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Socioeconomic and Environmental Impacts of Quarrying in Nigeria: A Comprehensive Review of Sustainable Quarrying Practices and Innovative Technologies

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ABSTRACT

The quarrying industry in Nigeria has far-reaching socioeconomic and environmental implications that demand careful consideration of sustainable practices and innovative technologies. This comprehensive review delves into the multifaceted impacts of quarrying on local communities and the environment, highlighting challenges such as habitat destruction, air, noise, water pollution, environmental degradation, and socioeconomic disparities. Furthermore, it accesses current sustainable quarrying practices and innovative technologies to mitigate these impacts and improve efficiency. To address these challenges, this paper also emphasizes the importance of implementing robust policies and regulations governing quarrying activities in Nigeria. Through analysis of real-world examples, case studies, and existing literature, this review uncovers promising solutions that can enhance quarrying operations' sustainability and environmental performance in Nigeria and worldwide. This paper unveils that, while quarrying is an important industry in Nigeria, it is critical to ensure it is carried out sustainably and responsibly. This can be achieved through improved regulations, strengthening sustainable quarrying practices, conducting thorough environmental impact assessments, establishing buffer zones around quarries, enforcing stricter pollution control measures, stakeholder engagement, and adoption of new technologies such as advanced blasting techniques, dust suppression technologies, automation and robotics machinery, water recycling, and treatment systems, waste recycling management, and reforestation and restoration techniques. It is evident that there are gaps and inconsistencies in Nigeria's policy and regulatory framework, and there is a lack of research on the effective implementation of sustainable practices and new technologies. Therefore, further research is recommended on areas such as the lasting impact of sustainable practices, the potential of new technologies, and the enhancement of policy and regulatory frameworks to improve the sustainability and efficiency of quarrying operations in Nigeria.

Keywords: Quarrying in Nigeria; impact of quarrying; socioeconomic; environmental; mitigation strategies; sustainable quarrying practices; innovative technologies; policy and regulatory framework; quarrying.

INTRODUCTION

Quarrying in Nigeria is a significant industry that involves extracting natural resources, primarily minerals and rocks, for construction and industrial use. Nigeria is endowed with abundant mineral resources, including limestone, granite, marble, gypsum, clay, tantalite, gold, coal, and gemstones (Adegbite, 2021; Fatoye & Yomi, 2013). These resources are found in various regions across the country, making quarrying a significant economic activity. Quarrying operations in Nigeria typically focus on the extraction of construction materials such as

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limestone, granite, and sand. Quarrying contributes to Nigeria's economy by providing raw materials for the construction industry, which drives infrastructure development and urbanization (National Council of Bhutan, 2013; Oladimeji et al., 2018; Lameed & Ayodele, 2010; Salawu & Sadiq, 2020). It also supports other industries such as cement manufacturing, concrete production, and asphalt production.

Quarrying activities create employment opportunities for both skilled and unskilled laborers, including miners, machine operators, drivers, technicians, engineers, and administrative staff (Oladimeji et al., 2018; Melodi & Ogunyemi, 2019; Hassan, 2022). These jobs contribute to livelihoods and economic development in local communities. However, quarrying generates significant amounts of waste (Wang, 2007; Ajide & Ajayi, 2015; Melodi, 2017; Turyahabwe et al., 2021; Umar & Oriri, 2023), with some quarries producing inert and non-hazardous waste like sand and gravel, while others generate substantial amounts of waste material such as clay and silt, posing a risk of environmental damage, particularly through water contamination.

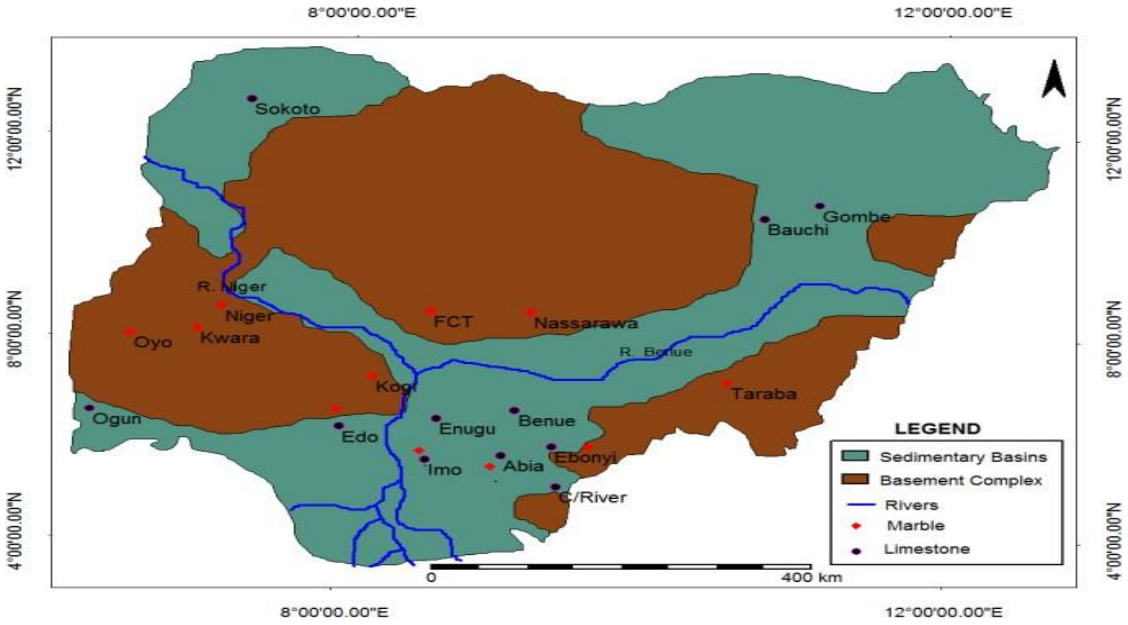

Fig. 1: Map of Nigeria showing areas with solid minerals/rock deposits (Fatoye & Yomi, 2013)

Rock quarrying and stone crushing have global implications and can be detrimental to the environment and human communities (Guach, 2001; Pona et al., 2021; Bahloul et al., 2024). The environmental impacts of quarrying are diverse and significant, affecting both the natural environment and human health. For instance, rock blasting, a commonly used method of mineral extraction, produces deafening noise pollution and triggers detrimental effects on plant and animal life in the surrounding areas (Okafor, 2006). Quarrying activities also contribute to air pollution (Ezichi, 2018; Mahapatra 2023; Okafor et al., 2023), with dust emissions posing a threat to vegetation health and crop yields (Iqbal & Shafiq, 2001). Dust particles emitted from quarry sites are a major source of air pollution, posing a severe threat to both plants and human health.

Quarrying also poses a substantial threat to biodiversity (Anand, 2006; Ndinwa & Ohwona, 2014; Adedeji et al., 2020). The disruption of habitats (Mabogunje, 2008; Pona et al., 2021) and the incessant noise from quarrying activities can profoundly impact wildlife, interfering with their reproductive success and overall well-being. Sustainable quarrying practices, such as reclamation and rehabilitation of mined areas, are essential to minimize these impacts (Legwaila et al., 2015; Shaun, 2023) Therefore, it is crucial to consider sustainable practices and environmental conservation efforts in quarrying activities to minimize these adverse effects. Tanko, 2007 suggests that quarries can serve as unexpected opportunities for habitat creation or restoration. By employing innovative techniques and leveraging available resources, quarries can be transformed into havens for wildlife, contributing to broader conservation efforts.

Sustainable quarrying practices in Nigeria are vital for preserving the environment, enhancing economic viability, improving social outcomes, ensuring regulatory compliance, mitigating climate change, fostering

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technological advancements, and supporting long-term strategic planning. By adopting sustainable approaches, Nigeria can achieve a balance between the benefits of quarrying and the need to protect its natural and social environment for current and future generations.

The methods adopted for quarrying are so poor concerning environmental sustainability in most societies in Nigeria and other African countries. However, the environmental, social, and economic impacts of quarrying necessitate a robust regulatory framework to ensure sustainable practices. Nigeria's regulatory landscape for quarrying is designed to balance resource exploitation with environmental protection, community development, and compliance with national and international standards.

Quarrying activities in Nigeria are regulated by government agencies such as the Ministry of Mines and Steel Development (MMSD) and the Federal Ministry of Environment. Companies involved in quarrying must obtain licenses and permits, comply with environmental regulations, and adhere to health and safety standards (Nigeria Minerals and Mining Act of 2007; the National Environmental (mining and processing of coal, ores, and industrial minerals) Regulation 2009).

The cornerstone of this regulatory framework is the Minerals and Mining Act of 2007, which establishes the legal foundation for mineral exploration, extraction, and processing. Complementing this act are the Nigerian Minerals and Mining Regulations of 2011, providing detailed guidelines on health, safety, environmental management, and community relations. Key environmental regulations, such as the Environmental Impact Assessment (EIA) Act of 1992 and the National Environmental (Quarrying and Blasting Operations) Regulations of 2013, further ensure that quarrying activities are conducted responsibly, with minimal harm to the environment and local communities.

Regulatory oversight is primarily managed by the Federal Ministry of Mines and Steel Development (FMMSD) and the Federal Ministry of Environment (FMEnv), alongside state-level agencies that address specific local conditions. Despite the comprehensive nature of these regulations, challenges such as enforcement issues, illegal quarrying, and community conflicts persist.

Extensive research has been conducted on the socioeconomic, health, and environmental impact of quarrying in Nigeria. However, there has been minimal investigation into the implementation of sustainable practices and innovative technologies in Nigeria, the effectiveness of the government's efforts to create a level playing field for all operators in the solid mineral industry, the impact of poor mining technologies on productivity, waste, and environmental pollution, and the exploration of alternative energy sources for powering mining equipment. This paper aims to assess the socioeconomic and environmental implications of quarrying activities in Nigeria to identify opportunities for sustainable practices and innovative technologies.

1.2 Consequences of Quarrying in Nigeria

The quarrying operations in Nigeria primarily serve as a vital source of raw materials for the construction industry and the extraction of various metallic and non-metallic industrial minerals (Olusegun et al., 2009). Over the years, the Nigerian quarry industry has witnessed significant growth, expanding from nine government-owned quarries in 1996 to approximately 1800 quarries by the early 2000s (Olusegun et al., 2009). This growth has been instrumental in meeting the demands of the construction sector and other related industries.

However, despite the positive regional importance of the quarry industry, it is crucial to acknowledge the adverse consequences it imposes on the communities where extraction occurs (Langer, 2001; Aggregates Industries, 2007; Akanwa et al., 2016; Akanwa & Ikegbuman, 2017b). These communities often bear the brunt of environmental degradation and social challenges associated with quarrying activities. The quarrying process in Nigeria involves open excavation to extract useful stone for building and engineering purposes, employing both heavy machinery and manual labour (Akabzaa & Darimani, 2001). Unfortunately, the operations lack proper siting, design, construction, operation, and follow-up monitoring, resulting in environmental disruption.

Traditional opencast quarrying methods are commonly employed in rural areas, where operations are carried out without adequate consideration for surrounding ecosystems and geological conditions (Akanwa et al., 2016).

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This lack of attention can lead to disruptions in wildlife, plant life, and water bodies, posing a threat to biodiversity and ecosystem services.

Moreover, surface mining and quarrying activities fundamentally alter essential ecosystem services such as climate regulation, water supply, nutrient cycling, and food production (Costanza et al., 1997; Akanwa et al., 2016). The resultant impacts include soil and vegetation degradation, uneven topography, loss of soil fertility, surface crusting, soil erosion, and habitat loss, as documented by Sort and Alcaniz (1996) and Akanwa et al. (2016). Even in developed countries, quarrying activities have led to significant environmental losses, with reports indicating extensive alteration of vegetation and soil degradation (Greenpeace International, 2010). Despite the socio-economic benefits, there is a notable link between quarrying processes and environmental degradation, particularly concerning landscapes and vegetation (BBC, 2014; Langer, 2002b; Akanwa et al., 2016).

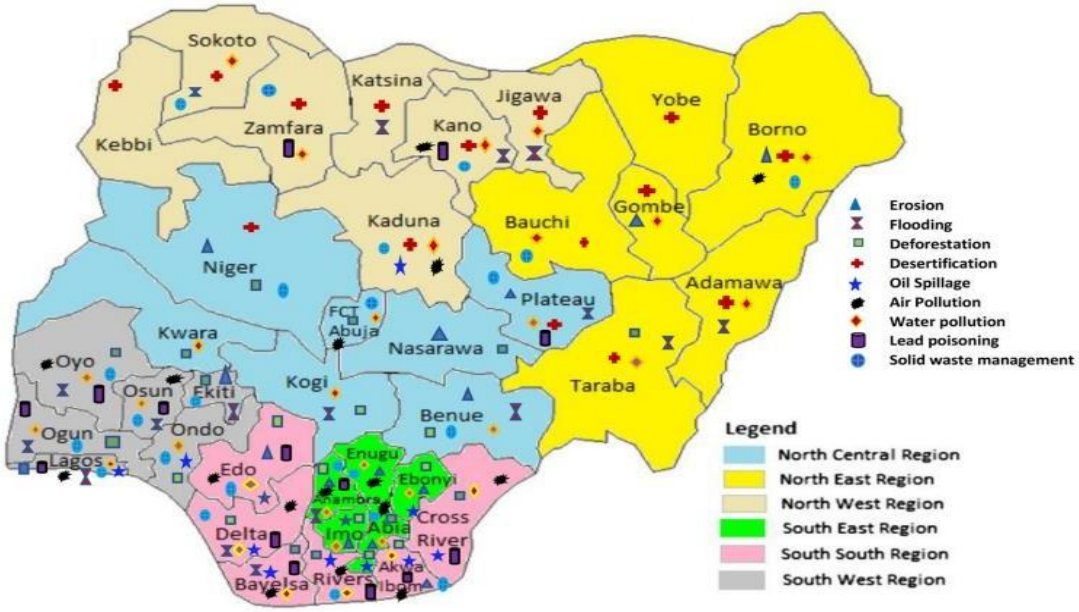

Fig. 2: Map of Nigeria showing areas affected by some of the environmental problems caused by quarrying activities (Pona et al., 2021)

For sustainable development, it is imperative to strike a balance between quarry exploitation and environmental preservation, as emphasized by Langer (2001). Adopting best practices aligned with the principles of sustainable development is essential to mitigate the adverse impacts of quarrying activities (Sustainable Approach to Aggregates, 2011). However, the present approaches in Nigerian quarrying operations have failed to adequately address critical environmental issues, leading to significant environmental problems in affected areas (Minerals Commission, 2001; Bamgbose et al., 2014).

Communities impacted by quarrying activities face numerous challenges, including poverty, health disparities, degraded landscapes, noise pollution, air pollution, lack of amenities, and loss of farmland and vegetation (Akanwa, 2016; Akanwa et al., 2017a). Addressing these challenges requires a concerted effort to implement sustainable practices and mitigate the environmental footprint of quarrying operations.

SOCIOECONOMIC IMPLICATIONS OF QUARRYING IN NIGERIA

Nigeria is endowed with over 44 different mineral types occurring in commercial quantities in over 500 locations across the 36 states and the Federal Capital Territory (Adegbite, 2021). Quarrying plays a significant role in shaping the socioeconomic landscape of regions where it operates (Oladimeji et al., 2018; Salawu & Sadiq, 2020). As a process of extracting valuable minerals and materials from the earth's surface, quarrying impacts various aspects of society, including employment, local communities, and income distribution (Oladimeji et al., 2018; Melodi & Ogunyemi, 2019; Hassan, 2022). The impacts of quarry operations are not uniformly distributed among affected parties and areas. While a project may be perceived as bringing overall benefits, certain groups

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and geographical locations may disproportionately bear the adverse effects, with the primary benefits accruing to other distant entities. As elucidated by Lameed and Ayodele (2010), companies typically establish and undertake quarrying endeavors to cater to their own social and economic interests, often disregarding the needs and aspirations of the directly affected communities and the surrounding environment.

In open-cast mining and quarrying settings, expansive swathes of land are typically excavated, leaving behind stagnant ponds within open pits. Numerous quarrying sites are situated near residential areas, railways, livelihoods, commercial centres, and educational institutions, exposing these locales to potential hazards. There have been numerous complaints regarding the nuisance and peril posed by unregulated and illegal blasting, dust emissions, and water accumulation in quarrying pits.

2.1 Economic Implications

The economic benefits of quarrying operations are numerous, impacting both the workers, the community and the society. Quarrying activities generate employment for both the local community and foreigners (Melodi & Ogunyemi, 2019; Hassan, 2022). It contributes to a country's gross national product, both through production for the local market and for export trade (NCB, 2013). Quarrying holds significant importance as it serves as a primary source for the materials utilized in traditional hard flooring. These materials include granite, limestone, marble, sandstone, and even clay, which are employed in the production of ceramic tiles. Products from quarrying are used in building and road construction.

2.1.1 Contribution to Economic Growth

According to the National Bureau of Statistics (NBS) 2023, The Mining and Quarrying sector encompasses activities such as Crude Petroleum and Natural Gas extraction, Coal Mining, Metal ore mining, Quarrying, and other Minerals-related activities. In the third quarter of 2023, this sector experienced nominal growth of 31.90% compared to the previous year. Coal Mining saw the highest growth rate at 162.76%, followed by Metal Ores at 82.66%. However, Crude Petroleum and Natural Gas extraction remained the primary contributor to the sector, accounting for 92.78% of its activity. Although there was a slight decline of 2.37% points in growth compared to the third quarter of 2022, there was a significant increase of 39.01% points compared to the second quarter of 2023. The Mining & Quarrying sector contributed 8.32% to the overall GDP in the third quarter of 2023, showing an increase from 7.32% in the same period of 2022 and 6.58% in the previous quarter. In real terms, the sector experienced a -1.96% year-on-year growth rate in the third quarter of 2023, which was higher by 19.34% points compared to the third quarter of 2022 and 10.20% points compared to the second quarter of 2023. Quarter-on-quarter, the growth rate was 10.91%. However, the contribution of Mining and Quarrying to Real GDP in the third quarter of 2023 stood at 5.64%, slightly lower than the rate of 5.90% recorded in the same quarter of 2022 but higher than the 5.58% recorded in the second quarter of 2023 (NBS, 2023).

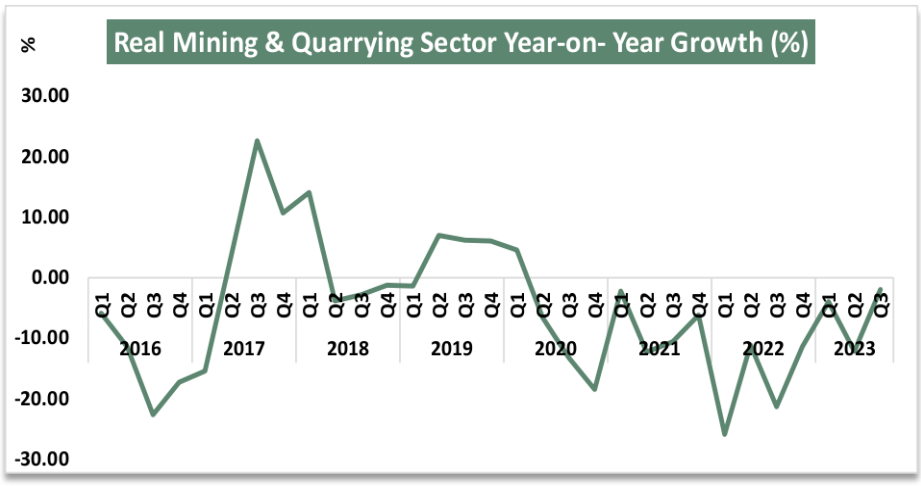

Fig. 3: Year-on-year Mining and quarrying sector growth (NBS, 2023)

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2.1.2 Youth Employment

Mining and quarrying activities create significant employment opportunities across various sectors through various means including;

a) Direct Employment in Mining Operations: Mining and quarrying operations require a skilled workforce to operate machinery, oversee extraction processes, and ensure safety protocols are followed. Positions such as miners, machine operators, engineers, geologists, and safety inspectors are essential for the efficient functioning of mining sites (Melodi & Ogunyemi, 2019). Artisanal and small-scale mining (ASM) is a globally significant industry, providing rural employment directly to at least 15 million people and indirectly to over 100 million in more than 70 countries (World Health Organization (WHO), 2013).

b) Supporting Industries and Services: Mining and quarrying activities stimulate demand for supporting industries such as equipment manufacturing, transportation, and logistics. Companies providing services like geological surveys, environmental assessments, and consultancy also benefit from the demand generated by mining projects. The creation of ancillary businesses, including food services, accommodation, and healthcare, to support mining communities further contributes to job creation.

c) Infrastructure Development: Mining projects often require significant infrastructure development, including roads, railways, ports, and power supply systems. Construction and maintenance of infrastructure projects provide employment opportunities for engineers, construction workers, and other skilled labourers.

d) Royalty and Community Youth Tax for Development of the Community: Responsible mining companies invest in community development initiatives to foster goodwill and sustainable development. Employment opportunities also arise through community programs focused on education, healthcare, skills training, and entrepreneurship (Melodi & Ogunyemi, 2019). Initiatives aimed at promoting local hiring and procurement also contribute to job creation within surrounding communities.

e) Technology and Innovation: The adoption of technology and innovation in mining operations creates opportunities for skilled professionals in areas such as data analysis, robotics, and automation. Research and development efforts to improve efficiency, safety, and environmental sustainability in mining practices also drive employment in specialized fields.

f) Government Policies and Incentives: Governments can promote employment in the mining sector through supportive policies, incentives, and capacity-building programs. Initiatives aimed at enhancing local participation, providing vocational training, and ensuring compliance with labour regulations can foster employment growth.

2.2 Social Implications

Social impacts of quarrying may include damage to land and decreased agricultural yield, conflicts with residents of nearby communities, accidents within quarry sites, forced migration due to noise from blasting, and environmental degradation (Hassan, 2022). Quarrying operations can exert pressure on local housing and markets, potentially leading to an increase in community conflict and crime, as noted by Afeni et al. (2015). However, the establishment of essential social infrastructure such as schools and hospitals have the potential to revitalize previously remote areas. Additionally, investments in transportation facilities can enhance accessibility to other economic centres, thereby bolstering the prospects for development, as highlighted by Melodi and Ogunyemi (2019).

2.2.1 Damage to land and agriculture

It is estimated that at the close of the mines, total land space acquired would be used for other purposes such as sitting of mines, heap leach facilities, and a residential and large tract of the land is cleared with the removal of topsoil and vegetation (Adedeji et al., 2020). These leave the land at the mercy of the weather. The extensive

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land clearance associated with open-pit mining has also destroyed vegetation, cultural sites, biodiversity, and some water, it also destroys the natural habitat of wildlife and the rich-tropical forest with its economic timber species (Ndinwa & Ohwona, 2014).

2.2.2 Conflicts over Resource and Land Use

Quarrying and mining activities can frequently spark conflicts over resources and land use due to various competing interests and impacts on local communities (Funder, 2012; Olumba & Ezenwa, 2022). Firstly, these operations often require large tracts of land, leading to disputes between the state and federal government or the government and the mining company for example disputes between BUA and Dangote cement in Edo state (BUA Group, 2024; Sahara Reporters, 2024). Additionally, the extraction of minerals and resources can result in environmental degradation, such as deforestation, soil erosion, and water pollution, which can directly affect the livelihoods of nearby communities dependent on agriculture, fishing, or other natural resources. Moreover, the influx of migrant workers to mining areas can strain local infrastructure, increase pressure on scarce resources like water, and contribute to social tensions with indigenous or traditional communities. Ewekoro, located in Ogun State, Nigeria, has experienced significant conflicts due to quarrying activities. The town hosts several cement and quarrying companies, which have had both economic and environmental impacts on the community (Oxford Business Group, 2021; KPMG Nigeria, 2022). Furthermore, disparities in the distribution of benefits from mining activities, such as employment opportunities and revenue sharing, can exacerbate existing inequalities and foster resentment among affected communities.

2.2.3 Forced Displacement and Migration

Mining and quarrying activities can often result in forced migration and displacement of communities due to various factors. The acquisition of land for mining projects may necessitate the disruption of their livelihoods and social structures. Additionally, the environmental impacts of mining, such as deforestation, pollution of water sources, and land degradation, can render areas uninhabitable, forcing residents to seek alternative living arrangements elsewhere. Furthermore, this can also lead to inflation, especially for the common man who isn't benefiting directly from mining areas, which can put pressure on local resources and infrastructure, leading to competition for housing and services and sometimes exacerbating social tensions. It is ideal to note that in many societies, the quarrying methods employed often fall short in terms of environmental sustainability. Furthermore, resource exploitation related to quarrying is frequently characterized by disorderly practices. This lack of proper regulation and oversight has led to the collapse of quarries, with inadequate rehabilitation efforts in place, as observed by Melodi and Ogunyemi (2019).

ENVIRONMENTAL IMPLICATIONS

The impact of quarrying on the environment is significant, with each stage of the process causing its negative effects. The high level of particulates generated at the drilling and crushing areas depicts them as hazard zones (Olusegun et al., 2009). Overburden removal and blasting cause destruction of the natural landscape and ecosystem, soil erosion, ground vibration, slope instability, and air and noise pollution (fig. 2). Many researchers have conducted extensive studies on the environmental impact of quarrying, including Olusegun et al. (2009), Lameed and Ayodele (2010), Ajide and Ajayi (2015), Bamgbose et al., 2014; Ndinwa and Ohwona 2014; Aigbedion and Iyayi 2017; Melodi (2017), Merem et al. (2017), Ezichi (2018), Akinluyi et al. (2019), Etabee and Okon (2021), Turyahabwe et al. (2021), Hassan (2022), Olotu et al. (2022), Mahapatra (2023) Okafor et al. (2023) Umar and Oriri (2023), Bahloul et al. (2024), Oruonye et al. (2024) and many others. The consensus among these researchers is that quarrying activities result in the destruction of habitats, soil erosion, environmental degradation, depletion of groundwater levels, water pollution, noise pollution, air pollution, and respiratory health risks. Bahloul et al. (2024) state that it is essential to consider the impact of quarrying on the local environment, including changes in air and water quality, noise pollution, and potential hazards to human health and safety. Nwachukwu and Feng (2012) added in their work that many quarry operators do not conduct proper intrusive mapping before excavation, leading to several abortive and abandoned quarry pits.

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Fig. 4: Deforestation and habitat destruction caused by mining activities at Rayfield, Jos Plateau (Oruonye et al., 2024)

3.1 Deforestation and habitat destruction

Solid minerals and rocks can be found on or near the surface of the earth. One of the stages of quarrying is stripping or removing the overburden. This helps to expose the desired rock or mineral, as well as remove any unwanted materials. However, this process also disrupts the ecosystem (Adedeji et al., 2020), leading to a loss of biodiversity and deforestation (Ndinwa & Ohwona, 2014). According to Bahloul et al. (2024), the negative impact of quarrying goes beyond just the destruction of wildlife and landscapes. Stone blasting can also result in damage to homes and other structures (Bamgbose et al., 2014; Ndinwa & Ohwona, 2014; Ajide & Ajayi, 2015). Ajide and Ajayi (2015) in their studies in Oba-Ile, Ondo State, Nigeria stated that most buildings that fall within buffer zones to quarry sites have high risks such as air pollution, noise pollution, and health effects and cracks on building walls as shown in fig. 3, 4 and 5. Unsustainable mining practices have caused devastating impacts on the environment and safety of the population but have endured because of the lackadaisical attitudes of the government and its agents to enforce the rules and regulations governing the mining of mineral resources in the Nigria (Oruonye et al., 2024). Nwachukwu and Feng (2012) added that abortive and abandoned quarry pits destroy the ecosystems which results in the loss of human life and arable land.

Fig. 5: A=an image of destroyed houses and B=an image showing. These are caused by the blasting of rocks (Ajide & Ajayi, 2015).

3.2 Soil erosion and land degradation

Soil erosion and land degradation are most commonly caused by activities such as stripping, blasting, and mineral/rock extractions (Melodi, 2017; Lameed & Ayodele, 2010; Turyahabwe et al., 2021; Olotu et al., 2022). These processes in Nigeria create open spaces on the surface of the earth which make it easier for soil erosion, landslides, and other geological hazards to occur as noted in researches conducted by Aigbedion and Iyayi (2017) and Dada (2018). Bamgbose et al., 2014 added that quarrying activities equally disrupt farming in Ogun State, Nigeria. During stripping, both plants and soil are removed, exposing the soil to degradation (lameed & Ayodele, 2010). Slope failure can also cause landslides and endanger workers (Olotu et al., 2022). In the event of slope failure, workers and machinery in the quarry pit may be buried by falling blocks of blasted rocks.

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3.3 Water pollution and depletion

Many minerals and rocks contain substances that can be very harmful to human health when they are released into the water (Ajide & Ajayi, 2015; Melodi, 2017). Blasting affects the surface water and groundwater quality by releasing pollutants from the quarry pit to find their way to surface water and shallow aquifers around the quarry site, this leads to water contamination (Turyahabwe et al., 2021; Umar & Oriri, 2023). During rainfall, quarry workers often need to remove water from the pit to drill blast holes and blast the rocks. This process is called dewatering, and it can lower the groundwater level and might lead to interaction with gangue. During the dry season, the recharge rate for the aquifer is reduced, so dewatering can exceed the rate of discharge. This can cause the water level to drop and even lead to a scarcity of water around the mining or quarry site. Ezichi (2018) researched the impact of quarrying on water, air, and soil quality in Ebonyi State and noted that the rainwater was slightly acidic, hard, turbid, and containing various amounts of phosphates, nitrates, and sulphates. Ezichi (2018) reported that the slight acidity of the rainwater could be linked to the air quality. These chemicals can change the quality of the water, making it unsafe for drinking or other uses.

Fig. 6: Abandoned mine filled with contaminated water in Igarra and Ikpeshi, Edo State, Nigeria (Ndinwa & Ohwona, 2014)

3.4 Air pollution and respiratory health risks

Quarrying can lead to air pollution in several ways. The blasting, crushing, drilling, loading, and transportation of quarried materials generate dust that is a significant source of particulate matter in the air (Olusegun et al., 2009; Bamgbose et al., 2014; Ndinwa & Ohwona, 2014; Melodi, 2017; Ezichi, 2018; Hassan, 2022; Mahapatra, 2023; Okafor et al., 2023). The combustion of fossil fuels during quarrying operations can also cause air pollution, resulting in emissions of particulate matter, nitrogen oxides, sulphur dioxide, and volatile organic compounds (Okafor et al., 2023). According to Ezichi (2018) and Okafor et al. (2023), the impact of quarrying on air quality is much more affected during the drying season than during the rainy season, as most of the parameters - such as CO, NOx, SOx, VOC, and particulate matter (PM10)- are higher in the drying season than rainy season. These pollutants can worsen respiratory conditions and pose health risks, especially to those who live or work near the quarry. Exposure to such pollutants for an extended period may lead to respiratory problems like coughing, catarrh, asthma, bronchitis, chronic obstructive pulmonary disease (COPD), and other lung diseases.

The most prevalent health problem of the Workers and Nearby Residents in most of the solid mineral/rock host communities in Ebonyi, Ogun, Cross River, Edo, Ondo, Oyo, and Osun was identified as nasal infection (Olusegun et al., 2009; Bamgbose et al., 2014; Ndinwa & Ohwona, 2014; Ajide & Ajayi, 2015; Melodi, 2017; Ezichi, 2018; Hassan, 2022; Umar & Oriri, 2023; Okafor et al., 2023). A study conducted by Hassan (2022) on the assessment of the Socio-Economic and Health Impact of Quarrying on the inhabitants of Kenta Logemo Village in Odeda Local Government Area, Ogun State, Nigeria, concluded that the level at which most parameters were very close to the Federal Ministry of Environment (FMEnv) Limit calls for caution; hence, to avert the danger all hands must be on desk. The tables below show that Seasonal variations have an influence on air quality and physicochemical properties at the quarry sites as the rain dissolves some of the suspended particulate matter which adds more impact on the soil and surface water (Ezichi, 2018).

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Fig. 7: Dust particles emitted into the atmosphere from quarrying sites (Ndinwa & Ohwona, 2014)

Table 1: showing the air quality during the dry season at an old quarry in Ishiagu, Ebonyi state, Nigeria (Ezichi, 2018)

Component	**Edge**	**250**	**500m**	**750m**	**Controle**	**FME**
CO	4100	3800	3000	1230	1000	1000
NO_X	40.5	38.5	30.6	15.5	15.5	20
SO_X	90.6	75.5	60.4	25.0	20.0	20
VOC	2000	1600	1200	200	200	250
PM_{10}	860	650	360	25	25	100

Table 2: showing the air quality during the rainy season at an old quarry in Ishiagu, Ebonyi state, Nigeria (Ezichi, 2018)

Component	**Edge**	**250**	**500m**	**750m**	**Controle**	**FME**
CO	3200	2800	1600	500	500	1000
NO_X	30.2	28.5	25.0	8.6	8.0	20
SO_X	60.0	50.0	40.0	16.0	16.0	20
VOC	1200	780	540	320	120	250
PM_{10}	270	160	100	20	20	100

3.5 Noise Pollution

Quarrying activities create noise pollution due to activities such as blast hole drilling, blasting, machinery operation, and material transportation (Ndinwa & Ohwona, 2014; Ajide & Ajayi, 2015; Mahapatra, 2023; Okafor et al., 2023). Heavy machinery, including excavators, crushers, and trucks, generate loud and continuous noise throughout the day, which can hurt the peace of nearby communities, impacting their well-being and quality of life (Melodi, 2017). Blasting operations break up rock formations and create sudden, loud noises that can travel over long distances, leading to potential hearing loss and other health issues for workers and nearby residents (Umar & Oriri, 2023).

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SUSTAINABLE QUARRYING PRACTICES

Sustainable quarrying practices are aimed at reducing the negative environmental and socio-economic impacts of quarry operations by maximizing the long-term benefits for communities and ecosystems. By adopting sustainable quarrying practices, operators can minimize environmental degradation, mitigate social impacts, and contribute to the long-term sustainability of natural resources and communities affected by quarrying activities. Oruonye et al. (2024) in their studies address the challenges of balancing the economic benefits of mining with the need for environmental conservation and sustainable development. Adedeji et al., 2020 added that despite the growing importance of quarrying for granite in the study area, there has been an increasing concern over environmental impacts associated with the activities and this makes environmental sustainability in the industry crucial

4.1 Environmental Impact Assessments (EIA)

Environmental impact assessment is a crucial process that aims to identify and evaluate potential environmental impacts that may arise from quarrying activities (Rahnema et al., 2023). This process involves continuous monitoring, evaluation, and adaptive management throughout the entire lifecycle of the quarrying activities. Merem et al. (2017) recommended the need for regular environmental assessment of mining and quarrying. This helps to predict damages, implement mitigation measures, and adhere to regulations. Additionally, this process assists in reducing negative environmental impacts by identifying risks, developing mitigation measures, engaging stakeholders, ensuring compliance, and supporting informed decision-making throughout the project lifecycle (Rahnema et al., 2023). Nwachukwu & Feng (2012) suggested the use of an electrical resistivity survey to map intrusive bodies before quarry development to reduce the number of the number of abortive pits and associated hazards.

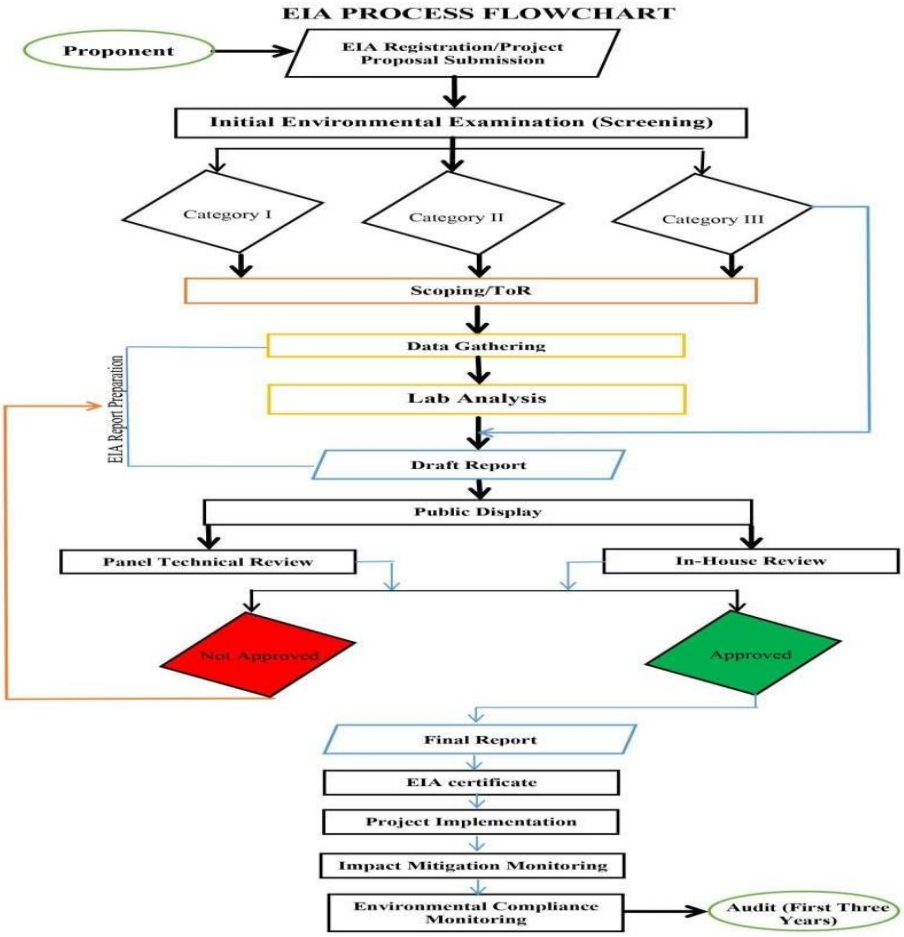

Fig. 9: EIA process flowchart (Federal Ministry of Environment, Office of Environmental Assessment Department, 2024)

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4.2 Rehabilitation and Reclamation Strategies

Rehabilitation and restoration efforts are vital in reducing the negative impact of quarrying by restoring ecosystems, enhancing biodiversity, preventing land degradation, improving aesthetic quality, supporting sustainable land use, and meeting regulatory requirements (Legwaila et al., 2015). Mine reclamation and restoration can be achieved through a variety of methods such as revegetation, erosion control, soil stabilization, and closing the open pit using waste (Ndinwa & Ohwona, 2014; Legwaila et al., 2015). Shaun (2023) carried out research on reclamation through extraction: a design-led approach to progressively reclaiming (DLPR) aggregate quarries, he concluded that (DLPR) approach would allow for greater community engagement and involvement, an expansion of design techniques and products for envisioning what post-mining landscapes can offer. Quarry pits can be repurposed into recreation centres or tourist attractions. lameed and Ayodele (2010) recommended an option for the restoration of abandoned quarry sites by infilling with quarry waste, and/or inert waste from Hyderabad and elsewhere and/or infilling with other non-inert or putrescible waste. Legwaila et al. (2015) added that reclamation techniques are mainly used to prepare quarry landforms to support vegetation, ensure safety at the site, as well as accommodate different after-uses. By implementing these measures into quarrying operations, environmental sustainability can be promoted, and the long-term impacts of quarrying on ecosystems and communities can be minimized. A study by Oruonye et al. (2016) reveals that approximately 50,000 m² of the coal mining site in the Maiganga community, located in the Akko Local Government Area (LGA) of Gombe State, Nigeria, has been reclaimed and planted with economic trees. Additionally, another 40,000 m² of the area has been reclaimed and is slated for tree planting soon.

Illegal mining can be tackled by Strengthening enforcement of existing regulations to prevent illegal mining activities and ensure penalties for those who violate laws, employing advanced technologies like satellite imagery, drones and GPS tracking to monitor mining activities and identify illegal mine sites and involving local communities in monitoring and reporting illegal mining activities, as they usually have valuable knowledge about the area.

Fig. 10: An abandoned quarry site restored and turned into a hotel (Legwaila et al., 2015)

4.3 Waste Management and Recycling

Waste management and recycling are very important in minimizing the negative impact of quarrying. Reuse and recycling of materials can conserve resources and minimize effective waste management and recycling plays a crucial role in reducing the negative impact of quarrying. By reusing and recycling materials, we can conserve resources and minimize waste generation. Proper waste management helps to prevent the release of harmful pollutants into the environment, such as runoff from stockpiles and leachate from landfills, which can damage soil quality. Aigbedion and Iyayi (2017) emphasized the need to shift from waste disposal to waste minimization and the enforcement of safe disposal of unavoidable waste in a stable and aesthetically acceptable structure through legislation. Biswas (2024) stated that quarry dust can be considered a sustainable alternative that helps to reduce the geoenvironmental problems related to handling stockpiling waste products in landfills.

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Incorporating waste management and recycling practices into quarrying operations will promote sustainability, reduce environmental impact, and contribute to the efficient use of resources.

A study by Qurix et al. (2023) found that quarry waste can be repurposed to meet local paint consumption needs, addressing cost, environmental, and health concerns in the paint industry. Embracing the circular economy paradigm, this shift from waste management to resource management can create jobs and reduce the capital needed for quarry waste management.

According to Afolabi et al. (2018), the construction industry in Nigeria generates a significant amount of waste, with materials waste accounting for 21-30% of project cost overruns. Globally, quarry waste makes up about 20-25% of total waste generation annually, amounting to 238 million tonnes (BGS, 2008).

Typically, quarry waste consists of particles smaller than 100μm and includes a variety of mineral compositions (Menéndez-Aguado, 2019). Gbenu et al. (2016) report that in Nigeria, 61-65% of quarry waste is composed of minerals such as zircon, monazite, apatite, magnetite, ilmenite, and riebeckite, while the remainder consists of rocks, soil, and gravel.

4.4 Energy Efficiency and Renewable Energy Adoption

Energy efficiency and renewable energy integration can significantly reduce the negative impact of quarrying activities. Quarrying operations often rely on fossil fuels, which contribute to greenhouse gas emissions and climate change. By switching to cleaner energy sources such as electric vehicles powered by renewable energy, we can minimize air pollution and improve air quality (Brychaeva, 2024). Investing in energy-efficient equipment and renewable energy technologies can also lead to significant cost savings for quarry operators (Capozza et al., 2021). Implementing sustainable practices can enhance environmental performance, achieve cost savings, and contribute to a more resilient quarrying industry. Examples of sustainable energy practices include installing solar photovoltaic panels, wind turbines, biomass fuels, and geothermal heat systems (Capozza et al., 2021). By embracing sustainable practices, quarry operators can contribute to a more sustainable and resilient industry. lameed and Ayodele (2010) recommended alternative power sources (like solar energy, and thermal radiation from rocks as a source of fuel) which have the potential to reduce input costs, thus increasing the profit margin, leading to the healthy growth of the industry.

4.5 Stakeholder Engagement and Community Involvement

Stakeholders work closely with the local communities to address their concerns, offering employment opportunities, and promoting the development of skills while ensuring the fair distribution of benefits derived from quarrying activities. They can also ensure compliance with environmental, health, safety, and social regulations and standards to ensure responsible and legal quarrying practices. Melodi and Ogunyemi (2019) recommended that technical training programs should be organized by quarry management on how workers can adequately adjust to the negative socio-economic impacts of quarry operations on them. Salawu and Sadiq (2020) suggested that Public enlightenment campaigns should be mounted to get the state, local government; traditional rulers, and community heads enlightened on environmental sustainability and the activities of artisanal quarrying or mining. This will help reduce illegal mining in most of the mining communities. Many of the researchers such as Umar and Oriri (2023), recommended that the government should enforce environmental laws and policies that will protect residents and the communities and ensure the environment is protected

INNOVATIVE TECHNOLOGIES IN QUARRYING

The quarrying industry is currently undergoing significant change. In the past, the industry has been criticized for its failure to embrace innovation and technological advancements. However, in recent years, quarrying firms

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have been compelled to adopt innovation to reduce overheads and improve efficiency. Innovative technologies offer promising solutions to enhance the sustainability and environmental performance of quarrying operations in Nigeria and around the world. This can be achieved by using remote sensing and GIS application technology, automated quarrying machinery, and water recycling and treatment systems. Zhou et al. (2024) concluded that exploring innovative approaches that combine data-driven machine learning (ML) techniques with knowledge-based or physics-based methods is a promising future direction. Several innovative technologies are being explored and implemented to address the challenges associated with quarrying activities. The application of new technologies in predicting the impact of quarrying before mineral/rock extraction will go a long way in minimizing the negative impact of quarrying. According to Lawal and Kwon (2021), rock fragmentation, slope stability, and environmental aspects of blasting can be predicted using Artificial Intelligence (AI). The impact of quarrying activities can be reduced by implementing innovative technology and sustainable quarrying practices. Olusegun et al. (2009) added that quarry companies should be mandated to adopt modern technology of dust strapping, such that a negligible quantity of dust escapes from the various operations at the quarry site. The particulate release can be controlled with scrubbers, precipitators, and filters, which can be retrofitted to dust stacks for pollutant removal from emissions.

5.1 Remote Sensing, AI, and Drone Technology for Surveying and Monitoring

AI, remote sensing, and drone technology are highly useful tools for quarry operators to improve efficiency, safety, and environmental stewardship. Drones equipped with cameras and sensors can provide aerial surveys of quarry sites, enabling real-time monitoring of operations, environmental changes, and compliance with regulations. Brantson (2024) emphasizes the role of AI optimization as the future of drilling and blasting as well as a future tool in moving quarries into autonomous dimensions. AI models such as artificial neural network (ANN), neuro-fuzzy inference system (ANFIS), k-nearest neighbour (KNN), support vector machine (SVM), and classification and regression tree (CART) can be utilized to predict ground vibration caused by blasting. These AI models have been studied and researched extensively in papers such as Armaghani et al. (2015a, 2015b), Nguyen (2019), Lawal and Kwon (2021), and Chen (2022). AI has simplified and streamlined environmental impact assessment studies by providing accurate results and analyzing vast datasets, including satellite imagery, and seismic and geologic data. According to Armaghani et al. (2015b), two intelligent systems, namely ANN and ANFIS, can be utilized to predict the environmental impact of blasting in quarrying. Armaghiani et al. (2015a) also conducted a study on the feasibility of the ANFIS model for the prediction of ground vibrations resulting from quarry blasting, which revealed that the ANFIS model can predict ground vibration with a high degree of accuracy. Lawal and Kwon (2021) concluded that AI is a promising tool for simulating predictors and the predicted variable. By accurately mapping and monitoring quarry sites, these technologies help to manage land use and minimize environmental impacts.

5.2 Dust Suppression Technologies

Dust suppression technologies play a crucial role in reducing the harmful effects of quarrying activities on the environment, human health, and nearby communities. These technologies help improve air quality, protect human health, ensure compliance with regulations, minimize environmental disturbance, enhance occupational safety, and promote positive community relations. Water is often used as a dust suppressant in quarrying operations, using sprays, misting nozzles, or fog cannons that apply a fine mist to areas where dust is generated (Garcia-Granda, 2024). Chemical suppressants, such as dust control agents or surfactants, can be added to water to enhance its effectiveness. Enclosing operations and equipment with structures or barriers can also help contain dust emissions. Dust collection systems, such as baghouses, cyclones, and electrostatic precipitators, can capture and remove dust particles from airstreams. Road stabilization techniques can also help reduce dust emissions from unpaved roads and haulage routes. These technologies mitigate health hazards and improve occupational safety conditions for quarry workers. Okafor et al. (2023) in their studies recommended installation of air pollution control equipment such as High-Efficiency Particulate Air (HEPA) Filters, Selective Non-Catalytic Reduction (SNCR), Absorbers (Activated Carbon), Packed-Bed Scrubbers, Selective Catalytic Reduction (SCR), and Wet Gas Scrubbers in-situ in the quarry area where free airflow is available.

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Fig. 11: A=Spray gun. B=Dry fog application. A and B are examples of dust suppression technologies used to reduce dust particles in the quarry site (Garcia-Granda et al., 2024)

5.3 Advanced Blasting Techniques for Reduced Vibrations

Advanced blasting techniques are now available to reduce the negative impact of stone blasting. These techniques can help to minimize vibrations during the blasting process, which in turn mitigates potential damage to nearby structures and minimizes disturbance to the surrounding environment. In 2021, it was suggested that a combination of expert opinion and advanced decision-tree algorithms could be used to accurately and easily predict air overpressure resulting from blasting in a quarry site (He, 2021). Pre-splitting, buffer blasting, and electronic detonation systems are the major advanced blasting techniques. Pre-splitting involves creating fractures along predetermined lines before the main blasting. This helps to control the direction of the rock breakage and reduce the amount of energy required during the main blasting, thereby reducing vibration. Buffer blasting helps to absorb and dissipate energy, which reduces the overall vibration transmitted to the surrounding rocks and structures. Electronic detonation systems allow for precise timing and sequence of charges, which can optimize energy distribution within the rock mass, resulting in reduced vibration (Singh, 2000). The development of innovative explosives with tailored properties can enhance fragmentation efficiency and minimize energy release. Bhatawdekar (2021) suggested that machine learning techniques could be used as an alternative technique for solving blasting problems with a high level of accuracy. This can further reduce vibration during the blasting operation. However, it's important to note that stone blasting has the potential for a negative impact on human health, as highlighted by Adedeji et al. (2020). Therefore, advanced blasting methods offer a practical and innovative solution for conducting safe mining operations near dwellings and sensitive structures, as pointed out by Bhagat (2024). There is a significant need to investigate advanced blasting techniques to reduce the negative impact of stone blasting on human health and the environment.

5.4 Water Recycling and Treatment Systems

Innovative technologies for water recycling and treatment can help reduce water consumption in quarry operations while ensuring that wastewater meets environmental standards before being discharged. Contaminated water is pumped out of the quarry pit during dewatering and flows towards nearby surface water. This water can be treated by creating a water reservoir or using an abandoned quarry as a water detention area where the water is channelled and treated (Rinishakartheeshwari et al., 2014). The treated water can then be used for agricultural or domestic purposes. There are various methods for treating a contaminated quarry site. Anakhu et al. (2024) found that modified Vetes doniana seeds biochar can effectively remove Cadmium and Chromium metallic ions from surface water. Rinishakartheeshwari et al. (2014) also suggested that using abandoned quarries can be an innovative and sustainable measure for flood mitigation and improving urban water supply. This method can reduce the surplus flow of water into the river and improve the water supply.

5.5 Automation and Robotics in Quarry Operations

Mining industries are increasingly adopting driverless trucks to work autonomously in and around quarry sites. Credential Authentication Technology (CAT) Inc., Komatsu, and other companies have implemented autonomous haulage systems in the last few years. Hitachi Construction Machinery has also confirmed the successful testing of its autonomous mine haul trucking software. Rio Tinto has recently started operating an

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intelligent mine using only autonomous trains, trucks, and robotics. Rio Tinto (2024) announced that they currently run more than 130 autonomous trucks across their iron ore operations. These trucks are operated by a supervisory system and a central controller, rather than a driver. The hope is that this machinery will allow mining companies to drill deeper and into narrower shafts that are generally unsafe for human miners (Rio Tinto, 2024). Automated machinery has revolutionized the quarrying industry by offering greater precision, accuracy, and efficiency compared to manual methods. It optimizes various processes such as drilling, blasting, material handling, and crushing, leading to a significant reduction in energy consumption, production costs, and increased productivity. It also minimizes the environmental impact by optimizing drilling patterns, controlling dust emissions, and reducing fuel consumption. Additionally, it eliminates manual labour in hazardous areas, improving worker safety and reducing accidents. The machinery can be equipped with sensors, cameras, and monitoring systems for real-time data, allowing remote monitoring and optimization of resource use. Mathur et al. (2024) in his studies gave insight into the current state of bulldozer technologies and explored the integration of cutting-edge technologies into bulldozer design with a focus on GPS-guided systems, automation features, and remote monitoring. Investing in automated technologies can lead to greater sustainability, resilience, and competitiveness in the quarrying industry. The use of autonomous mining dump trucks has several advantages. The machinery can now work all the time, increasing productivity and ensuring the safety of the mining operation (Dubinkin & Golofastova, 2024).

POLICY AND REGULATORY FRAMEWORK

Quarrying activities in Nigeria are subject to various legal and environmental regulations that require the exploration and exploitation of solid minerals to be carried out within a framework of environmental protection, land restoration, waste management, and emission control. The Nigeria Minerals and Mining Act of 2007 and the National Environmental (mining and processing of coal, ores, and industrial minerals) Regulation 2009 are the primary legislation that regulates mining and quarrying activities in the country. It provides guidelines for environmental protection and management in mining and quarrying operations, in addition to state governments having their policies and regulations governing quarrying activities within their jurisdictions. The Act aims to ensure sustainable mining practices, environmental protection, community engagement, and revenue generation for the government. The government has directed its attention to small-scale mining operations, which constitute a significant portion of Nigeria's mining community. Artisanal miners have been encouraged to form and register Artisanal Mining Cooperatives, facilitating their eligibility for Small-Scale Mining Licenses. Mineral Buying Centres have also been established to ensure fair market transactions for proceeds derived from small-scale mining activities, curtail smuggling activities, and ensure the government receives appropriate royalties from mined products.

Compliance with environmental laws and policies is essential to minimize the environmental impact of quarrying, protect the communities, and ensure the environment is protected. However, the Nigerian mining policy is criticized for being ambiguous, with the government solely promoting the oil and gas sector and offering incentives while doing nothing for solid minerals (Merem et al., 2017). Melodi (2017) and Akinluyi et al. (2019) recommend that the government agencies responsible for mining activities should revise their environmental management policies to reduce the environmental effects of mining activities to the barest minimum. Umar and Oriri (2023) also recommend that the government enforce environmental laws and policies that protect residents and communities.

6.1 Legal Framework for the Perfection of Environment Against Quarrying Activities in Nigeria

The legal framework for environmental law in Nigeria is based on several national and international laws. Some of these laws include the Constitution of the Federal Republic of Nigeria, 1999 (as amended), and the National Environmental Standards and Regulations Enforcement Agency (Establishment) Act, No. 25, 2007. The Constitution contains provisions concerning the protection and enhancement of the environment, as well as the preservation of water, air, land, forests, and wildlife within Nigeria. However, it is important to note that the constitutional acknowledgment of environmental protection is non-justiciable. The National Environmental

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Standards and Regulations Enforcement Agency (Establishment) Act, No. 25, 2007, repealed the Federal Environmental Protection Agency, Cap F10, Laws of the Federation of Nigeria, 2004, and provides for the establishment of the National Environmental Standards and Regulations Enforcement Agency (NESREA) charged with responsibility for the protection and development of the environment in Nigeria. This Act outlines the objectives of the Agency and its responsibility for the protection and development of the environment, biodiversity conservation, and sustainable development of Nigeria's natural resources.

The Environmental Impact Assessment Act, Cap E12, LFN, 2010, is a direct reflection of Principle 17 of the Rio Declaration and serves as the primary legislation governing environmental impact assessment for proposed projects. Before any final decision or approval is granted for activities expected to have a significant impact on the environment, the potential effects of such activities must be thoroughly considered.

The Mineral and Mining Act, Cap M12, LFN, 2010, was originally promulgated as the Mining Act, Cap. 226, LFN, 1990. The Act was passed as a legislative response to environmental degradation. Minerals referred to in this Act exclude mineral oil, as per section 2. It sought to amend and consolidate the laws relating to mines and minerals.

The Land Use Act (LUA) 2004 vests authority over all land in the territory of each state (except land vested in the Government or its Agencies) solely in the Governor of the state. The Governor is expected to exercise authority over the land judiciously for the benefit of all.

The Company and Allied Matters Act (CAMA) 2020 requires that all companies, including extractive companies, must be incorporated under the Act before they can carry on business in Nigeria. The Act also provides for reporting and disclosure requirements.

6.2 Policy Implications

Upon thorough examination of the quarry industry in Nigeria, encompassing prevailing practices, operations, and associated challenges, a clear correlation between quarrying and environmental degradation emerges. The primary causal factors impacting the quarry industry in Nigeria have been duly emphasized. Consequently, it becomes imperative to propose initiatives promoting best practices in quarrying to ensure its sustainability.

Balancing economic development through activities like quarrying with responsible environmental stewardship is essential to safeguard the environment's capacity to support natural and ecological systems and human well-being, as posited by Morgan (2008). Attaining sustainable development in Nigeria necessitates significant changes, particularly in how exploitation is perceived and executed. Mitigating environmental impacts from aggregate quarrying, as often witnessed in developed countries, entails the adoption of best management practices. This entails both institutional reforms by competent authorities and the adoption of innovative exploitation techniques by operators, in alignment with future needs (SARM, 2011). Such guidelines are readily available in handbooks and publications issued by various organizations, including government agencies and industry associations.

In industrialized nations, industry practices emphasize that aggregate extraction adheres to best management practices as a temporary activity rather than a permanent one (Wellmer & BeckerPlaten, 2002). This underscores the importance of adhering to a set of guidelines, ethics, or ideas representing the most efficient or prudent courses of action. Best practices are typically established by authoritative bodies or management, depending on the circumstances. While they generally dictate the recommended course of action, adherence to best practices should also consider the specific situation and unique needs at hand (Natural Stone Industry, 2009).

7.1 CASE STUDIES

There are numerous quarries in Nigeria that have contributed to the country's economic development. However, due to negligence or unavoidable circumstances, these quarry industries significantly contribute to environmental degradation in the regions where they operate.

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Fig. 12: Spatial Distribution of Mine and Quarry sites in Nigeria (Merem et al, 2017)

A field study conducted by Melodi and Ogunyemi (2017) indicates that quarry jobs in selected areas of Ogun and Ekiti States, Nigeria often do not include provisions for children's education sponsorship or housing for workers. Additionally, quarry workers rarely have access to basic infrastructure, medical facilities, or loan facilities provided by the quarry. Despite these shortcomings, quarry workers interviewed for the study generally agree that engaging in quarry work has led to an improvement in their standard of living. They concluded that most quarry workers experience an enhanced standard of living as a result of their involvement in quarry work.

Quarrying activities in Nigeria, notably in Uturu, Abia State, have inflicted considerable environmental harm. The practice involves blasting rocks with explosives to extract mineral rocks, leading to various detrimental effects such as noise and air pollution, biodiversity loss, and habitat destruction, as noted by Okafor (2006). According to Sam-Otuonye et al. (2022), quarrying in Ugwuele-Uturu, also in Abia State, Nigeria has adversely affected available land for housing investments due to factors like thick dust emissions, intense vibrations, loud noise, and sudden shocks experienced by residents.

The existing quarry operations in Ebonyi State, Nigeria encompass a variety of activities, ranging from stone quarrying to small and medium-sized operations utilizing heavy machinery. According to Ademola (2019), there are estimated to be between 100 and 150 such industries in the state. However, these quarry activities have inflicted severe environmental damage, as noted by Gauch (2021). The explosive blasting of rocks has led to air and water pollution, biodiversity loss, and man-made environmental degradation. This includes the creation of unfinished or abandoned pits, which not only mar the landscape but also pose risks to livestock, wildlife, and human safety.

Research conducted by Mathew et al. (2022) highlights the effects of mining activities in the Bosso Local Government Area (LGA) of Niger State, Nigeria on various land use and land cover categories. These categories include built-up areas, forest cover, grasslands, cultivated land, bare surfaces, and water bodies. Analysis spanning from 1987 to 2020 reveals significant changes in these categories. The environmental and socio-economic impacts of mining activities indicate a negative effect on agricultural production, likely due to soil contamination from particulate matter deposits. While there has been an increase in employment opportunities, there is a pressing need for better organization and education among miners.

Research conducted by Ukpong (2012) shows that quarrying in Akamkpa Local Government of Cross River State, Nigeria has caused significant adverse environmental effects in host communities. These include heightened noise levels and deteriorated air and water quality, surpassing acceptable standards. This poses

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potential health risks to residents. While some trace metals, like iron, are currently within safe limits, regulating quarry waste is crucial to prevent further contamination. Aggregate mining in Old Netim has also resulted in negative impacts on the environment, including health risks such as hearing loss among workers and high levels of suspended particulate matter exceeding FEPA standards. Without preventive measures, workers and nearby residents are at risk of developing silicosis.

The analysis results of the research conducted by Omeiza et al. (2022), indicate that approximately 30% of the mining land allocated to quarry companies in Mpape, Abuja, Nigeria has been degraded to some extent. Their findings from the analysis of gaseous pollutants, including CO, NOx, and SO2, released into the atmosphere from quarrying activities, revealed significant environmental pollution. Additionally, smoke from chimneys impairs respiratory organs and reduces visibility, potentially leading to accidents for pedestrians and motorists. The emission of stone dust also contributes to discolouration and weakening of nearby house pillars due to acid rain.

Adiea et al. (2012), opine that residents living within 600 meters of the Gunduwawa quarry in Kano State, Nigeria are subjected to excessive noise levels. He recorded peak noise levels during blasting activities, while the operation of heavy machinery and drilling further contributed to the significant noise hazards experienced. Both workers and residents are adversely affected by this, posing risks to their health and potentially resulting in permanent disabilities. He also significantly noticed cracks in buildings as a result of the noise.

According to Oyinloye et al. (2017), air pollution, particularly from dust, is the primary form of pollution generated in the industrial zones of Akure, Nigeria. This pollution adversely affects the health of residents living near the sites, making their lives challenging. The local environment shows signs of dust accumulation, covering plants and vegetation with a whitish layer. This dust emission has the potential to disrupt photosynthesis processes, leading to reduced plant productivity or even the death of vegetation. They also noted that noise pollution in the area is predominantly attributed to various quarrying activities such as blasting, drilling, crushing, loading, unloading, machinery operation, and transportation. Despite these negative impacts, stone quarrying also brings benefits such as employment opportunities, community development, and income generation to the area.

Despite the employment opportunities and infrastructure provided by sand mining, Ohaeri et al. (2021) opines that sand mining in the Choba, Abuloma, and Chokocho areas of Port Harcourt, Nigeria has resulted in numerous environmental consequences, including the destruction of ecosystems, disruption of livelihoods, and loss of biodiversity in coastal communities. Their research identified six primary impacts, including soil erosion, land subsidence, alteration of land, loss of vegetation, noise pollution, and damage to roads due to ongoing sand mining activities in coastal areas. Despite its economic significance, the study concludes that socially and environmentally, sand mining is causing more harm than good.

Due to the necessity of blasting in large-scale quarry operations, the entire environment of the Iyuku community on the outskirts of Auchi, Edo State, Nigeria is exposed to vibrations. While these operations create employment opportunities and royalties for the community, an investigation by Oboirien (2005) revealed that vibrations and impact sounds from the quarry operations are significant contributors to building failures. Furthermore, intermittent intra-family conflicts, often resulting in loss of life and property, emanate from dissatisfaction over the distribution of royalties paid by the quarry firms.

7.2 Challenges

According to the Mining Review Africa blog (2023), mining in Nigeria has been hindered by a complex regulatory framework and legal issues. Inconsistent policies, overlapping responsibilities between federal and state governments, and unclear land tenure systems have deterred investors and hindered the industry's growth.

Inadequate infrastructure, including transportation, power supply, and access to water, has been a significant challenge. These deficiencies increase operational costs and make mining less attractive to potential investors. Similarly, mining regions in Nigeria face security challenges, including illegal mining activities, community

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conflicts, and in some cases, armed banditry. This has deterred investments and created an unstable operating environment.

Quarry miners do not use the recommended protective safety wear instead they use improvised safety apparel such as eyeglasses or shades for safety goggles and pieces of water host tubes for hand gloves (Salawu et al., 2020). The quarry workers improperly kitted for the quarry work are exposed to heavy metal pollution. Simple protective measures and safety gear could make the difference between life and death, thereby ensuring the sustainability of human life.

CONCLUSION

This paper is a review of the socioeconomic and environmental implications of quarrying in Nigeria. It explores the policy and regulatory framework governing quarrying activities, as well as sustainable quarrying practices and innovative technologies designed to mitigate the impact of quarrying and promote responsible quarrying practices. The review draws on 114 published works, comprising 85% journal articles, 5% conference papers, and the remaining 10% newsletters, blog reports, case law, textbooks, and eBooks. Quarrying is a major economic activity in Nigeria, and the industry has grown significantly over the past few decades which has contributed significantly to the country's GDP and provided employment opportunities for many. Over the past few decades, the quarrying industry in Nigeria has experienced substantial growth, driven by increased demand for construction materials due to urbanization, infrastructure development, and the expansion of the real estate sector. However, quarrying has also caused several environmental and socioeconomic problems, such as air and water pollution, loss of agricultural land, conflicts with nearby communities, damage to land and reduced agricultural yields, accidents within quarry sites, and forced migration due to blasting noise. This review provides insight into how the negative impacts of quarrying can be minimized through the implementation of sustainable quarrying practices and innovative technologies. These include the use of automated and robotic machinery, water recycling and treatment systems, dust suppression technologies, waste recycling and management, advanced blasting techniques, and more. Currently, there are some gaps and inconsistencies in the regulatory framework, which need to be addressed to ensure adequate protection of the environment and the rights of affected communities. Therefore, this paper recommends further research in areas such as the long-term effects of sustainable practices, potential for new technologies, policy, and regulatory framework and equally recommends the implementation of sustainable quarrying practices and innovative technologies to improve efficiency and reduce the negative impacts of quarrying.

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