitted level of 5 NTU stipulated by WHO and NSDWQ. TSS values of water samples taken from Okpella varied from 4.2 mg/l to 7.6 mg/l, with a mean value of 5.87 mg/l (Table 1) indicating that the water samples meet the maximum allowable limit of 5 mg/l stipulated by WHO and NSDWQ.

TDS of the water samples taken from the mine site

RESULTS AND DISCUSSIONS

Table 1: Mean Values of Surface and Groundwater Physico-Chemical Compositions of the Study area

Parameters Unit	pH	EC μS/cm	Col. TCU	Turb. NTU	Sal.	TSS	TDS	COD	HCO ₃	Na	K mg/l	Ca	Mg	Cl	P	NH ₄ N	NO ₂	NO ₃	SO ₄
WHO	6.5-8.5	1000	3	5	N.S	5	1000	N.S	100	200	10	75	20	200	N.S	N.S	0.2	10	200
NSWDQ	6.5-8.5	1000	15	5	N.S	5	500	N.S	100	200	10	75	20	250	N.S	N.S	0.2	50	100
Mine site																			
L1	8.4	765	N.D	N.D	360	N.D	300.3	22.3	480.1	2.37	1.12	7.46	4.47	177	0.29	0.24	0.06	0.37	1.79
L2	8.5	764	N.D	N.D	340	N.D	358.1	23.5	442.9	2.49	1.15	6.83	4.83	211	0.32	0.25	0.07	1.94	1.86
L3	8.7	727	N.D	N.D	330	N.D	352.7	28.0	322.0	0.86	0.43	7.42	1.51	105	0.13	0.21	0.04	0.18	1.52
L4	8.6	711	N.D	N.D	320	N.D	380.3	25.2	427.6	3.72	1.34	5.42	5.33	319	0.51	0.28	0.11	2.76	2.17
L5	8.7	715	N.D	N.D	320	N.D	382.3	21.7	316.4	2.87	1.32	5.08	5.10	247	0.35	0.27	0.08	2.42	1.86
L6	8.4	712	N.D	N.D	310	N.D	347.7	18.1	275.7	1.92	0.51	4.82	2.88	123	0.15	0.22	0.05	0.25	1.65
L7	8.7	675	N.D	N.D	310	N.D	338.8	18.2	268.3	2.14	0.85	4.80	3.05	123	0.27	0.24	0.05	0.32	1.65
L8	8.7	603	N.D	N.D	270	N.D	284.1	27.4	266.3	1.35	0.68	4.70	2.71	89	0.27	0.48	0.09	1.41	1.96
L9	8.6	574	N.D	N.D	260	N.D	248.3	21.4	426.7	1.09	0.52	5.11	2.64	88	0.21	0.37	0.07	1.32	1.17
Mean	8.6	674	N.D	N.D	310	N.D	332.5	22.9	358.4	2.09	0.88	5.74	3.61	165	0.28	0.28	0.07	1.22	1.74
Control (Okpella Town)																			
L10	6.5	172	N.D	1.7	190	4.3	228.6	4.1	182.7	1.79	0.78	5.10	3.11	106.8	0.28	0.68	0.11	1.83	2.64
L11	6.5	284	N.D	3.6	180	7.6	212.3	8.1	103.7	0.82	0.22	4.68	1.56	54.1	0.16	0.30	0.06	0.17	0.77
L12	6.6	344	N.D	N.D	130	N.D	90.7	8.2	140.8	0.85	0.34	4.81	1.72	70.8	0.16	0.36	0.06	0.57	0.89
L13	6.5	353	N.D	N.D	150	N.D	141.7	2.6	151.3	0.82	0.33	2.07	1.58	101.4	0.22	0.25	0.04	0.18	1.46
L14	7.0	372	N.D	N.D	260	N.D	171.7	5.2	268.3	3.68	1.41	3.14	5.48	317.7	0.51	0.26	0.11	2.76	2.17
L15	7.1	343	N.D	N.D	160	N.D	175.0	8.1	183.4	2.13	0.83	2.09	3.03	121.3	0.27	0.24	0.05	0.32	1.65
L16	7.0	351	N.D	1.5	170	4.2	187.0	12.2	101.4	1.78	0.76	2.81	3.11	106.5	0.28	0.68	0.11	1.82	2.84
L17	7.1	573	N.D	3.4	150	7.4	170.0	2.5	150.3	0.82	0.21	1.91	1.54	52.8	0.15	0.30	0.05	0.17	0.77
L18	8.4	343	N.D	N.D	160	N.D	174.0	8.0	232.4	1.07	0.51	1.95	2.62	88.4	0.21	0.37	0.07	1.32	1.17
Mean	7.0	348	N.D	2.55	170	5.87	172.3	6.6	168.3	1.53	0.60	3.17	2.64	113	0.25	0.38	0.07	1.02	1.60

N.D depicts Not Detected, N.S depicts Not Stated, WHO depicts World Health Organisation, NSWDQ depicts Nigerian Standard for Drinking Water Quality

Table 2: Values of the Heavy Metals of the Surface and Groundwater samples of the study area

Parameters	Fe	Mn	Zn	Cu	Cr	Cd	Ni	Pb
WHO	0.3	0.1	4.0	2.0	0.05	0.003	0.07	0.01
NSWDQ	0.3	0.2	3.0	1.0	0.05	0.003	0.02	0.01
Mine site								
L1	0.43	0.15	0.21	0.09	0.03	0.01	0.01	0.02
L2	0.28	0.14	0.19	0.87	0.03	0.01	0.01	0.01
L3	0.55	0.19	0.33	0.13	0.06	0.03	0.02	0.04
L4	0.11	0.05	0.07	0.04	0.02	0.01	0.00	0.01
L5	0.23	0.12	0.18	0.08	0.02	0.01	0.01	0.01
L6	0.55	0.17	0.29	0.11	0.05	0.02	0.01	0.03
L7	0.51	0.16	0.21	0.11	0.05	0.02	0.01	0.02
L8	0.42	0.16	0.21	0.09	0.03	0.01	0.01	0.02
L9	0.27	0.14	0.19	0.08	0.02	0.01	0.01	0.01
Mean	0.37	0.14	0.21	0.18	0.03	0.01	0.01	0.02
Control (Okpella Town)								
L10	0.54	0.19	0.33	0.13	0.06	0.03	0.02	0.04
L11	0.11	0.05	0.07	0.04	0.02	0.01	0.00	0.01
L12	0.23	0.12	0.18	0.08	0.02	0.01	0.00	0.01
L13	0.55	0.17	0.29	0.11	0.05	0.02	0.01	0.03
L14	0.41	0.15	0.21	0.09	0.03	0.02	0.01	0.02
L15	0.11	0.06	0.07	0.05	0.02	0.01	0.01	0.01
L16	0.24	0.14	0.19	0.09	0.02	0.01	0.00	0.01
L17	0.42	0.15	0.20	0.09	0.03	0.01	0.01	0.02
L18	0.53	0.16	0.22	0.12	0.05	0.02	0.01	0.03
Mean	0.35	0.13	0.20	0.09	0.03	0.02	0.01	0.02

N.D depicts Not Detected, N.S depicts Not Stated, WHO depicts World Health Organisation and NSDWQ depicts Nigerian Standard for Drinking Water Quality.

ranged from 248.3 mg/l to 382.3 mg/l, with a mean value of 332.5 mg/l while the waters samples obtained from Okpella town ranged from 90.7 mg/l to 228.6 mg/l, with a mean value of 172.3 mg/l (Table 1). TDS in water samples in the mine sites contain more dissolved solid compared to the samples in the town. These results indicate that the water bodies meet the maximum allowable limit of 1000 mg/l stipulated by WHO and 500 mg/l set by NSDWQ. COD of the water samples taken from the mine sites ranged from 18.1 mg/l to 28.0 mg/l, with a mean value of 22.9 mg/l while the waters

samples obtained from Okpella town ranged from 2.5 mg/l to 12.2 mg/l, with a mean value of 6.6 mg/l. Water samples L1 to L9 representing the mine area have higher COD values while the Okpella community has lower COD value (Table 1). Iron was the most abundant in the soil samples determined with values ranging from 0.11 mg/l to 0.55 mg/l as gotten from the mine, with mean concentration of 0.37 mg/l while the values for the control point (Okpella town) ranged from 0.11 mg/l to 0.54 mg/l with mean concentration of 0.35 mg/l (Table 2).

Table 3: Mean Values of the Soil - Chemical Compositions from the Study Area

Parameters	Mg	Al	P	S	K	Ca	Si
Units(Mg/kg)							
FAO/WHO	100	NS	NS	NS	NS	NS	NS
Mine site							
B1	0	21430	384	1441	7162	1421	39137
B2	0	17743	640	309	5801	62546	92034
B3	0	16332	856	1470	10344	41571	48133
B4	0	13716	82	168	6877	2184	25284
E1	0	13986	1201	1245	648	185679	28530
E2	0	14438	878	1076	5771	111892	31727
E3	0	15581	1063	2186	6148	142455	31439
E4	0	23589	227	1219	11024	1005	40607
Mean	0	17102	666	1139	6722	68594	42111
Control (Okpella Town)							
C1	0	15197	219	0	7718	1636	25278
C2	0	13994	391	399	11386	167	38135
C3	0	22235	653	1010	12261	1175	62931
C4	0	18029	307	411	19060	1374	42653
Mean	0	17364	393	455	12606	1088	42249

NS = Not Stated

Table 4: Mean Values of the Heavy Metals in the Soil Sample from the Study Area

Parameters	Fe mg/ kg	Mn mg/ kg	Zn mg/k g	Cu mg/ kg	Cr mg/ kg	Ni mg/ kg	Pb mg/ kg	V mg/ kg	Co mg/ kg	As mg/ kg
FAO/WHO (2001)	5000	2000	300	100	100	-	50	NS	50	20
WHO (1996)	NS	NS	NS	NS	NS	35	NS	NS	NS	NS
Mine site										
B1	200367	482	2676	1003	112	2084	142	46	215	0
B2	98833	486	2409	1517	0	1335	69	107	220	0
B3	114351	465	2570	817	0	1530	0	78	337	0
B4	173918	810	2727	2874	0	2085	0	17	0	0
E1	120084	1078	1796	726	0	1070	0	0	0	0
E2	114311	901	1806	2237	0	1053	0	0	0	0
E3	164649	993	1636	876	0	1132	0	0	0	0
E4	267837	1704	2499	554	0	1571	0	0	725	0
MEAN	156794	865	2265	1326	14	1541	26	31	187	0
Control (Okpella Town)										
C1	259456	174	2494	996	0	1378	0	231	4622	0
C2	149865	478	2284	3168	214	1444	0	19	746	0
C3	165275	911	1817	907	0	1061	144	600	2958	0
C4	227071	937	1855	493	0	881	270	265	2944	0
MEAN	200117	625	2113	1391	54	1191	104	279	2818	0

N.S=Not Stated

Soil

Aluminium content in the mine soil ranged from 13,716 mg/kg to 23,589 mg/kg, with the mean value of 17,102 mg/kg while that of the control (Okpella town) ranged from 13,994 mg/kg to 22,235 mg/kg, with the mean value of 17,364 mg/kg (Table 3). The control mean value is slightly higher than that of the mine site. FAO/WHO (2001) maximum allowable limit for heavy metals shows that there is no set guideline for aluminium, nonetheless the recorded mean values depict a higher concentration of aluminium in the study area. The FAO/WHO (Food and Agriculture Organization/World Health Organization) does not provide a specific permissible limit for aluminium in soil.

Phosphate values gotten from the mine site were in the range of 82 mg/kg and 1201 mg/kg, with the mean of 666 mg/kg, also which of the Okpella town were between 219 mg/kg and 653 mg/kg, with a mean of 393 mg/kg (Table 3). The mine site mean value is significantly higher than that of the control. The FAO/WHO (Food and Agriculture Organization/World Health Organization) does not provide a specific permissible limit for phosphate in soil.

The values of Potassium (K) in the mine site ranged from 648 mg/kg to 11,024 mg/kg, with the mean value of 6,722 mg/kg, the control point values were between 7,718 mg/kg and 19,060 mg/kg, with the mean of 12,606 mg/kg (Table 3). The mean values of potassium in the mine site are significantly higher than that of the control. The FAO/WHO (Food and Agriculture Organization/World Health Organization) does not provide specific permissible limits for potassium in soil.

The values of calcium recorded from the mine site ranged from 1,005 mg/kg to 185,679 mg/kg, with the mean value of 68,594 mg/kg while the values from the control points were between 167 mg/kg and 1,636 mg/kg and the mean of 1088 mg/kg (Table 3). The mean values of the concentration of calcium in the soil sample at the mine site and the control (68,594 mg/kg and 1088 mg/kg respectively) are significantly higher than the peak concentration of calcium in soil samples (570 mg/kg) recorded by Ogunlana *et al.*, (2020).

Iron occurs in concentrations of 7,000 to 500,000 mg/kg in soils (Fageria *et al.*, 2002). As shown in Table 4, iron (Fe) contents from the soil obtained from the mine site ranged from 98,833 mg/kg to

267,837 mg/kg, with the mean value of 156,794 mg/kg and that of the control point were between 149,865 mg/kg and 259,456 mg/kg, with mean value of 200,117 mg/kg. Comparison of iron contents in the mine soil samples with that of the control soil samples indicates that higher iron contents were recorded in Okpella town. Iron contents in all the soil samples far exceed the FAO/WHO (2001) permissible limit of iron in soil (5000 mg/kg).

Manganese (Mn) contents in soil gotten from the mine site were in the range of 465 mg/kg and 1704 mg/kg, with the mean of 865 mg/kg, the control point had values from 174 mg/kg to 937 mg/kg, with the mean value of 625 mg/kg (Table 4). These were higher than those obtained by Anjali *et al.*, (2017) in their study in Sonapat, Haryana (India), where the concentration of manganese in the soil was found to be in the range of 104.15 to 214.90 mg/kg.

Copper (Cu) values from the mine site were between the range of 554 mg/kg and 2874 mg/kg, with the mean value of 1326 mg/kg, that of the control point were in the range of 493 mg/kg and 3168 mg/kg and the mean value of 1391 mg/kg (Table 4). The mean value shows that the mine site has a slightly higher concentration compared to the control. The concentrations of copper recorded in soils at the mine site and Okpella town were significantly above the FAO/WHO (2001) permissible limit of 100 mg/kg. The results obtained were significantly higher than the 6.55 mg/kg reported by Fosu Mensah *et al.*, (2018). Additionally, Iyaka and Kakulu (2012) discovered a mean Cu level of 467 mg/kg in the soils of an industrial area in Bida, Niger State.

Conclusion

The physical and chemical properties of the water sampled show that water bodies are slightly alkaline. Water quality indicators assessed with physical and chemical parameters like phosphorus, electrical conductivity, turbidity and pH agreed to be unaffected by mining activities and population growth in the study area with almost all meeting the required limits stipulated by WHO and NSDWQ. Elevated levels of iron, cadmium, lead, vanadium, and manganese in water bodies can harm fish, invertebrates, and other aquatic organisms. It can disrupt their reproductive cycles, impair growth and development, and even lead to population decline.

Sequel to the findings of this study, soil

conservation and management practices to improve soil fertility and structure must be prioritized. Environmental experts and relevant authorities that can help to develop a tailored plan to address the implications of heavy metal contamination in the soil must be involved.

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Assessment of Granite Quarrying Compliance to the Nigerian Mining Laws and Regulations of Some Selected Quarries in Jos, Plateau State, North Central Nigeria

¹V.G. Haji and ²A.D. Bida

No.1, ECWA II Takau, Kafanchan, Kaduna State

²Department of Mineral and Petroleum Resources Engineering, Kaduna Polytechnic
Corresponding Author: Email address: Victorgeso166@gmail.com

Abstract

This research investigates the level of compliance of granite quarrying industries in Jos, Plateau State, Nigeria to the Nigerian Mineral and Mining Act, 2007 (NMMA) and the Nigerian Minerals and Mining Regulations, 2011 (NMMR). Despite the significant role of granite quarrying in Nigeria's mining sector and its potential impact on economic development, issues of compliance with safety and environmental regulations remain a concern. The study focuses on assessing the level of compliance of Apex Construction Quarry concentrate, Afrimines Quarry Limited, Moulds Nigerian limited, and Rick Rock Construction Company (RRC). The objectives are to evaluate quarrying operations, compare their compliances with mining laws, and suggest improvements for operations not aligning with the extant laws. Key findings indicate that some quarries show good compliance in areas such as lease status and machinery maintenance, while significant gaps were observed in safety, environmental issues, and community engagement initiatives. The study identifies the need for improved enforcement and supervision of mining regulations, enhanced safety training and stronger community development efforts towards safer and more sustainable mining practices that align with national regulations. It was recommended that there should be stricter regulatory enforcement and capacity building for quarry operators to ensure consistent adherence to legal and safety standards.

Key words: Compliance; Granite Quarrying; Environmental Regulations; Mining Laws; Safety Standards.

Introduction

Although granite quarrying is a major contributor to Nigeria's mining industry, raising questions about how well granite quarrying practices adhere to the country's mining laws and regulations has been brought up. Granite is a necessary material for building and infrastructure development. In Ebonyi State, mining activities are an important source of government revenue with more than 1.4 million metric tons of granite, lead/zinc, limestone and laterite produced in 2018 alone (Obaje, 2009). Currently, Nigeria's policy framework for safety and environmental compliance during mining activities stems mainly from the Nigeria Mineral Mining Act of 2007 (NMMA 2007). Nigeria's Ministry of Mines and Steel Development (MMSD) is saddled with enforcing the country's policy framework through MMSD's mines inspectorate department (general oversight and safety compliance), mines environment and compliance

department (enforcing environmental standards) and artisanal/small-scale mining department (responsible for small-time miners with lower capacity) Klynveld Peat Marwick Goerdeler (KPMG Report 2017). Section 17 of the Nigerian Minerals and Mining Act 2007, Places safety regulatory enforcement under the mines inspectorate department Similarly, Section 18 of Nigerian Minerals and Mining Act No. 20 of 2007 empowers the mines environmental compliance department to enforce all environmental statutes, while Section 19 establishes an environmental committee in each of Nigeria's thirty-six states, to ensure that stakeholders comply with applicable environmental protection measures. In addition, Parts IV (mines health and safety) and V (mines environmental management) of the Nigeria Mineral Mining Regulations of 2011 provide specific guidelines on the safety and environmental management during mining activities in Nigeria (NMMR 2011). Nonetheless,

availability of a safety and environmental policy framework for mining activities does not essentially mean it will be complied with design and implementation (Wozniak, 2020), thereby fostering regulatory compliance. Therefore, it is necessary to identify prevalence of safety and environmental noncompliance in Nigeria, as well as factors affecting regulatory compliances during mining activities (Liu et al, 2019).

Arewa and Farrell (2012) remarked that compliance is often used to mean an art of conforming to health and safety rules and regulations. It refers to safety behaviours like the use of personal protective equipment and others (Ford, 2011). In this study, compliance refers to obedience, acceptance and practice of health and safety measures in quarry industries. The reviewed of mining sector in Nigeria has led to the creation of a Federal Ministry of solid mineral development in 1995 and review of legislation guiding all mining activities in 1999 gave rise to the Mineral and Mining Act (MMNA) of 2007 (Adefulu, 2016). The Federal Ministry of Mines and Steel development is giving the power to, supervise and enforce the compliance to mining Act 2007 (MMSD, 2011). Minerals are blessing, they are gift of nature available to be developed, sold and used to better the lot of a nation's citizen (Iar, 2018). A number of industrialized countries like Australia, Canada, Sweden and the United States of America have depended on the exploration and extraction of minerals for their economic development (Lange *et al.* 2018). While exploration and extraction is Important, there is also need for the regulation of activities of mining companies. The Mining laws and guideline according to Ladan (2014) report highlighted what can be done in

terms of regulation, administrative control, and mine management to achieve an acceptable level of environmental performance and productive operation. Nwachukwu and Agorn-czc (2017) referred to regulation as a form or governance. Although regulation varies in that the type of regulation needed to govern the market is different from that required in health and welfare. The need for coordinated action by the government requires a set or policies and capacity to implement them. In Nigeria, the basic legislation governing the mining sector is the Minerals and Mining Act or 2007 adeptly supported by the Minerals and Mining Regulation or 2011 (Alokolaro, 2015). Minerals and Mining Act of 2007 is aim to regulate the mining sector in various ways, and some environmental requirement such as waste disposal, occupational safety, control or water contamination are sometimes incorporated into the laws (MMSD, 2016). According to Ladan (2014), he pointed out that mining regulation and policies require an effective and regular enforcement mechanism if they arc to work. Although, large number of technical standards and codes or conduct in form of laws have been developed over the years to ensure efficient and safe operation, most or the mining and quarrying industries still operate in partial compliance or non-compliance to those mining laws and thus necessitate a time to time compliance evaluation and assessment.

MATERIALS AND METHODS

Field samples were collected from four different firms of Plateau state at specific locations indicated by GPS coordinates shown on Table 1.

Table 1: Sample Collection points and coordinates

S/N	HOLDER	QUARRY TYPE	STATE	CORDINATES
1	Ric Rick Construction Company	Granite	Plateau	09° 00' 30.00" N 09° 51' 30.00" E
2	Afrimines Nig. Ltd	Granite	Plateau	09° 40' 00" N 08° 51' 00" E
3	Moulds Nig. Ltd	Granite	Plateau	
4	Apex Construction Company	Granite	Plateau	09° 48' 27.44"N 08° 57' 24.33"E

Results

Table 4.2 presents the distribution of questionnaires to the participated groups as well

educational qualifications, age distribution and general information.

Table 2: General Information of Respondents

RESPONDENTS INFORMATION		RESPONSE (%)			
Position of Respondent		Afrimnes	RRC	Moulds	Apex
Quarry Manager		1 (3.3)	1(3.3)	1(3.3)	1(3.3)
Worker		6 (20)	5 (16.6)	8 (26.6)	7 (23.3)
Educational Qualification	M.Eng/Ph.D	1 (3.3)	-	1 (3.3)	-
	B.Sc/HNI	6 (20)	4 (13.3)	3 (10)	5 (16.6)
	OND/NCE	3 (10)	5 (16.6)	4 (13.3)	2 (6.6)
	SSCE and Below	-	1 (3.3)	2 (6.6)	3 (13.3)
Age Distribution	18-25yrs	-	2 (6.6)	-	1 (3.3)
	26-36yrs	2 (6.6)	1 (3.3)	5 (16.6)	6 (20)
	36-45yrs	4 (13.3)	5 (16.6)	2 (6.6)	2 (6.6)
	46 and above	1 (3.3)	2 (6.6)	3 (10)	1 (3.3)

Table 3: Compliance with Quarry Lease and Renewal Application

S/N	Enquiry	Afrimnes (%)	RRC (%)	Moulds (%)	Apex (%)
1	Status of Lease	3 (10)	3 (10)	2 (6.6)	3 (10)
2	Duration of approval of quarry Lease.	2 (6.6)	4 (6.6)	2 (6.6)	3 (10)
3	Area of Land approved	2 (6.6)		4 (13.3)	1 (3.3)
4	Survey or approved Cadastre area	1 (3.3)	2 (6.6)	2 (6.6)	2 (6.6)
5	Renewal of quarry lease	2 (6.6)	3 (10)	1 (3.3)	3 (10)

Interpretation of Respondents

The data from four quarries were interpreted using Bar charts as presented in Figure 4 to

Figure 6 showing the names of the Quarries visited, their marital status, age, and educational level.

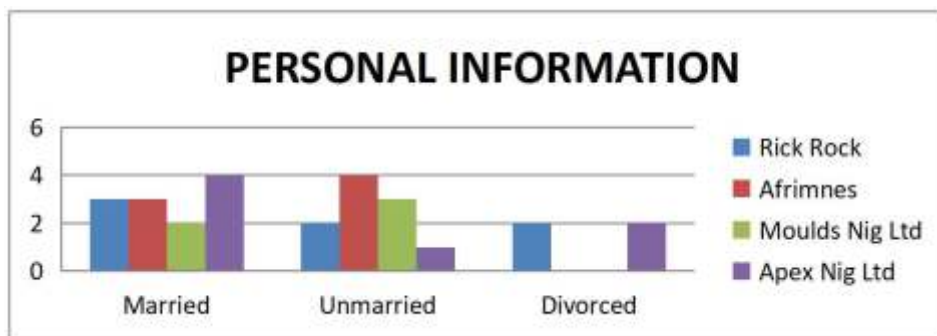


Figure 4: Personal information of Respondents

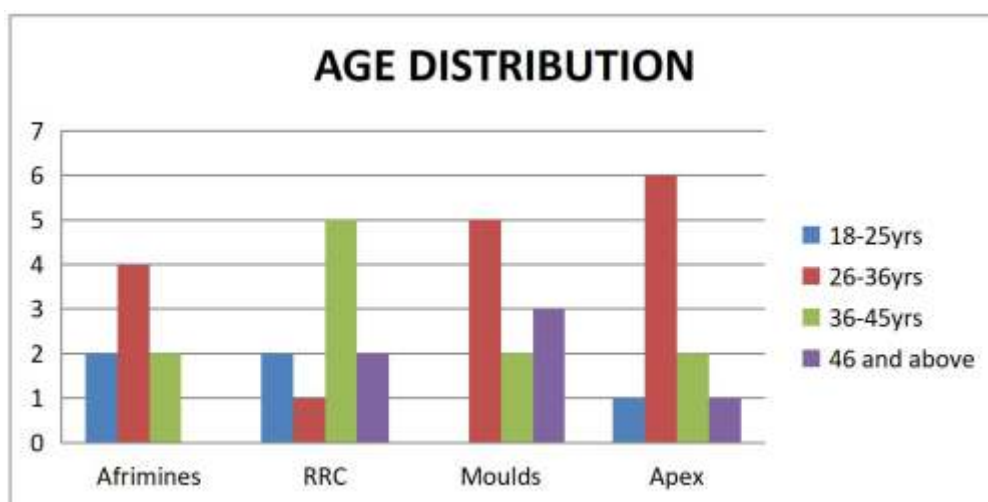


Figure 5: Highest level of educational qualification of respondents

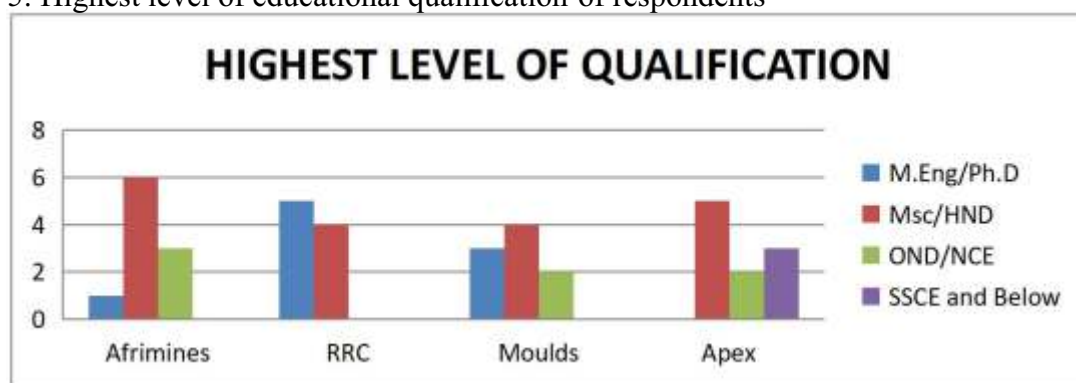


Figure 6: Highest level of educational qualification of respondents from the four Quarries

Regulatory Compliance of the four Quarries

Then status of Apex Construction Company and Moulds Nig. Ltd quarry lease are active to be 16.6 %, followed by Afrimines Nig. Ltd Company having 13.3 %, while Rick Rock Construction Company having 10 % active, their overall rate of Quarry lease activeness is 56.6 %. It has also been revealed that their compliance to implementation of environmental impact assessment (EIA) according Mines Environmental Compliance Department (MECD) in accordance with Section 119 of Nigerian Mineral and Mining Act, (NMMA 2007) of which Apex Construction company, Moulds Nig. Ltd and Afrimines Nig. Ltd has 10 % while Ric Rock Construction company has 3 %.

Apex Construction Company and Afrimines Nig. Ltd regular reporting to the National Environmental Standards and Regulations Enforcement Agency (NESREA) shows their level of compliance to be 13.3 % each while

Moulds Nig. Ltd have 10 % level of compliance. QQAWAASZ. However, Ric Rock construction company has not been complying with environmental standards and regulations for failing to submit the required monthly report.

Provision of safety training to personnel of Moulds Nig. Ltd and Afrimines Nig Ltd is 6.6 %, and Ric Rock Construction Company has 3.3 % level of compliance. However, Apex Construction Company do not provide safety training to her personnel. According to the respondents, the working condition of machineries of Afimines Nig. Ltd. and Ric Rock Construction Company is 13.3 % each.

Apex Construction Company measures set in place to manage and handle waste materials are 10 % while Afrimines Nig. Ltd and Moulds Nig. Ltd has 6.6 % each. Ric Rock Construction Company has 3.3 % level of compliance.

The four quarries accident reporting system for Ric Rock Construction Company indicates 16.6 % followed by Apex Construction Company which is 10 %. Meanwhile Moulds Nig. Ltd shows 6.6 % and Afrimines Nig. Ltd do not provide accident reporting system.

The quarries compliances to environmental pollution and dust control shows that Moulds Nig. Ltd level of compliance to National Environmental Standards and Regulation

Enforcement Agency (NESREA) is 13.3% and Afrimines Nig. Ltd to be 10 %. Ric Rock Construction Company and Apex Construction Company have 6.6 % level of compliance.

To obtain general regulatory compliance for the four quarries, the respondents for each quarry is divided by the total number of questionnaires received, and the computed values are presented in table 4.4.

Table 4: Regulatory Compliance

GENERAL REGULATORY COMPLIANCES OF THE FOUR QUARRIES									
S/N	Enquiry	Respondents from Afrimines		Respondents from RRC		Respondents from Apex		Respondents from Moulds	
		Number	(%)	Number	(%)	Number	(%)	Number	(%)
1	Status of Lease Active or Not Active)	4	13.33	3	10	5	16.6	5	16.6
2	Environmental impact assessment (EIA)	3	13.3	2	3	3	10	3	10
3	Monthly NESREA Report	4	13.3	-	-	4	13.3	3	10
4	Provision of Safety training	2	3	1	3.3	-	-	2	6.6
5	Health and Safety committee	3	10	3	10	-	-	4	13.3
6	Condition of Machineries	4	13.3	4	13.3	3	10	3	10
7	Waste Management	2	3	1	3.33	3	10	2	6.6
8	Measures of Dust control	3	10	2	6.6	2	6.6	4	13.3
9	Monitoring system	2	6.6	6	20	1	3.3	-	-
10	Access Road	3	10	-	-	2	6.6	1	3.3
11	Accident Reporting Mechanism	-	-	5	16.6	3	10	2	6.6
12	Community Development Initiative	-	-	3	10	4	13.3	1	3.3

Table 4.5: Compliance Level of the Four Quarries

S/N	Enquiry	Compliance Level (%)			
		Afrimines	RRC	APEX	Moulds
1	Status of Lease	13.33	10	16.6	16.6
2	Environmental impact assessment (EIA)	10	3	10	10
3	Monthly NESREA Report	13.33	-	13.3	10
4	Provision of Safety training	6.6	3.3	-	6.6
5	Health and Safety committee	10	10	-	13.3
6	Condition of Machineries	13.33	13.33	10	10
7	Waste Management	6.6	3.33	10	6.6
8	Measures of Dust control	10	6.6	6.6	13.3
9	Monitoring system	6.6	20	3.3	-
10	Access Road	10	-	6.6	3.3
11	Accident Reporting Mechanism	-	16.6	10	6.6
12	Community Development Initiative	-	10	13.3	3.3

Comparison of level of compliance of the four Quarries

Table 4.5 shows the comparison of the four different Quarries; the Status of Lease stands out with the highest score of 56.6 %, indicating a robust and secure foundation for the organization's operational premises. This suggests that lease management is highly effective, ensuring a stable legal and operational environment.

Condition of Machineries follows with a score of 46.6%, reflecting a strong focus on maintaining the equipment essential for the operation. This high score highlights the organization's commitment to operational efficiency and safety through regular maintenance and updates.

In the environmental and safety compliance domain, Environmental Impact Assessment (EIA), Monthly NESREA Report, and Measures of Dust Control each score 36.6%. These scores underscore a solid commitment to environmental stewardship and adherence to regulatory standards, albeit with potential room for further enhancement.

The Health and Safety Committee and Accident Reporting Mechanism both receive a score of

33.3%, pointing to a well-established structure for overseeing health and safety concerns. However, these areas might benefit from further attention to elevate safety practices and incident management.

The Monitoring System receives a score of 30%, suggesting that while there is a system in place for ongoing monitoring of operations, enhancing its capabilities or effectiveness could further bolster operational oversight.

Community Development Initiative scores 26.6%, indicating a moderate engagement in contributing to local community well-being. This area presents an opportunity for the organization to deepen its impact and strengthen community relations.

Waste Management and Access Road are scored at 23.3 % and 20 %, respectively. These lower scores signal challenges in effectively managing waste and ensuring reliable access, areas critical to environmental responsibility and operational logistics.

The most notable area for improvement is the Provision of Safety Training, with the lowest score of 16.6 %. This suggests that while there may be various safety measures and structures in place, the organization significantly

underperforms in equipping its workforce with the necessary safety training, a gap that urgently needs addressing to ensure a comprehensive safety culture, while the organization demonstrates strong performance in lease management and machinery condition, reflecting effective operational foundations and

efficiency, it shows varied effectiveness across environmental compliance, safety oversight, and community engagement. Particularly, the provision of safety training emerges as a critical area for immediate enhancement to ensure a well-rounded approach to operational excellence and regulatory compliance.

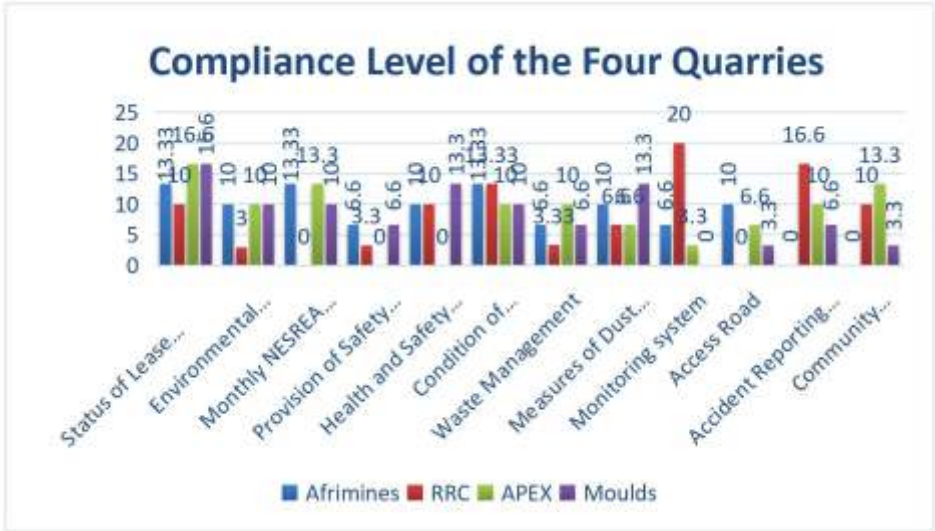


Fig. 4.4: Comparison Level of Compliances of the Four Quarries

Findings

The findings from the survey conducted across the four quarries in Jos Plateau State are given below:

- (i) Compliance levels varied across the companies, with some performing better in certain areas than others. Overall, the quarry lease activeness rate was 56.6%, and the compliance rate to environmental impact assessments (EIA) was 36.6%. Reporting to NESREA showed a low overall compliance rate of 10%, indicating a significant area for improvement.
- (ii) Safety training and machines conditions varied significantly among the companies, highlighting differences in operational priorities and safety culture.
- (iii) Waste management and dust control measures had varying levels of implementation across the quarries, with Moulds Nig. Ltd having the highest level of compliance to dust control followed by Afrimines Nig. Ltd. companies showing more initiative than Ric Rock Construction Company and Apex Nig. Ltd.
- (iv) Environmental and Safety Measures: The companies showed differing levels of commitment to environmental and safety measures, with Moulds and Afrimines Nig.Ltd making more effort to comply with regulations and implement best practices than Ric Rock Construction Company

and Apex Construction Company. This is indicative of the broader challenges within the industry regarding environmental stewardship and worker safety.

- (v) Community Engagement and Development Initiatives: The level of engagement with community development initiatives from these companies indicate that Apex Construction Company and Ric Rock Construction Company have constructed bridge and road respectively while Afrimines and Mould Nig. Ltd are making efforts to do the same.

Conclusion

The study conducted on the compliance levels of four quarries in Jos Plateau State has provided a detailed snapshot of the industry's adherence to regulatory standards and its commitment to environmental and community welfare. Despite the varied performance across different compliance areas, the following key insights emerge that highlight both strengths and areas for improvement within the sector.

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Geochemical Studies of Kaolin and Its Industrial Applications in Kajita, Kwara State, North-central Nigeria

¹Obaro, R.I., ²Agbalajobi, S.A., ³Hammed, A and ⁴Obaro N.T.

^{1,2,3}Department of Minerals and Petroleum Resources Engineering Technology
Kwara State Polytechnic, Ilorin.

⁴Department of Social Sciences, University of Ilorin.

Corresponding Email: reubenobaro1@gmail.com

Abstract

Geochemical studies of kaolin has been examined in order to assess their geochemical characteristics and industrial applications. The laboratory analysis carried out on the samples include X – Ray Diffraction for only two samples. Three different samples was examined using X – Ray Fluorescence. The X – Ray Diffraction for both samples suggest that kaolinite and quartz are the major minerals with other minor minerals such as illite, pyrophyllite and pyrite in the area. The occurrence of these minerals can be attributed to intensity of weathering or the extent of transportation of the clay during deposition. The X – Ray Fluorescence results for Samples A, B and C suggest a wide composition of kaolin with high silica oxide (SiO_2), Aluminum oxide (Al_2O_3) and minor amount of MgO , CaO , Na_2O and K_2O . The predominance of SiO_2 and Al_2O_3 were mainly associated with quartz and kaolinite minerals. Based on industrial applications, the average weight composition of SiO_2 and Al_2O_3 can be used for paper coating, paper filler, ceramics, pharmaceuticals and cosmetics. The Fe_2O_3 and the loss on ignition is relatively higher, except for TiO_2 which can only be used for paper filler, pharmaceuticals and cosmetics. However, the use of high magnetic separators, along with other techniques such as flotation and/or selective flocculation would be effective in refining the kaolin to increase their commercial applications.

Keywords: Geochemical, Kaolin, Applications.

Introduction

Kaolin or china clay is a mixture of different minerals. It belongs to the group of clay minerals that contains atoms of silicon, aluminum, oxygen, ferrous and ferric iron and hydroxyl groups as the main constituents. It also has other elements such as phosphorus, potassium, calcium, sodium, magnesium, etc. Common impurities in kaolins are quartz, mica, illite, smectite, feldspar, goethite, hematite, pyrite, anatase, rutile, ilmenite, and trace quantities of tourmaline, zircon, kyanite, and a few other heavy minerals. Kaolin has also found extensive usage in the pharmaceutical, paint and composite materials industries (Murray *et al.*, 1993). According to Murray (2000) kaolinite is one of the most common minerals and large volumes of it are used for production of cement, ceramics, bricks

and porcelain. Kaolin is a versatile industrial mineral with wide application. It is used as a raw material in papermaking, rubber, plastics, paints, pharmaceuticals, soap, refractories and tiles, cement, fertilizers, textile, insecticides, toothpaste, etc. The choice of china clay or kaolin for industrial applications is dependent on several factors including specific requirements for developing a particular technology (Nkoumbou *et al.*, 2009). These requirement are dependent on the geological conditions under which the kaolin deposits originate, as well as their mineralogical and chemical composition and degree of kaolinite crystallinity, and physical properties such as colour and firing characteristics (Siddiqui *et al.*, 2005 and López-Galindo *et al.*, 2007). The process of kaolin formation is called kaolinization (Grim, 1968). Kaolinite is formed mainly by decomposition of feldspars (potassium feldspars), granite, and aluminum silicates. It frequently contains quartz,

mica, feldspar, illite, and montmorillonite. Kaolinite is one of the mineral phases used widely in the clay industry for making many products, including paper (Olupot *et al.*, 2010). Several authors such as Rees *et al.* (1992); Aliyu and Aluko (1996), Johnson (2000), Onyemaobi, (2002), Idenyi and Nwajagu (2003) and Dill, (2016) among others has worked on the origin and geochemistry of kaolin and its applications in Nigeria.

Geological Settings

Nigeria is mostly covered by crystalline rocks and other less than 50% by sedimentary rocks. (Fig. 1). The study area also lies within the sedimentary basin of North-central Nigeria. The Bida Basin, also known as the Mid-Niger Basin or Nupe Basin, is one of the inland NW-SE trending intracratonic sedimentary basins extending from Kontagora in Niger State of Nigeria to areas slightly beyond Lokoja in the south (Fig. 2). The basin is a gently downwarped

trough whose genesis may be closely connected with the Santoian orogenic movements of southeastern Nigeria and the Benue valley, nearby. The basin is a NW-SE trending embayment, perpendicular to the main axis of the Benue Trough and Niger Delta Basin. It is usually considered as the north-western extension of the Anambra Basin, both of which were major depocentres during the third major transgressive cycle of southern Nigeria in Late Cretaceous time (Obaje *et al.*, 2011).

The study area is in Kajita in Pategi, Edu Local Government Area of Kwara State (Fig. 2). The coordinate of the study area is at latitude N08° 31' 76" and longitude E04° 54'. The study area enjoys tropical climate marked by alternating raining and dry season. The annual temperature ranges from 30C and a mean 35C and a mean annual rainfall of 800 to 1200mm. The natural vegetation of the study area is Guinea savanna and rain forest.

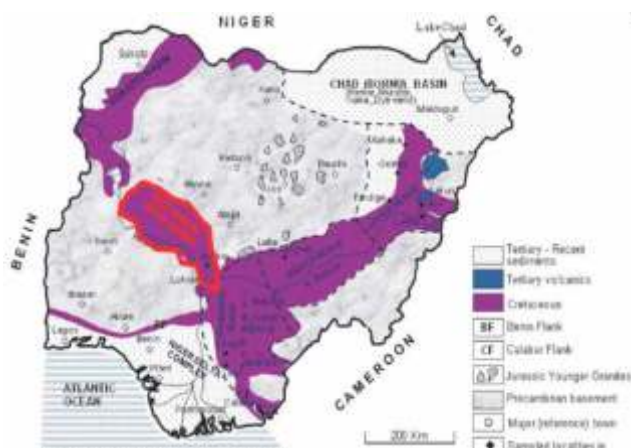


Fig. 1: Geological Map of Nigeria
(after Obaje *et al.*, 2011)

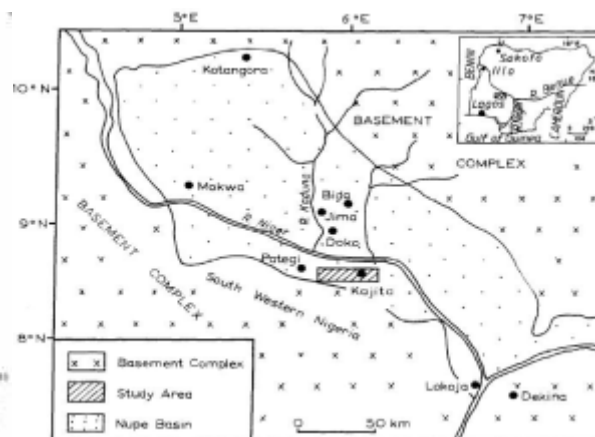


Fig. 2: Geological Map of the study area
(after Olaniyan and Olobaniyi, 1996)

Materials and Methods

The research work include field work and laboratory analyses. The field work involve collection of fresh representative samples of kaolin from Kajita, in Pategi Edu Local Government Area in Kwara state. The samples was tagged sample A, B and C and it was separated in different sample bags and transported to Department of Chemical and Petroleum Engineering, Afe Babalola University, Ado – Ekiti, Ekiti State for analysis. In the laboratory, the rock samples were pulverized in

preparation for the geochemical analysis. The geochemical analysis carried out include X – Ray Diffraction and X – Ray Fluorescence analysis.

Results and Discussion

X – Ray Diffraction

Summary of the quantitative XRD analysis results are presented in Table 1. The diffractogram peaks (Fig. 3 and 4) revealed the dominant kaolinite at highest weight composition, which ranges from 63.55% to 65.58% with an average of 64.57% followed by

X – Ray Fluorescence

The results of the X – Ray Fluorescence for Sample A, B and C is presented in Table 2. The average percentage weight composition for kaolin suggests that SiO₂ is 47.59wt.%, Al₂O₃ is 37.52wt.%, Fe₂O₃ is 8.81wt.%, CaO is 0.39 wt.%, Na₂O is 0.54wt.%, MgO is 0.40.wt%, TiO₂ is 1.47wt.% FeS₂ is 5.42wt.% while the Loss of Ignition is 19.86wt.%. Inferences on the chemical analysis of kaolin suggest that the SiO₂ (47.62 wt %) and Al₂O₃ (38.07 wt %) contents were consistent with mineralogical observation. The most abundant oxides were SiO₂, Al₂O₃, Fe₂O₃ and TiO₂ whereas MgO, CaO, Na₂O and K₂O were present in small quantities. The SiO₂ measured belong to the silicon dioxide detected by the X – Ray Diffraction (XRD). The predominance of SiO₂ and Al₂O₃ were mainly associated with quartz and kaolinite minerals. Omag et al. (2019) reiterates that the amount of silica and alumina composition present in all samples obtained is an indication that the tetrahedral to octahedral layer in the clay structure is approximately in

ratio 1:1 which is typical of kaolin clay. Fe₂O₃ and TiO₂ which are metallic oxides not only occur as minor oxides but are the main decolourising component and it can be associated with hematite and geotite minerals (Oyebanjo *et al.*, 2020). The high amount of Fe₂O₃ in all the samples account for the presence of FeS₂ minerals, marcasite and pyrite. It can be concluded that hematite contributes to the iron content of the deposit as depicted with an average of 8.81wt.% while the concentration of MgO is attributed to smectite (Ojo *et al.*, 2017). The formation of smectite is however favoured by microenvironment with poor drainage and hence minimum leaching conditions with relatively high metal ion concentrations (Keller, 1985). However, the distribution of TiO₂ has no particular trend and could be indicative of its immobile nature during weathering (Heckroodt and Buhmann, 1987). The loss of ignition could be as a result of organic matter lost and/or some non – metals in form of SO₂ (Eze *et al.*, 2012).

Table 3: Result of X – Ray Fluorescence of Kaolin

S/N	Basic Oxides	Formulae	Percentage Weight Composition of Kaolin (Sample A)	Percentage Weight Composition of Kaolin (Sample B)	Percentage Weight Composition of Kaolin (Sample C)	Average Percentage Weight Composition of Kaolin Sample A, B and C
1	Silicon Oxide	SiO ₂	46.32	48.91	47.54	47.59
2	Aluminum Oxide	Al ₂ O ₃	38.82	37.31	36.43	37.52
3	Ferric Oxide	Fe ₂ O ₃	9.81	8.17	8.44	8.81
4	Calcium Oxide	CaO	0.43	0.34	0.42	0.39
5	<u>Magnesium Oxide</u>	MgO	0.18	0.40	0.47	0.40
6.	Sodium Oxide	Na ₂ O	0.55	0.57	0.50	0.54
7.	Potassium Oxide	K ₂ O	0.60	2.13	1.43	1.39
8.	Titanium dioxide	TiO ₂	1.44	1.53	1.45	1.47
9.	Ferrous Oxide	FeS ₂	2.15	9.56	4.54	5.42
10.	Loss of Ignition	LOI	17.33	21.62	20.63	19.86

Industrial Application of kaolin

Kaolin have been widely used for the manufacture of bricks, paints, refractories and ceramics, and sold locally or exported to the neighbouring countries, even though it could have promising applications in several clay-based industries. Based on the XRD, the Illite

contents can also be used to coat welding rods. Based on its fluxing properties, it increases the plasticity and workability of the porcelain mass and produces superior end product by filling the gap in the kaolin crystals. Fan and Aw (1998) also suggested that illite could serve as a less expensive substitute for feldspar in ceramics, while the general chemical composition of the

studied kaolin is suitable in pigment production according to standard parameters (Mesbah *et al.*, 2011). The major uses of kaolin are directly related to its chemical properties (Ekosse, 2010). The major elemental oxides of the Kajita kaolin compare favourably with specifications for paper coating, paper filler, ceramics, pharmaceutical and cosmetics industries (Table 4). Siddiqui *et al.* (2005) and Lopez-Galindo *et al.* (2007) disclosed that they cannot be used in their raw state without proper beneficiation. The average weight

composition of SiO_2 and Al_2O_3 can be used for paper coating, paper filler, ceramics, pharmaceuticals and cosmetics. The Fe_2O_3 and the loss of ignition is relatively higher, except for TiO_2 which can only be used for paper filler, pharmaceuticals and cosmetics (Nkoumbou *et al.*, 2009 and Fitos *et al.*, 2015). However, the use of high magnetic separators, possibly with other techniques such as flotation and/or selective flocculation will be effective in refining the kaolin to increase their commercial use (Murray, 2007).

Table 3: Comparison of the Average Basic oxides of Sample A, B and C with Standard Commercial Kaolin (Nkoumbou *et al.*, 2009 and Fitos *et al.*, 2015)

S/N	Basic Oxides	Formulae	Average Weight Percentage Composition of Kaolin (Sample A, B and C)	Paper Coating	Paper Filler	Ceramics	Pharmaceuticals and Cosmetics
1	Silicon Oxide	SiO_2	47.59	45 – 47	46 – 48	48 – 50	44.6 – 46.4
2	Aluminum Oxide	Al_2O_3	37.52	37 – 38	37 – 38	36 – 37	38.1 – 39.5
3	Ferric Oxide	Fe_2O_3	8.81	0.5 – 1.0	0.5 – 1.0	0.6 – 1.0	0.1 – 0.2
4	Calcium Oxide	CaO	0.39	-	-	-	0.1 – 0.2
5	Magnesium Oxide	MgO	0.40	-	-	-	
6.	Sodium Oxide	Na_2O	0.54				0.02
7.	Potassium Oxide	K_2O	1.39			1.2 – 2.7	0 – 0.2
8.	Titanium dioxide	TiO_2	1.47	0.04 – 1.5	0.02 – 1.0	0 – 1.4	
9.	Ferrous Oxide	FeS_2	5.42	-	-	-	-
10.	Loss of Ignition	LOI	19.86	13.9 – 14.3	12.3	11.2 – 12.5	13.8 – 13.9

Conclusion

The mineralogical and chemical analysis of the kaolin samples obtained from Kajita in Kwara State has been investigated. The mineralogical composition indicates the variation in percentages of kaolinite, quartz, illite, pyrophyllite and pyrite. The chemical analysis establishes its consistency with mineralogical observation and its application in paper coating, filler, ceramic, pharmaceuticals and cosmetics. However, the use of high magnetic separators, possibly with other techniques such as flotation and/or selective flocculation will be effective in refining the kaolin to increase their commercial use.

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