SUITABILITY OF NIGERIAN BARITES FOR DRILLING MUD PRODUCTION AND SUSTAINABILITY OF ARTISANAL AND SMALL-SCALE MINING (ASM) OF BARITES IN NIGERIA

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by

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CERTIFICATION

This is to certify that the thesis titled "**SUITABILITY OF NIGERIAN BARITES FOR DRILLING MUD PRODUCTION AND SUSTAINABILITY OF ARTISANAL AND SMALL-SCALE MINING (ASM) OF BARITES IN NIGERIA**"

submitted to the

African University of Science and Technology (AUST), Abuja, Nigeria

for the award of the Doctorate degree is a record of original research carried out by

Otoijamun, Itohan in the Department of Materials Science and Engineering.

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By

Otoijamun, Itohan

A DISSERTATION APPROVED BY THE MATERIALS SCIENCE AND ENGINEERING DEPARTMENT

RECOMMENDED: ---
Supervisor, Professor Azikiwe Peter Onwualu

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Chief Academic Officer

June, 2021

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ABSTRACT

The aim of this dissertation is to contribute to efforts towards increasing the use of Nigerian barites in drilling mud production and other industrial applications. In order to achieve the above objectives, three projects were conceived and implemented.

The aim of the first project was to characterize barite samples from selected different locations in Nigeria and determine their suitability for different industrial applications. The properties determined include chemical composition, functional groups and specific gravity. Samples were obtained from ten locations in Nasarawa and Taraba states as well as a standard Working Sample (WS) obtained from a drilling site. The samples were characterized using Scanning Electron Microscope & Energy Dispersive X-Ray (SEM-EDX), Fourier Infrared Analysis (FTIR) and X-Ray diffraction (XRD). Specific Gravity (SG) was determined using pycnometer method. Results of SEM-EDX analysis show that the WS has a B-S-O empirical composition of 66.5%while the ten samples investigated had compositions of between 59.36% and 98.86%. The FTIR analysis shows that the functional groups of S-O, SO_4^{-2}, B-S-O, OH of the ten samples match that of the WS. Results of XRD show that the ten samples have the same elemental composition as the WS and all meet American Petroleum Institute (API) standard for industrial barite. Similar matching results are shown from EDXRF spectra intensity, position and composition analysis of the ten samples compared to the WS. Specific Gravity (SG) results show that six out of the ten samples have SG above 4.2 which is the recommended minimum for API standard. The other four samples will require beneficiation to meet the standard for drilling fluid formulation. Using all the parameters of the assessment together, results show that while some (6) of the samples can be used for drilling fluid formulation, some (4) require beneficiation but all ten samples can be used for other industrial applications.

The second study is focused on improving the productivity and sustainability of Artisanal and Small- scale Mining (ASM) of barites This study: reviewed the existing policies and government interventions on ASM of Nigerian barite; evaluated the operations of ASM through a survey of mines in Nasarawa state, Nigeria; identified factors that affect sustainability of the sector and proffered solutions to foster sustainability of ASM of barite in the region. The study adopted the 4Is optimization technique (Information gathering, Interpretation, Implication

Implementation) through personal interactions with the stakeholders at the barite mining sites, regarding policies and interventions specific to ASM of barite. Challenges identified include: weak implementation and enforcement of mining laws; inadequate support from government and development partners; poor access to mining equipment and technology; poor infrastructure (access road, water, electricity); poor pricing of products (marketing challenges); poor remuneration of mine workers; poor mining skills; inadequate formal education; limited awareness on environmental health and safety hazards; fragility and conflict; insufficient information and data on mines and miners; security, fragility, and conflicts; lack of access to finance; lack of formalization of operations and poor legal framework for operations. The strategies suggested for fostering the sustainability of ASM of barites include: enhanced policy and legislation formulation and implementation, strengthening of institutions, formalization of ASM operations, training of miners, awareness campaign, improvement in environmental and safety of operations, empowerment and support by government and development partners for individual miners and processors and organized groups within the sector.

The third project examined the role of male and female miners and the impact of Artisanal and Small-Scale Mining (ASM) of barites in Nigeria on environment and safety through a field survey using a structured questionnaire and Focused Group Discussion. Results show that barite miners consist of 52% male and 48% female. Men (100%) are mostly involved in blasting, digging and cracking while women (100%) are involved in cleaning, washing and transfer of excavated barite to designated locations for stacking. The gender challenges identified include: unsafe work environment and poor remuneration for women; inadequate enforcement of mining laws and regulation, poor access to finance, disparity in access to safety gears, degraded environment and devastation of agricultural land. Recommendations include: modification and implementation of existing ASM policy to emphasize gender mainstreaming, support programs for gender parity for the sector, formalization of activities of ASM and creation and support for women cooperative miners.

KEYWORDS: Barite, drilling mud, Artisanal and Small-Scale Mining (ASM), sustainability, mineral value chain, specific gravity, beneficiation, mineralogy, gender issues in technology, morphology.

DEDICATION

This Dissertation is dedicated to the poor African women miners and under aged children who are involved in mining because they have no choice. For such women, we hope that government and other stakeholders will use the results of this study to improve their working environment and improve the productivity of the sector.

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NCMB – Nigerian Content Monitoring Board; RMRDC – Raw Materials Research and Development Council

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1. **Itohan Otoijamun,** Moses Kigozi, Sikiru Ottan Abdulraman, Adelana Rasak Adetunji and Azikiwe Peter Onwualu. 2021. Fostering the Sustainability of Artisanal and Small-Scale Mining (ASM) of Barite in Nasarawa State, Nigeria. *Sustainability 13,* 5917. MDPI, The Netherlands. https://doi.org/10.3390/su13115917 SCOPUS Indexed.
2. **Otoijamun, Itohan.**; Kigozi, Moses.; Adetunji, Adelana Rasak; Onwualu, Azikiwe Peter. 2021. Characterization and Suitability of Nigerian Barites for Different Industrial Applications. Minerals, MDPI, 11, 360. https://doi.org/10.3390/min11040360 (SCOPUS indexed).
3. **Itohan Otoijamun**, Kigozi Moses; Sikiru Ottan Abdulraman, Adelana Rasak Adetunji and Azikiwe Peter Onwualu. Gender Dimensions of Artisanal and Small Scale Mining (ASM) of Barite Ores in Nasarawa State, Nigeria. Submitted to a Journal, Under Review.

CHAPTER ONE

INTRODUCTION

1.1 Background

Since independence in 1960, Nigeria has implemented different economic development plans, policies and programmes [1]. These include: the first, second, third and fourth National Development Plans, Structural Adjustment Programme, National Rolling Plans, 7-Point Agenda, National Economic Empowerment and Development Strategy (NEEDS), National Economic Recovery and Growth Plan (NERGP), among others [2]. Even with these programmes, the economy of Nigeria is still dominated by oil which provides over 90% of foreign exchange for the country. With challenges of the sector, the federal government of Nigeria is currently implementing programmes to diversify the economy. One of the sectors being developed is the mineral sector.

Although Nigeria is blessed with about 44 minerals at a commercial level, the government selected seven strategic minerals for development. One of these seven minerals is barite. Incidentally, barite is a key mineral used in making drilling mud, a major material used for drilling operations in oil extraction. Although there are large occurrences of barite in Nigeria, most of what is used by the oil industry is imported. The reasons for this include the unavailability of the mineral in the right quantity and quality for operators of the sector. This situation can be attributed to the fact that most of the mining in Nigeria is by Artisanal and Small-Scale Mining (ASM).

There is therefore the need to evaluate the mining sector to identify challenges and proffer solutions that will ensure sustainable supply of barite in the right quantity and quality for the operators. It is also important to evaluate Nigerian barite ores in order to provide scientific data to show the suitability of barite for drilling mud and other industrial applications. This will help investors towards taking informed decisions on mining and processing of barites.

1.2 Problem Statement

Two major problems are addressed by this study. First is the low level of use of Nigerian barite by the oil industry. The second problem is the inability of Artisanal and Small-Scale Mining (ASM) to supply barite to the oil industry sector in a sustainable manner. The study therefore characterized barite samples from different locations to assess their suitability for making drilling mud, studied the ASM sector and developed a strategy for fostering sustainability of ASM of barites in Nigeria.

1.3 Aim and Objectives

The main aim of this study is to contribute to efforts toward ensuring that Nigerian barite is used for production of drilling mud by oil industry operators and for other industrial applications. The specific objectives are to:

- characterize barite samples from different locations in Nigeria and determine their suitability for different industrial applications;
- assess the mining aspect of the value chain of Artisanal and Small-Scale Mining (ASM) of barite in Nasarawa state, Nigeria and identify the challenges in this aspect;
- evaluate gender issues in ASM of barites in Nasarawa state, Nigeria, in order to improve the productivity of the sector;
- identify socioeconomic and environmental impacts of ASM;
- assess the effectiveness of government policies and regulations for the sector;

- suggest sustainable strategies toward improving the productivity and sustainability of ASM of barites.

1.4 Justification

The project can be justified by the benefits that can be derived from the results as follows:

- Characterization of barite ores from different locations will indicate the industrial applications they are suitable for and assist in promoting the usage of the material.
- Data on the properties of the barite will indicate the type of beneficiation that is required to upgrade the quality of the barite.
- Study of ASM of barite will provide scientific data on the dynamics of the sector and assist in identifying the challenges which can lead to proffering solutions for improving the productivity of the sector.
- The study can also assist in mitigating the socio-economic and environmental impact of artisanal and small-scale mining (ASM).
- The study has the potential of reducing the importation of barites into Nigeria, save foreign exchange and create employment through improved productivity and livelihood of local miners and dealers of barite.

1.5 Scope and Arrangement of Work

The value chain for barites include: exploration, mining, beneficiation, marketing, drilling mud formulation, utilization of drilling mud for crude oil drilling. The main goal of the research is to contribute towards ensuring sustainable supply of drilling mud to the oil industry using Nigerian barites as opposed to using barites imported from outside the country. However, due to constraints of time and resources, it is not possible to conduct research for the entire value chain.

Therefore, this research is focused on the supply side, specifically on the mining of barites. It is believed that if the mining sector is working well, the supply of barites to the next component of the value chain, namely the companies involved in marketing, supply and production of drilling mud will be sustainable. Since the mining sector in Nigeria is still dominated by Artisanal and Small Scale mining (ASM) the work is limited to an in-depth study of the following:

- Suitability of Nigerian barites for making drilling mud and other industrial applications
- Current status of ASM mining of barites in Nigeria
- Challenges and suggestions on improving sustainability of ASM of barites
- Socio-economic and environmental impacts of ASM
- Gender dimensions of ASM of barites in Nigeria
- Effectiveness of Institutional and Regulatory Framework for ASM in Nigeria.

The dissertation is arranged in six Chapters as follows:

Chapter 1 – Introduction: background to the study, statement of the problem, aim and objectives, justification and scope.

Chapter 2 – Literature Review: Barite – Properties and Uses; Global Occurrence and Trade in Barites; Occurrence of Barites in Nigeria; Barite Value Chain in Nigeria; Government Policy on Barites; Characterization and Standards for Barites; Barite beneficiation Methods; Artisanal and Small Scale Mining (ASM) – Definition and Concept; Artisanal and Small Scale Mining (ASM) in Africa; Artisanal and Small Scale Mining (ASM) in Nigeria; Institutional and Regulatory Framework for ASM; Gender Issues in ASM; Impacts of ASM in Africa and Unresolved Issues and Directions of Present Research

Chapter 3 - Research Methods: brief description of approach and methods used for the research.

Chapter 4 – Suitability of Nigerian Barites for drilling mud production and other industrial applications:

Chapter 5 – Sustainability of ASM of Barites:

Chapter 6 – Gender Dimensions of ASM of Barites:

Chapter 7 - Conclusions: Conclusions, recommendations and contributions to knowledge.

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CHAPTER TWO

LITERATURE REVIEW

For each of the Projects, Literature Review relevant to that project has been included as part of the Introduction in Chapters 4,5 and 6. However, a general Literature review is provided in this Chapter.

2.1 Barite – Properties and Uses

Barite is a solid mineral that is made up of barium and sulphur (barium sulfate, $BaSO_4$) [1]. It appears in nature in granular or crystalline form, nodules, rosette-like aggregates. Specific gravity, crystallinity and its cleavage distinguish barites from other minerals. Barite ores of different grades vary from one location to the other and within deposits. In Nigeria, most barite occurrences are vein and cavity filling type of occurrence and this type of occurrence may be hosted by different rock types such as sandstone, limestone, migmatite, shale, mudstone and porphyritic granite. Barite is often associated with magnetite, fluorite, calcite, siderite, quartz, galena, dolomite. The mineral can be found in the following states in Nigeria: Ebonyi, Cross River, Benue, Nassarawa, Plateau, Adamawa and Gombe states [2,3,4,5].

The main use of barite is in the production of drilling mud for oil and gas industry. But the mineral can be used for glass, paint, industrial chemicals and medical applications in X-rays [6.7.8]. For the oil industry, barite is used in as a weighting material in drilling mud. Since high reservoir pressure is experienced during drilling operations, this requires a heavy circulating fluid that will compensate for high-pressure zones to control the pressure of the reservoir and prevent blowout. Pulverized barites are added to the clay-water mixture to form the drilling mud. The softness of the barite also prevents it from damaging drilling tools during drilling operations and enables it to serve as a lubricant. The main ore of barium is barite and its compounds are used for x-ray shielding. Barite is used in hospitals, power plants and laboratories to block gamma rays and x-rays emissions. Compounds of barite are also used in a diagnostic medical test for determination of normal and abnormal anatomy. Coarse sand size of barite is added to the mixture in glassmaking, it serves as flux, enhanced brilliance of glass and also makes the mixture workable. In glassmaking industry, barite is used to reduce bubble when melting material and it is also used in product transparency and luminosity. Barite is the source of most barium compounds such as barium sulphide, barium chloride, barium nitrate, barium carbonate etc. that are widely used as reagent and catalyst. Barium chloride is used in the manufacture of cloth and leather, oxides of barium are used in glassmaking and electric furnace metallurgy, the carbonate of barium is a component of ceramic glazes and enamels, while the hydroxide is used in sugar recovery and nitrate, an ingredient of detonators and flares.

2.2 Occurrence of Barite in Nigeria

Barite was first discovered in Ogoja province of Cross River State in Nigeria [9]. The occurrence of barites in some parts of Benue and Plateau was later reported by Geological Survey Agency of Nigeria. Since these discoveries, barites have been discovered in more states in Nigeria. Barite deposits can be found from eastern flank of south-south geopolitical zone to south east, all the way to north central and north east geopolitical zones. Deposits of barite have been reported in the following states of Nigeria [10].

- Cross River state
- Ebonyi state
- Benue State
- Nasarawa state
- Adamawa state

- Plateau state
- Gombe state

However, it should be noted that published information on the occurrences are scarce. These include the reserve estimates and the characteristics of the mineral.

2.3 Barite Value Chain in Nigeria

Barite value chain in Nigeria includes exploration, mining, processing, beneficiation, marketing, transportation, utilization for different industrial purposes including production of drilling mud. Each of the components of the value chain has different actors and for sustainable supply of the commodity to the users (industrialists) to be achieved, each of these components should be working optimally. As noted earlier, the mineral occurs in at least 9 states of the country. However, extensive exploration to determine the actual locations and reserve estimates to guide investors are still lacking. This can be covered under the current initiatives by government to use satellite and GIS technology to carry out a comprehensive mapping of minerals in Nigeria.

The second component of the value chain is mining. Currently, mining in Nigeria is dominated by small and medium scale miners. This sector is faced with many challenges including: lack of modern mining equipment and techniques, poor investment, poor regulation, negative impact on the environment and unorganized system of operation. These lead to inefficient operations, poor productivity and poor supply of barite to those who need it. In order to solve this supply chain problem, there is need to under study the Artisanal and Small-Scale Mining (ASM) sector in order to identify challenges and impacts and proffer solutions to the problem.

The next component in the value chain if processing and beneficiation. Just like the mining sector, this sector is characterized by lack of investment, poor technology and general low productivity leading to scarcity of high quality barite in the market. There is therefore the need to develop technologies and promote investments in such a way that operators will have access to modern technology.

The last component of the value chain is industrial utilization of barite. This sector is dominated by medium scale oil servicing companies who use the locally produced and imported barite in combination with other materials to produce drilling mud. Most of the technologies used by the sector are imported. There is therefore the need to develop technologies and develop different drilling mud using different combinations of the materials in order to study and optimize the production of the mud.

2.4 Government Policy on Barites

Government policy on barites in Nigeria is informed by the overall policy on diversification of the economy and promotion of minerals development. At the last estimate, Nigeria spends at least $300m in foreign exchange to finance importation of the product. Of all industrial minerals imported into the country in 2016, barite represented 3.6 per cent. In order to reverse this trend, the Federal Ministry of Mines and Steel development facilitated the development of an industrial mineral road map aimed at optimizing Nigeria’s industrial minerals to meet the standards of the manufacturing, industrial, and construction industry and to reduce import dependency. The road map delineated seven key minerals for quick development of which barite is one of them.

The long term plan is to place a ban on the importation of Barite once the local market is satisfied and, export Barite to other African countries where oil and gas drilling activities are taking place. The road map is a development strategy towards creating a sustainable industry in Nigeria to support, regulate and monitor stakeholders along the Barite value chain. The ministry notes that the Accelerated Development of the Barite Industry will take into consideration the fact that the industry has been operated largely by artisanal miners, and there has been the challenge of poor data showing details of Barite deposits, quantity and quality; access to market which has a lot of challenges including the not meeting specifications by the industry, packaging not standardized yet, supply shortage, no enough barite to supply the market currently.

The government hopes to establish a barite processing cluster in Cross River State and support artisanal and small scale miners with technology and funds to improve their operations towards supply of high quality barites for the industry. Part of the plan is to eventually ban importation of barites into the country. We note that for this plan to succeed, there is need to support these efforts with research to generate data on the reserve estimates and quality of the barite as well as the operations of ASM in Nigeria [9,10].

2.5 Artisanal and Small Scale Mining (ASM)

The industrial sector is classified into three major categories namely: large-scale industries, small and medium industries and micro, and cottage industries. For the extractive (mining and mineral processing) industry, several criteria are used for classification which include: level of mechanization, degree of formalization, legal framework for operations, degree of labor intensity, level of capital involvement, level of planning of operations, etc. Using these criteria, three categories have emerged namely: large-scale mining (LSM), medium-scale mining

(MSM), and artisanal and small-scale mining (ASM). The LSMs are large-scale mining activities using heavy-duty equipment, employing many professionals, and operating in a very formalized environment. For MSM, the level of investment and machinery use is most minor and negligible for ASM.

Definitions of ASM by different multilateral organizations such as International Institute for Environment and Development (IIED), World Bank, International Council on Mining and Metals (ICMM), United Nations Economic Commission for Africa (UNECA), United Nations Environment Program (UNEP), and Swiss Agency for Development and Cooperation are well documented [11]. ASM is characterized by the use of rudimentary techniques for mineral extraction and often operate under hazardous, labor-intensive, highly disorganized, and illegal conditions; low productivity since ASM often takes place in very small or marginal plots, is limited to surface or alluvial mining and uses inefficient techniques; lack of safety measures, health care, or environmental protections; may be practiced seasonally (e.g., to supplement farm incomes) or temporarily in response to high commodity prices; and lack of long-term mine planning [12]. Because many factors are used in describing and characterizing ASM globally, specific categorization varies from country to country. For Nigeria, the Minerals and Mining Act, 2007 defines ASM as “informal mining activities undertaken by individuals or groups, which rely heavily on manual labor, using simple implements and methods without prior exploration activities” [13]. Many of such unskilled activities are informal operations since they do not operate under regulatory framework, as stipulated under the Minerals and Mining Act, 2007.

It appears that many operators in the artisanal and small-scale mining (ASM) sector became miners because they could not find any other work to do. It is also a very diverse sector with challenges that vary from region to region and often from site to site. There is a wrong perception that artisanal and small-scale mining sector is a homogenous sector. This has misinformed legislation and extension programs and led to the development and application of uniform policy for the mining and mineral sector. However, people working in ASM are far from this. They range from those whose livelihoods rely on subsistence farming to skilled workers who migrated from urban areas in search of work. In 2016, about 500,000 personnel were directly involved in ASM of gold in Africa with an estimated 2,500,000 dependents [14]. Despite its low productivity, ASM is an essential source of minerals in Nigeria. It accounts for about 20% of the global gold supply, 80% of sapphire supply, and 20% of diamond supply. The sector is also a significant producer of tantalum and niobium minerals for manufacturing capacitors in the electronic industry (laptops and cell phones). Reports show that 26% of global tantalum production and 25% of tin come from ASM.

Although ASM has been criticized and often referred to as illegal operation, this sector is very critical to the economy of sub-Saharan Africa. Available information shows that about 60% of mining activities in Africa is by ASM. In Nigeria, this figure is even higher, with current estimates at 90% [15]. This has been recognized by the government of Nigeria, resulting in the creation of a full department of artisanal and small-scale mining by the Federal Ministry of Mines and Steel Development (MMSD) to take care of oversight and regulation of activities in the sector [16].

Artisanal and small-scale mining in Africa has attracted the attention of many researchers [17,18,19,20,21,22]. In Nigeria, only a few studies have provided some insight into the dynamics, challenges, and prospects of artisanal and small-scale mining [23,24,25,26,27]. These studies have shown that the sector is greatly misunderstood and that is why in many cases, the operators are referred to as illegal miners. But in a large country such as Nigeria with large deposits of many minerals, the combination of many factors has driven many resource poor people into mining. However, the operations of ASM are hindered by many factors including weak implementation and enforcement of mining laws, limited awareness of environmental, health, and safety issues, fragile ecosystems of the mining environment, host community conflicts, poor infrastructure, and lack of access to financing.

To mitigate the problems facing ASM in Nigeria, the government has over the years implemented various reforms, usually with support from donor agencies and partners. But the issue of inclusiveness and formalization of the sector remains a major constraint. Also, in implementing the sectorial policy of licensing, many mining titles are held by speculators who are usually rich or influential people that easily obtained the licenses. The government has also introduced the formation of miners' cooperatives to enable groups of miners to have the capacity and capability to obtain licenses and formalize their operations, but this policy has not yielded appreciable results.

There is therefore the need for a deeper understanding of the dynamics of ASM in Nigeria vis a vis the mining laws, policies, and programs being implemented by the government with support from development partners as well as the impact of ASM on the socio-economic well-being of the miners, safety of the miners, and the environment. Such an understanding will be used to make informed decisions toward formulating and implementing policies and programs that can be used to foster the sustainability of ASM for some of the strategic minerals such as barite.

ASM is highly inefficient compared to large-scale industrial mining. It represents a very important element of the economy both at the local and regional level, especially for low-income population groups. The socioeconomic, environmental, safety, and health impacts of ASM on the miners, the society, and environment in Africa have been discussed by several researchers. These studies have shown that the impact depends on the environment and location. Extensive studies have been done in eastern and southern Africa. In west Africa most of the studies have been done in Ghana and a few other countries. There is a need for a more understanding of the dynamics of ASM for Nigeria especially with respect to the strategic minerals that are being promoted by the government. Such studies can generate useful information that can drive policy toward fostering sustainability of artisanal and small-scale mining (ASM) in Nigeria and Africa in general [9, 10]. These will complement the efforts of development partners such as the World Bank in supporting ASM in Nigeria.

2.6 Institutional and Regulatory Framework for ASM in Nigeria

Government policies and regulation for the mining sector are captured various policy documents and laws as follows [28,29,30]:

- Nigerian Mineral and Mining Act 2007
- Nigerian Mineral and Mining Act 1999
- Nigerian Mineral and Mining Regulation, 2011

In addition, there are regulations from related government agencies such as those related with environmental protection. These laws, guidelines, and policies are implemented by a number of organizations including:

- Federal Ministry of Mines and Steel Development (FMMSD)
- Nigerian Geological Survey Agency

- Mining Cadastre Office
- Raw Materials Research and Development Council
- Artisanal and Small Scale Mining Department of FMMSD
- Mines Inspectorate Department of FMMSD
- Mines Environmental Compliance Department of FMMSD
- Federal Ministry of Environment
- Nigerian Environmental Standards Regulations Agency (NESREA)
- Sustainable Minerals Development Project
- Solid Minerals Development Fund
- Bank of Industry

There is need to assess the impact of these programmes and interventions on the ASM sector.

2.7 Gender Issues in ASM

A very important criterion for sustainable development is that men and women have a right to live decent lives with equal opportunities free from hunger, discrimination, violence, oppression, injustice. Gender refers to the behaviours, attitudes, values, beliefs that a particular socio-cultural group considers appropriate for males and females. Gender equity has not always been guaranteed in the work place all over the world. In some sectors of the global economy, there is gender disparity in roles of male and female workforce. In most cases, societies are organized in such a way that men have more opportunities to move up the ladder of economic progress than women. This disparity is probably more in the mining industry in general and ASM in particular.

Globally, up to 30% of the world's artisanal miners are women [31]. This percentage varies from one part of the world to the other. In Asia, less than 10% of miners are women [32,33,34]. In Latin America, the percentage is higher (10-20%). The percentage is highest in Africa, where it is estimated at any where between 40% and 50%. Empirical evidence has shown that even with this high number of women in the sector, the society and environment has made it impossible for women to achieve their potentials and hence contribute meaningfully towards improved productivity in the sector. In most cases, the women are involved in those aspects of work that do not attract comparable remuneration with their male counterparts and yet they are exposed to more environmental and health hazards.

The perceived differences in gender roles have been attributed to differences in physical abilities of male compared to female, cultural biases, stigmatization and socio-economic differences. These differences have been studied in different countries of Africa including Ghana, Sierra Leone, Kenya, Democratic Republic of the Congo, DRC and Uganda. In Nigeria, only a few studies have been carried out to highlight the issue of gender in ASM. The government and the donor agencies especially the World Bank have also realized that this issue needs more studies and understanding.

These and other studies have shown that any initiative that is aimed at improving ASM must take into consideration the role of men and women. The first step towards achieving this is to understand the roles and then make informed recommendations on how to ensure gender parity in the sector. In planning to optimize the contributions and participation of men and women in ASM, the concerns of men and women must be taken into consideration in designing intervention projects These concerns include: awareness on the different roles of men and women, equitable participation of women, empirical studies on gender based differences in labour, regulatory bodies and agencies of government should be manned by both male and female, networks of women in ASM should be formed or strengthened where they exist, training and special micro-financing targeted at women [35].

2.8 Challenges of ASM in Nigeria

Different researchers have identified and discussed challenges and constraints to Artisanal and Small Scale Mining (ASM) in Nigeria. These challenges vary from one location to the other. The challenges include: insecurity; poor geophysical and geoscience data and information; poor infrastructure; poor mine safety and risks; poor regulation, absence of governance; poor investment and poor support by government [36,37].

Security: Most of the mines are located in rural remote communities with little or no government security agencies. With the current wave of insurgency and kidnapping, it means that most miners are exposed to kidnapping and similar crimes.

COVID Challenges: In addition to absence of health facilities, the emergence of COVID and other infectious diseases has adversely affected the small-scale miners.

Poor Geophysical and Geoscience Data and information: The Geological and Geoscience data for barite are out of date in Nigeria. This affects the integrity of the resource information and has impacted the bankability of barite mining projects. For instance, significant deposits of barite veins have been identified (but not quantified) in some states in Nigeria and no mining activity is going on. A good geological data can aid in the approval of a business plan or the release of funds by the government for the exploration and development of minerals.

Poor Infrastructural Development: Poor infrastructural facilities include poor road network, inadequate electricity supply, poor communication facilities. For the barite mining industries to thrive, there should be a good transportation network linking the mining sites. This will help in the movement of machinery and equipment to the barite mining sites. Having good roads to the sites will also create a local market for small and medium enterprise. Water is needed in the mining sites to ensure that the minerals are mined efficiently. Processes that are automated need electricity to function.

Poor Mine Safety and Risks: Risks are involved in the mining of barite and other valuable minerals. Explosion in the mining sites have been recorded in Nigeria. Barite is mined in the country majorly by artisanal and small-scale miners. These artisanal miners have exposed themselves to high risk from dangerous metals. There have been report of cases where miners were exposed to these metals beyond the limit of exposure to humans. For example, very high values of manganese and chromium have been recorded which exceeds the maximum admissible concentration in some mine ponds that were abandoned in Jos, Plateau State.

Poor Regulation and Absence of Governance: Government agencies that are supposed to assist miners and also regulate the sector are mostly in cities which are hundreds of kilometres away from the mines.

Poor Investment: Banks and other financial institutions also find it difficult to finance projects within the ASM sector.

2.9 Unresolved Issues and Directions of Present Research

Based on the above review, the following are identified as unresolved research issues, some of which are addressed in this research:

i. Although, information exists on the location of barite deposits in Nigeria, there is paucity of published data and information on reserve estimates of barite in these locations.

ii. There is no comprehensive published scientific data showing the suitability of Nigerian barites for making drilling mud and other industrial applications, especially those from Nasarawa state, Nigeria, based on determination of the relevant properties of the mineral, in comparison to established standards for these industrial applications.

iii. Although some work has been reported on Artisanal and Small-Scale Mining (ASM) of some minerals such as gold, there is dearth of published information on the dynamics of ASM of barites including socio-economic impacts, environmental impacts and gender dimensions of ASM for the area under study;

iv. There is lack of published work on assessment of existing policies and programmes of government on promoting ASM of different minerals in Nigeria (for the study location). Such data and information are necessary for policy interventions for ensuring sustainable supply of barite in particular and other minerals in general in Nigeria.

v. There is need to evaluate existing barite beneficiation methods in order to come up with optimized technologies and methods for improving the quality of barites in Nigeria.

vi. There is need to evaluate methods, technologies and materials for making drilling mud for the oil industry and other industrial applications. This will enable new and novel methods to be developed for more utilization of Nigerian barites for industrial applications.

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CHAPTER 3

RESEARCH METHODS

The research was divided into three distinct but related projects as follows:

Project 1 - Characterization and Suitability of Nigerian Barite for Different Industrial Applications

Project 2 - Fostering The Sustainability of Artisanal And Small-Scale Mining (Asm) of Barite in Nasarawa State, Nigeria

Project 3 - Gender Dimensions of Artisanal And Small-Scale Mining (Asm) of Barite Ores on Nasarawa State, Nigeria

The methodology for each project and the results are presented in Chapters 4,5 and 6.

CHAPTER FOUR

CHARACTERIZATION AND SUITABILITY OF NIGERIAN BARITE FOR DIFFERENT INDUSTRIAL APPLICATIONS

4.1 Introduction

The Federal Government of Nigeria is currently implementing the National Economic Recovery and Growth Plan (ERGP) aimed at re-directing the economy back to the path of recovery [1]. A major aspect of the plan is diversification of the economy away from oil and increasing the local content in operations of the oil industry. One way of diversifying the economy is by developing the mining sector, including adding value to extracted minerals. Approximately 85% of barite goes into the oil industry, about 10% into the chemical industry, 5% into the filler market. Barite is used as a weight density agent in drilling mud for gas and oil exploration to avoid the high-pressure formation and prevent blowouts. This is compressing the high pressure created by the drill bit as it passes through various formations with different characteristics. The deeper the drilling hole, the more barite is required for the total mud mix. For oil drilling, a specific gravity of barite is the only property checked. Other chemical and physical properties are needed for other barite applications. The physical appearance of barite used in drilling petroleum wells can be black, blue, brown, or grey dependent on the ore body. The used barite must be dense enough so that its specific gravity is greater than 4.1 and smooth not to damage the drill bit [2,3]. One of the minerals being promoted by the Federal Ministry of Mines and Steel Development is barite [4]. This mineral is not only useful in the oil industry but can also be used for other industrial applications. Most of the current use of barite in the oil industry is imported [4]. Therefore, there is a need to promote the exploitation and use of barite for the oil industry and other industrial applications.

One way of diversifying the economy is by developing the mining sector, including adding value to extracted minerals. This is mainly in the oil industry which depends on the appreciable supply of barite ore as a key constituent of drilling mud used to stabilize the oil well; prevent blow-outs; remove drill cuts by the fluid. It is a key constituent of drilling mud, which is the fluid pumped into the oil or gas well to lubricate the bit and drill stem, removes rock chips, prevents a collapse of well walls, and prevents blowouts if over pressured strata are encountered [5–8]. Barite is chemically stable, making it useful as an additive in the manufacturing of different products like rubber, paints, enamels, plastics, paper goods, wallpapers, asbestos goods, glass, and ceramics. Moreover, it is used in radiology for X-rays of the intestines and to make high-density concrete resistant to nuclear radiation [7]. Barite ($BaSO_4$) is crucial to the oil and gas industrial application. This is due to a key constituent of the drilling mud used in oil and gas wells. Additionally, elemental barium is an additive in ceramic glazes, optical glass, paint, and other products. Barite deposits are categorized into different main types which include; bedded-volcanic, bedded-sedimentary, vein, cavity-fill, and metasomatic and residual. Bedded-sedimentary deposits are found in sedimentary rocks with properties of high biological productivity during sediment accumulation and they are the major sources of barite production that account for the majority of barite reserves worldwide [8]. In recent years, barite has found usage in brake shoe linings, noise reduction in engine compartments, and spark-plug alloys [9].

Barite is a heavy mineral that normally occurs with Pb-Zn ore, barite vein, barite-fluorite vein deposit, strata bound SEDEX-type deposit among other deposits as a gangue mineral, in sedimentary deposits, and rarely in salts [8]. It is usually mined as barium content. It occurs either in crystalline form, as tabular, prismatic, or bladed crystals. The pure crystals are often colorless, cream-colored, or white, but may also acquire various colors based on the impurities it contains. Granitic rocks characteristically have a somewhat higher content of barium than average continental crust, and basaltic rocks characteristically have lower barium content. The range of barium content of shales spans approximately the same range as the barium content of granitic rocks [8]. Some smaller mines exploit barite in veins, which formed when barium sulfate was precipitated from hot subterranean waters. In some cases, barite is a by-product of mining lead, zinc, silver, or other metal ores [10], in the paper and rubber industries, as a filler or extender in cloth, ink, and plastics products; in radiography ("barium milkshake"); as getter (scavenger) alloys in vacuum tubes; deoxidizer for copper; lubricant for anode rotors in X-ray tubes, spark-plug alloys, and white pigment. Other uses of barite include as an additive for friction materials, rubbers, plastics, paints, feedstock for chemical manufacturing, and shielding in X-ray and gamma-ray applications [8,11].

The status of barite mining activities in Nigeria currently shows that the barite quality from these different localities proves that Nigeria does not necessarily need to import high grade or any other specification of barite from foreign countries for its usage in the desired industries [12]. However, a large percentage of the barite used in the oil industry is imported. In 2020 alone, this is valued at about $96 million, and the estimated consumption is 440,000 metric tons for this year [12]. To boost the mineral sector, the Federal Government of Nigeria has taken initiatives to encourage local mining, beneficiation, and mining of barite for the industries [4]. The valuation activities are usually done by the Federal Ministry of Mines and Steel Development (MMSD), Nigerian Geological Survey Agency (NGSA), and Nigerian Content Development and Monitoring Board (NCDMB).

Drilling activity accounts for nearly 95 percent of domestic consumption and about 90 percent of global consumption. Economic deposits of barite are relatively common and are found in many countries [8]. Literature shows that a few of some Nigerian barites are suitable for drilling fluid formulations [13]. In another study, it was shown that barite and oil drilling fluid additives affect reservoir rock characteristics [13]. Another study reported on the effect of barite and ilmenite mixture on enhancing the drilling mud weight [14]. Mohamed et al. showed that barite sag can be prevented in oil-based drilling fluids using a mixture of barite and ilmenite as weighting material [7]. The future of drilling-grade barite weight material was presented by [15]. There are frequently auxiliary criteria used to compare deposits of barite. Some raw materials have sensitive costs which include transportation of raw materials and market, involving land and sea costs. This can inform how much surplus remains for mining and milling for the deposits to be considered economically viable. The grade of the deposits also renders economic viability including the revenue for the cost of mining and milling [16]. The mining process may have little or no effect on the policy change of the companies or management. For example, the change of management from a GmbH and Co. KG to a GmbH did not affect the economic identity of the legal entity and never lead to a transfer of assets. The alteration was limited to changing the legal control while preserving the legal identity. This is because there is no act of company asset transfer and results in no exchange of services, hence no legal taxes charged [17]. Characterization results from previous work were mostly centered on discovering the chemical composition (XRF), mineralogy (SEM), organic, polymeric (FTIR), specific gravity (SG), needed for the same oil industry. Even at that, these are only a few studies from a few states where barite occurs. The use in other industries is not well documented even though it plays an important role in these industries.

This work aims at the characterization of barite samples from different locations in Nigeria and the determination of their suitability for different industrial applications. The properties determined include chemical composition, functional groups, specific gravity and the physical appearance of the powdered samples.

4.2 Materials and Methods

4.2.1 Study Location

Barite occurs in various locations within the Benue Trough. These include Adamawa, Benue, Cross River, Ebonyi, Gombe, Nasarawa, Plateau, and Taraba. But studies have shown that the major producing states are Benue, Cross River, Nasarawa, and Taraba. Samples used in the study were taken from Nasarawa (NS) and Taraba states (TS). The samples from Nassarawa state were obtained from nine different locations: Azara vein 1, Azara vein 17, Azara vein 18, Aloshi, Keana, Kumar, Ribi, Sauni, and Wuse. One sample was from Ibi in Taraba state. A sample was picked from one active well as a working sample was obtained from Port Harcourt (Rivers state) from a drilling site. These state locations are shown on the map of Nigeria in Figure1.

4.2.2 Sample Collection

Different barite deposit sites were visited, including Nasarawa and Taraba states of Nigeria with representative samples collected from mining pits being worked by artisanal miners. Samples were collected across the veins and stored in sample bags with name tags as highlighted in the supplementary information.

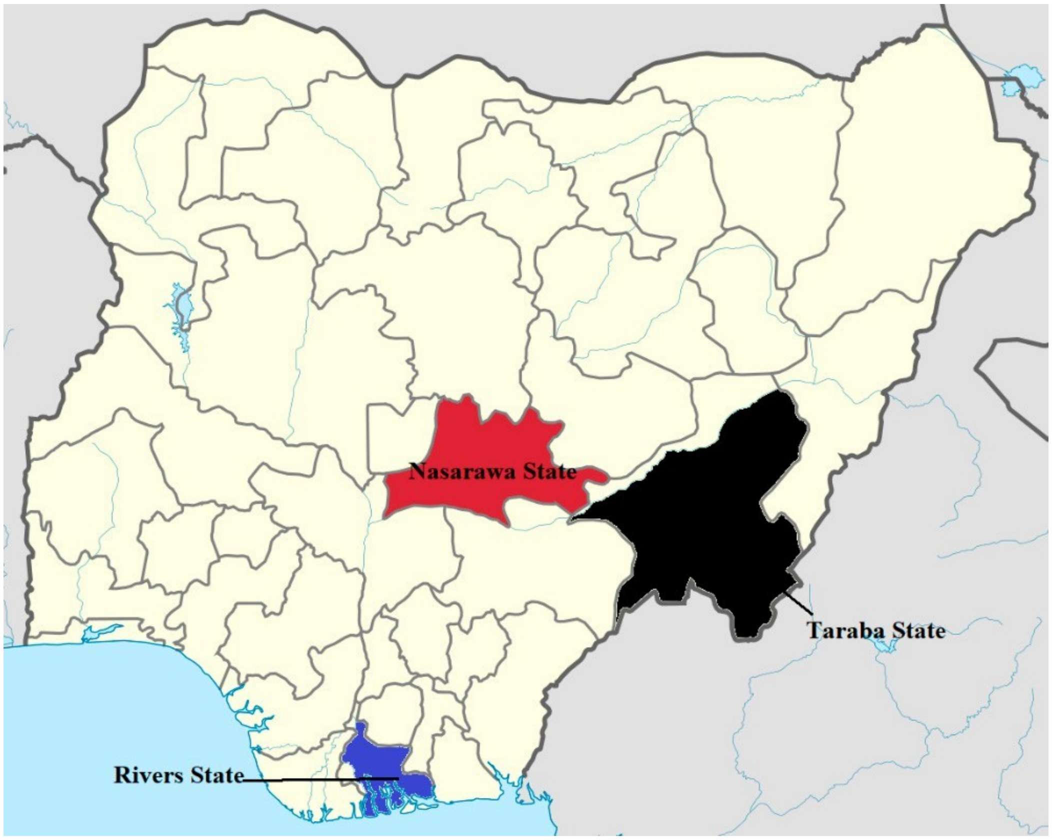


Figure 1. Map of Nigeria showing active mining sites for various minerals [18]. The location and local Government area of the mine sites is shown in Table S1 (Supplementary Materials).

4.2.3 Sample Characterization

The samples were studied in the field as hand specimens and further characterized for physical and chemical properties which include: scanning electron microscope and energy dispersive X-ray (SEM-EDX, Carl ZEISS, Bangalore, India) for the in-depth surface analysis, the FTIR (Fourier transform infrared, Bruker Optik GmbH Vertex 70, Ettlingen, Germany), the XRD (X-ray diffraction, Riguku Smartlab Autosampler (RIGAKU Corp., Tokyo, Japan), the EDXRF (Malvern Panalytical B.V., Almole, Netherland) for oxides analysis [18–20]. SG was used to evaluate the physical, mineralogical, and chemical properties of the barite ores from the various locations [21–23] as described in the supplementary information.

Sample from Aloshi Nasarawa state was labeled as (NT) and Sample from Ibi, Taraba state was labeled as (TS); all other samples were labeled by the name of the location it was obtained from. The sample which was picked from the Port Harcourt drilling site labeled as (WS) was taken as the working standard.

4.3 Results and Discussion

The scanning electron microscope (SEM) and energy dispersive X-ray (EDX) analysis of morphology and element percentage composition data are shown in Figure2and supplementary information Figure S1 (Supplementary Materials). The morphology of samples NS, TS, Azara vein 1, Azara vein 17, Azara vein 18, Keana, Kumar, Ribi, Sauni, Wuse, and WS, showed surfaces of barite embedded form of material structure with clear unit boundaries. The working standard sample (WS) showed a fine surface in the morphology monograph. The surface chemical analysis was carried out with EDX, revealing the different elemental compositions of the material in-depth surfaces (Table1). Sample NS revealed a composition of Ba as 46.73%, S as 33.55%, and oxygen as 1.93%. This gave 82.21% of the Ba-S-O empirical composition. Sample TS showed a composition of Ba as 50.37%, S as 35.63%, and oxygen as 1.87%. This gave 87.87% of the Ba-S-O empirical composition. Sample Azara vein 1 showed a composition of Ba as 51.73%, S as 43.36%, and oxygen as 2.11%. This gave 97.2% of the Ba-S-O empirical composition. Sample Azara vein 17 showed a composition of Ba as 38.59%, S as 36.84%, and oxygen as 2.88%. This gave 78.31% of the Ba-S-O empirical composition. Sample Azara vein 18 showed a composition of Ba as 34.79%, S as 31.48%, and oxygen as 3.74%. This gave 70.01% of the Ba-S-O empirical composition. Sample Keana showed a composition of Ba as 50.12%, S as 42.75%, and oxygen as 3.14%. This gave 96.01% of the Ba-S-O empirical composition. Sample Kumar showed a composition of Ba as 31.36%, S as

23.82%, and oxygen as 4.18%. This gave 59.36% of the Ba-S-O empirical composition. Sample Ribi showed a composition of Ba as 51.38%, S as 44.17%, and oxygen as 2.59%. This gave 98.14% of the Ba-S-O empirical composition. Sample Suani showed a composition of Ba as 51.17%, S as 44.75%, and oxygen as 3.94%. This gave 99.86% of the Ba-S-O empirical composition. Sample Wuse showed a composition of Ba as 51.42%, S as 42.58%, and oxygen as 2.98%. This gave 96.98% of the Ba-S-O empirical composition. Sample WS showed a composition of Ba as 38.26%, S as 25.89%, and oxygen as 2.35%. This gave 66.5% of the Ba-S-O empirical composition. The working standard sample showed a much lower element composition empirical percentage indicating that most of the samples will be suitable for drilling purposes [23–26].

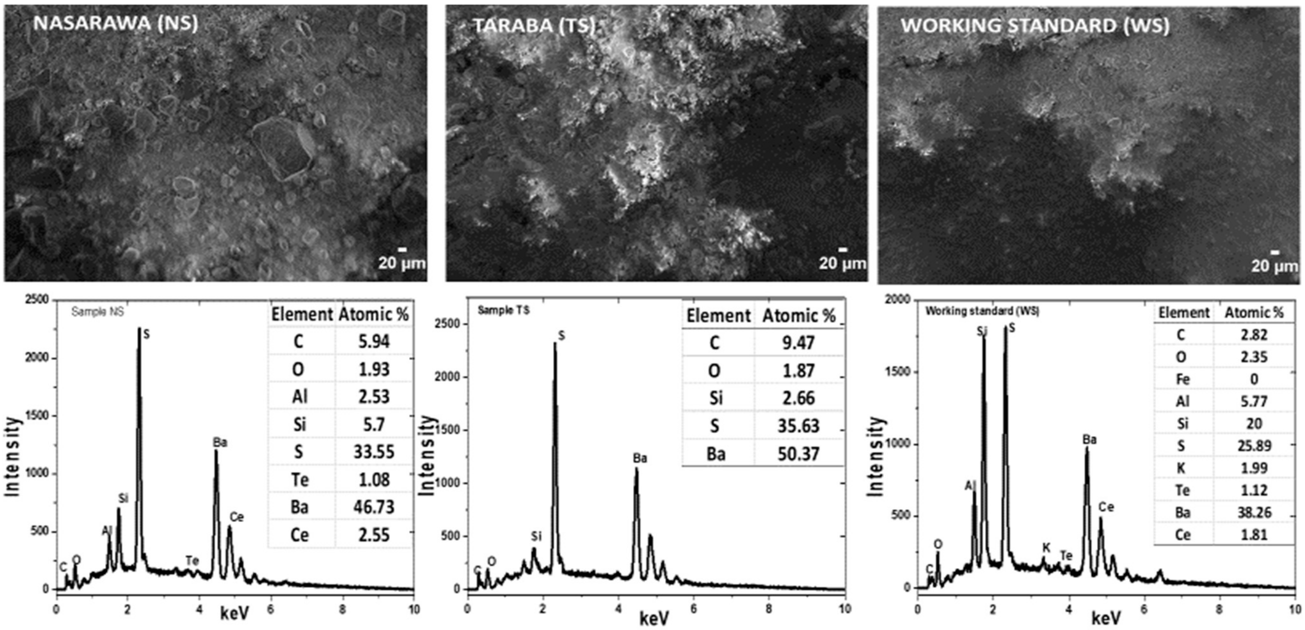


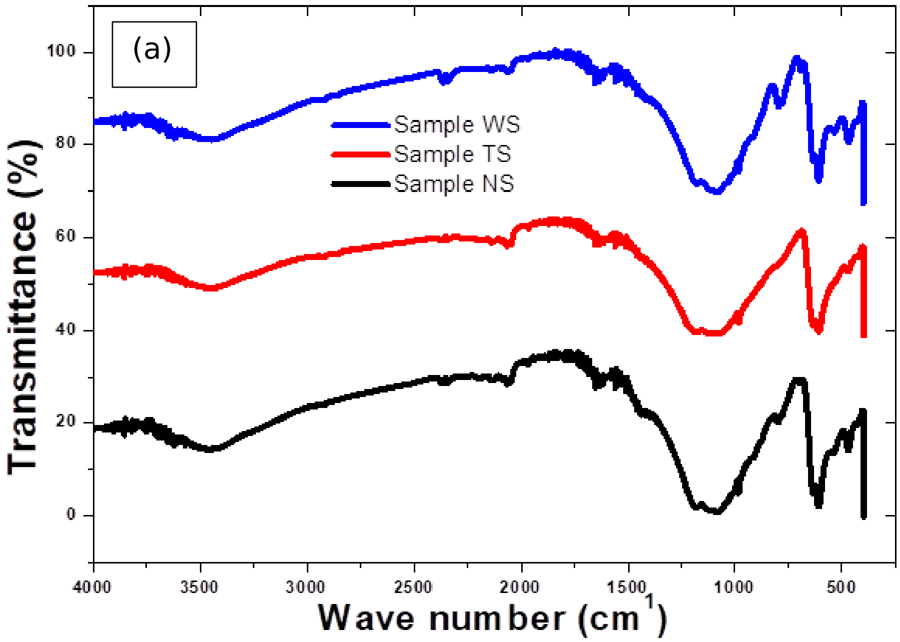
Figure 2. SEM-EDX morphology and sample element atomic percentages.

Table 1. Energy-dispersive X-ray spectroscopy (EDS) atomic percentage of elements from barite samples from different mining sites.

Samples	EDS elemental percentage composition									
	Ba	S	O	Fe	Al	Si	Te	Ce	K	La	Nb
NS	46.73	33.55	1.93		2.53	5.7	1.08	2.55			
TS	50.37	35.63	1.87	-	-	2.66	-	-	-	-	-
Azara Vein 1	51.73	43.36	2.11	-	-	2.64	0.17	-	-	-	-
Azara Vein 17	38.59	36.84	2.88	-	-	21.66	-	0.03	-	-	-
Azara Vein 18	34.79	31.48	3.74	23.89	2.2	3.25	0.29	-	-	0.36	-
Keana	50.12	42.75	3.14	-	-	2.21	-	0.02	-	-	-
Kumar	31.36	23.82	4.18	28.64	-	11.68	0.32	-	-	-	-
Ribi	51.38	44.17	2.59	-	-	-	0.07	-	-	-	1.79
Sauni	51.17	44.75	3.94	-	-	-	0.14	-	-	-	-

Wuse	51.42	42.58	2.98	-	-	2.05	-	-	-	-	-
WS	38.26	25.89	2.35	-	5.77	20	1.12	1.81	1.99	-	-

The FTIR technique was used for bond identification for chemical structures in the materials. This is used as a fingerprint for the mineral group identification and information about the structure of the mineral. The FTIR spectra for the samples are shown in Figure3a,b and supplementary information Figure S2. All samples show several peaks in both fingerprint and functional regions which are comparable to the working standard material (WS). There are strong peaks at 600, 1059, 1197 cm^{-1} wavenumber in the finger- print region and 1640, 2047, and 3468 cm^{-1} wave number in the functional region. The peaks at 600 cm^{-1} with strong transmittance indicate the Ba-S-O polyhedral stretching which is the sheet structure of barite minerals. The peak at 1059 cm^{-1} demonstrates the triple asymmetric S-O stretching in barite which also indicates the stretching of SO_4^{2-} tetrahedral. The peak at 1197 cm^{-1} shows the asymmetric and bond vibration [27]. In the functional region, the samples depicted peaks at different wavenumbers. The peak at 1640 cm^{-1}, which is medium, indicates the stretching vibration of the oxygen group. This is an indication of the S-O bond for the structure. The peak at 2047 cm^{-1} shows the formation of the Ba-S-O bond stretching vibration in the functional region. This contributes to the empirical structure of barite [28]. The peak formation at 3468 cm^{-1} indicates the OH stretch which is due to the formation of crystalline structure in the material [27,29]. The peaks in the samples NS and TS are matching with those of the working standard sample. This means that the samples have the same functional groups which match the working standard sample. The sample results are identical to others in the literature [30].



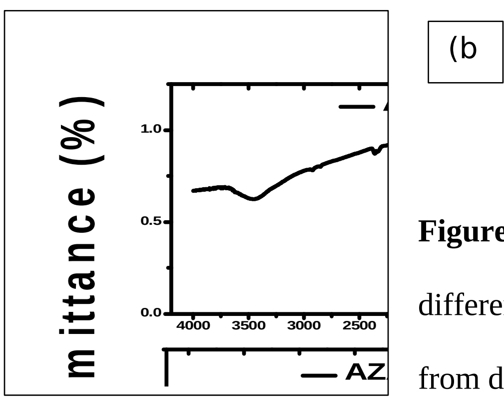


Figure 3. (**a**) FTIR spectra for the barite samples from different mining sites; (**b**) FTIR spectra for the barite samples from different mining sites.

The XRD spectra for all the samples are shown in Figure4. Samples exhibit the main peak at 2θ = 28.75° with d-spacing of 3.102 Å with a plane of (211). Other peaks appeared at 2θ = 26.85° with d-spacing of 3.32 Å and plane of (102), at 2θ = 25.8° and d-spacing of 3.44 Å and plane of (210), and 2θ = 42.89° with d-spacing of 2.10

Å and plane of (112). The XRD data revealed a structure formation with a phase of $BaSO_4$ in the chemical form of $Ba_4S_4O_{16}$ and the calculated density of 4.47 g/cm^3. Sample NS exhibited different peaks at slightly no difference in position from other samples with a peak from 2θ = 25.86° with d-space of 3.44 Å and plane of (210), the main peak at 2θ = 28.75° with d-spacing of 3.10 Å and plane of (211) same as other samples. Other peaks appeared at 2θ = 26.85° with d-spacing of 3.32 Å and plane of (102) also at 2θ = 31.54° with d-spacing of 2.83 Å with a plane of

(112) for all the samples. The samples also revealed a structure formation with a phase of $BaSO_4$ and the same chemical form of $Ba_4S_4O_{16}$ and the calculated density of 4.47 g/cm^3. XRD peaks of the crude Barite powder, which indicates peaks corresponding to Barite with chemical formula $BaSO_4$ on ICPDS card number 00-024-0020 [16,29,30].

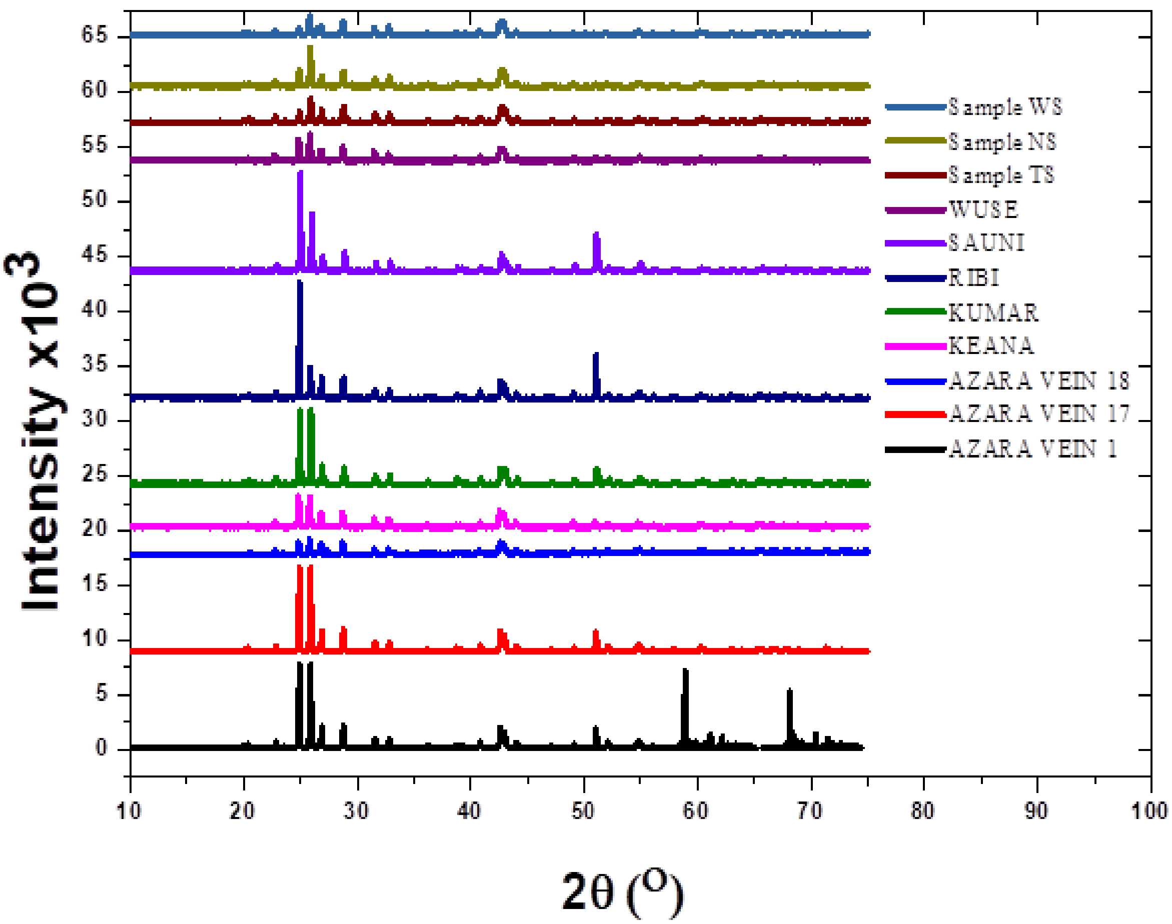


Figure 4. XRD spectra for samples from different mining sites.

The working sample (WS) depicted the main peaks at 2θ = 28.737° with d-spacing of 3.104 Å and a plane of (211) as the main peak. Other peaks appeared at 2θ = 25.841° with d-spacing of 3.445 Å and plane of (211), 2θ = 26.837 with d-spacing of 3.319 Å and plane of (102), 2θ = 31.522° with d-spacing of 2.836 Å and plane of (112), 2θ = 32.797° d-spacing of 2.729 Å and plane of (020), 2θ = 42.871° with d-spacing of 2.11 Å. The main peaks in the working sample at 2θ of 28.737, 25.841, 26.837, 32.797, and 42.871° match with the main peaks in the samples. This means that the samples have the same composition which was also shown by FTIR results (Figure3a,b). The amount of barium sulphate shown by the chemical analysis revealed that the tested local barite samples are following the API requirements for barite [12,30].

The samples were further analyzed by EDXRF as shown in the supplementary information (Figure S3–S10 in Supplementary Materials), show the spectra of a K feldspar and their quantification results as listed in Table2. All the samples match well the chemical data of the working sample (WS) as shown in other figures in the supplementary information (Figure S3–S10). In general, the mineral distribution maps of both classifications of the samples correspond well with that of the working sample in the spectra intensity, position, and composition. Texture and grain structures of samples' complex intergrowth are notice- ably well in the monographs. A few variances can be found in details of the other trace elements which were able to be detected in the microstructures such as micro-perthitic intergrowth in sample WS and other samples. This was due to the smaller beam diameter and the crushing limitations to a few micrometers.

Table 2. EDXRF elemental oxide percentage composition of the samples from different mining sites.

OXIDES/ Elements	Percentage of elemental oxide composition for samples										
	WS	**NS**	**TS**	**AZARA VEIN 1**	**AZARA VEIN 17**	**AZARA VEIN 18**	**KEANA**	**KUMA R**	**SAUNI**	**RIBI**	**WUSE**
Fe_2O_3	0.175	0.307	0.028	0.101	0.292	9.76	0.028	0.553	0.165	0.102	0.015
SiO_2	1.831	1.878	1.164	6.752	5.036	10.11	1.709	2.989	0.592	4.355	1.362

Al_2O_3	0.722	0.681	0.667	1.193	0.914	2.415	0.783	1.281	0.397	1.229	0.463
MgO	1.731	0.34	1.14	0.18	0.19	0.05	1.69	0.53	0.28	-	1.18
P_2O_5	0.023	0.05	-	0.023	0.021	0.056	0.033	-	-	0.05	-
SO_3	**17.3**	**7.609**	**7.687**	**13.73**	**16.3**	**10.81**	**16.65**	**16.53**	**12.3**	**16.29**	**13.44**
TiO_2	-	6.353	6.572	-	-	-	-	-	-	-	-
MnO	-	-	-	-	0.013	0.421	-	0.014	0.069	-	-
CaO	-	0.389	0.166	0.01	0.004	0.113	-	-	-	0.002	-
K_2O	0.030	0105	0.092	0.092	0.048	0.496	0.029	0.055	0.015	0.116	0.008
CuO	0.002	0.001	0.001	0.002	0.002	0.015	0.002	0.003	0.005	0.001	0.003
ZnO	-	0.001	-	-	-	0.045	-	-	-	-	-
Cr_2O_3	0.023	-	-	0.03	0.028	0.002	0.032	0.018	0.011	0.034	0.02
PbO	0.281	0.006	0.001	-	0.001	-	0.274	0.001	0.001	-	-
Rb_2O	0.002	-	-	0.001	-	0.001	0.002	-	-	-	-
Cl	0.451	0.494	0.644	0.432	0.526	0.469	0.447	0.556	0.314	0.515	0.322
BaO	**30.45**	**18.04**	**18.62**	**26.32**	**31.42**	**24.18**	**32.57**	**31.32**	**22.94**	**31.64**	**24.33**
Ta_2O_5	-	0.017	0.003	-	0.003	0.001	-	-	-	0.002	-
WO_3	0.312	-	-	-	0.016	0.106	0.304	-	-	-	-
SrO	2.855	0.546	4.687	4.258	3.309	2.72	2.834	5.68	2.666	1.421	6.148
CeO_2	1.712	-	-	1.42	1.744	1.513	1.661	1.772	1.3	1.658	1.234
ThO_3	-	-	-	0.001	0.001	0	-	0.001	0.001	-	-
Y_2O_3	-	-	-	0.002	0.017	0.002	-	-	-	-	-
Nb_2O_5	0.001	0.001	0.001	0.002	0.002	0.002	0.002	0.002	-	0.002	0.02
SnO_2	-	-	-	-	-	-	-	0.017	-	-	-
Sb_2O_3	0.001	-	0.11	-	0.001	0.001	0.001	-	-	0.001	-
Cs	-	0.156	0.055								

The specific gravity of the samples was determined, and the results are shown in Table3 for all the samples from different mining sites. In reference to the American Petroleum Institute (API) standard specification of not less than 4.15, barite is used to increase the apparent density of a liquid drilling fluid system. Most of the samples showed higher SG apart sample TS, NS, and Azara vein 18 with lower SG than the API standard. This makes barite [$BaSO_4$] the most common weighting agent used today. It is a mined material ground to an API specification such that particle sizes are predominantly in the 3 to 74 µm. The results in Table3displayed that the specific gravity (SG) of the samples is higher than that of the working sample. This implies that these samples from the field can be used as a replacement for the working sample.

Table 3. The specific gravity of samples from different mining sites.

Sample	Specific Gravity (g/cm^3)
SAMPLE TS	4.0087
SAMPLE NS	3.8122
AZARA VEIN 1	4.2138
AZARA VEIN 17	4.3761
AZARA VEIN 18	4.0106
KEANA	4.4052
KUMAR	4.4000
RIBI	4.4200
SAUNI	4.3800
WUSE	4.4000
WORKING SAMPLE (WS)	3.6001

4.4 Suitability of Barites for Industrial Applications

As noted earlier, barites can be used in several industries including oil and gas (drilling fluid formulation); healthcare (X-ray, Plaster of Paris, making barium stomach and intestine reflections); construction (paints, blocking emission of gamma-rays through walls in hospitals, power plants, and laboratories)); plastic (filler), cosmetics, paper (filler), and rubber industries. The suitability of the barite samples for different industrial applications was evaluated. The samples which were analyzed from selected mining sites have a barite percentage ranging between 30 to 50% of barium content before beneficiation and removal of other impurities. This means that the barite from those different mining sites can be used for preliminary mining activities and other application which require a barite composition in the range of 18 to 34% like kilns, mud drilling, construction, among others [29–31]. If the materials are to be used for the main applications, some of the impurities need to be removed which will help to increase the composition percentage of barite. The removal of silica from the samples can increase the purity of the material for applications where silica is not needed [6]. Some impurities are used with barite to improve the properties of the materials as shown in Table4. All samples can be beneficiated and hence improved for different applications as shown in Table4because they have the required chemical constituents. When the unwanted impurities are removed, the percentage composition of barite can be increased to suit the required application. In chemical manufacturing, some samples were eliminated because they lack $CaCO_3$ in their initial composition.

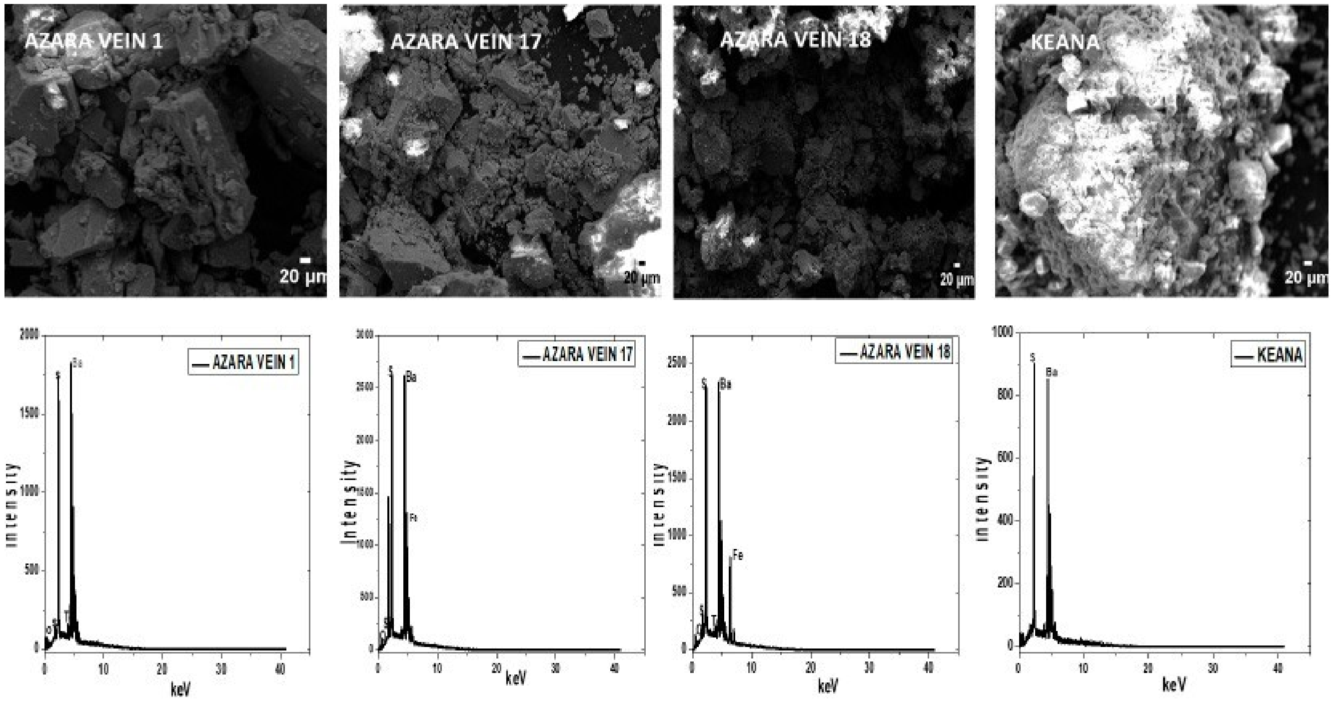
Table 4. American Petroleum Institute (API) and American Society for Testing and Materials (ASTM) general specification standards for various uses of barite ores for different industrial applications.

Barite application	**(%) $BaSO_4$ minimum std**	**Constituents**	**Specific gravity minimum std (g/cm^{3})**	**Study samples suitable for application after purification**
Oil well drilling	90	-	4.15	All samples apart from TS
Chemical manufacturing	97	SiO_2, $CaCO_3$, Al, Fe	4.0	NS, TS, Azara 1, Azara 17, Azara 18, Ribi
Paint manufacturing	95	--	4.45	All samples
Glass	90 – 96	SiO_2, Al, Fe	--	All samples
Pharmaceuticals	97	Fe_2O_3, SiO_2, Al_2O_3	--	All samples
Rubber	99.5	SiO_2	--	All samples
Asbestos products	90	Fe_2O_3, SiO_2, Al_2O_3	--	All samples
Plastering	95	SiO_2, Al_2O_3	--	All samples
Cement	95	SiO_2	--	All samples

4.5 Conclusions

The ten barite samples were obtained from different mining locations in the Nasarawa and Taraba states of Nigeria. Their properties were determined and compared with a standard working sample used by an oil industry operator in Nigeria. Using different characterization parameters (SEM-EDX, FTIR, XRD, SG, and physical appearance) exhibiting the molecular structure of $BaSO_4$. The characterization has shown that some (6) of the samples can be used for drilling fluid formulation for the oil and gas industry due to their good specific gravity greater than 4.15 for API. Samples like TS, NS, and Azara vein require beneficiation to reach the standard for oil application due to their low specific gravity. All ten samples can be used for other industrial applications including healthcare, construction, plastic, cosmetics, paper, and rubber industries due to their level of barium content in the range of 30 to 50%. The results of the study are being used to develop beneficiation procedures, actions, and technology along with new materials for industrial applications. Different samples exhibited different colour appearances from white to off-white which be used as filler materials in paint and ceramics as shown in Table S2. These samples will further be purified by the removal of some other mineral content to increase the yield of barium concentration.

Supplementary Data


AZARA VEIN 1
AZARA VEIN 17
AZARA VEIN 18
KEANA
20 µm
Intensity
keV
S
Ba
Fe

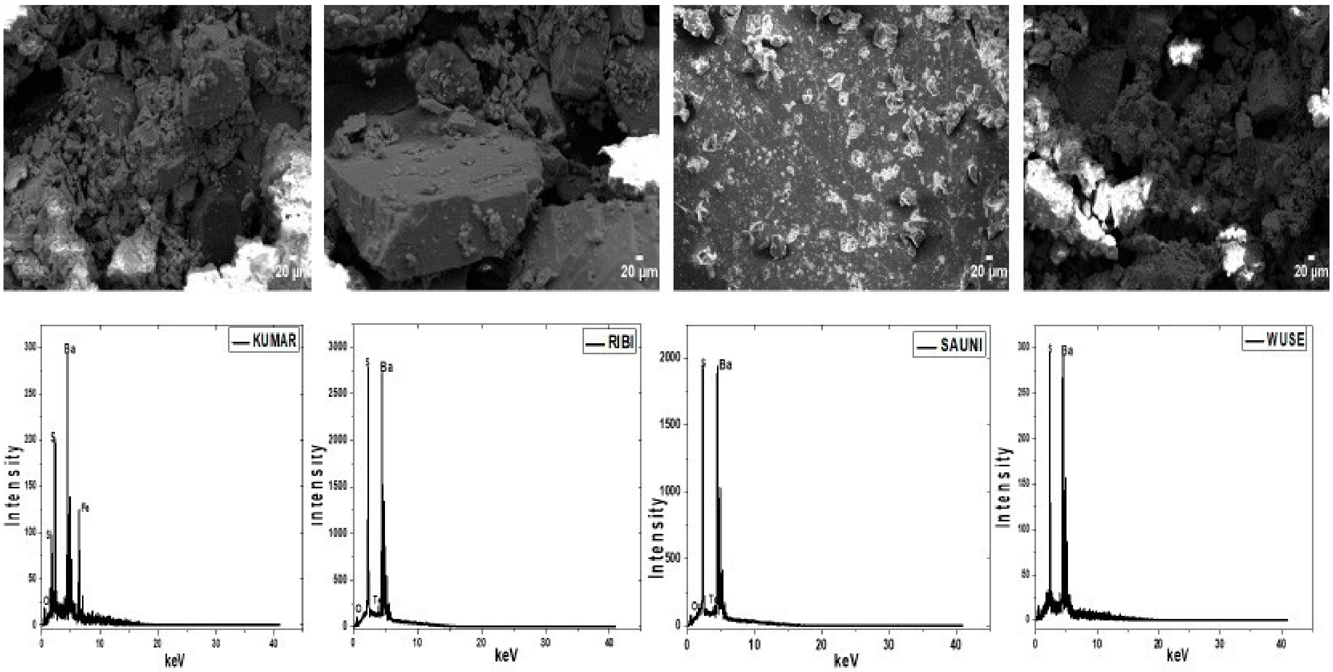


Figure S1. SEM-EDX morphology and sample element atomic percentages.

Table S1. Mine site location in the Local Government Area.

NUMBER	SAMPLE LOCATION	LOCAL GOVERNMENT AREA	STATE
1	Azara Vien 1	Awe	Nasarawa
2	Azara Vien 17	Awe	Nasarawa
3	Azara Vien 18	Awe	Nasarawa
4	Keana	Keana	Nasarawa
5	Ribi	Awe	Nasarawa
6	Kumar	Awe	Nasarawa
7	Sauni	Awe	Nasarawa
8	Wuse	Awe	Nasarawa
9	NS (Aloshi)	Keana	Nasarawa
10	TS (Ibi)	Ibi	Taraba

11	WS	Drilling Site	Port Harcourt

Table S2. The physical appearance of the samples.

Number	Sample	Physical Appearance / Colour
1	Azara Vien 1	White
2	Azara Vien 17	Cream
3	Azara Vien 18	Light Brown
4	Keana	White
5	Ribi	White
6	Kumar	Ivory (Off White)
7	Sauni	White
8	Wuse	White
9	NS	Cream
10	TS	White
11	WS	Brown

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CHAPTER FIVE

FOSTERING THE SUSTAINABILITY OF ARTISANAL AND SMALL-SCALE MINING (ASM) OF BARITE IN NASARAWA STATE, NIGERIA

5.1 Introduction

The Federal Government of Nigeria is implementing the National Economic Recovery and Growth Plan (NERGP) aimed at diversifying the economy to achieve the Sustainable Development Goals (SDGs) [1,2,3]. This development plan has become imperative because of uncertainties currently surrounding the revenues from crude oil. Critical aspects of this developmental plan need to be supported with research, technology, and innovation to transform the economy from import-based to locally sourced goods and services. Although the development of the solid minerals sector has been implemented under different development plans (1st, 2nd, 3rd, and 4th National Development Plans, Rolling Plans, National Economic Empowerment, and Development Strategy (NEEDS), Vision 2020 and the 7-Point Agenda), the sector contributes only 5% to the national gross domestic product (GDP) [4,5,6,7]. This sector has the potentials for contributing up to 30% of the GDP if appropriate strategies and technologies are used to improve the sustainability of operations [8,9].

Nigeria is richly endowed with varieties of mineral resources in commercial quantities in different parts of the country [10]. These minerals include: ferrous and non-ferrous minerals; precious minerals and metals; energy minerals; industrial minerals and construction minerals. Exploration and mining of mineral resources have assumed prime importance in developing countries including Nigeria and to harness mineral resources, they must pass through the stages of exploration, mining, and processing [11,12,13]. Each of these components of the value chain requires technologies for mineral extraction and value addition. Such technologies may not be available to ASM operators. Nasarawa state which lies within the north-central zone of Nigeria is known as the home of solid mineral because of the vast deposits of mineral resources in the 13 local government areas of the state. Some of these minerals include; cassiterite, granite, barite, salt, lime, zinc, lead, clay, silica, aquamarine, sapphire, amethyst. In 2016, Nasarawa State produced a total of 73, 360,157 tons of solid minerals [13]. However, most of the mineral resource exploitation is carried out by artisanal and small-scale miners (ASM). The operations of ASM are characterized by low productivity, unsafe mining environment, exposure to health hazards, and degradation of the environment [14,15,16].

Barite is an industrial mineral that is used in drilling mud and making other engineering products [17,18,19]. The mineral is found in commercial quantities in Cross River, Benue, Nasarawa, Plateau, Taraba, Adamawa and Gombe states of Nigeria [20,21,22,23]. The exploration of Nigerian barite deposits is primarily by ASM using crude implements and technologies. Sector analyses indicate that industry demand for barite cannot be met by local production. A large percentage of this demand is met through importation because of the inability of Nigerian barite ore producers to meet users' requirements both in quantity and quality. The government is making efforts toward reversing this trend [24]. As part of efforts to diversify the revenue base of the country, Nigeria is implementing policies and interventions aimed at decreasing importation of barites and increasing local production. This sectoral intervention will ensure a sustainable supply of the mineral to the industry with a resultant positive socio-economic impact. These efforts can only succeed if they are supported with research to identify challenges and proffer solutions that can inform policy.

Several studies have highlighted the challenges of artisanal mining of different minerals in Nigeria [25,26,27,28]. Only a few studies focused on artisanal mining of Nigerian barites [29,30,31]. There is a need to extend the study to other locations of barite deposits to widen the knowledge base of the mineral resource environment and sector policy. In addition, there is a need to extend the studies to other locations of barite deposits in order to widen the knowledge base of the mineral industry. Also, the earlier studies showed that the mineral sector in Nigeria is dominated by artisanal and small-scale miners. The sector has many challenges threatening its existence. Therefore, there is a need for more studies that can focus on how to make the sector more sustainable.

The main aim of this study is to contribute to efforts toward fostering the productivity and sustainability of artisanal and small-scale mining (ASM) of barite in Nasarawa state, Nigeria. The specific objectives are to:

- assess the value chain of barite mining and processing in Nasarawa state, Nigeria
- identify challenges of the sector;
- identify socioeconomic and environmental impacts of ASM;
- assess the effectiveness of government policies and regulations; and
- suggest sustainable strategies toward improving the productivity and sustainability of the sector.

This work is organized in four (4) sections. Section 1 presents the Introduction containing the background and objectives. Section 2 is the literature review on artisanal and small-scale mining. Section 3 describes the Research Methods. Section 4 is a presentation and discussion of the results including a presentation of the strategy suggested for sustainability of ASM. The conclusions and policy implications of the study are presented in Section 5.

5.2 Artisanal and Small-Scale Mining (ASM)

The industrial sector is classified into three major categories namely: large-scale industries, small and medium industries and micro, and cottage industries. For the extractive (mining and mineral processing) industry, several criteria are used for classification which include: level of mechanization, degree of formalization, legal framework for operations, degree of labor intensity, level of capital involvement, level of planning of operations, etc. Using these criteria, three categories have emerged namely: large-scale mining (LSM), medium-scale mining (MSM), and artisanal and small-scale mining (ASM). The LSMs are large-scale mining activities using heavy-duty equipment, employing many professionals, and operating in a very formalized environment. For MSM, the level of investment and machinery use is most minor and negligible for ASM.

5.2.1 Concept of ASM

Definitions of ASM by different multilateral organizations such as International Institute for Environment and Development (IIED), World Bank, International Council on Mining and Metals (ICMM), United Nations Economic Commission for Africa (UNECA), United Nations Environment Program (UNEP), and Swiss Agency for Development and Cooperation are well documented [32]. ASM is characterized by the use of rudimentary techniques for mineral extraction and often operate under hazardous, labor-intensive, highly disorganized, and illegal conditions; low productivity since ASM often takes place in very small or marginal plots, is limited to surface or alluvial mining and uses inefficient techniques; lack of safety measures, health care, or environmental protections; may be practiced seasonally (e.g., to supplement farm incomes) or temporarily in response to high commodity prices; and lack of long-term mine planning. Because many factors are used in describing and characterizing ASM globally, specific categorization varies from country to country. For Nigeria, the Minerals and Mining Act, 2007 defines ASM as "informal mining activities undertaken by individuals or groups, which rely heavily on manual labor, using simple implements and methods without prior exploration activities" [33]. Many of such unskilled activities are informal operations since they do not operate under regulatory framework, as stipulated under the Minerals and Mining Act, 2007.

It appears that many operators in the artisanal and small-scale mining (ASM) sector became miners because they could not find any other work to do. It is also a very diverse sector with challenges that vary from region to region and often from site to site. There is a wrong perception that artisanal and small-scale mining sector is a homogenous sector. This has misinformed legislation and extension programs and led to the development and application of uniform policy for the mining and mineral sector [34,35]. However, people working in ASM are far from this. They range from those whose livelihoods rely on subsistence farming to skilled workers who migrated from urban areas in search of work. In 2016, about 500,000 personnel were directly involved in ASM of gold in Africa with an estimated 2,500,000 dependents [36]. Despite its low productivity, ASM is an essential source of minerals in Nigeria. It accounts for about 20% of the global gold supply, 80% of sapphire supply, and 20% of diamond supply. The sector is also a significant producer of tantalum and niobium minerals for manufacturing capacitors in the electronic industry (laptops and cell phones). Reports show that 26% of global tantalum production and 25% of tin come from ASM [37,38].

5.2.2 Artisanal and Small-Scale Mining (ASM) in Africa and Nigeria

Although ASM has been criticized and often referred to as illegal operation, this sector is very critical to the economy of sub-Saharan Africa. Available information shows that about 60% of mining activities in Africa is by ASM. In Nigeria, this figure is even higher, with current estimates at 90%. This has been recognized by the government of Nigeria, resulting in the creation of a full department of artisanal and small-scale mining by the Federal Ministry of Mines and Steel Development (MMSD) to take care of oversight and regulation of activities in the sector.

Artisanal and small-scale mining in Africa has attracted the attention of many researchers [39,40,41,42,43,44,45]. In Nigeria, only a few studies have provided some insight into the dynamics, challenges, and prospects of artisanal and small-scale mining [46,47]. These studies have shown that the sector is greatly misunderstood and that is why in many cases, the operators are referred to as illegal miners. But in a large country such as Nigeria with large deposits of many minerals, the combination of many factors has driven many resource poor people into mining. However, the operations of ASM are hindered by many factors including weak implementation and enforcement of mining laws, limited awareness of environmental, health, and safety issues, fragile ecosystems of the mining environment, host community conflicts, poor infrastructure, and lack of access to financing.

To mitigate the problems facing ASM in Nigeria, the government has over the years implemented various reforms, usually with support from donor agencies and partners. But the issue of inclusiveness and formalization of the sector remains a major constraint. Also, in implementing the sectorial policy of licensing, many mining titles are held by speculators who are usually rich or influential people that easily obtained the licenses. The government has also introduced the formation of miners' cooperatives to enable groups of miners to have the capacity and capability to obtain licenses and formalize their operations, but this policy has not yielded appreciable results.

There is therefore the need for a deeper understanding of the dynamics of ASM in Nigeria vis a vis the mining laws, policies, and programs being implemented by the government with support from development partners as well as the impact of ASM on the socio-economic well-being of the miners, safety of the miners, and the environment. Such an understanding will be used to make informed decisions toward formulating and implementing policies and programs that can be used to foster the sustainability of ASM for some of the strategic minerals such as barite.

ASM is highly inefficient compared to large-scale industrial mining. It represents a very important element of the economy both at the local and regional level, especially for low-income population groups. The socioeconomic, environmental, safety, and health impacts of ASM on the miners, the society, and environment in Africa have been discussed by several researchers [48,49,50,51,52,53]. These studies have shown that the impact depends on the environment and location. Extensive studies have been done in eastern and southern Africa. In west Africa most of the studies have been done in Ghana and a few other countries. There is a need for a more understanding of the dynamics of ASM for Nigeria especially with respect to the strategic minerals that are being promoted by the government. Such studies can generate useful information that can drive policy toward fostering sustainability of artisanal and small-scale mining (ASM) in Nigeria and Africa in general.

5.3 Research Methods

The research methodology adopted for this work was a two-stage procedure involving quantitative and qualitative approaches to data collection and analysis. The first stage involved a comprehensive review of literature obtained from published works and unpublished works in relevant ministries and government agencies. These provided sources for qualitative data and subsequently, content analysis was used to synthesize and analyze information which informed the quantitative data collection. Quantitative data were obtained from physical surveys using semi-structured questionnaire. More details of these procedures can be found in [54,55,56,57]. In applying the quantitative and qualitative data collection approaches, the 4Is optimization strategy was developed and adopted for data collection and analysis. The first I refers to information gathering on ASM of barite. This was accomplished through qualitative and quantitative approaches using existing published materials and survey of miners and key stakeholders. The second I refers to an interpretation of the information which was accomplished using content analysis. The third I refers to a discussion of the implication of the information with respect to the existing knowledge both in Nigeria and other African countries. The fourth I refers to the implementation of the results for developing a comprehensive strategy for a sustainable ASM sector in Nigeria. This approach is similar to that used by others for study of ASM for different minerals in other parts of Africa [58,59,60]. Details of the research method are given below.

5.3.1 Conceptual Framework

The conceptual framework that underpins this research is shown in Figure 1. The problem addressed is how to ensure a sustainable supply of Nigerian barites in the required quantity and quality to increase the local content in the sector. The National Content Monitoring Board (NCMB) has indicated the drive toward ensuring that all barite used by the Oil and Gas industry is sourced locally. For this to happen, the supply chain for the ore needs to be understood to ensure a sustainable supply. To generate empirical and evidence-based knowledge, the study starts with a comprehensive assessment of the entire value chain for local mining and beneficiation of barite using Nasarawa state, Nigeria as a case study. Sustainable supply can only improve if the different components of the value chain are studied to identify the bottlenecks and weak links in the supply chain. Thus, the study looked at the different components of the value chain while identifying the challenges and suggestions for improvement. The interaction of these would enable the evolution of sustainable strategies and policy adjustments toward ensuring a sustainable supply of barites to the oil industry. Lessons learned from the study can be applied to ASM for other minerals in Nigeria and other west African countries.

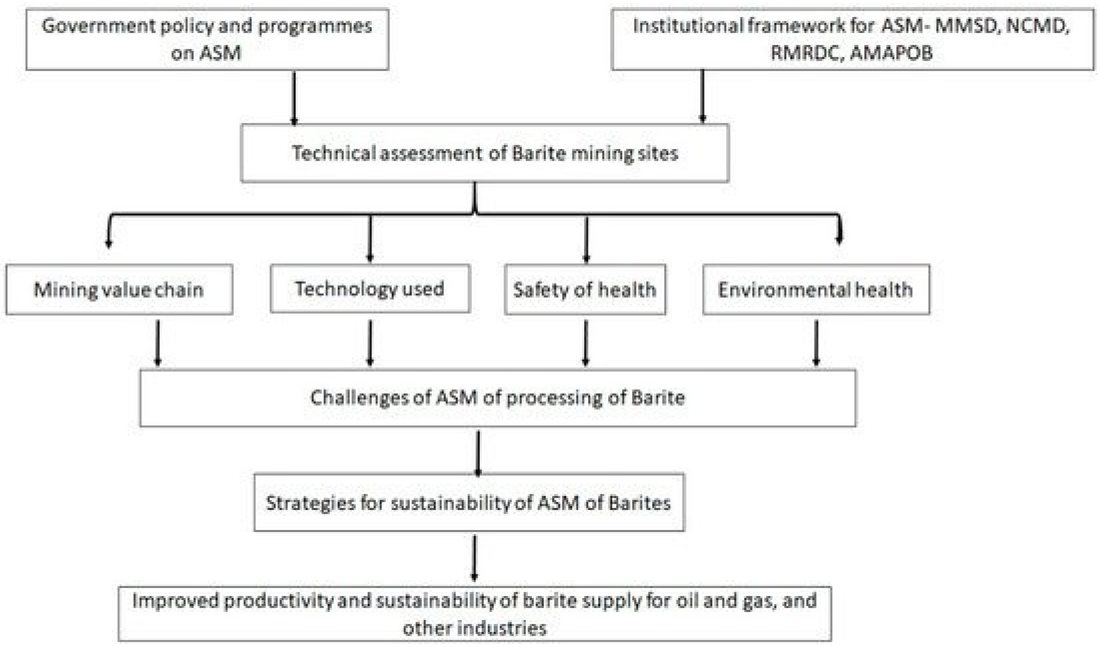

Figure 1. Conceptual framework for the study of ASM of barite in Nigeria. NCMB—Nigeria Content Monitoring Board; RMRDC–Raw Materials Research and Development Council; FMMSD–Federal Ministry of Mines and Steel Development; AMAPOB–Association of Miners and Processors of Barites.

5.3.2 Study Area

The study area is Nasarawa state, Nigeria which lies between latitude 7°45′ and 9°26′ north and longitude 6°55′ and 9°42′ east. Some of the sites are accessible through motorable roads and others are by motorcycles or boats when crossing rivers. The barite mineralization zones of the state lie within Latitude 8°01′ N–8°29′ N and Longitude 9°3′ E–9°23′ E.

5.3.3 Research Questions

In a bid to gather relevant information on the subject matter, the following research questions were asked:

- What are the components of the value chain for ASM of barites in Nasarawa state?
- Is there an adequate policy framework for artisanal and small-scale mining (ASM) of barite and is it aligned with broad national, regional, and local development agenda, including rural development plans?
- Do the extant mining laws align with policies to facilitate ASM transformation to large-scale barite production?
- What factors are responsible for illegal and informal activities associated with ASM operations for barite?
- What are the challenges militating against sustainable mining and the supply of high-quality barites?
- Do institutional and administrative structures for promoting streamlined ASM exist and are they adequate?
- Are there adequate capacity building programs for the ASM workforce?
- Is the environment for ASM conducive for finance and marketing opportunities?
- What are the socio-economic and environmental impacts of ASM in the study location.

5.3.4 Questionnaire Design

A semi-structured questionnaire was designed and used for the study as shown in Supplementary Material. Model answers are provided in the questionnaire for some of the questions such that the respondent will only tick the answer corresponding to his/her situation. In some cases, the use of Likert scales for qualitative answers was provided. The questions in the questionnaire are grouped into seven sections as follows:

Section A: Demographic characteristics of the respondents.

Section B: Mineral Mining and Processing activities (ASM Value chain).

Section C: Socio-economic impact of ASM activities.

Section D: Safety, Health, and Environmental Impact of ASM of barite.

Section E: Existence of government policy or intervention on ASM of barite

Section F: Alignment of ASM policy with other policies on Sustainable Development Goals (SDGs).

Section G: Socio-cultural profile of the mining communities

Questions in section A included: name of community/settlement, type of Location (a) Town (b) Village (c) Hamlet (d) Others (Specify), Community type (a) Mining Community (b) Non-Mining Community, Local Government Area, nationality, Gender (a) Male (b) Female, Marital Status (a) Married (b) Single, Household size of respondents, How long have you been living in this town/village?, Age of respondent, highest educational level attained (a) Primary School (b) Secondary School (c) Polytechnic (d) College of Education (e) University (f) No formal Education, present occupation of respondents (a) Agriculture (b) Mining (c) Petty Trading (d) Agriculture and Mining (e) Agriculture and petty trade (f) Government employee (g) Construction worker (h) Agriculture and livestock (i) Others (Specify), What was your initial occupation before you switched to the present occupation (a) Agriculture (b) Mining (c) Petty Trading (d) Agriculture and Mining (e) Agriculture and livestock (f) Government employee (g) Construction worker (h) Agriculture and petty trade (i) Others (Specify), List some of the reasons for the occupation change, how long have you been engaged in this present occupation? How many years did you spend in the previous occupation? What is your annual income then? What is your annual income now?

Questions in section B included: who determines the site: (a) Professionals (b) Nonprofessionals (c) Investors (c) By inhabitants; How is the site determined: (a) seismic (b) GPS (c) Coincidence; What technology is used in the mining process: (a) hand tools (b) Heavy machines; where are the stones washed? Collection point of the ore after mining (a) Mining site (b) Close to site (c) Market (c) Factory; Collectors of minerals (barite ore); On site Buyers (a) Investors (b) Mineral processors (c) Local market (d) End users; Challenges in the mining activities (a) Lack of Technical know-how (b) Poor mining tools (c) Poor road network (d) Health hazards (e) Environmental hazards (f) Poor remuneration (g) Poor pricing (h) Government action and inaction; Challenges in processing of barites (a) Few processing plants/companies (b) Distance between mining sites and processing plants (c) Impurities associated in the core (d) Old Equipment for processing (e)Expert/professionals to operate the machines.

For section C–Socio-economic impact, the questions asked included: creation of employment; improved electricity supply; improved social life; improvement in living standard; improvement in sale of petty trade items; conflict between indigenes and migrant worker; drop in school enrollment, increase in crime; increase in health-related diseases; increase in land price; increased food crop sales; increased house rent price; increase social vices; large-scale influx of immigrants and visitors in search of jobs; low agricultural productivity; security threat (see Table S1).

Questions in Section D—Environmental impact included information on: dust release; air pollution; mine pit collapse; threat to farmland and crops; damages to buildings; noise from blasting; deforestation; land degradation (see Table S2).

Section E asked questions on the awareness by miners of existence of government policy or intervention on ASM of barite. These include the existence of administrative and institutional framework for regulating the sector.

Section F deals with questions on alignment of ASM policy with other policies on Sustainable Development Goals (SDGs) and efforts done by government in ensuring sustainability of ASM.

The questionnaire was validated by three experts in scientific surveys. Moreover, a trial survey was conducted by administering the questionnaire to ten respondents in a pilot study, and issues raised during this pilot study were used to improve the questionnaire for the final survey.

5.3.5 Data and Information Collection through Literature Review, Questionnaires, and Focus Group Discussions

Data and information were collected through three major routes. The first was through an extensive literature review of ASM in Africa. The second route was through a physical survey which involved administration of questionnaires to miners. The third was through focused group discussions with miners and other stakeholders in the mining sector. To collect data using the questionnaire, a physical survey was conducted by visiting the mining sites and interacting with the miners. The questionnaire was used to collect information. Where the miner was literate, he/she completed the questionnaire. Where otherwise, the questionnaire was completed by the researcher, assisted by two research assistants by asking the questions in the local language and filling the questionnaire by himself or herself. A total of 13 mining sites were visited. In each site, 10 miners completed the questionnaire. Although we had tour guides and survey assistants from the communities, it was difficult to get the miners to agree to be interviewed. In order to overcome this, snowball sampling technique [61,62] was used where the first set of miners that agreed were used to get the others. A total of 130 questionnaires were completed, in addition to the miners, other stake holders who were visited and interviewed using Focus Group Discussion approach [63] to obtain required information. The stakeholders include: Ministry of Solid Minerals in Nasarawa State, Federal Ministry of Mines and Steel Development in Abuja (Artisanal and Small Scale Mining Department), Raw Materials Research and Development Council (RMRDC), Nigerian Content Monitoring Board (NCMB), Miners Association of Nigeria and Association of Miners and Processors of Barites (AMAPOB). In each case, a group of officials were engaged in discussion using a checklist based on the research questions.

Ethical clearance was obtained from African University of Science and Technology Research Ethics Committee and Raw Materials Research and Development Council of Nigeria.

5.3.6 Data Analysis

Data were generated from the questionnaires through frequency tabulation. Simple descriptive statistics (mean, standard deviation, percentages) were employed.

5.3.7 Strategies for Fostering Sustainability of ASM of Barites

All the factors that affect the sustainability of ASM of barites were identified and used to develop strategies for improving the productivity and sustainability of the sector.

5.4 Results and Discussion

5.4.1 Characteristics of Respondents

The characteristics of the respondents are described in Figure 2, Figure 3 and Figure 4. Figure 2 shows that most of the miners (62%) are between the ages of 31 and 50. It is interesting to note that up to 12% of the miners are children below the age of 18. This calls for policy and regulatory guidelines implementation to prevent mine operators from using minors who should be in school. When pooled together, 49% of the miners are married as shown in Figure 3a.

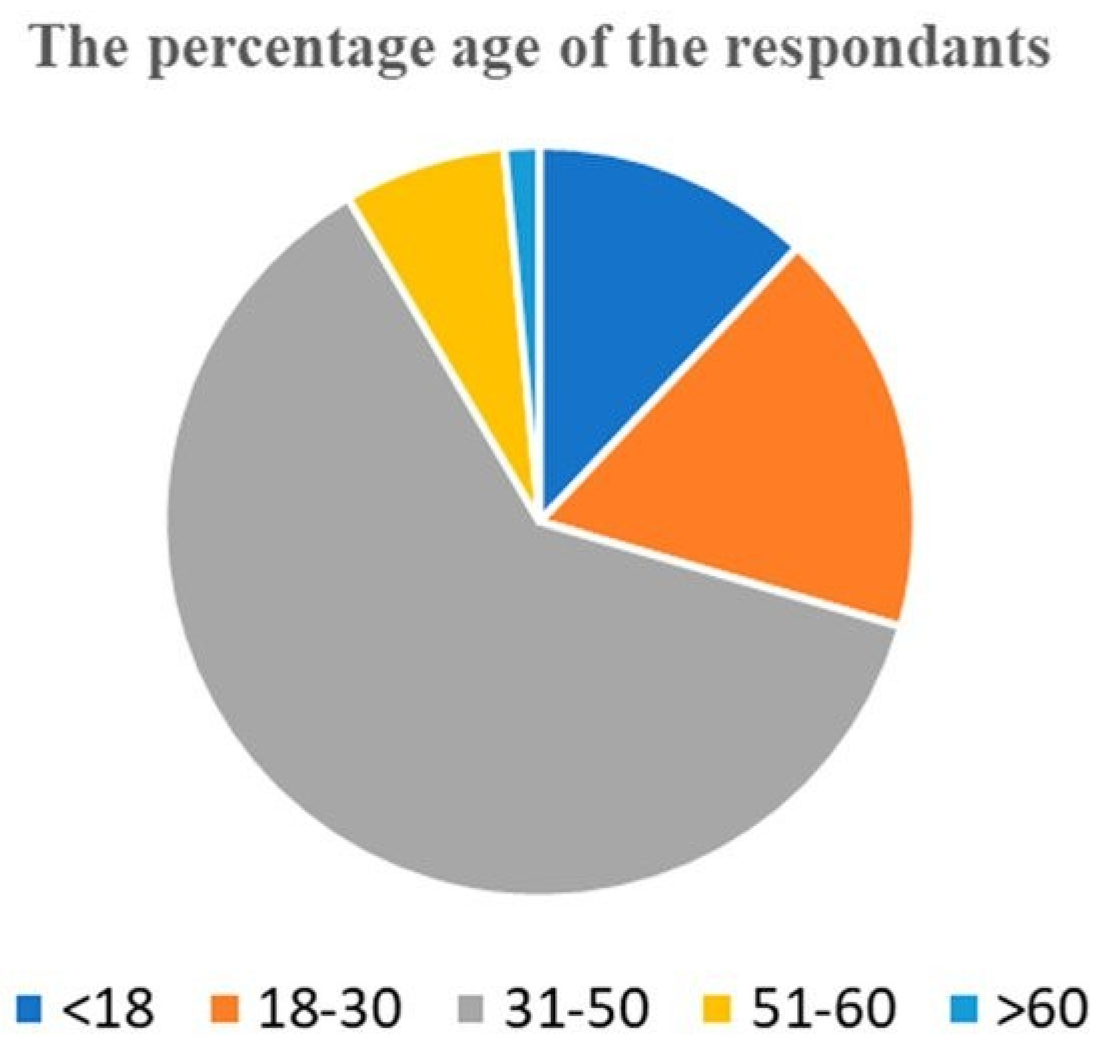

Figure 2. Percentage age of the respondents.

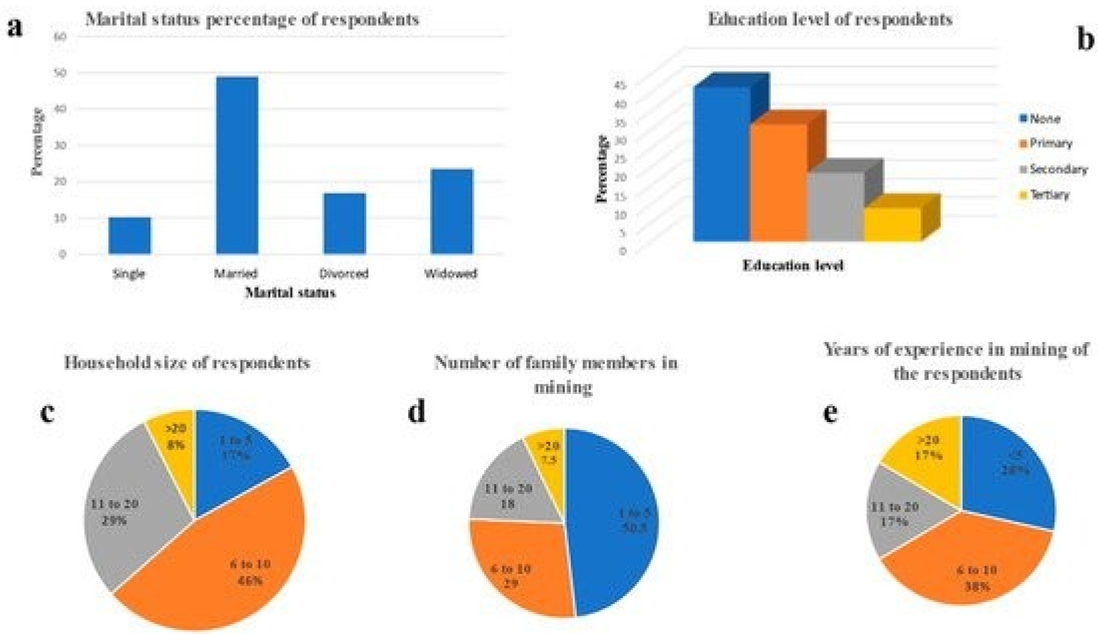

Figure 3. Respondents (**a**) marital status, (**b**) Education level, (**c**) Household size, (**d**) Number of family members in the mining, (**e**) years of experience in mining; (**e**) Years of experience in the mining of the respondents.

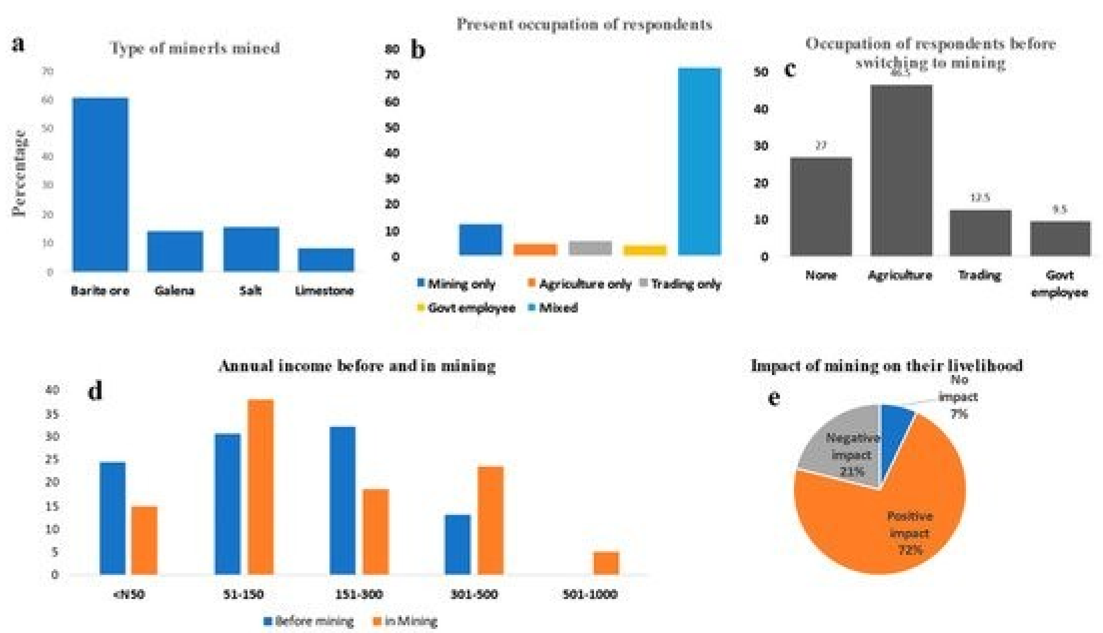

Figure 4. Respondent (**a**) type of minerals mined, (**b**) present occupation, (**c**) Occupation before switching to mining, (**d**) annual income before and after, (**e**) impact of mining on their livelihood.

In terms of educational qualifications, overall, up to 41.5% of the miners have no educational qualification and 31.5% attained only primary education. For family size, 17% of the miners have a family size between 1 and 6, 46% have a family size between 6 and 10, 29% have a family size between 11 and 20, and 7.5% have a family size above 20. Up to 50% of the respondents indicated that the size of their family members involved in mining is between 1 and 5 while 29% of the respondents indicated between 6 and 10 (Figure 3a–d).

In terms of the experience of the respondents in mining, 28.5% of the respondents have been in mining for less than 5 years. The percentage for those who have been in mining between 6 and 10 years was 38%, between 11 and 20 was 17%, and above 20 years, 16.5% as exhibited in Figure 3e.

Although the mines are primarily for barite, the results in the figures show that there are other mineral occurrences. The respondents indicated that 61% of the minerals mined are barites, followed by galena (17.5%), salt (16%), and limestone (8.5%). What this means is that any beneficiation technology to be employed must be able to remove these associated minerals to upgrade the quality of the barite. The processing of these associated minerals as secondary values can bring in additional income to the operators as shown in Figure 4a.

Most of the miners are involved in other economic activities as shown in Figure 4b. These other activities are agriculture, petty trading, government work, and those who are unemployed. Up to 73% of the respondents indicated they are involved in mixed economic activities for survival. This means that they are involved in more than one economic activity including mining, agriculture, and trading. This is typical of most rural dwellers and is practiced because the miners do not earn enough revenue to take care of their needs if they are involved in only one economic activity. This was followed by those who practice mining only (12.5%), agriculture (4.5%), trading only (6%), and government employees (4%).

Most of the miners were involved in other occupations before venturing into mining. Table 1 shows that the majority of them (46.5%) were involved in agriculture before mining. This was followed by unemployed people (27%), traders (12.5%) and those who were government employees (9.5%) as shown in Figure 4c.

Table 1. Challenges of artisanal and small-scale mining (ASM) of barites as presented by miners and other stakeholders.

Attribute	**Percentage of Respondents (%)**		
	Very Important	**Important**	**Not Important**
Weak implementation and enforcement of mining policies and laws.	70.4	20.5	9.1
Inadequate support from government and development partners.	60.5	24.0	15.5
Poor access to mining equipment and technology.	58.5	31.5	10.0
Poor infrastructure (access road, water, electricity).	45.0	22.0	33.0
Poor pricing of products (marketing challenges).	47.5	21.5	31.0
Poor remuneration of mine workers.	52.0	33.0	15.0
Poor mining skills.	25.0	53.5	21.5
Lack of formal education.	26.0	44.5	29.5
Health hazards.	31.5	35.5	33.0

Environmental hazards.	33.0	31.0	36.0
Lack of safe working environment.	46.4	29.7	23.9
Insufficient Information and data on Mines and Miners.	25.0	21.5	53.5
Security, fragility, and conflicts.	35.0	32.5	32.5
Lack of access to finance.	80.5	15.0	4.5
Lack of formalization of operations and poor legal framework for operations.	65.4	21.3	13.3

About 24.5% of the respondents earned less than (N50,000) USD 143 per annum before venturing into mining. Those who earned between (N51,000) USD 145 and (N150,000) USD 429, constituted 30.5%.; (N151,000–N300,000) USD 431–857 constituting 32% and (N301,000–N500,000) USD 860–1429 constituting 13%. As shown in Figure 4d, those who earned above (N500,000) USD1429 after joining the mining occupation were up to 5% compared to 0 before. The others were 23.5% for those who earned between (N301,000-N500,000) USD 431–857; 18.5% for those who earned between N151,000-N300,000 USD431–857; 38% for those who earned between (N51,000–N150,000) USD 145–431 and 15% for those who earned less than (N50,000) USD143 as shown in Figure 4d.

For the impact of mining on livelihood as perceived by the miners, 72% of the miners indicated that mining has a positive impact on their lives while 21% indicated mining has a negative impact (Figure 4e).

5.4.2 Barite Mining Value Chain

The typical value chain for ASM of barite in Nasarawa State is shown in Figure 5. The figure shows eight distinct phases in the ASM mining of barite which include overburden removal; disintegration of barite ore; transfer of as-mined barite to the washing point; washing of the barite; drying of the barite; sorting of the ore; collection, stacking and loading of barite; sale of the ore to millers.

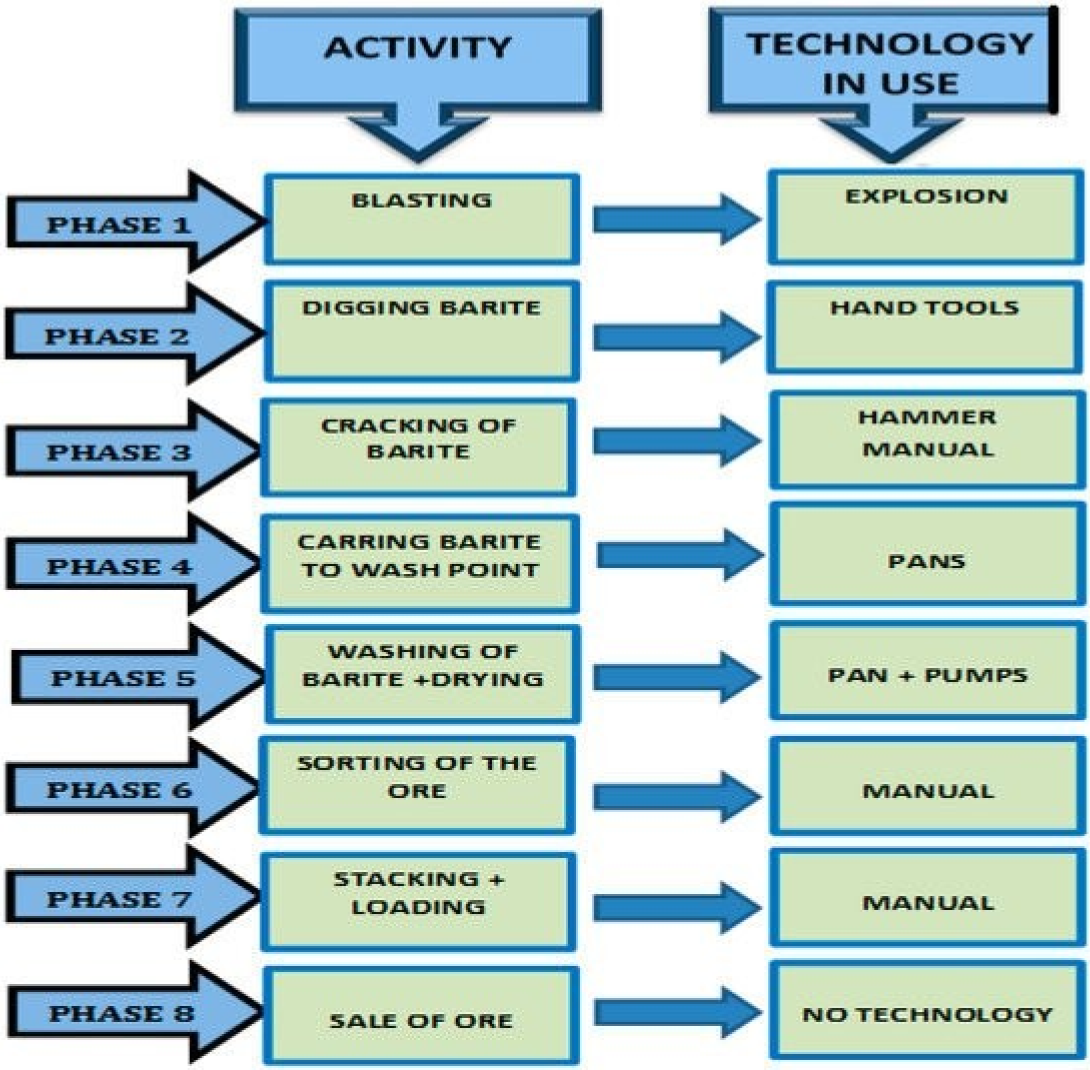

Figure 5. Components of the value chain for barite mining showing activities and technology.

Nasarawa barite deposit is of cavity filling type (Veins). The veins are averagely 1 m wide and stretch through the entire lengths of paddocks opened up for barite mining, which is more than 950 m. Nasarawa barite mineralization is composed of about 20 veins running either almost parallel or different orientations to each other, sometimes with split veins occurring at a shallow depth of about 4m below the ground level. Main veins are overlaid by an overburden of 15–20 m thickness consisting of Topsoil, Laterite, Shale, and Sandstone in some places. The barite ores occur with impurities such as Hematite, Sphalerite, and Siderite.

The exploitation of the barite veins is largely (100%) by artisanal and small-scale mining (ASM). Mine developments are directed intuitively and operations are carried out archaically. Miners follow the visible mineralization vertically and laterally without having a clear idea of the location and grades of the mineral reserves. A deep part of the barite mineralization is abandoned as soon as the extraction becomes delicate, expensive, or dangerous (Figure 6). Productions are done using crude implements such as diggers, hoes, shovels, and buckets (Figure 7). When the pits become deep, extracted materials are transferred to the pit collar (using draw buckets with long ropes) for onward transfer to the washing location (Figure 7). At the collection point, boxes with dimensions 0.9 m by 0.9 m by 0.6 m are used to evaluate the barite productions (Figure 8) for operational economics. A full box is estimated as one ton of barite. Transfer of materials to the washing point and the processing (i.e., actual washing, sorting, and drying) and stacking of barite are done by the women who are engaged by the site owners or the vendors (Figure 9).

Figure 6. Deep and dangerous barite artisanal mining in Nasarawa state ((**A**)—potential pit wall failure supported by wooden props, (**B–D**) shows artisanal miners working at deeper levels). Photo credit: authors.

Figure 7. Mining and other activities using crude implements (**A**) excavating using crude implements such hoe; (**B–D**) excavated minerals are carried from the pit to the earth surface using plastic bucket and rope.

Figure 8. Evaluation of barite production in Azara, Nasarawa State, Nigeria using wooden boxes (**A**) researcher measuring the quantity unit box with (0.9 × 0.9 × 0.6) m, (**B**) respondents filling the boxes. Photo credit-authors.

Figure 9. Women involvement in barite production in Azara, Nasarawa state (**A**) women transferring run-of-mine ore to designated washing point; (**B**,**C**) washing of barite by women; (**D**) stacking of barite at collection area. Photo credit: authors.

This exploitation method poses a challenge to the sustainable development of Nasarawa state barite deposits. Despite available global best processing techniques for barite ores, a manual and crude method of washing is the norm in these sites. This practice reduces the economic value of the ore and increases the transport cost to the end-users. Barite produced are transported out of the production site in trucks to millers who then further process, mill, and package them in bags for use by downstream industries who make drilling mud and other products.

5.4.3 Challenges Facing Artisanal and Small-Scale Mining (ASM) of Barites

The challenges confronting the ASM of barite are quite similar to those facing the ASM of mineral commodities generally. These include weak implementation and enforcement of mining laws; inadequate support from government and development partners; poor access to mining equipment and technology; poor infrastructure (access road, water, electricity); poor pricing of products (marketing challenges); poor remuneration of mine workers; poor mining skills; inadequate formal education; limited awareness on environmental health and safety hazards; fragility and conflict; insufficient information and data on mines and miners; security, fragility, and conflicts; lack of access to finance; lack of formalization of operations and poor legal framework for operations.

The relative importance of these challenges as seen by miners and other stakeholders (government workers and policymakers) are shown in Table 1. The data in the table show that the challenges that are very important to the miners and stakeholders with more than 50% of respondents are: weak implementation and enforcement of mining policies and laws; inadequate support from government and development partners; poor access to mining equipment and technology; poor remuneration of mine workers; lack of access to finance and lack of formalization of operations and poor legal framework for operations. This means that the issue of sustainability of ASM of barites can be solved if the institutional framework for policy, law, and enforcement, as well as technical and financial support for miners, can be addressed. There is a need to revolutionize the ASM sector by formalizing their systems of operation through knowledge-based operation; skill acquisition and capacity building; research and development; fabrication of local machines for mining; injection of much-needed capital and enforcement of mining laws and regulations to ensure safe mining practices. These results agree with earlier findings by several researchers for other minerals in Africa [64,65].

5.4.4 Challenges of Barite Processing

Barite normally occurs in association with other minerals. The ore is also in form of rocks that need to be milled into a powder. If the quality of the barite does not meet established standards (API), there is a need for beneficiation. These are all done on processing plants before the product moves to the end-users. Part of this study was to identify the challenges facing the few inadequate processing centers located within the vicinity of the mining sites. The challenges identified include: few processing plants; long-distance between mining sites and processing plants; lack of technologies for removing the impurities; lack of professionals with skills for operating the machines; most of the technologies are imported; lack of sustained orders from end-users; lack of infrastructure (access roads, electricity, water); poor access to funds for industrial machines and multiple taxations from local authorities. The relative importance of each of these challenges as presented by the miners is shown in Table 2.

Table 2. Challenges in processing barites as seen by miners and other stakeholders.

Attribute	**Percentage of Respondents (%)**		
	Very Important	**Important**	**Not Important**
Few processing plants for beneficiation.	65.6	25.4	9.0
Long-distance between mining sites and processing plants.	46.8	30.4	22.8
Lack of technologies for removing impurities from barite ores.	75.8	13.8	10.4
Lack of professionals with skills to operate beneficiation machines.	34.8	45.0	20.2

Most of the technologies are imported	45.2	25.9	28.9
Lack of sustained orders from users of barites.	52.1	30.6	17.3
Lack of infrastructure (access roads, electricity, water)	50.7	20.0	29.3
Poor access to funds for industrial machines.	80.5	10.2	9.3
Multiple taxations from local authorities.	70.3	15.0	14.7

5.4.5 Safety and Health Impact of ASM

Table 3 shows that only 25.6% of the respondents have safety and protective gear for use during mining operations while only 10.2% of the miners have access to first aid facilities in case of accidents. Only 20.5% of the miners had training on safety and health issues. These are definitely below standards for safe mining practice. This is one of the consequences of having very poor regulatory oversight by government agencies that are supposed to supervise the operations of the mines. The government officials, during the discussions blamed their inability to supervise the mines on lack of funds for their operations. In most cases, the owners of the mines indicate on paper that they have all the required mining equipment for safety of the mine workers but in practice, they do not make these equipment available to the miners. In addition to the fact that the miners do not have access to safety equipment and first aid, the primary health facilities are far away from the mining sites. This means that when there are accidents, sickness, or exposure of miners to health hazards, they are not able to access healthcare timely.

Table 3. Summary of environmental impact of ASM in Africa.

Environmental Impact	**Country**	**Reference**
Land use changes	Tanzania	Malisa [66]

	Rwanda Great lakes	Kinyondo and Huggins [53] Lehmann et al. [67]
Water use changes and water pollution Mercury contamination Effect of water habitat	Tanzania Ghana Nigeria	Harada et al. [68] Hilson and Pardie [69] Adewumi and Laniyan [70] Zolnikov [71]
Air pollution High dustiness	Great Lakes	Lombe [72]
Changes in landscape structure Deforestation Erosion Land cover changes	Zimbabwe Rwanda Kenya	Maponga [73] Kampamibwa [74]
Soil contamination Influence on soil fertility	Africa	Wantezen [75]
Geomorphological processes Weathering Mass movement Land slides Fluvial processes	Ghana Africa Great lakes	Serfor-Armah, [76] Lombe [72]
Hydrological regime Sedimentation of water stream Contamination of stream Stream bed stability	Africa Great lakes	Maponga [73] Machacek [51]
Harm to biodiversity	Tanzania	Lehmann et al. [67]
Creation of new anthropogenic forms	Tanzania Great Lakes	Machacek [52]

5.4.6 Environmental Impact of ASM

Only about 10% of the respondents are aware of government policy and regulatory agencies for environmental issues in mining as shown in Table 4. However, the miners and other stakeholders identified the following as environmental impact of ASM of barites in the area: increased dust release; air pollution; increase in mine pit collapse; threat to farmland and crops; damages to buildings; noise from blasting; deforestation, land degradation, and water contamination. These impacts are similar to those identified and discussed by other researchers in different countries and for different minerals as summarized in Table 3. One of the environmental impacts observed was that miners abandon mining sites once they have exploited the mine up to their capacity. Such abandoned sites constitute environmental hazards and lead to further erosion, land degradation, and further leaching of heavy metals into nearby water ways. There is a need for land reclamation activities to return such lands to agricultural use.

Table 4. Effectiveness of government policies, laws, and enforcement on mining as presented by the miners.

Attribute	**Percentage (%) of Respondents**	
	Yes	**No**
Access to training on health, safety, and environmental issues in mining	20.5	79.5
Access to protective safety gear (helmet, booths, eye goggle, nose mask, overall)	25.6	74.4
Availability of first aid facility	10.2	89.8
Any quality control measures in place?	5.0	95.0

Awareness of Mining Acts and Regulations (Nigerian Minerals and Mining Act, 1999; Nigerian Minerals and Mining Act 2007, Nigerian Minerals and Mining Regulations, 2011.	22.6	77.4
Awareness of Activities of National Environmental Standards and Regulation Enforcement Agency (NESREA), Federal Ministry of Environment.	10.4	89.6
Awareness of Institutional Framework under Federal Ministry of Mines and Steel Development (MMSD)–Mining Cadestre Office, Mines Inspectorate Department, mines Environmental Compliance department, Artisanal, and Small Scale Mining Department	26.7	73.3
Awareness of government and donor agency support programs eg Solid Minerals Development Fund, Bank of Industry	35.6	64.4
Benefitted from government and donor agency support programs e.g. Solid Minerals Development Fund, Bank of Industry	12.4	87.6
Member of cooperative or other commodity associations such as AMAPOB	40.4	59.6

5.4.7 Quality Issues

Only 5% of the miners indicated that there are quality assessment procedures for the products (Table 4). This means that the uniformity of the products is compromised. Most of the barites being mined are sold to mineral trades who in turn sell them to processing industries that produce drilling mud for oil companies. This lack of quality control may be one of the major reasons why these companies are still importing barites from other countries since they must use barite that meet international standard. Recent characterization work by the authors show that with adequate quality control and little beneficiation, Nigerian Barite can meet the required international standard [77,78].

5.4.8 Awareness, Effectiveness and Impact of Government Policy, Mining Laws, Guidelines and Programs

Government policies and regulation for the mining sector are captured various policy documents and laws as follows:

- Nigerian Mineral and Mining Act 2007
- Nigerian Mineral and Mining Act 1999
- Nigerian Mineral and Mining Regulation, 2011

In addition, there are regulations from related government agencies such as those related with environmental protection. These laws, guidelines, and policies are implemented by a number of organizations including:

- Federal Ministry of Mines and Steel Development (FMMSD)
- Nigerian Geological Survey Agency
- Mining Cadastre Office
- Raw Materials Research and Development Council
- Artisanal and Small Scale Mining Department of FMMSD
- Mines Inspectorate Department of FMMSD
- Mines Environmental Compliance Department of FMMSD
- Federal Ministry of Environment
- Nigerian Environmental Standards Regulations Agency (NESREA)
- Sustainable Minerals Development Project
- Solid Minerals Development Fund

- Bank of Industry

Table 4 shows that most of the miners are not aware of these government policies, programs, and agencies. This is responsible for their inability to benefit from such programs.

5.4.9 Socio-Economic Impact of ASM

The positive socio-economic impacts identified include: creation of employment; improved electricity supply; improved social life; improvement in living standard; improvement in sale of petty trade items. The negative impacts include: conflict between indigenes and migrant worker; drop in school enrollment, increase in crime; increase in health-related diseases; increase in land price; increased food crop sales; increased house rent price; increase social vices; large-scale influx of immigrants and visitors in search of jobs; low agricultural productivity; security threat. Some of these have been identified and discussed by other researchers in other countries as shown in Table 5.

Table 5. Socio-economic impact of ASM in Africa.

Environmental impact	**Country**	**Reference**
Employment generation	Ghana Tanzania Liberia	Kinyondo and Huggins [53] Lehmann et al. [67]
Support livelihood of rural poor	Africa	Harada et al. [68] Bansah et al. [48]
Contribution to national income through taxes, export earnings, raw materials for industries	Ghana	Ofosu et al. [60]
Boosting of living standards	Tanzania	Fisher [79]

Startup capital for other SMEs	Ghana Malawi	Smith [80] Tiyamike [81]
Education and medical costs of miners	Ghana	Hilson [82]
Funding of agricultural activities		Adu-Baffour [83]
Supply of industrial raw materials for other industries	Ghana	Penderson [84] Bensah et al. [48]
Boosting economic activities for miners, traders, mineral speculators and transporters	Liberia	Van Bockstael [85]

5.4.10 Strategies for Fostering Sustainability of ASM of Barites

This study has shown that the factors that affect the sustainability of ASM of barites include: mining laws, guidelines, and regulations; governance and implementation of the laws; economic issues including access to finance; access to technology; access to skills and education; mining environment; socio-cultural issues; mine safety; health hazards and quality and standards as shown in Figure 10.

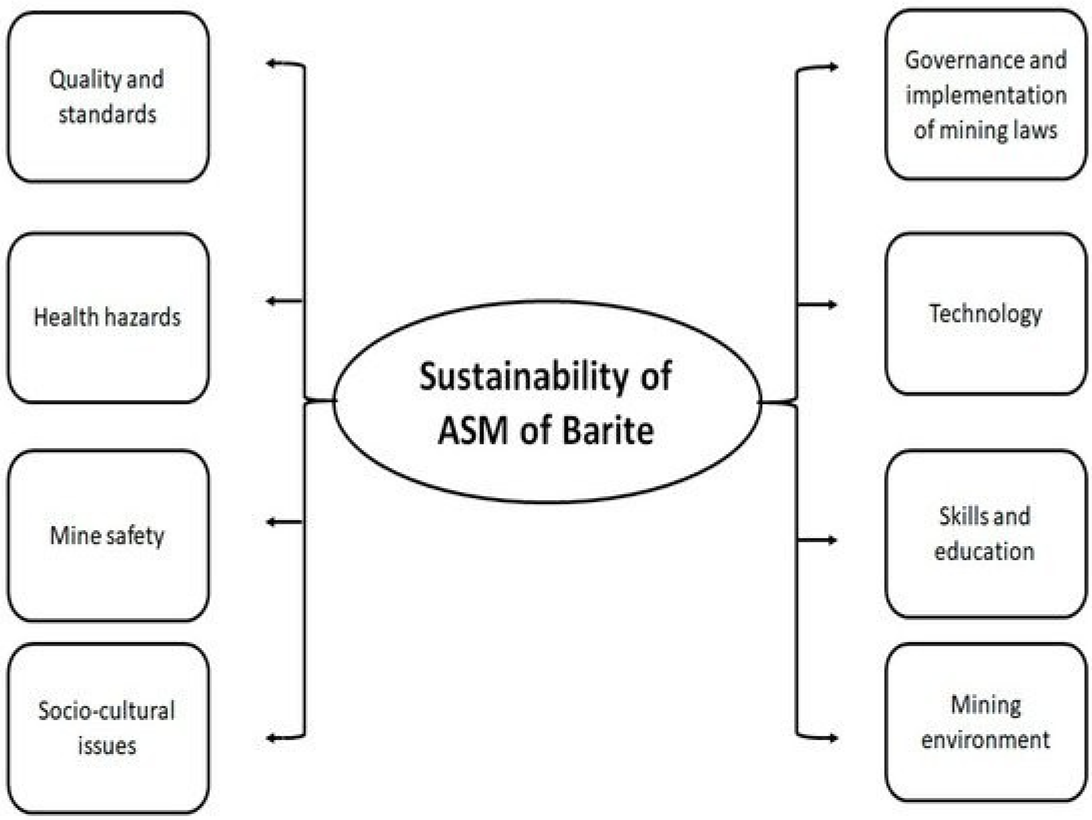

Figure 10. Factors that affect the sustainability of ASM of barites.

Different approaches have been proposed for achieving sustainability of the mining sector in Africa in order to change the resource curse to resource gain [85,86,87,88,89]. However, each of the approaches has to be aligned and domesticated to suit country-specific needs and environment. Based on the results of this study, to transform the ASM of barite into a sustainable one that contributes to the socio-economic growth of Nasarawa state and by extension Nigeria, the following strategies are proposed:

5.4.11 Policy Implementation and Legislation Enforcement

- Integrate ASM policy into the nation's poverty alleviation programs.

- Develop policy, legal, and regulatory provisions, along with institutional capacity, that integrate ASM into wider rural development strategies and programs, taking cognizance of ASM impact on other economic activities with the involvement of all stakeholders, including all relevant government agencies, financial institutions, and civil society.
- Review extant laws to encourage ASM mentoring programs by professional bodies and/ or large-scale mining operators.
- Efforts should be made to improve on formalization of ASM in Nigeria. Already there are mining policies and laws that encourage the formalization of ASM but the implementation is poor. The formation of Miners' Cooperatives should be encouraged to pool resources together to be able to meet up with the requirements of formalization of their operations and hence achieve inclusiveness.

5.4.12 Awareness Campaign

There is a need to create awareness within the ASM communities regarding the skill gap in the barite value chain. Inadequate target spotting of barite reserves has culminated in poor recoveries, mine safety challenges, and other socioeconomic issues. In addition to formal education, there is a need for periodic training of the miners. Seminars and workshops should be organized to create awareness among miners and processors on government programs and interventions that can be of benefit to them. This should be done by the Federal Ministry of Mines and Steel Development (ASM department) in collaboration with state government and Investment Promotion parastatals such as Raw Materials Research and Development Council (RMRDC).

5.4.13 Support for ASM of Barites

Technology providers should be encouraged to supply simple processing facilities for upgrading run-of-mine ores, just as it has been done in ASM of gold through the presidential artisanal gold mining initiative (PAGMI).

- Association of Miners and Processors of Barites (AMAPOB) should be encouraged to establish economic ventures specifically for value-added offering as side linkages to the barite mining. Barite-buying centers could be established by the association to enhance proper marketing of barite, and address ASM sector taxation and revenue collection.
- Support to ASM operators and host communities materially and technically regarding safety, health, and environmental standards would ensure knowledge of safe mining and processing practices and minimize mine accidents and environmental pollution. There is a need to have environmental safety guidelines to ensure that the mining activities do not degrade the environment. These guidelines are actually in existence but are not implemented. The role of mine inspectors needs to be enhanced.
- The use of safety gear at worksites is imperative for the protection of the miners. This must be implemented in such a way that every miner is provided with appropriate safety gear including helmets, goggles, boots, gloves, etc. There should be first aid centers within the vicinity of the mines.

5.4.14 Investment Promotion

- Mining and processing of minerals require investment to enable the operators to acquire technology. In addition to existing interventions by the Bank of Industry (BOI), there should be a special intervention fund that can be put together by oil companies with coordination from the Nigerian Content Monitoring Board (NCMB), Solid Minerals Development Fund, and Central Bank of Nigeria. This fund can be accessed by ASM operators to improve productivity. Efforts should be made to build the capacity of the ASM operators to access these funds.

- The role of development partners in investment promotion in the sector cannot be overemphasized. The challenge with some of the interventions is that they do not trickle down to the actual intended beneficiaries due to bureaucracy. This needs to be addressed.
- The survey part of this study was conducted in 2019, before COVID-19. COVID-19 is currently devastating the livelihood of the miners since the economy is shut down. Most likely, the miners are currently idle. It is therefore important that the Central Bank of Nigeria (CBN) and other intervention agencies implement special fund intervention to assist the miners to overcome the extra challenges imposed by COVID-19.

5.4.15 Social Considerations

Social issues relating to ASM of barite which include: gender participation, enforcement of child labor laws, banditry, violence, and social disruption due to land disputes and encroachment on large-scale mining operations must be seriously looked into. The sector should be reformed and brought into the formal sector of the economy for inclusiveness. These and other issues can be resolved if more attention is paid to research and development to generate data and understand the operations of the sector better.

5.4.16 Strengthening of Institutional Framework for ASM

The Federal Ministry of Mines and Steel Development (MMSD) has created several institutions including the Mining Cadastre Office, Mines Inspectorate Department, Mines Environmental Compliance Department, Artisanal and Small Scale Mining (ASM) Department among others. Moreover, the state government has established an investment promotion agency. There are also other parastatals within the system that one way or the other are supposed to impact the operations of the miners and processors. However, these institutions have not been able to discharge their functions optimally because of some inherent weakness. They should therefore be strengthened.

5.5 Conclusions and Policy Recommendations

This study on artisanal and small-scale mining (ASM) of barite ores in Nasarawa state, Nigeria has identified the barite ore value chain and several challenges that affect the sustainable development of ASM of barite in Nasarawa state. It was discovered that the miners are caught in a poverty trap and their activity is associated with illegalities, social vices, safety, health, and environmental challenges that prevent sustainable development of the sector. Nation’s policy on ASM has not been adequately focused on barite neither has it been appropriately aligned with other poverty alleviating programmes.

We have therefore proposed policy and legal frameworks for ensuring sustainable ASM of barite in Nasarawa state which include integration of ASM into wider rural development programmes, support for capacity building in ASM, social considerations, investment promotion, and formalization of operations to benefit from government interventions. The frameworks should also be applicable to other solid minerals within the sector.

Future research will include extending the work to an analysis of the value chain for barites from mining, pre-processing, sales, marketing, and the use of the mineral for making drilling mud for oil and gas industry as well as other industrial applications. Future research should also carry out deeper studies on other strategic minerals and explore how ASM can be formalized and integrated with large-scale mining. Finally, it will be useful to evaluate the donor funded projects currently being implemented by the Federal Ministry of Mines and Steel Development (MMSD) to determine their actual impact on ASM.

SUPPLIMENTARY DATA.

QUESTIONNAIRE /SURVEY FORM

ARTISANAL BARITE MINING IN NASARAWA, PLEATEAU AND TARABA STATES

PhD Research

Name: Itohan Otoijamun

Institution: African University of Science and Technology, Abuja Nigeria

Department: Material Science and Engineering

Sir/Ma,

This study aims at investigating the presence of Barite, types of Barites, reserve estimate, mining activities, machineries, environmental, health and socio-economic effects of artisanal mining in …………………………… region of ………………………state. This survey is carried out solely for the purpose of academic research work. Any information provided will be strictly confidential and not intended for any purpose outside research.

SECTION A: DEMOGRAPHIC CHARACTERISTICS OF RESPONDENTS.

1. Name of Community/Settlement ……………………………………………
2. Type of Location (a) Town (b) Village (c) Hamlet (d) Others (Specify) ……………….
3. Community type (a) Mining Community (b) Non-Mining Community
4. Local Government Area ……………………………………………...
5. Nationality…………………………………………………..
6. Gender (a) Male (b) Female
7. Marital Status (a) Married (b) Single (c) Others
8. Household size of respondents ..…………………………………………….
9. How long have you been living in this town/village? ....
10. Age of respondent ………………………………………………………

11. Highest educational level attained (a) Primary School (b) Secondary School

    (c) Polytechnic (d) College of Education (e) University (f) No formal Education.

12. Present occupation of respondents (a) Agriculture (b) Mining (c) Petty Trading (d) Agriculture and Mining (e) Agriculture and petty trade (f) Government employee (g) Construction worker (h) Agriculture and livestock (i) Others (Specify) …………………………………………………….

13. What was your initial occupation before you switch to the present occupation (a) Agriculture (b) Mining (c) Petty Trading (d) Agriculture and Mining (e) Agriculture and livestock (f) Government employee (g) Construction worker (h) Agriculture and petty trade (i) Others (Specify) ……………………………

14. List some of the reasons for the occupation charge ……………………………………

15. How long have you been engaged in this present occupation? ....

16. How many years did you spent on the previous occupation . …………………………

17. What is your annual income then? ....

18. What is your annual income now?...

19. Do you own or rent house here? ....

20. How much do you pay as rent? ....

21. Are you aware of any mining activity around you? Yes / No

22. How many members of your family are in the business of mining? ....

23. How has mining in your area affected you? A) Positively, b) negatively, c) no effect.

24. Estimated distance from your residence to the nearest mining site in kilometers

    a) 1 kilometer
    b) 2 kilometers
    c) 3 kilometers
    d) 4 kilometers
    e) 5 kilometers

25. what is the means of transportation to the mining site

    a) Foot
    b) Bicycle
    c) Motorcycle
    d) Car
    e) others

26. Estimate cost of transportation to the nearest mining site from your residence ……..………......

27. Do you have any family member in the mining industry? Yes No

28. If you are mining worker, which aspect of mining do you work

a) Mine owner/proprietor of mine shaft

b) Digger

c) Security

d) Mine intermediary

e) Mineral buyer

f) Please give names of minerals mined here ……………………..

g) What is your annual, monthly, or daily remuneration? …………

29. If you are mine owner how much do you pay as royalty? ....

SECTION B: MINING AND PROCESSING ACTIVITIES

30. Who determines the site

a) Professionals

b) Nonprofessionals

c) Investors

d) By inhabitants

31. How is the site determined

a) seismic

b) GPS

c) Coincident

32. What technology is used in the mining process

a) Hand tools

b) Heavy machines

33. Where are these stone washed?...

34. Collection point of the ore after mining

a) Mining site

b) Close to site

c) Market

d) Factory

35. Collectors of minerals (barite ore)

a) On site Buyers

b) Investors

c) Mineral processors

d) Local market

e) End users

36. Challenges in the mining activities

a) Lack of Technical knowhow

b) Poor mining tools

c) Poor road network

d) Health hazards

e) Environmental hazards

f) Poor renumeration

g) Poor pricing

h) Government action and inaction

37. Challenges in processing of barites

a) Few processing plants/companies

b) Distance between mining sites and processing plants

c) Impurities associated in the core

d) Old Equipment for processing

e) Expert/professionals to operate the machines

f) Others

38. How much is a bag of 20/50 kilogram of barite …………………………

SECTION C: SOCIO-ECONOMIC IMPACT OF MINING ACTIVITIES

Table 1: SOCIO-ECONOMIC IMPACT OF MINING ACTIVITIES

Benefits	Very high (5)	High (4)	Moderate (3)	Low (2)	Very low (1)
Conflict between indigenes and migrant worker					
Creation of employment					
Drop in school enrollment					
Improved electricity supply					
Improved social life					
Improvement in living standard					
Improvement in sale of petty trade items					
Increase in crime					
Increase in health-related diseases					
Increase in land price					
Increased food crop sales					
Increased house rent price					

Increase social vices. Specify	
Large scale influx of immigrants and visitors in search of jobs	
Low agricultural productivity	
Security threat	
Truancy	
Others (Specify)	

SECTION D: ENVIRONMENTAL IMPACT OF MINING ACTIVITIES

Table 2: kindly rate the environment effects of mining on this community as indicated in table (Please tick as appropriate)

Disadvantages	Very high (5)	High (4)	Moderate (3)	Low (2)	Very low (1)
Increased dust release					
Air pollution					
Increase in mine pit collapse					
Threat to farmland and crops					
Damages to buildings					
Noise from blasting					
Deforestation					
Land degradation					
Others (Specify)					

SECTION E: HEALTH & SAFETY IMPACT OF MINING ACTIVITIES

39. Please indicate any of the under listed diseases you or your family member may have had as a result of mining of barite:

a) Pulmonary diseases e.g asthma, lung inflammation etc. please indicate……………..

b) Infectious diseases Please indicate………………………………

c) Skin rashes

d) Others

40. Has there been any loss of relative as a result of mining and processing of barite

a) Yes

b) No

41. Which of the following do you wear to your mining sites?

a) Coverall

b) Safety boots

c) Helmet

d) Safety glasses

e) Nose mask

f) Hand gloves

42. Have you experienced any accident at the mining site?

a) Incident

b) Accident

c) Near miss

d) Others

43. Have you received any training on Health and Safety in mining

a) Yes

b) No

44. Do you have any safety protocol/permit to work before mining

a) Yes

b) No

45. Do you have any first aid kit at the site

a) Yes

b) No

46. Where is the nearest health Centre or facility

a) 1km

b) 2km

c) 3km

d) 4km

e) Others

47. Is there anything to make your operation safer? ………………………

SECTION F: GENDER IMPACT

48. Are there gender roles in mining?

a) Blasting M/F

b) Digging M/F

c) Washing M/F

d) Collection M/F

e) Drying M/F

f) Sorting M/F

49. Any negative impact on women? …………………………………….

50. Any role for children? ………………………………………………..

51. Any income disparity between men and women?

SECTION G: GENERAL

52. What are the problems confronting the mining of barite …………. ……………………………………………………………..

53. Is state government involved in the mining of barite...………..………

54. What steps is government taking towards exploiting this mineral for the development of this Community ……………………………………………. ………………………………………………………………………………… ………………………………………………………………………………….

55. What other relevant information do you have in respect of mining in this Community ………………………………………………………………….. ………………………………………………………………………………….. …………………………………………………………………………………..

1. Supplementary information

The socio-economic characteristics of respondents are shown in Table S2.

Table S2. Socio-economic characteristics of the respondents.

Socio-economic characteristics	**Range**	**Percentage of respondents**
Age	<18	12.0

	18-30	17.5
	31-50	62.0
	51-60	7.0
	>60	1.5
Marital status	Single	10.5
	Married	49.0
	Divorced	17.0
	Widowed	23.5
Highest Educational Qualification	None	41.5
	Primary	31.5
	Secondary	18.5
	Tertiary	9.0
Household size	1-5	17.0
	6-10	46.5
	11-20	29.0
	>20	7.5
Number of family members in mining	1-5	50.5
	6-10	29.0

	11-20	18.0
	>20	7.5
Years of experience in mining	<5	28.5
	6-10	38.0
	11-20	17.0
	>20	16.5
Type of mineral mined	Barite ore	61.0
	Galena	14.5
	Salt	16.0
	Limestone	8.5
Present occupation	Mining only	12.5
	Agriculture only	4.5
	Trading only	6.0
	Govt employee	4.0
	Mixed	73.0
Occupation before switching to mining	None	27.0
	Agriculture	46.5
	Trading	12.5

	Govt employee	9.5
Annual income before mining (1000 Naira)	<N50	24.5
	51-150	30.5
	151-300	32.0
	301-500	13.0
	501-1000	0.0
Annual income now as a miner	<N50	15.0
	51-150	38.0
	151-300	18.5
	301-500	23.5
	501-1000	5.0
Impact of mining on your livelihood	No impact	7.0
	Positive impact	72.0
	Negative impact	21.0

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CHAPTER SIX

GENDER DIMENSIONS OF ARTISANAL AND SMALL-SCALE MINING (ASM) OF BARITE ORES IN NASARAWA STATE, NIGERIA

6.1 Introduction

Most of the mining activities currently going on in Nigeria and indeed other African countries can be classified as Artisanal and Small-Scale Mining (ASM) [1,2,3]. Basically, this class of miners see the activity as a way out of poverty or as an activity to complement insufficient income from their primary occupation which may be agriculture or hunting. It is also a very diverse sector with challenges that vary from region to region and often from site to site. This fact has been missed by government and other intervention agencies over the years. This has misinformed legislation and extension programs and led to the application of one-size-fits-all policy for the mining and mineral sector in Nigeria and other parts of Africa [4,5]. However, people working in ASM and their operating conditions are far from this notion. They range from those whose livelihoods revolve around subsistence farming to skilled workers who migrated from urban areas in search of work to land speculators and unemployed uneducated and untrained miners. Therefore, there is need for comprehensive study of the operators and their working environment in order to optimize operations and ensure sustainable supply of barites.

Artisanal and small scale mining (ASM) plays a significant role in the mineral supply chain of Africa. In 2016, about 500,000 personnel were directly involved in ASM of gold in Africa with an estimated 2,500,000 dependants [6]. Although the ASM is characterized by low efficiency and productivity, it is an important source of minerals and metals in Nigeria and other developing countries, accounting for about 20% of the global gold supply, 80% of sapphire supply and 20% of diamond supply [7]. The sector is also a major producer of tantalum and niobium minerals for manufacturing capacitors in electronic industry (laptops and cell phones) with 26% of global tantalum production and 25% of tin coming from ASM [8].

Although there is lack of data regarding percentage of women in the labour force of ASM, women are believed to constitute about 30% of global ASM workforce [9] and up to 50% in Africa [10]. In some parts of Africa (such as Guinea), the proportion is as high as 75% [11]. Despite this significant participation of women in ASM in various capacities, they are rendered inconsequential in all aspects of the ASM value chain with respect to economic gains. This impacts negatively on productivity in the sector. Although relatively many researchers have worked on gender roles in mining in other parts of Africa, only a few of studies have been done in Nigeria [12,13,14]. Knowledge from such studies can help in optimizing ASM and hence improve the supply of minerals in Nigeria. This is important for Nigeria whose government has identified 7 strategic minerals for development in order to diversify the economy. One of these 7 minerals is barite.

Barite is an industrial mineral which is used in making drilling mud and other engineering applications [15,16,17]. Current estimates indicate that demand for barite by the industry in terms of quality and quantity cannot be met in a sustainable manner by local production, leading to importation. The mineral is found in commercial quantities in Cross River, Benue, Nasarawa, Plateau, Taraba, Adamawa Zamfara and Gombe states of Nigeria [18,19,20,21,22]. Thus, any technological and policy intervention that can lead to sustainable supply of the mineral to the industry will lead to foreign exchange earnings savings and creation of jobs and livelihoods for different operators in the value chain. In fact, as part of efforts to diversify the revenue base of the country, Nigeria through some agencies of government is implementing some policies and guidelines aimed at decreasing importation of barites and hence increasing local production [23].

In Nigeria, exploitation of barite deposits is largely dominated by ASM using crude implements and technologies. As with other ASM of other minerals in Nigeria, women and under aged children are involved in some aspects of the value chain. Several studies on the gender dimensions of ASM for other minerals such as gold and granite have led to suggestions on how to improve the value chain operations and hence ensure the sustainable supply of the mineral [24,25,26]. Although studies have been conducted on gender issues in ASM of other minerals such as gold, there is no published work on gender dimensions of ASM of barites in Nigeria. Yet this is an important supply chain issue for an important mineral such as barite in a major mineral zone of Nigeria.

The main aim of this study was to evaluate gender issues towards improving the productivity of ASM operations for barite in Nasarawa state and hence ensure sustainable supply of the mineral for the relevant industry in Nigeria without adversely affecting the livelihood and health of the workers in the supply chain. The specific objectives of the study were to: assess gender participation in the barite production value chain in Nasarawa state; evaluate specific roles of men and women in the barite mining value chain; determine gender dimensions of operational challenges and impact of the mining operations and evolve sustainable strategies towards improving the productivity of the female mine operators and hence the productivity of the entire value chain.

6.2 Review of Gender Issues in Artisanal and Small-Scale Mining in Nigeria

6.2.1 Artisanal and Small Scale Mining (ASM) in Nigeria

A very comprehensive review of definitions of Artisanal and Small Scale Mining (ASM) by different multilateral organisations such as International Institute for Environment and Development (IIED), World Bank, International Council on Mining and Metals (ICMM), United Nations Economic Commission for Africa (UNECA), United Nations Environment Program (UNEP) and Swiss Agency for Development and Cooperation was given by Hilson & McQuilke [1]. From the above, ASM is characterized by: use of rudimentary techniques for mineral extraction or technology and often operate under hazardous, labor-intensive, highly disorganized and illegal conditions; low productivity since ASM often takes place in very small or marginal plots, is limited to surface or alluvial mining, and uses inefficient techniques; lack of safety measures, health care or environmental protections; may be practiced seasonally (e.g., to supplement farm incomes) or temporarily in response to high commodity prices; lack of long-term mine planning and use of rudimentary techniques.

Artisanal and Small Scale Mining in Africa has attracted the attention of many researchers [27,28,29,30]. In Nigeria, only a few studies have provided some insight into the dynamics, challenges and prospects of Artisanal and Small Scale Mining [3]. These studies have shown that the sector is greatly misunderstood and that is why in many cases, the operators are referred to as illegal miners. But in a large country such as Nigeria with large deposits of many minerals, the combination of many factors has driven many resource poor people into mining. However, the operations of ASM are hindered by many factors including weak implementation and enforcement of mining laws, limited awareness of environmental, health and safety issues, fragile ecosystems of the mining environment, host community conflicts, poor infrastructure and lack of access to financing. These challenges have limited the contribution of artisanal and small-scale mining (ASM) to the nation's economy to less than 1% currently [31,32,33]. In order to mitigate these problems, government has over the years implemented various reforms, policies and programs, usually with support from donor agencies and partners. These include: Mining Act of 1999, 2007, National Minerals and Metals Policy, 2008 and the first Strategy road map in 2012; Vision 2020 Report of the National Technical Working Group on Minerals and Metals, 2009; Nigerian Minerals and Mining Regulations, 2011; Roadmap for Sustainable Development of Mining and Metals sector in Nigeria in 2016. These policies and programs were aimed at liberalizing the sector in order to attract large scale mining companies back to Nigeria. The institutional framework that came out of the various reforms is now responsible for regulatory, oversight and technical support to the private sector. Some of the institutions operate directly as departments under the Federal Ministry of Mines and Steel Development and include: Mines Inspectorate; Mines Environmental Compliance; Artisanal and Small Scale Mining; Mining Cadastre Office; Metallurgical Inspectorate and Raw Materials Development and Steel and non Ferrous Metals. The other institutions operate as semi-autonomous institutions under the supervision of the Ministry. These include: Nigerian Geological Survey Agency; Nigerian

Institute of Mining and Geosciences; Nigerian Metallurgical Development Centre; National Steel Raw Materials Exploration Agency, Council of Mining Engineers and Geoscientists and Nigerian Extractive Industries Transparency Initiative (NEITI). It should be noted that while these efforts were going on, the educational sector also witnessed the establishment of different departments of Mining and Minerals processing in Nigerian universities and polytechnics to train required high level manpower for the sector.

Although these policies and reforms have helped in repositioning ASM in Nigeria, the issue of non-inclusiveness and non-formalization of the sector remains a major constraint. In addition, in implementing the sectorial policy of licensing, many mining licenses are held by absentee miners who are usually rich people who have the resources to obtain the license. Government has also introduced the formation of miners cooperatives in order to enable groups of people have the capacity and capability to obtain license and hence formalize their operations. These have not worked very well also because of inability of the miners to work in groups. Cooperatives have been faced with challenges of trust and accountability and difficulty in accessing government interventions, leading disintegration and inability to work together. Thus, ASM operations are still dominated by unorganized peasant operators with little or no equipment and largely unregulated and uncontrolled. There is therefore the need for a deeper understanding of the dynamics of ASM in Nigeria vis a vis the mining laws, policies and programs being implemented by government with support from development partners.

6.2.2 Gender Issues in ASM

A very important criterion for sustainable development is that men and women have a right to live decent lives with equal opportunities free from hunger, discrimination, violence, oppression, injustice [34]. Gender refers to the behaviours, attitudes, values, beliefs that a particular socio-cultural group considers appropriate for males and females. Gender equity has not always been guaranteed in the work place all over the world. In some sectors of the global economy, there is gender disparity in roles of male and female workforce. In most cases, societies are organized in such a way that men have more opportunities to move up the ladder of economic progress than women. This disparity is probably more in the mining industry in general and ASM in particular.

Globally, up to 30% of the worlds artisanal miners are women [7]. This percentage varies from one part of the world to the other. In Asia, less than 10% of miners are women. In Latin America, the percentage is higher (10-20%) [8]. The percentage is highest in Africa, where it is estimated at any where between 40% and 50% [9]. Empirical evidence has shown that even with this high number of women in the sector, the society and environment has made it impossible for women to achieve their potentials and hence contribute meaningfully towards improved productivity in the sector [14]. In most cases, the women are involved in those aspects of work that do not attract comparable remuneration with their male counterparts and yet they are exposed to more environmental and health hazards.

The perceived differences in gender roles have been attributed to differences in physical abilities of male compared to female, cultural biases, stigmatization and socio-economic differences. These differences have been studied in different countries of Africa including Ghana, Sierra Leone, Kenya, Democratic Republic of the Congo, DRC and Uganda [35,36,37,38]. In Nigeria, only a few studies have been carried out to highlight the issue of gender in ASM. The government and the donor agencies especially the World Bank have also realized that this issue needs more studies and understanding [39].

These and other studies have shown that any initiative that is aimed at improving ASM must take into consideration the role of men and women. The first step towards achieving this is to understand the roles and then make informed recommendations on how to ensure gender parity in the sector. In planning to optimize the contributions and participation of men and women in ASM, the concerns of men and women must be taken into consideration in designing intervention projects These concerns include: awareness on the different roles of men and women, equitable participation of women, empirical studies on gender based differences in labour, regulatory bodies and agencies of government should be manned by both male and female, networks of women in ASM should be formed or strengthened where they exist, training and special micro-financing targeted at women.

6.3 Research Methods

6.3.1 Conceptual Framework

The conceptual framework that underpins this research is shown in Figure 1. The problem addressed is how to ensure sustainable supply of Nigerian barites in the required quantity and quality to increase local content in the sector with a fair balance in gender roles and recognition. Nigeria, through the National Content Monitoring Board (NCMB) has indicated the drive towards ensuring that all barite used by the Oil and Gas industry is sourced locally. For this to happen, the supply chain for the mineral needs to be understood to ensure sustainable supply. In order to generate empirical and evidence based knowledge, the study starts with a comprehensive assessment of the entire value chain for local mining and beneficiation of barite using a selected state in Nigeria (Nasarawa state) as case study. Sustainable supply can only improve if the different components of the value chain are studied with a view to identifying bottlenecks, weak links in the supply chain and determining how the different types of miners (male and female) can be assisted to optimize their operations in the sector. A major aspect of the value chain is the human resource that is involved in mining and preliminary beneficiation. Based on published work on ASM of other minerals such as gold and preliminary survey, women play a major role in the value chain, but this has not been scientifically quantified and recognized. Thus, the study looked at the

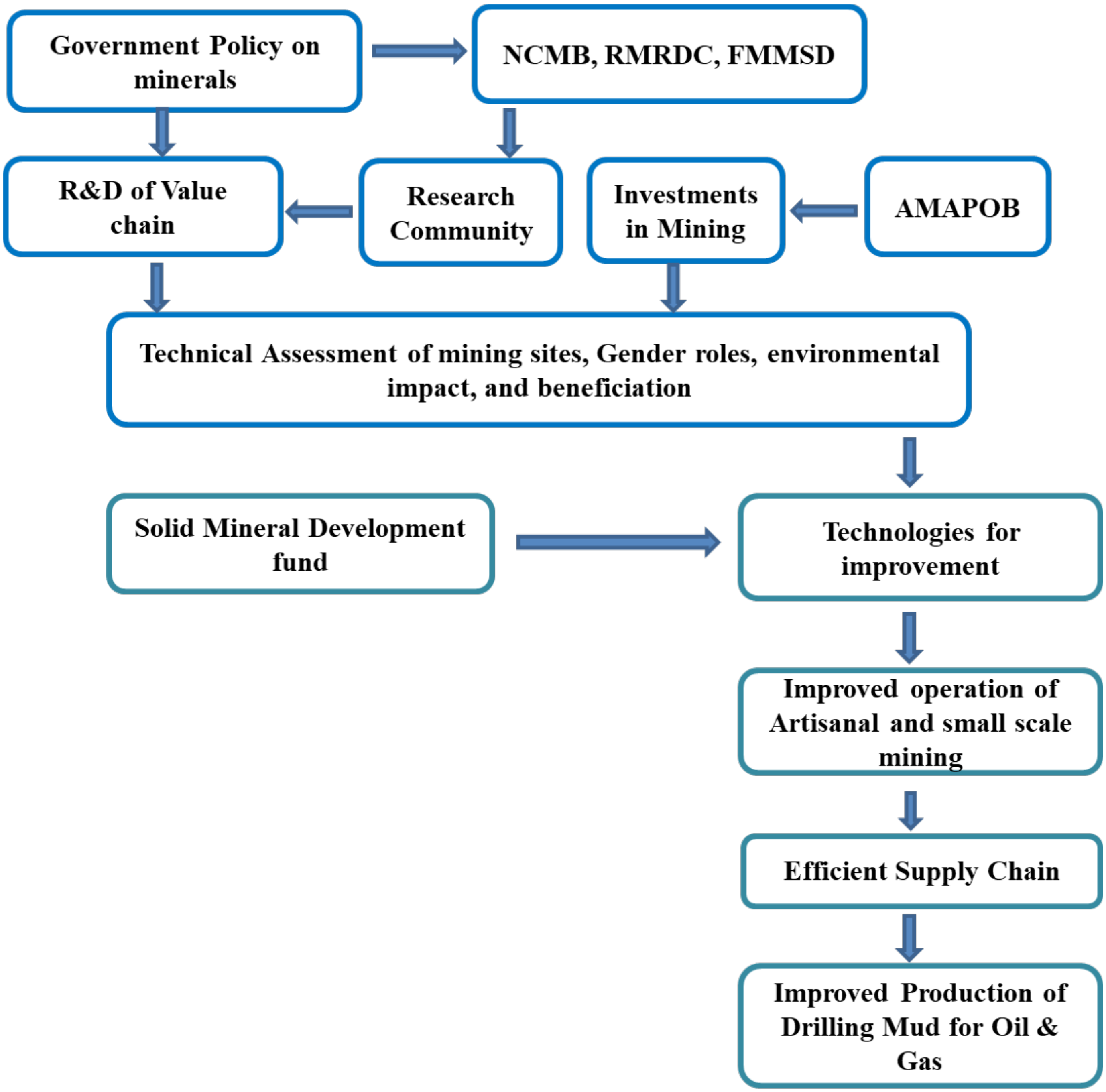


Fig. 1 Conceptual framework for the study of Gender dimensions of ASM of barite.

NCMB – Nigerian Content Monitoring Board; RMRDC – Raw Materials Research and Development Council

FMMSD – Federal Ministry of Mines and Steel Development; AMAPOB – Association of Miners and Processors of Barites; R&D – Research and Development

role of men and women in different aspects of the chain while identifying the challenges and suggestions for improvement. The interaction of these would enable the evolution of sustainable strategies and policy adjustments towards ensuring improved supply while improving the work environment for the key players, especially women.

6.3.2 Study Area

The study area is Nasarawa state, Nigeria which lies between latitude 7˚ 45′ and 9˚ 26′ North and longitude 6˚ 55′ and 9º 42′ East. A few of the sites are accessible by motorable roads and others that are not by motorcycles or boats when crossing rivers. The barite mineralization zones of the state lies within Latitude 8˚ 01′ N – 8˚ 29′ N and Longitude 9˚ 3′ E – 9˚ 23′ E

6.3.3 Research Questions

The research questions are:

(i) What are the roles of men and women in the different components of the barite mining value chain?

(ii) Are there differences between men and women miners in perception of challenges of ASM of barite?

(iii) What are the strategies for improving the productivity of male and female barite miners for the area?

6.3.4 Questionnaire Design

A semi-structured questionnaire was designed and used for the study. Model answers were provided in the questionnaire for questions such that the respondent will only tick the answer corresponding to his/her situation. In some cases, the use of Likert scales for qualitative answers were provided. The questions in the questionnaire are grouped into seven sections as follows:

Section A – Demographic characteristics of the respondents, male and female.

Section B – Mineral Mining and Processing activities (Value chain) and the role of male and female.

Section C – Socio-economic dynamics of mining activities in relation to male and female miners.

Section D – Health and Safety aspects of mining activities as they affect male and female miners.

Section E – Gender Impact of Mining.

Section F – Problems confronting the miners and how these problems affect male and female miners.

The questionnaire was validated by three experts in scientific surveys. In addition, a trial survey was conducted by administering the questionnaire to ten respondents in a pilot study and issues raised during this pilot were used to improve the questionnaire for the final survey.

6.3.5 Data Collection

To collect data using the questionnaire, a physical survey was conducted by visiting the mining sites and interacting with the miners. Where the miner is literate, he/she completed the questionnaire. Where otherwise, the questionnaire was completed by the researcher, assisted by two research assistants by asking the questions in the local language and completing the questionnaire by himself or herself. A total of 13 mining sites were visited. These were selected based on those with sizable number of miners. There are many mining sites within the area of study but many of these sites are small with 10 to 20 workers. Thus a purposive sampling technique [40] was used to select only those sites with at least 10 miners. In each site, there were about 20 people working but only about 10 were actual miners. Therefore, on the average, 10 questionnaires were completed per site, giving a total of 130 questionnaires. There were also Focused Group Discussions (FGD). These discussions were held with four groups of people separately. These were the miners in the field, officials of Association of Miners and Processors of Barites, (AMAPOB), Miners Association of Nigeria (MAN) and government and regulatory agencies at the state and federal government levels. For the Focused Group Discussions, the relevant officials were engaged in discussions using a checklist made up of the research questions. Approval of the participants were obtained before the commencement of the interviews and discussions. Their consent for recording the discussions and taking photographs was also obtained. Ethical approval for the research was obtained from Research management office of the university before commencement of the field survey.

6.3.6 Data Analysis

Data were extracted from the questionnaires through frequency tabulation. Simple descriptive Statistics (mean, standard deviation, percentages) were calculated. In some cases, graphs, pie charts and bar charts were used for graphical representation of the data.

6.4 Results and Discussion

6.4.1 Characteristics of the Respondents

The socio-economic characteristics of the respondents are shown in Table 1. The table shows that most of the miners (62%) are between the ages of 31 and 50. It is interesting to note that up to 12% of the miners are children below the age of 18. This calls for policy and regulatory guidelines implementation to prevent mine operators from using minors who should be in school.

Results show that more of the male miners (77%) are married compared to 21% for the females. Most of the women (41%) miners are widows while another significant percentage (29%) are divorced. This means that the economic motive is important in women becoming miners. For educational qualifications, 49% of the female respondents do not have any education compared to 31% male. For family size, 14% of males have family size of 1-5, 50% have size 6-10, 26% have family size 11-20 while 10% have family size above 20. The corresponding figures for females are 20%, 43%, 32% and 5%.

In terms of experience of the respondents in mining, the percentage for those who have been in mining for less than 5 years, between 6 and 10 years, 11-20 years and above 20 years are 10%, 50%, 22% and 18% respectively for men and 47%, 26%, 12% and 15% respectively for women. Although the mines are primarily for barite, the results in Table 1 show that there are other mineral occurrences. The respondents indicated that 60% of the minerals mined are barites, followed by salt (17%), galena (14%), and limestone (9%) for males and 62%, 15%, 15%, 8% for female respondents. What this means is that any beneficiation technology to be employed must be able to remove these associated minerals in order to upgrade the quality of the barite. This can bring in additional income to the operators.

Most of the miners are involved in other economic activities as shown in Table 1. These other activities are agriculture, petty trading, government work and those who are unemployed. The response is similar for both men and women. Most of the miners were involved in other occupations before venturing into mining. Table 1 shows that for men, 14% were not involved in any activity, 52% for agriculture, 20% trading, and 14% government employees. The corresponding figures for females are 40%, 4%, 5% 5%.

Table 1 shows that more women earned less than men before joining the mining business. Whereas 80% of women earned ₦150,000 or less, the equivalent figure for men was 30%. The earning capacity increased as the respondents entered the mining business. The results show that more women miners are in the very low earning capacity bracket compared to men since up to 30% of the female respondents earned less than ₦50,000 per annum compared to 0% of men earning less than ₦50,000. For the impact of mining on livelihood as perceived by the miners, there are differences between the response of men and women. More men (80%) indicated that mining has positive impact on them compared to women (64%). On the other hand, more women (31%) indicated that mining has negative impact on them compared to men (11%). This area therefore needs policy intervention. Earlier studies have indicated socio-economic impacts of ASM for other minerals similar to results of the present study [41,42].

Table 1. Socio-economic characteristics of the respondents.

		Percentage of respondents %	
Socio economic characteristics	**Range**	**Male**	**Female**
Age	<18	14	10
	18-30	20	15
	31-50	60	64
	51-60	5	9
	>60	1	2
Marital status	Single	12	9
	Married	77	21
	Divorced	5	29
	Widowed	6	41
Highest Educational Qualification	None	34	49
	Primary	28	35
	Secondary	26	11
	Tertiary	13	5
Household size	1-5	14	20
	6-10	50	43
	11-20	26	32
	>20	10	5
Number of	1-5	55	46

family members in mining	6-10 11-20 >20	30 20 5	28 16 10
Years of experience in mining	<5 6-10 11-20 >20	10 50 22 18	47 26 12 15
Type of mineral mined	Barite ore Galena Salt Limestone	60 14 17 9	62 15 15 8
Present occupation	Mining only Agriculture only Trading only Government employee Mixed	15 5 7 6 67	10 4 5 2 79
Occupation before switching to mining	None Agriculture Trading Government employee	14 52 20 14	40 40 5 5
Annual income before mining (1000Naira)	<N50 51-150 151-300 301-500	14 16 50 20	35 45 14 6

	501-1000	0	0
Annual income now as a miner	<N50	0	30
	51-150	20	56
	151-300	25	12
	301-500	45	2
	501-1000	10	0
Impact of mining on your livelihood	No impact	9	5
	Positive impact	80	64
	Negative impact	11	31

6.4.2 Gender Roles in ASM of Barites

Figure 2 shows the phases involved in ASM of barites. It shows that Phases 1 and 2 namely blasting and digging (open caste mining) of barite ore are carried out 100% by men. Nasarawa state mining pits are typically 15 – 20m deep with very delicate entry points beyond the capability of women. As such, women are not involved in the actual digging of the barite ore, nor are they involved in the operational management of the site. This result is in agreement with earlier reports for other locations [7,8].

The next activity in the value chain (cracking of barites) is carried out by 90% men, 5% women and 5% children. We can see that as the required energy decreases, more women are involved in the value chain. However, we believe that if appropriate technology is introduced which will not require physical energy to operate, both men and women will participate in mining without hindrance. The main tasks carried out by women are Phases 4 to 7 (Figures 2). These include transfer of mined materials from the pit collars to washing point (70% women and 30% children); washing and drying of the barite ore (90% women and 10% children); sorting of the ore (men=25%; women=75%; children-0%); and stacking of processed materials for collection by vendors (men=25%; women=65%; children=10%). Women process the barite to ensure that the mined barite meets certain requirement as directed by the site managers or vendors. They also provide other services that are not directly connected to the barite production such as food and cigarette vending; supply of working tools, working garments and recharge cards for cell phone, and selling drinks.

Overall data show that when the entire mining workforce was considered, 52% were male and 48% were female.

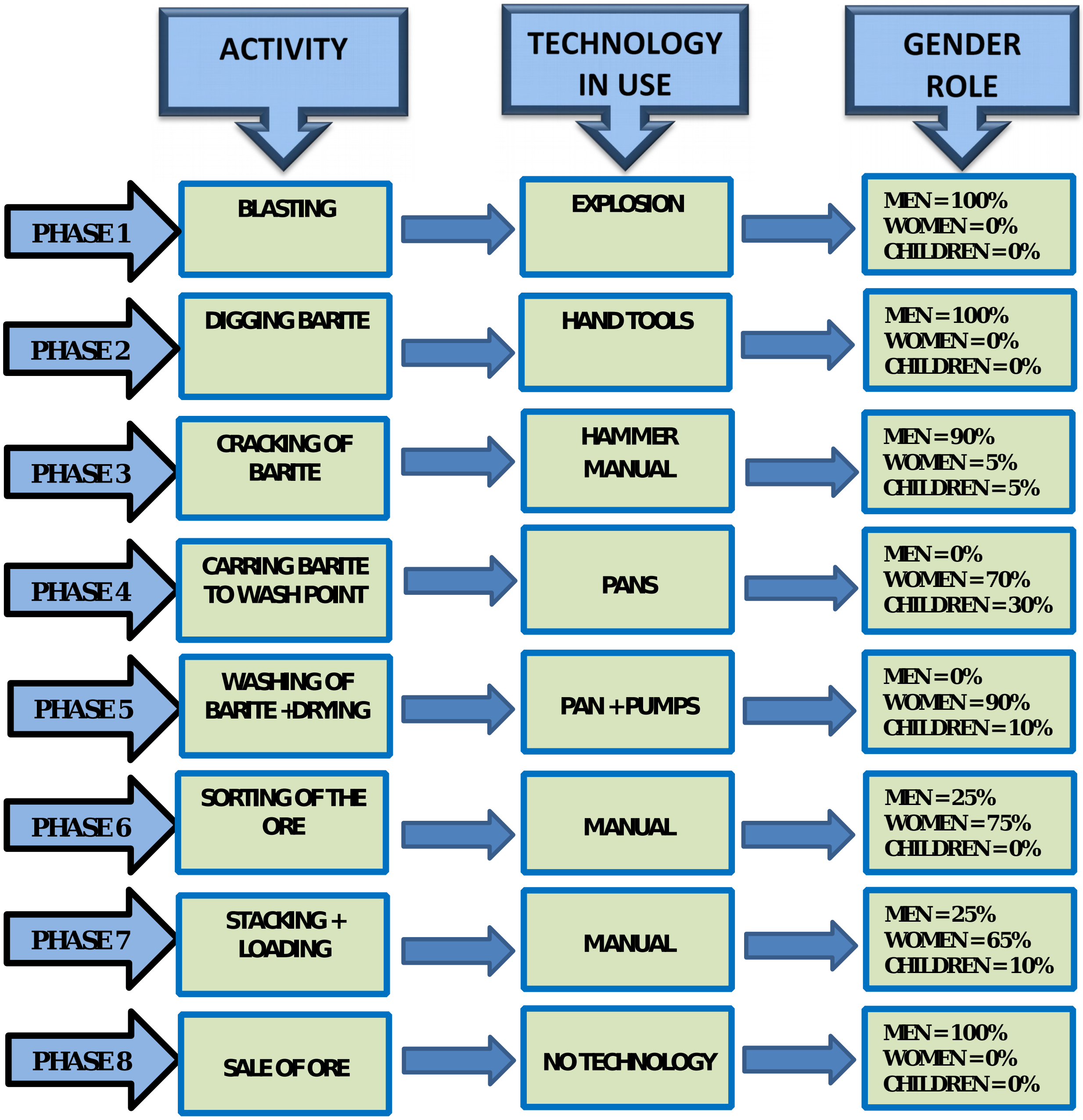


Figure 2. Components of the value chain for barite mining showing activities, technology and gender roles.

6.4.3 Challenges Facing Artisanal and Small Scale Mining (ASM) of Barites as seen by Male and Female Miners

The challenges confronting ASM of barites were identified to include government action/ inaction; poor mining tools; poor access roads; poor pricing; poor remuneration; lack of technical know how; health hazards and environmental hazards. These are in line with the earlier findings of other studies for other minerals [43,44,45,46,47]. As shown in Figure 3, the most important ones as perceived by the miners are: government action/inaction; poor mining tools; poor access roads; poor pricing (where over 50% of the respondents indicated very important).

Like the men folks, the tasks of the women are associated with operational challenges characteristic of such tasks in ASM operation, ranging from health to safety hazards. For instance, the women are not provided any safety gear to protect them from possible accidents such as falls and/or injuries that can occur from the tasks. The working environment of ASM site is often an uneven ground that is prone to slips; as such, carrying heavy loads around the site can be very tedious and stressful. Majority of the women labour complained of incessant body pains, back and headaches; even falls and first aid arrangement is not available, nor medical/ health center close to the mining site in the event of any accident or health challenge. The processing of barite in Nasarawa state does not involve the use of chemicals like in ASM for gold, so there is no risk of chemical pollution.

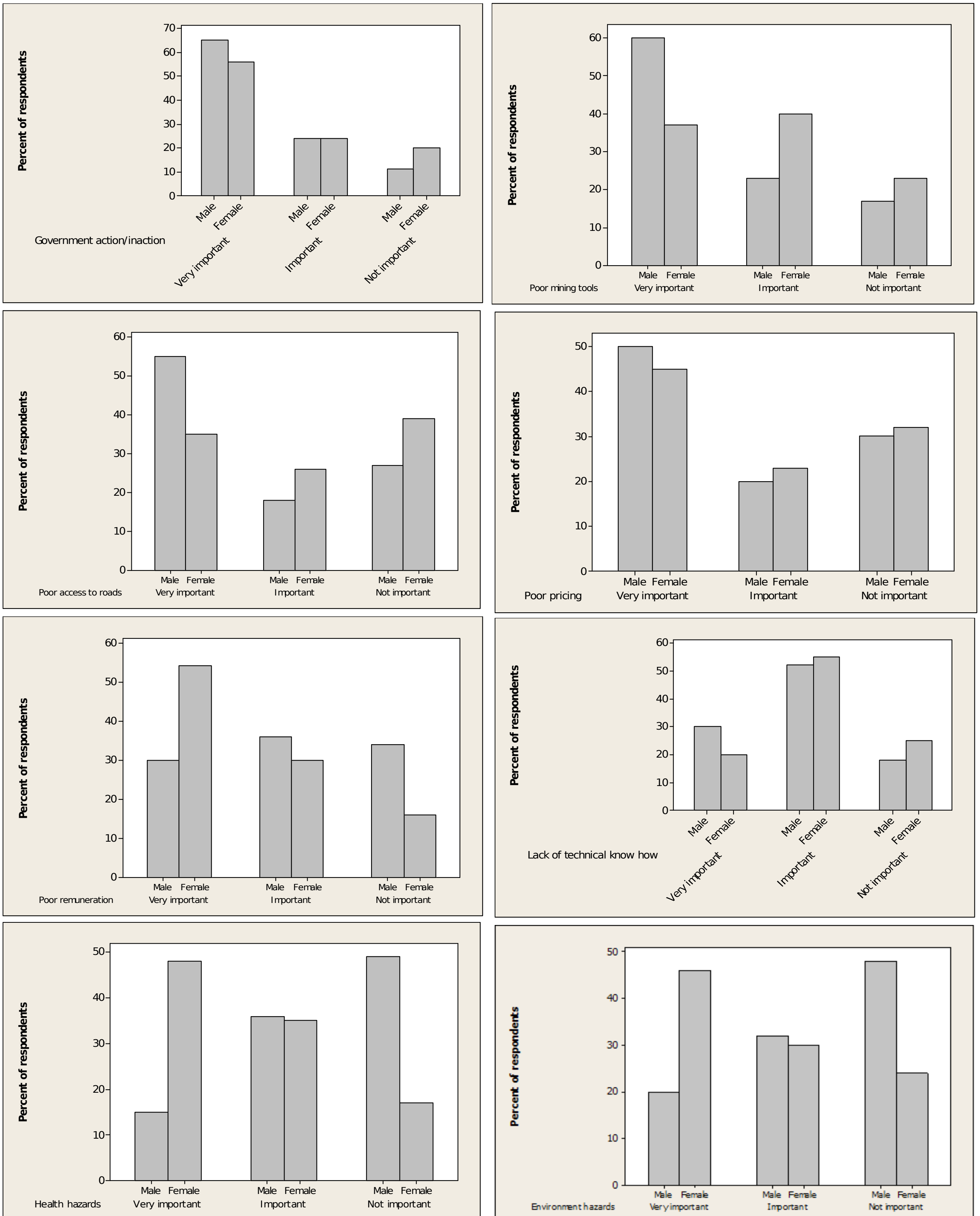
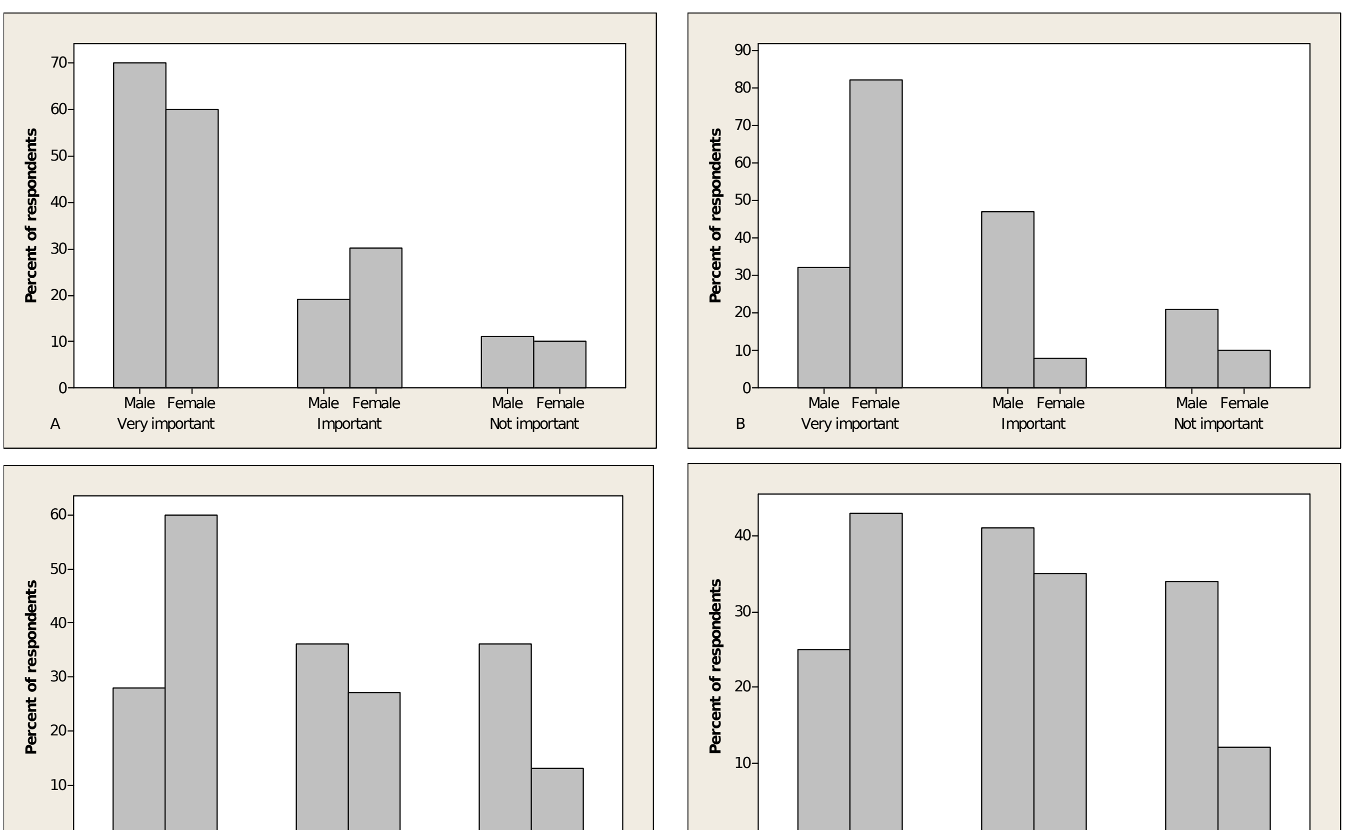
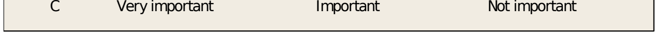


Figure 3. Challenges of Artisanal and Small Scale Mining of Barites as seen by male and female miners

6.4.4 Challenges Facing Processing of Barites as Seen by Male and Female Miners

The major challenges confronting the processing of barites were identified to include: few processing plants; long distance between mining sites and the plants; impurities in the ore; old and nonfunctional equipment; lack of professionals to operate the machines and provide training. The perception of the miners (male, female) on these problems are shown in Figure 4. For inadequate processing plants, both male and female miners think the problem is very important (60-70%). For long distance between processing plants and mines, 80% of women think it is a problem while 30% of the men think so. For impurities, 8% of women think it is a very important problem while 30% of men think so. For old equipment, both male and female miners think it is not a serious problem since only 45% of the females and 25% of the males think it is a very important problem. The same applies to professionals to operate the machines (men – 15%, women – 45%). These results show the need for investments in technology to ensure that machines for processing the mineral are available.





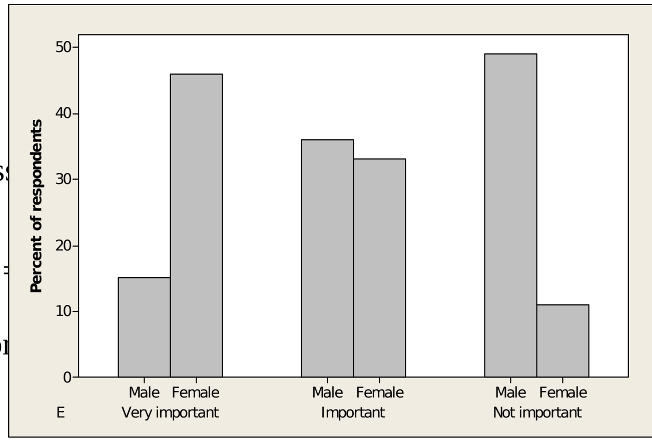


Figure 4. Challenges in process ners

A = Few processing plants; B = = Impurities in the ore; D = Old equipment fo ines

6.4.5 Safety Issues

The miners’ responses for ownership and use of protective gear are shown in Figure 5. The Figure shows that only men have protective gear, compared to women. Even at that, the only major protective gear used by men is the head gear (helmet) which is used by only 50% of men. This data reveals serious safety issues within the mines as well as gender disparity in access to protective gear.

Other unsafe working environment issues identified at the sites especially for women are shown in Figure 6. These results amplify the need for the regulators to enforce mining policies and regulations and encourage investments in the sector. In doing so, the needs of male and female miners should be considered. The miners admitted that mine inspectors from the relevant government agencies hardly visited the mines to monitor their operations.

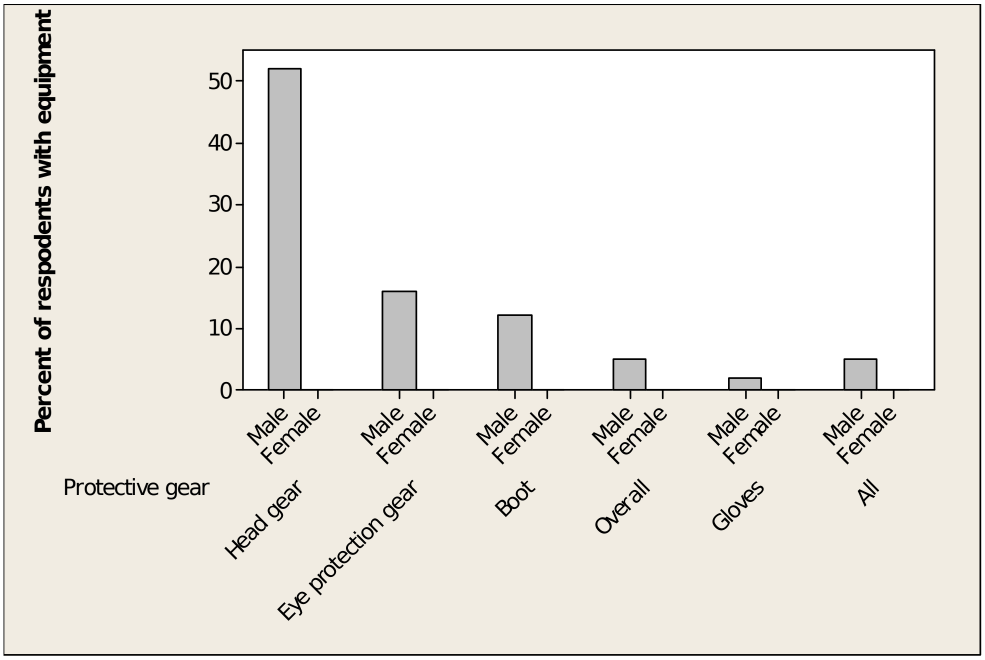


Figure 5: Ownership of protective gear (helmet, boots, overall, eye goggle) by male and female miners

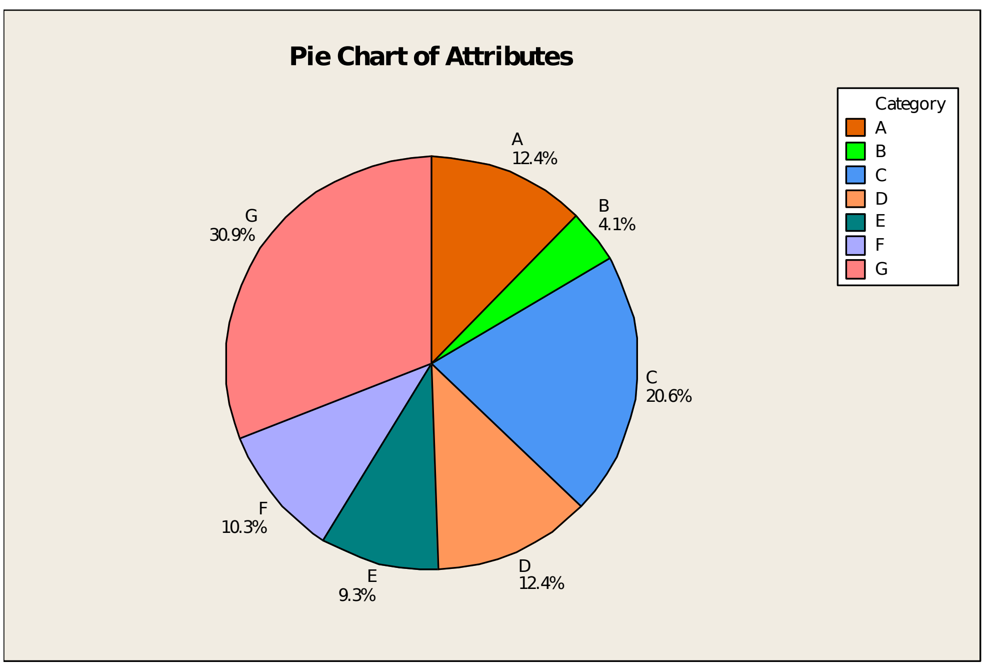


Figure 6: Conditions of unsafe working environment for women in the mines.

A = Cultural and family issues; B = Sexual exploitation; C = Physical limitation of what women can do; D = Unfavourable sanitation facilities; E = Accidents on site and pits; F = Insecurity in mines; G = Low payments for too much.

6.4.6 Discussion

The contribution of artisanal and small-scale mining (ASM) to the nation's economy is less than 1% currently [31,32,33] and for mining and mineral processing industries to contribute more to the nation's economy, there is need to revolutionize the ASM sector by formalizing their systems of operation through knowledge – based operation; skill acquisition; capacity building; research and development; fabrication of local machines (i.e. development of domestic processing facilities) and injection of much needed capital, enforcement of regulations on safety and environment.

Unlike in the ASM for gold and gemstones where women can be involved in the entire production value chain, the role of women in barite production is restricted to processing and stacking of mined barite. The miners that carry out heavy mining duties in pits tend to receive most of the recognition and remuneration, whereas women's participation in activities outside pits gets poorly remunerated, although they contribute to a significant part of the mining value chain by upgrading the value of mined barites and stacking them in designated locations for easy collection by buyers.

6.4.7 Sustainable Strategies for Improving Gender Parity in ASM of Barites

Based on the findings from the study, Gender Mainstreaming and Equality are recommended as strategies for improving gender parity in the ASM of barites in order to ensure sustainable supply of barite to the oil and gas sector in Nigeria [39,49]. These can be achieved through: implementation of regulations and guidelines set out in the Nigerian Mining Act 2007; (b) formalization of the activities of ASM; (c) promotion and support for activities of organized private sector groups such as the Miners Association of Nigeria (MAN), Association of Miners and Processors of Barites (AMAPOB) and miners cooperatives; (d) mainstreaming of gender into policies, laws, regulations, institutional restructuring programs and activities and ensuring that all government policies and programs are gender sensitive; (e) strengthening the operations of the ASM department in the Ministry of Mines and Steel Development (MMSD) and creation of a gender desk in that department; (f) support for the implementation of women-designed programs at educational institutions to ensure that women also participate in the educational and training programs (g) strengthening institutional collaboration between the MMSD and the Federal Ministry of Women Affairs and Women Development Centre, development partners and donor agencies supporting women development (h) awareness creation on role of women in mining through seminars; (i) build capacity of government officials at different levels, to recognize the livelihood needs of ASM communities, and particularly the significant roles played by women in securing livelihoods; (j) train, and provide capacity building support for ASM staff, women operators and other Ministry officials; (k) develop and maintain a database of women, engaged in the mining sector, to enhance systematic monitoring, information management and support to them.

6.5 Conclusions and Policy Implications

The study of gender dimensions of Artisanal and Small Scale Mining (ASM) of barite minerals in Nasarawa state of Nigeria has shown that there are differences in roles of men and women in the value chain for mining of barites. The disparity was observed in the different phases including: blasting; digging to barite ore depth; cracking of barite; carrying of barite to the wash point; washing of the barite; drying of the barite; sorting of the ore; collection, stacking and loading of barite; sale of the ore to millers. When all the miners surveyed are considered, women constitute 48% of the workforce while men constitute 52%. Yet in terms of remuneration, women earn less than men. The women are made to work with little or no protection against accidents and in inhuman environments. There is need to modify the existing policy and guidelines on ASM in such a way that gender disparity is eliminated in order to ensure inclusiveness and a sustainable mining sector that will ensure sustainable supply of high quality barites to the oil and gas industry in Nigeria.

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CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

This study is divided into three parts and based on the results; the following conclusions can be drawn:

(i) In the first study, ten barite samples were obtained from different mining locations in the Nasarawa and Taraba states of Nigeria. Their properties were determined and compared with a standard working sample used by an oil industry operator in Nigeria **u**sing different characterization parameters (SEM-EDX, FTIR, XRD, SG, and physical appearance). The characterization showed that some (6) of the samples can be used for drilling fluid formulation for the oil and gas industry due to their good specific gravity greater than 4.15 for API. The other samples require beneficiation to reach the standard for oil application due to their low specific gravity. All ten samples can be used for other industrial applications including healthcare, construction, plastic, cosmetics, paper, and rubber industries due to their level of barium content in the range of 30 to 50%.

(ii) In the second study, the survey approach was used to study artisanal and small-scale mining (ASM) of barite ores in Nasarawa state, Nigeria. has identified the barite ore value chain and several challenges that affect the sustainable development of ASM of barite in Nasarawa state. It was discovered that the miners are caught in a poverty trap and their activity is associated with illegalities, social vices, safety, health, and environmental challenges that prevent sustainable development of the sector. Nation's policy on ASM has not been adequately focused on barite neither has it been appropriately aligned with other poverty alleviating programmes.

(iii) The challenges of ASM of barites identified include: These include weak implementation and enforcement of mining laws; inadequate support from government and development partners; poor access to mining equipment and technology; poor infrastructure (access road, water, electricity); poor pricing of products (marketing challenges); poor remuneration of mine workers; poor mining skills; inadequate formal education; limited awareness on environmental health and safety hazards; fragility and conflict; insufficient information and data on mines and miners; security, fragility, and conflicts; lack of access to finance; lack of formalization of operations and poor legal framework for operations.

(iv) The challenges of processing barites were identified to include: few processing plants; long-distance between mining sites and processing plants; lack of technologies for removing the impurities; lack of professionals with skills for operating the machines; most of the technologies are imported; lack of sustained orders from end-users; lack of infrastructure (access roads, electricity, water); poor access to funds for industrial machines and multiple taxations from local authorities.

(v) The study proposed policy and legal frameworks for ensuring sustainable ASM of barite in Nasarawa state which include integration of ASM into wider rural development programmes, support for capacity building in ASM, social considerations, investment promotion, and formalization of operations to benefit from government interventions. The frameworks should also be applicable to other solid minerals within the sector.

(vi) The third study was on gender dimensions of Artisanal and Small-Scale Mining (ASM) of barite minerals in Nasarawa state of Nigeria. Results show that there are differences in roles of men and women in the value chain for mining of barites. The disparity was observed in the different phases including: blasting; digging to barite ore depth; cracking of barite; carrying of barite to the wash point; washing of the barite; drying of the barite; sorting of the ore; collection, stacking and loading of barite; sale of the ore to millers. When all the miners surveyed are considered, women constitute 48% of the workforce while men constitute 52%.

7.2 Recommendations

(i) Recommended future research include extending the work to an analysis of the other components of value chain for barites including: sales, marketing and the use of the mineral for making drilling mud for oil and gas industry as well as other industrial applications.

(ii) Future research should also carry out deeper studies on other strategic minerals and explore how ASM can be formalized and integrated with large-scale mining.

(iii) It will be useful to evaluate the donor funded projects currently being implemented by the Federal Ministry of Mines and Steel Development (MMSD) to determine their actual impact on ASM.

There is need to modify the existing policy and guidelines on ASM in such a way that gender disparity is eliminated in order to ensure inclusiveness and a sustainable mining sector that will ensure sustainable supply of high quality barites to the oil and gas industry in Nigeria.

7.3 Contributions to Knowledge

(i) New knowledge in form of data and understanding of characteristics and suitability of Nigerian barites for production of drilling mud and other industrial applications. The data generated is useful for the investors and operators in the oil industry and small and medium industries interested in processing barites.

(ii) The study has contributed knowledge and data on ASM in Nigeria by providing a deeper understanding of the dynamics of Artisanal and Small-Scale Mining (ASM) of barites in Nigeria including the challenges and socio-economic and environmental impacts, leading to development of a framework for ensuring sustainability of ASM of barite in Nigeria. This recommendation, if implemented for barite and other minerals can ensure an increase in the contribution of ASM to the national GDP.

(iii) Before now, there are many published works on gender issues in ASM of minerals in other African countries but only a few from Nigeria. The present study has contributed new knowledge in this direction.

(iv) The results of the study will assist in improving the availability of Nigerian barite for production of drilling mud for oil and gas industry and other industrial applications.