



## Article

# Fostering the Sustainability of Artisanal and Small-Scale Mining (ASM) of Barite in Nasarawa State, Nigeria

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**Abstract:** The exploration and mining of Nigerian barite are primarily by artisanal and small-scale miners (ASM) whose operations are characterized by poor productivity. As a result, the quantity and quality of barites produced do not satisfy the nation's oil sector demands and other industries that require the mineral. This situation leads to massive importation of the mineral with negative impact on the country's drive toward increasing the contribution of solid minerals to the gross domestic product (GDP). This study reviews the existing policies and government interventions on ASM of Nigerian barite; evaluates the operations of ASM through a survey of mines in Nasarawa state, Nigeria; identifies factors that affect sustainability of the sector and proffers solutions to foster sustainability of ASM of barite in the region. The study adopted the 4Is optimization technique (Information gathering, Interpretation, Implication, and Implementation) through personal interactions with the stakeholders at the barite mining sites, and government agencies, 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 issues; 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 (such as Miners Association of Nigeria, Association of Miner and Processors of Barite, AMAPOB). Implementation of these strategies will lead to sustainable operations of the sector and hence improved rural livelihoods, stimulation of entrepreneurship in an environmentally responsible manner, and improvement in the contribution of the mineral sector to the nation's gross domestic product (GDP), and hence national development.

**Keywords:** barite; artisanal and small-scale mining (ASM); mineral value chain; sustainability



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## 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) [1–3]. 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) [4–7]. 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 [11–13]. 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 [14–16].

Barite is an industrial mineral that is used in drilling mud and making other engineering products [17–19]. The mineral is found in commercial quantities in Cross River, Benue, Nasarawa, Plateau, Taraba, Adamawa Zamfara, and Gombe states of Nigeria [20–23]. 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 [25–28]. Only a few studies focused on artisanal mining of Nigerian barites [29–31]. 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:

- i assess the value chain of barite mining and processing in Nasarawa state, Nigeria
- ii identify challenges of the sector;
- iii identify socioeconomic and environmental impacts of ASM;
- iv assess the effectiveness of government policies and regulations; and
- v 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.

## 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.

### 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].

## 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 [39–45]. 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 [48–53]. 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 in particular and Africa in general.

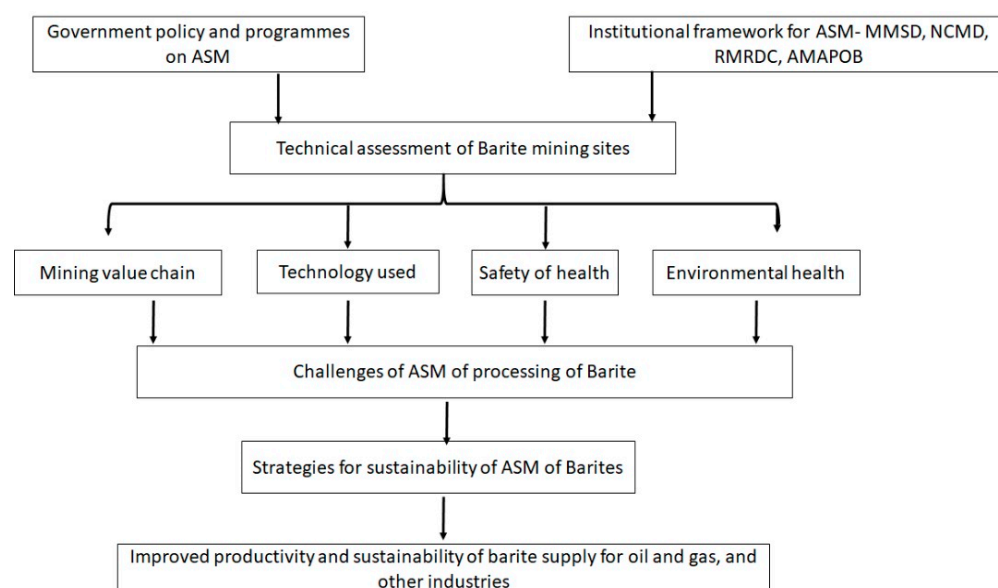
## 3. Research Methods

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 [54–57]. 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 [58–60]. Details of the research method are given below.

### 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.

### 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.

### 3.3. Research Questions

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

1. What are the components of the value chain for ASM of barites in Nasarawa state?
2. 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?
3. Do the extant mining laws align with policies to facilitate ASM transformation to large-scale barite production?
4. What factors are responsible for illegal and informal activities associated with ASM operations for barite?
5. What are the challenges militating against sustainable mining and the supply of high-quality barites?
6. Do institutional and administrative structures for promoting streamlined ASM exist and are they adequate?
7. Are there adequate capacity building programs for the ASM workforce?
8. Is the environment for ASM conducive for finance and marketing opportunities?
9. What are the socio-economic and environmental impacts of ASM in the study location.

### 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.

### *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 stakeholders 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.

### 3.6. Data Analysis

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

### 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.

## 4. Results and Discussion

### 4.1. Characteristics of Respondents

The characteristics of the respondents are described in Figures 2–4. 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.

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.

The percentage age of the respondents

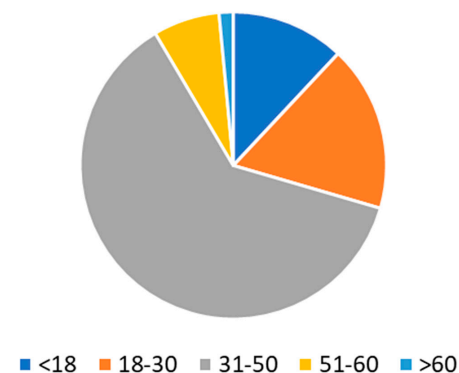
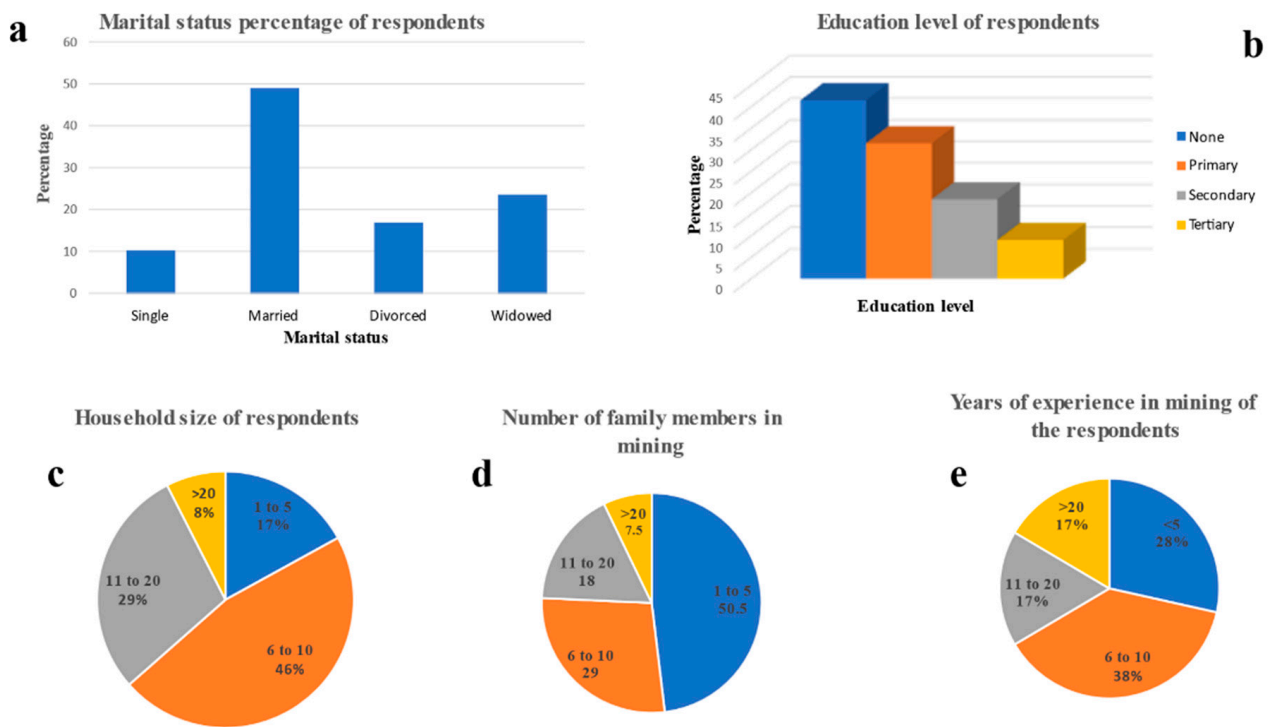
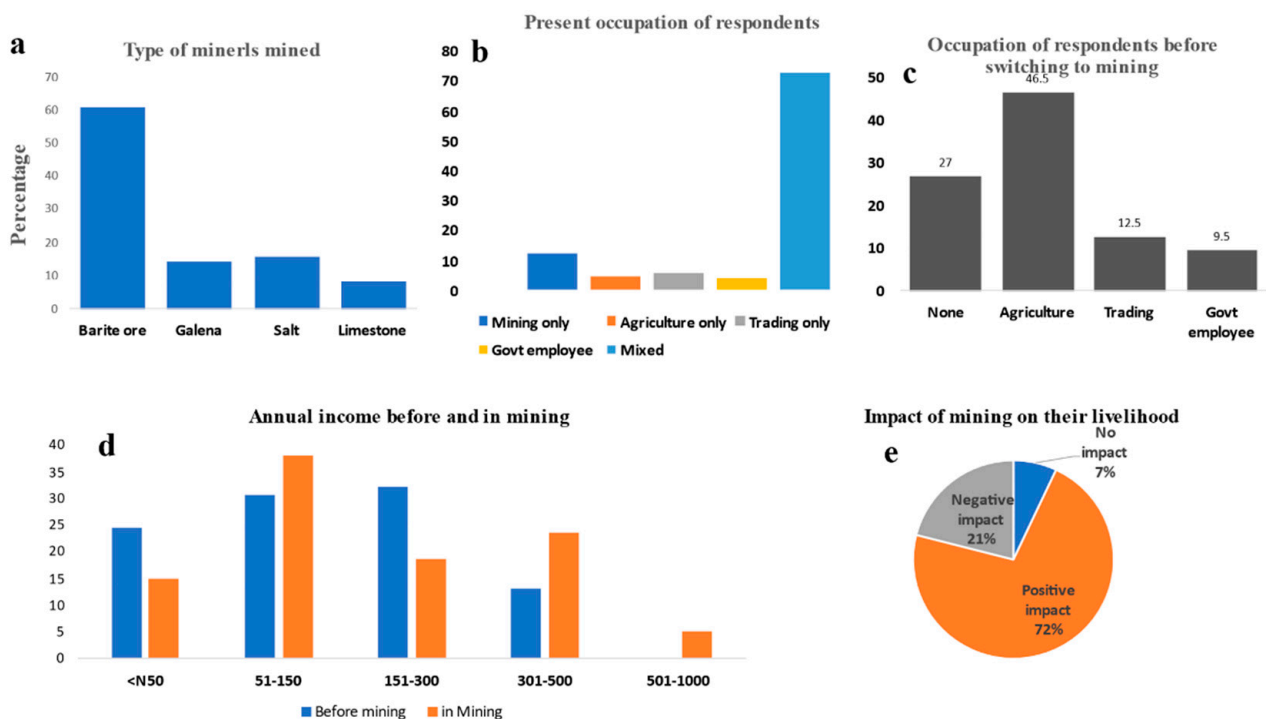


Figure 2. Percentage age of the respondents.



**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.

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).

#### 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.

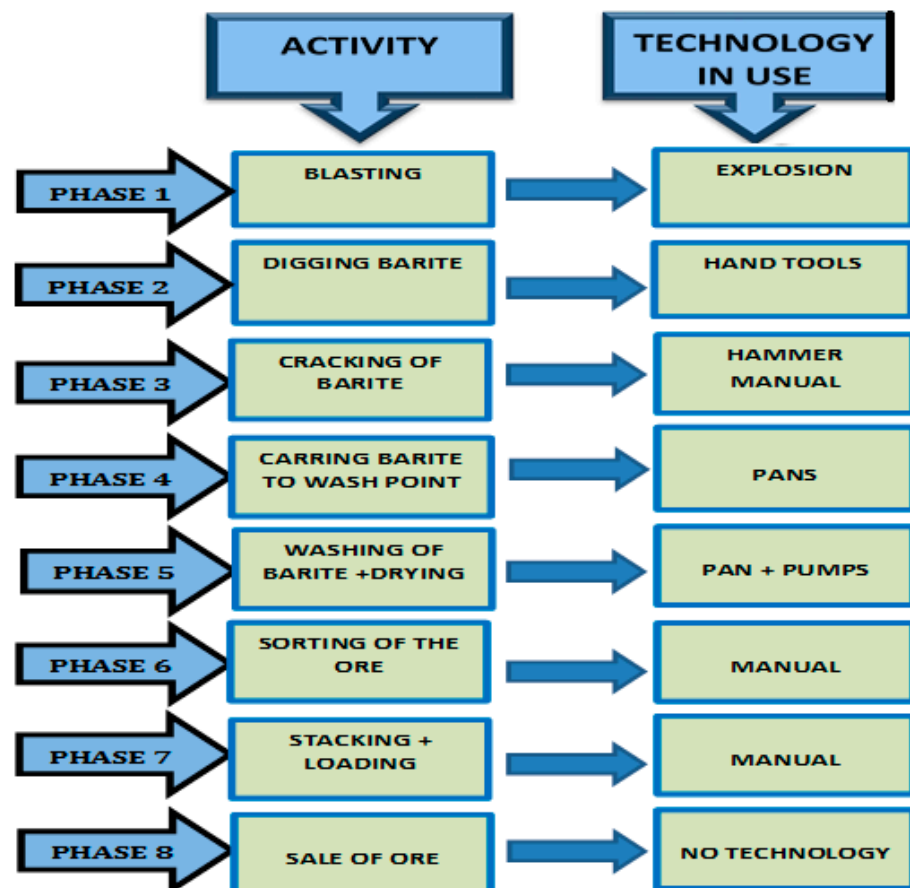


Figure 5. Components of the value chain for barite mining showing activities and technology.

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 as 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  $(0.9 \times 0.9 \times 0.6)$  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.

#### 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].

#### 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

#### 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 Rwanda Great lakes	Malisa [66] Kinyondo and Huggins [53] Lehmann et al. [67]
Water use changes and water pollution	Tanzania	Harada et al. [68] Hilson and Pardie [69]
Mercury contamination	Ghana	Adewumi and Laniyan [70]
Effect of water habitat	Nigeria	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]

#### 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 Cadastre 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 eg 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

#### 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].

#### 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.

#### 4.9. Socio-Economic Impact of ASM

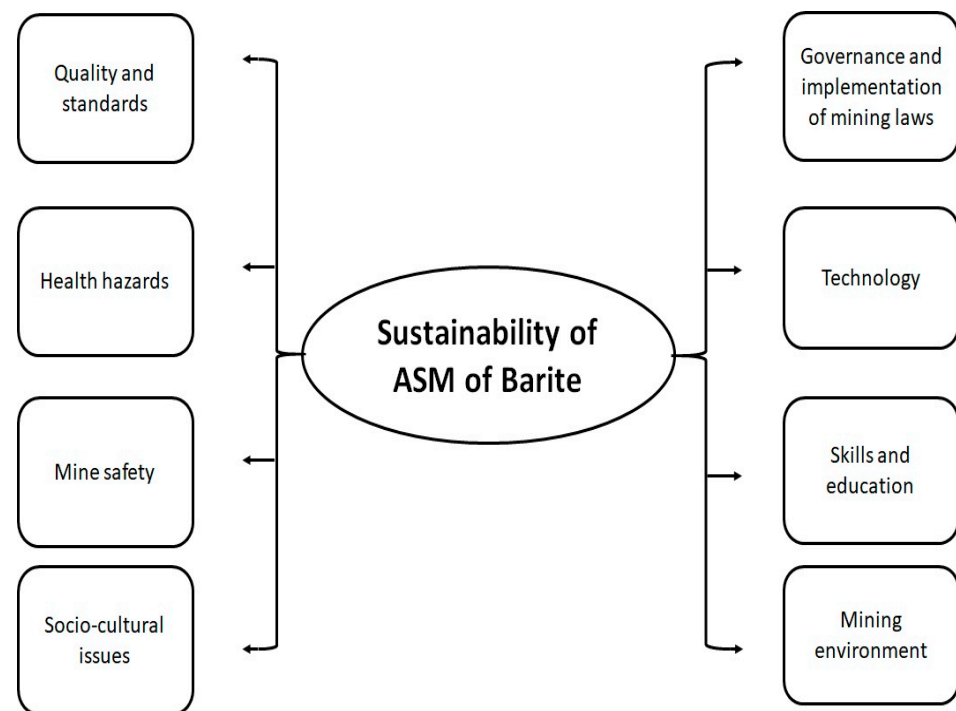
The positive socio-economic impacts identified include: creation of employment; improved electricity supply; improved social life; improvement in living standard; improvement in sale of petty trade items. The negative impacts include: conflict between indigenes and migrant worker; drop in school enrollment, 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	Ofose et al. [60]
Boosting of living standards	Tanzania	Fisher [79]
Start up capital for other SMEs	Ghana Malawi	Smith [80] Tiyamike [81]
Education and medical costs of miners	Ghana	Hilson [36]
Funding of agricultural activities		Adu-Baffour [82]
Supply of industrial raw materials for other industries	Ghana	Penderson [83] Bensah et al. [48]
Boosting economic activities for miners, traders, mineral speculators and transporters	Liberia	Van Bockstael [84]

#### 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 [85–89]. 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:

#### 4.10.1. Policy Implementation and Legislation Enforcement

1. Integrate ASM policy into the nation's poverty alleviation programs.
2. 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.
3. Review extant laws to encourage ASM mentoring programs by professional bodies and/ or large-scale mining operators.
4. 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.

#### 4.10.2. 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).

#### 4.10.3. 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).

1. 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.
2. 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.
3. 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.

#### 4.10.4. Investment Promotion

1. 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.
2. 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.
3. 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.

#### 4.10.5. 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.

#### 4.10.6. 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) De-

partment 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. 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.

**Supplementary Materials:** The following are available online at <https://www.mdpi.com/article/10.3390/su13115917/s1>, Table S1: Socio-economic impact of mining activities; Table S2: Environmental impact of mining activities. Table S3: Socio-economic characteristics of the respondents.

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