

Review Article

Artisanal and Small-Scale Gold Mining in Ethiopia: A Comprehensive Review of the Sector's Trend, Performance and Potential

Misganu Kabeta* 

Mineral Industry Development Institute, Ministry of Mines, Addis Ababa, Ethiopia

Abstract

Mining is the backbone for ASGM community livelihood and it is a difficult and risky occupation operated without guarantee. Artisanal and small-scale mining in Ethiopia was poor industry dominated by a large number of unskilled and semi-skilled labor force. Because of vast informal engagement, ASGM history has not been properly recorded. Though the ASGM provides employment for a million peoples directly and indirectly in Ethiopia, mainly it operates informally, working without license, lack legal protection, and government support and not complying with government regulations and environmental mitigation matters. The legal enforcement level of proclamations is weak. Nearly all ASGM miners use manual tools in the country, and this strictly need technology interventions. Proclamation, regulations, laws, guidelines, policy and directives pertaining to ASGM on mining, environment, and related issues should be reviewed. This review article based on the previous study in assessing and analyzing ASGM sector in Ethiopia by addressing technical, legal, economic, and social factors. This aimed to gather information on ASGM in Ethiopia and assess previous study to improve productivity and market links, and promote sustainable development in the ASGM sector. The study revealed that the ASGM sector in Ethiopia remains underdeveloped, with minimal contribution to country's GDP. Indeed, this review cannot go by without appreciating the current awareness and alertness that is happening within ASGM sector.

Keywords

Artisanal Gold Mining and Processing, ASGM, Gold Production, Environmental Impacts, Socio-economic Challenges, Technology, Sustainable Practices, Ethiopia

1. Introduction

1.1. Artisanal and Small-Scale Gold Mining (ASGM) Definition from Different Perspectives

Before we talk about the function and nature of artisanal

scale gold mining, artisanal and small-scale gold mining, (ASGM), it is good to know what ASGM mean, so let us start to look at its definition and description from various literatures perspectives because the ASGM lacks a common definition has many descriptions. Artisanal and small-scale gold mining (ASGM) can be defined as work and activity

*Corresponding author: Misganu.kabeta@aait.edu.et (Misganu Kabeta)

Received: 22 August 2025; **Accepted:** 12 September 2025; **Published:** 18 October 2025



Copyright: © The Author(s), 2025. Published by Science Publishing Group. This is an **Open Access** article, distributed under the terms of the Creative Commons Attribution 4.0 License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution and reproduction in any medium, provided the original work is properly cited.

practiced by utilizing local traditional mining means within the specified area [1]. Artisanal and small-scale gold mining refers to a condition of mining activities that carried by individuals, groups or families, using rudimentary methods and techniques or low technology with minimal machinery to mine [1], and process gold often through the formal, informal, legal and illegal forms [2]. The scope of ASGM activities depend on the number of work force, the methods employed to carry out the operations, and the status of the operations, including whether they are legal, illegal, formal, or informal [3, 4]. Accordingly, there is a big and meaningful differences in the size and extent of ASGM work vary widely depending on certain features factors and characteristics [2, 5]. In the absence of a common definition, ASGM is often characterized by its key features, such as relying on simple and inefficient techniques and intensive labor instead of use machinery or technology, mostly operates without legal mining concession, low productivity, lack of safety measures, health care and environmental protections [5-7].

Artisanal scale mining is often purely manual on a very small scale where mechanization is nearly nonexistent in artisanal mining operations, whereas small-scale mining is more mechanized [4, 8, 9]. According to Ethiopian mining operations proclamation, 1993, an artisanal small-scale miner is a surface miner who is engaged in mining activities to some extent a minimum depth, generally working with hand tools independently or in group [10]. Artisanal miners tend to work mining activity all through the year, but some also work on but some also work seasonally on farm lands [11]. It is hard to estimate exact extent of ASGM due to this kind of mining lack a common definition, lack of official statistics and based on occasional works [12]. The miners who engaged to work on ASGM activity reason out similar factors such as push (landlessness, poverty, unemployment, economic crisis, conflict, natural disasters) and pull (commodity price, engage in gold production work & have a land of potential gold) [13-16]. ASGM is commonly associated with informal, unregulated and unlicensed economic activity to extract and process gold ore without accessible right such as land rights, any legitimate document that permit the mining operation. Artisanal mining encompasses a wide range of operations from easy as panning for gold in rivers to as complex as construction of underground working facilities [16, 17].

1.2. Significance of the ASGM for Communities and National Economy Growth

The ASGM activities have important contributions in foreign exchange earnings and employment opportunity [18]. ASGM may be used as an unemployment and poverty reduction tools where the economic conditions are problem in the country where potential mining exist. ASGM was continuing as a source of income generation for rural area communities by filling their existing economy deficit gap issues [19].

ASGM operations, used as an emerging important socio-economic and have the capacity to lift communities from poverty. [8]. ASGM has power to support sustainable economic growths in local communities by creating better and improved health and environmental conditions [9]. The ASGM sector in Ethiopia potentially plays a significant role contributing to poverty alleviation and provides many socio-economic benefit opportunities such as growth of country's economy, such as job creation and employment, income generation, foreign investment attraction, foreign exchange earnings with high revenue rewards, curbing rural-urban migration, stimulating local economic growth for rural areas development, market linkages, illegal transaction control, natural resource management system and discoveries of new mineral deposits [18].

1.3. The Purpose and Scope of the Review

The main purpose of this review article on ASGM in Ethiopia is to present a comprehensive analysis focusing on the sector's performance, trends, and potential which helps to understand sector's historical context, socio-economic benefits implications, environmental impact consequences and potential areas for growth. The review tried in assessing the practical trends of the Ethiopia's ASGM sector, and intended to provide future strategies and substantial interventions needed in order to promoting sustainable economic growth and protected environmental in the sector.

A thorough examination and analysis of the review covers key areas such as the ASGM practices overviews, socio-economic significance of ASGM, and overall sector's contributions to the growth of Ethiopian economy, its role for local communities, in jobs creation and employment, income generation and poverty reduction in rural areas, foreign exchange earnings, evaluating the environmental impacts and consequence of ASGM, such as deforestation, pollution, land degradation, resource depletion, and social aspects of ASGM activities operations including community health, safety, and gender dynamics. Furthermore, this review analysis the technological advancements and development, market dynamics, discusses current laws, regulation and policies governing ASGM in Ethiopia. Additionally, this review highlights how to minimize ASGM's negative impacts on social and environment, events of gold production changes within years, technology usage and its potential in gold production efficiency increase, how well legal framework and regulatory governing ASGM works with regard to sustainability, formalization, and adopting and promoting sustainable practices and investigate anticipated the future sector's potential to bring sustainable development and growth and identify areas where the sector need improvement to maximize benefits, future potential opportunities to enhance the sustainability and profitability of the ASGM sector, including possible markets and partnerships.

2. Methodology

This paper is a review article conducts a thorough critical review of existing the available and reliable literature, academic literature, analyze past studies reports, policy papers, and government documents related to the ASGM sector in Ethiopia to understand the historical trends, regulatory frameworks, and existing knowledge on the ASGM sector including previous work experience of authors. Also, key informant interviews and discussions was used in the review to address and evaluate ASGM productivity, legal framework, economic, environmental, health, safety, gender, child labor, and community aspects. It aimed at to review and summarize existing information on the Ethiopia's ASGM sector to development of a sector covering broad understanding of ASGM sector in Ethiopia focusing on assessing previous history and anticipated significantly to contribute on currently existing information on ASGM sector in Ethiopia by prescribing a series of recommendations the future way to boost ASGM productivity improving ASGM performance in the country.

One of this review importance is that more it increases the comprehensive understanding of the ASGM sector in Ethiopia for research, policy-makers etc. and insights into how to improve its productivity and contribution to the national economy. Also, it will support broadly the government initiative effort to harness the untapped potential of the mining sector with in collaboration of international researchers on these areas.

3. Result and Discussion

3.1. The Historical Trends of Artisanal and Small-Scale Gold Mining (ASGM) Sector Development and Practices in Ethiopia

ASGM operations activities in Ethiopia was a poor mining industry sector primarily and largely dominated and characterized by a large number of unskilled and semi-skilled labor force [3, 9].

The most economic motivation that individuals engage in ASGM activity practice in Ethiopia was mainly driven by poverty problem which mainly done by rural area community with or without minimal mechanization [4, 13]. Because of the minimal entry requirement, ASGM is an activity that employs many people in the far rural areas. Totally over 1.26 million communities were estimated to legally and illegally engaged, involved and participate in ASGM activity and about 7.5 million population indirectly benefit from this sector [19].

Ethiopia has favorable geological conditions and endowed with a wide variety of available untapped mineral and rocks resources that are yet unmined to benefit from it [20, 21]. Despite promising potential of various types of abundant

mineral resources are available in Ethiopia, their utilization is not reached the substantial level [22]. Also, mineral exploration and mining that carried out by government sector was decrease from time to time due to human resource migration/flow to private sector, security problem and also there is a gap between mining industry & educational institutions [20].

In Ethiopia, ASGM practices has a long years of poor mining experiences with hidden unexplored and untapped resources. Nowadays, digging pits using picks and shovels are currently a basic step used in the mineral mining and beneficiation process. The sample is then removed from the pits, often by filling it to the top of the pit with a shovel or using buckets. The sample is manually sorted by hand to extract gold particle. The sorting and washing activities are carried out at the top of the pit by the small group of labor working on that specific pit hole. There is no communal sorting or washing effort. The artisanal miners tend to miss many smaller-sized gold particles during manual sorting process. The current ASGM practices in Ethiopia can be described and characterized by primitive and lacking effectiveness, low degree of capitalization or mechanization, low level of productivity and recovery, unrecyclable wastes, use inappropriate obsolete technologies, poor information, low levels of environmental awareness [3, 4, 6, 8, 18, 19].

Even though the mineral industry sector in Ethiopia is significantly remained a key contributor to the country's GDP and particularly, largely plays a vital role in rural areas economy growth, it remains insignificant contribution of less than 1% to the Ethiopian economy (GDP), [19]. However, the stagnant trend of the potential contribution of this sector to the Ethiopian economy is changing in recent years due to attention is currently being given to the development of the ASGM sector. The government now view and consider the profitability and contribution of the mining sector as a key pillar of the country's economy growth by focusing on the setting rules for development and formalization of the ASGM sector through promotion and prioritization reforms. Therefore, Ethiopia has changed its mineral laws to make the mining industry a significant driver of the country's economic growth.

In the previous year's the profitability and contribution of ASGM sector gain attention by Ethiopian government and many baseline studies was conducted to enhance ASGM productivity [6]. Therefore, Ministry of Mines in collaboration with different organizations and stakeholders made various assessments [3, 6, 19]. The most research and studies carried out on ASGM in Ethiopia were focused on improving the existing problematic situation of ASGM. These different assessments and study were seeking to collect data with aims to identify constraints and opportunities on various aspects of ASGM, including current ASGMs existing technology use, need of technology intervention and skill gaps, legal and policy interventions, environmental, and social factors to increase production of the ASGM sector was just identified [3, 4, 8, 9].

Accordingly, analyzing the “various aspects of artisanal mining operations in Ethiopia, its economic value, social contribution and social impacts”, [19], “roadmap that sketches the vision, objectives and key activities that need to be prioritized for implementation, [9], base line study on “formalizing and enhancing performance of artisanal and small-scale gold mining in Ethiopia” [3, 4] are among research and studies carried out on ASGM in Ethiopia. Specially, the study undertaken by Ethiopian Extractive Industries Transparency Initiative has come up with findings that the overall contribution of ASGM to the country’s economy or GDP is low [19]. The government of Ethiopia in efforts to reform its mining sector to formalize and legalize ASGM, and recognized the ASGM sector as potential contribution to country’s economy and established ASGM regulating department for the first time in 2008 G.C.

3.2. Mineral Exploration and Artisanal Gold Mining Practices Evolution in Ethiopia

Mineral resources play a key role in the economic development of a country. Ethiopia is blessed with an abundance of natural minerals resources which are distributed in the various geological formations [21, 22]. Modern mineral exploration in Ethiopia commenced during the British army expedition in 1867 and first mineral concession was granted in 1898 [20, 23]. During this era the army studies the geology and mineral resources deposits of North Ethiopia and they name most of the rocks and lithostratigraphy of the rocks of Northern Ethiopia. Later, during the Italia stay in Ethiopia the extensive mineral exploration activity accelerated for any mineral deposit in Ethiopia [20, 23].

However, systematic modern mineral exploration was performed in the country when the United Nations Development program (UNDP) carryout a mineral survey in western and southern Ethiopia. Following this, the former Ethiopian Institute of Geological surveys (EIGS) become renamed to Ethiopian geological survey (GSE), now called Ethiopian Institute of Geology (GIE) started systematic and integrated mineral exploration with the aim to explore and evaluate potential economic minerals deposits reserve of the country. During this era, evolution of the geological terranes of Ethiopia for their economic mineral deposits potential was understood. Most of the Ethiopian geological survey (GSE) activities were successful in locating economic mineral deposits in different parts of the country [20, 23]. Accordingly, the geological terranes of north, south and west of the country are most promising for gold and base metal deposits source (figure 1).

The many resources that discovered in different regions of

the country are mainly metallic minerals (Gold, Platinum, Silver, Tantalite Iron, Nickeliferous, Chromite, Copper, Zinc and lead, Molybdenum, Radioactive, Ilmenite, Manganese etc), non-metallic minerals (Diatomite, Bentonite, Clays, Kaolin, salt, Soda ash, Magnesite, Feldspar, Talc, Graphite, Phosphate, Pumice, Natural Zeolite, Mineral water, Mica, Kyanite, Silica, Quartz, Gypsum, Dolomite, Limestone, Marble, Granite, basalt, etc.), different varieties of gemstones (Opal, Emerald, Beryl, Garnet, Apatite, sapphires, amazonite, amber, rubies, tourmaline, aquamarine, chrysoprase, peridotes, fossils fuel minerals (Coal, Oil shale, Petroleum) and geo-thermal energy [20, 23].

Gold deposits occurrences discovered through studies carried out on the greenstone belts in the Proterozoic basement rocks of country are the most promising natural resources that may have a potential to change the aspects of country's economic outlook among identified varieties of metallic and non-metallic mineral resources occurrences. Ethiopia has ancient history of mineral utilization and being experienced gold mining for a century, primarily it is from alluvial gold deposit and it is believed that the Asosa gold mine could be the oldest mine in the world, dating back over 6,000 years (<http://www.mom.gov.et/index.php/artisanal-and-small-scale-mining/artisanal-mining-asm-in-ethiopia/>).

Most of the rich placer gold deposits places in Ethiopia have been exploited and extracted by artisanal and small-scale miners who were engaged in mining activities employing primitive techniques to beneficiate themselves and their families from it. Most of ASGM in Ethiopia is predominantly and primarily focus on alluvial gold deposits and now shifted to focus on primary gold deposit due to near surface resources are depleted [19]. Geographically, the ASGM activity was practiced and carried out in the Benishangul-Gumuz, Gambella, Oromiya, Tigray, and Southwestern Peoples of Ethiopia regions. Proterozoic basement rocks of Ethiopia are mainly the most significant known terrain for gold occurrence in greenstone belts of Western, Northern and Southwestern. Mostly a majority of well-known artisanal and small-scale gold mining operations history in the country was confined to this greenstone belts (Figure 1). However today, apart from gold, artisanal and small-scale miners are also engaged in conducting activities of mining, processing and producing a wide variety of other minerals such as platinum gemstones, diatomite, tantalum, as well as construction and industrial minerals such as sand and silica sand, clay, gypsum, crushed stone, salt, and more other minerals [19]. Figure 1 illustrates the locations with high potential mineral deposit areas suitable for artisanal and small-scale gold mining in green stone belts and other parts of Ethiopia.

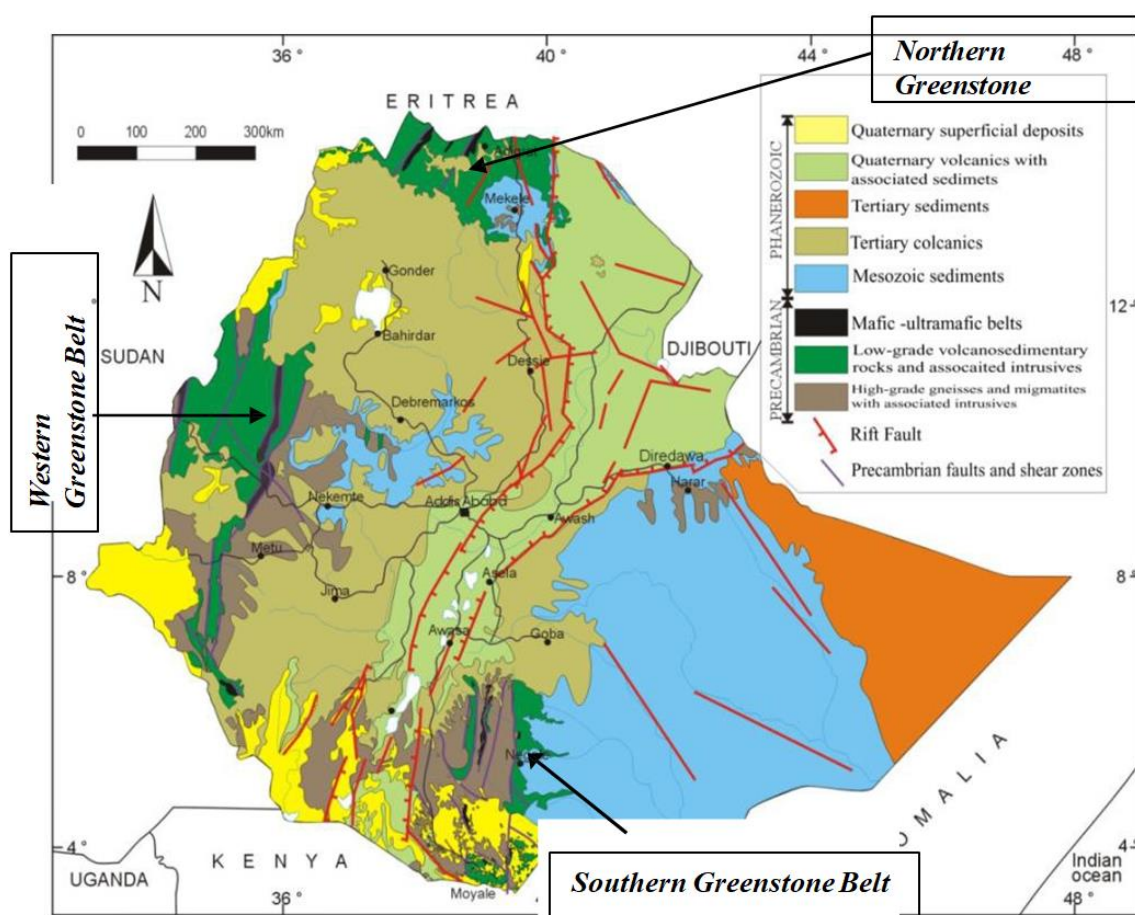


Figure 1. The Location Map of ASGM Geological Distribution Area in Ethiopia.

3.3. Trends of Gold Production and Market Dynamics in Ethiopia

Globally, ASGM are major sources of gold production and while difficult and hard to give precise estimates, according to world gold council, they contribute above 20% annual gold product and provided direct livelihoods around 20 million people [7, 8, 12]. Gold has been mined since ancient times primarily from alluvial gold deposit and it is Ethiopia's main mineral export [19]. Gold is considered to have the high potential for internal and external investment, and the government estimates that gold production may increase double annually if sufficient fiscal year was given, enough revenue will collect.

Currently the Ethiopian government permits a free market driven economy in mining sector, in a transparent manner that would help to boost the economy of the country [25, 26]. The mining sector was one of the economy pillars strategies that the government hoped for revenue generation. The gold market dynamics involves much transaction with many smuggling routes from the mining sites to the final buyer (NBE). Simply the identification of gold traceability can't easy because each step of supply chain is complex as the following diagram illustrates (Figure 2). However, recently

the gold traceability of artisanal mining sector in Ethiopia is easily identified, because government reforms and each step of supply chain is documented and gold suppliers are easily known [18]. As there are who work illegally, many of ASGM are organized as cooperatives, micro and small-scale miners, on gold and others minerals production. The local gold purchasing centers opened around gold mining area, incentives for gold suppliers and gold miners were encouraged to strengthen governance and formalization strive made to fight against gold smuggle.

However, still there are challenges, such as declining of continuous gold production, that need to be addressed to ensure the sustainability and growth of the ASGM sector. As the below Figure 3 illustrates, during the period of years from 2014/15 to 2021/22 a gold production level were relatively remains consistently stable period of low gold production with a significant fluctuation suggesting low output of gold production over the years. The graph detailly illustrates the trends in gold production by artisanal mining methods over a period spanning from the budget year 2014/15 to 2023/24 and along with this 2024/25 production year was presented which reveals significant trend of gold production levels by artisanal mining method, particularly with a notable significant dramatic increase with spike of production in recent years. The key trends and potential implications of the gold production

from the graph were analyzed. Analyzing if this transformation is driven by a combination of factors like economic, technological, and regulatory, is essential for stakeholders, such as policymakers, investors, and local communities to understand it.

When we assess the gold production levels within indicated consecutive five (5) years, the ASGM sector shows a continuous reduction of gold produced by the artisanal and small-scale gold mining (ASGM) sector in Ethiopia. Gold production starts with a solid beginning but the production further declines showing significant downward drop for consecutive five (5) years.

Throughout these years the gold production remains relatively stable and very low output, showing that there is continuous decrease of gold production that sold to the National Bank of Ethiopia (NBE) by the ASGM sector. Then production remains continued decline with decrease rate and dramatically further drop recording the lowest production indicating possible challenges and ongoing issues. Overall, trends of gold production for ten (10) years shows significant fluctuations within given years with a notable gold production in 2021/22 indicating a possible increase in mining and processing activity or improved better techniques leading to high yields, followed by a sharp decline.

Generally, the sharp decline of gold product within indicated consecutive five (5) years, may suggest several potential factors such as regulatory constraints and environment which put restrictions on artisanal gold mining activities contributing to low production, policy and regulatory barriers that strictly regulates or enforce against illegal mining and limit production capacity, market conditions and economic factors like gold market fluctuations affecting artisanal gold mining activity operations, operational challenges and constraints in which artisanal miners may face challenges such as lack of access to advanced mining technologies, capital and financial resources, skills or favorable mining conditions that hindered production capacity of artisanal mining.

The high amounts of gold produced in 2021/22 stimulated mineral economic sectors in the mining areas. The increased gold production in 2021/22 year could be associated with increased number of gold miners, issue a number of mining licenses, favorable market conditions, or slightly changed and improved mining practices.

The significant drop of gold production in subsequent years suggests challenges such as near surface resource depletion, shift from placer to primary gap, regulatory changes, environmental concerns, foreign exchange pressure, or market saturation affecting artisanal gold miners. The last two years gold production levels indicate a potential stabilization at lower outputs, which might reflect a new norm for artisanal mining in the region.

Generally, the chart indicates there was a period of significant gold production growth, by artisanal gold miners in Ethiopia and following the years artisanal gold miners experienced a significant markable decline of gold production.

Understanding the factors behind these trends which contribute to these changes could be essential for addressing and providing insights into the challenges faced by the artisanal miners in Ethiopia. This could involve exploring policy adjustments, improving mining techniques, and better market access to enhance sustainability and productivity.

However, after ten (10) years of gold production fluctuations, recently in the 2024/25-year, the gold production sharply starts to increase with a dramatic significant increase in gold production in Ethiopian history and slight recovery which indicates that significantly the highest increased gold production achieved. This increment may be come from improved production methods, government regulatory and policy conditions changes, foreign currency exchange rate equalization, strengthening of border security, an increase in the number of producer mines, improved awareness of miners on gold market conditions, improved incentives given through NBE, regional governments policy revision, improve and tighten mining regulations, improved mining and processing technique and expected to continue this success in artisanal gold mining for further investment in this sector (figure 3).

The year of sustained high production levels 2024/25 suggests that the high production level will remain elevated, may be indicating the high output is expected to continue, continued economic viability conditions for artisanal mining, sustainability concerns regarding environmental and social impact and resource sustainability of artisanal mining practices, community engagement for better community benefits by avoiding negative social and environmental impacts, investment opportunity in artisanal mining by fostering economic growth in local communities. The increased gold production can significantly benefit local economies, providing livelihoods for miners and associated businesses and have economic impact implications. The increased revenue gained from gold production could lead to enhancement of local community infrastructure services and improve living standards.

The possible factors contributing this substantial production spikes marking a notable shift can be analyzed through various possible explanations such as economic factors and incentives like rise of gold prices and miners incentivization to increase gold production due to higher profitability, miners can be used better improved mining techniques or equipment enabled to higher efficient productivity yields, newly supportive government initiatives such as formalization efforts, providing training, or improving access to resources could be impacted gold production and contributed to artisanal mining gold production increment.

This dramatical highest spike increases in gold production could have various implications, including economic benefits for local communities, potential environmental impacts, and changes in market dynamics. As artisanal mining gold production potentially moves into a new phase of growth, it is essential for stakeholders for careful management to ensure that the benefits of increased gold production are sustainable

and equitable by balancing economic growth with environmental and social responsibility. For future this entail to evaluate continuous sustainability of the increased in gold production, evaluation of the economic impact of increased production how can it benefit local communities, assess environmental concerns how to mitigate and control potential environmental impacts artisanal mining activities will bring. Therefore, the government may need to stretching out regulatory to balance the economic benefits of increased gold production by artisanal mining with sustainable practices to

mitigate environmental degradation by engaging local communities in decision-making to enhance compliance with regulations that support sustainability and promote responsible mining practices and community welfare. Additionally, while artisanal mining was economically beneficial, often artisanal mining activities leads to potential environmental issues such as deforestation, soil erosion, land morphology degradation and water pollution and needs implementation of crucial sustainable mining practices and rehabilitation efforts to minimize these impacts.

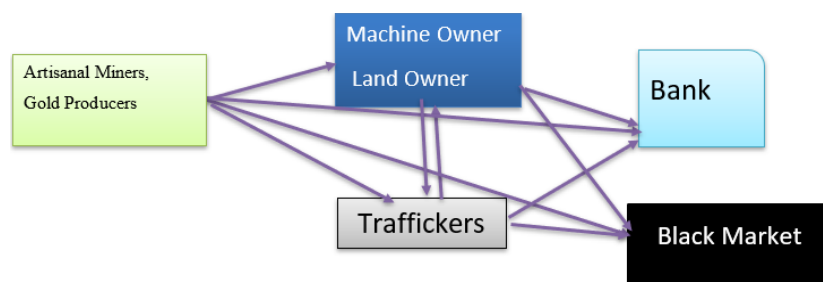


Figure 2. Gold Market Route in ASGM.

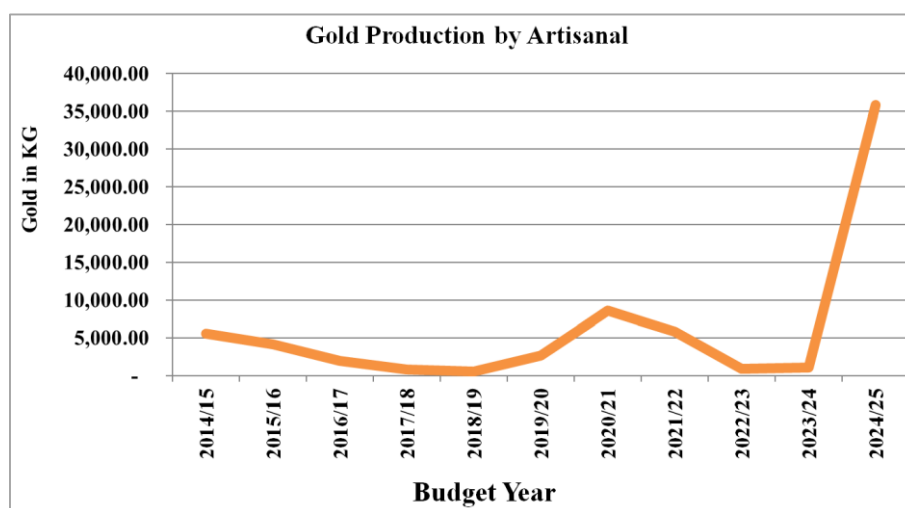


Figure 3. Ten^{plus} (10⁺) Year Gold Produced by ASGM.

3.4. The Role of Incentives in Curbing Gold Smuggling

Specifically, incentives are employed to achieve certain specific objectives and used to boost gold productivity and block smuggling in the gold market supply chain. Accordingly, Ethiopia's mining sector has different types of mining incentives to able the sector to play its role in spurring the economic growth of the country. The government takes significant action to control informal flow of gold to the black market by improving its gold buying system against decline of official gold supplies by incentivizing a person that supply

above 50g of gold.

The Ethiopian mining operations proclamation offers the licensee with significant incentives including low royalties, exemption from customs charges and taxes on equipment, machinery, vehicles and essential spare parts for mineral operations, as well as a reinvestment deduction and losses carry forward. However, still holders of artisanal mining license are not eligible to exemption of import taxes and duty-free materials. The exemptions are not provided at any stages of small-scale operations since article 73(2) of mining proclamation states that the materials to be exempted from customs duty and taxes should be required to start mining operations. Also, reinvestment deduction and losses carry

forward eligibility was only for a licensee who pays mining income tax. Therefore, to support the adoption of technology in ASGM, government may grant artisanal miners the privilege of importing equipment duty-free. Additionally, the government may offer extra incentives which not mentioned in the mining proclamation under certain situation. This provision allows the government to grant additional incentives for mining investments that may be considered more crucial to promote the development of the country's growth [13, 27].

3.5. Role of Technology in Ethiopia's Artisanal Mining Sector

Individual types of ASGM can be defined by technological procedures and their effect on geomorphological processes while technology involved in ASGM are especially associated with surface and subsurface mining. Technology portrays a significant role in each mine life stage extensively to improve productivity. The role of technology in artisanal mining sector of Ethiopia has been a topic of discussion and regulatory changes in recent years. Initially, the mining operation proclamation No. 678/ 2010 prohibited the use of mining technology in any form for artisanal level mining. However, due to high demand for the ASGM sector transformation later resulted in the amendment of the law in 2013 under proclamation No. 816/2013 to grant special small-scale miners to adopt and use mining technology to enhance gold production and productivity. Despite these regulatory amendment action changes, there has been limited expansion of technology

usage in the ASGM sector and majority of miners still rely on primitive tools for both mineral mining and mineral processing operations. The SuDCA development consultant study, identified major obstacle within majority of the ASGM community that they lack appropriate technology in their mining activity practice for mining, processing, and beneficiation and prepared the training manual for miners community [28]. Therefore, the primitive technology usage and lack of advanced technology in the ASGM sector, has contributes a direct negative influence on the gold production and community growth, and environmental conservation and preservation (figure 4).

Miners often follow mining sites and stages that are easily accessible for mineral extraction. But as mining activities progresses further, minerals become harder to extract, and the absence of advanced mining technologies poses challenges for the ASGM community. The lack of appropriate mining technologies leads miners to move after exploiting minerals that have easy access relatively without exploiting the full potential of resources, and in turn resulting in the high mobility of miners and presenting community development challenges. The full stage of ASGM gold extraction techniques share similarities throughout the country. Miners commonly use simple hand tools such as axes, hammers, shovels, and chisels/picks for mining. Comminution of primary gold was manually conducted using metal mortar and pestles by human labor and sizing is performed using carpet in sluicing. The final concentration stage was performed using wooden and plastic pans (figure 4).



Figure 4. Local Mining and Processing Equipment.

Developing suitable technology within the artisanal gold mining sector requires intensive learning and understanding for operation. The lack of appropriate technology selection and evaluation, usage guidance and local contextual consideration in the importing of mining equipment can lead to dissatisfaction of technology among miners. Additionally, the

complex structure, design and lack of training on maintenance and operation further hinder the effective use of advanced technology. As an example, some gold detectors equipment distributed by ministry of mines for gold miners perceived as high in price with spare parts and maintenance problems, lack of operational training by suppliers, shortage of inspection

and maintenance experts, limited power alternative and lack of training on maintenance and operation, a high level of illiteracy among the ASGM community was reduce acceptance of the equipment [29].

The sector's dependence on the imported mining and processing equipment without a focusing on the local manufacturing were make this sector an unhealthy which could not transform the sector and further limits technological advancement within the ASGM sector. In conclusion, the current situations indicate that the technology advancement demand in the Ethiopian ASGM sector could not adequately and properly addressed. The limited adaption of technology and the challenges associated with imported equipment have hindered productivity, community development, and environmental conservation in the sector.

3.6. Ethiopian Mining Legislation and Proclamation History with Respect to ASGM

Ethiopia's mining legislation have undergone through substantial alterations and experienced significant transformations, particularly concerning the ASGM sector. This review focuses to examine how these legislative changes have impact on the ASGM sector, emphasizing both the progress of advancement achieved and the challenges and issues that remain persist. The improvement growth in the regulatory frameworks shows Ethiopia's continuous progress effort to balance profitable economic growth with sustainable resource management and community wellbeing [30, 31].

3.6.1. Early Legislation and ASGM

(i). Initial Prohibitive Measures (1943-1951)

The first, early mining legislation in Ethiopia, started with the 1943 proclamation, were primarily prohibitive in nature, essentially focusing on controlling and preventing the miners from the export of precious metals like gold, silver, and platinum out of country. These laws were crucial key to retain mineral wealth in the country, making sure that no one was not exploited valuable resources without government supervision. However, still they did not address the real requirement needs of the ASGM sector, which was broadly informal and unregulated at the time. Artisanal miners operate outside of the legal framework; due to this case they have limited access to resources or support from the government.

(ii). The Mining Proclamation and Regulation (1971-1993)

The 1971 proclamation was Ethiopia's first comprehensive attempt to control and regulate mining operation activities. It established a set of rule and regulations to govern for mineral prospecting, exploration, and mining operations. However, it did not specifically address to the ASGM sector, which con-

tinued to operate largely outside the formal legal system. Artisanal miners get little and limited oversight support from government because artisanal miners lack clear provisions, and their work continuously remained unofficial. This laws gap showed the clear improvement needed for more inclusive policy program that recognize and acknowledge the contributions and challenges of the ASGM sector.

The 1975 mining proclamation of no. 39/1975 for natural mineral resources issued, the government control with new economic policy on activities such as mineral prospecting, exploration, and mining operations. Later, amendments have been made to the proclamation to include exploitation of precious minerals and energy minerals by clarifying ferrous and non-ferrous metals with specific names in the legislation.

The 1993 Ethiopia's mining proclamation formulated a new regulatory framework for mineral resource development. This proclamation setup the principles allowed to do in mining development and eligibility criteria for miners such as mining rights, prospecting, exploration, mining licenses procedure in order to operate mining activity in Ethiopia. The mining operations proclamation No. 52/1993 defines artisanal mining as non-mechanized mining operations for precious minerals, metals, salt, clay, and other similar minerals, essentially manual operations carried out by Ethiopian individuals or groups of such persons with less than fifteen meters (15m) in depth vertical excavations operations permit for one-year valid license with new probability and can be canceled where the deposit require more advanced exploration and mining methods. However, preferential treatment is given for license holders who have necessary technical and financial resources or compensation instead of license cancellation. The Proclamation also defines no financial resources, technical competence, or professional skill are required to get an artisanal mining license. This type of license permits miners to mine within limited boundary specified and determined minister. License holders must comply with applicable laws and regulations as specified by directive issued by the minister on timber cutting and submit reforestation plan. The proclamation repealed previous mining proclamations and regulations and was later introduced minor amendments in 1996 1998 and 2006. During this period, the Ethiopian government has been made efforts to reform its mining sector, bringing ASGM into the formal economy line through legalization. Therefore, for the first time, the government established ASGM regulating department in 2008 G.C, after government itself special attention to the growth of ASGM sector, recognizing its potential contribution to the country's economy.

3.6.2. Modern Legislative Framework and ASGM: The 2010 Proclamation and 2013 Revised Proclamation

The 2010 proclamation has a significant major advancement for the ASGM sector. It introduced a setup new mining license, allowing them to operate, and work by the rules, profit and benefit with support from government. This inte-

gration of ASGMs into the formal economy and curbing illegal activity, and this helped to formalize the ASGM sector. Further the emphasis on the environmental regulations, health, and common safety standards also showed the government's dedication and commitment for sustainable mining practices. The proclamation aimed to enhance the sector's contribution to national development through ensuring the natural resources protection by providing legal framework basis for artisanal miners. By revising, modifying and introducing Artisanal Special Small-Scale Mining (ASSM) license under 2013 mining proclamation further enhanced the regulatory framework improvement for the ASGM sector. This new license category was designed to facilitate the transition of artisanal miners to more advanced operations, allowing them for partial mechanization with limited employment. The big importance of sustainable mining practices in the ASGM sector was underscored to focused on the environmental impact protections. By encouraging the adoption of better efficient mining techniques, the revised update the proclamation aimed to increase productivity and reduce environmental degradation [30, 31].

3.6.3. Achievements and Challenges of Regulatory Framework in ASGM Sector

(i). Achievements

The many miners introduction into the formal economy was as a result of artisanal mining licenses created which have given them access to resources and support from government. As a result of this formalization illegal mining activities has decreased in many areas by increasing sector's transparency. In addition to illegal mining activities reduction, formalization has enabled the government to collect taxes and royalties from ASGM activities which has contribution in national revenue increment which has brought additional funds for infrastructure services development. As a result, the government provides the legal pathways for artisanal miners which has contributed in poverty reduction within artisanal miners communities. The artisanal miner communities having access to legal mining opportunities has improved their livelihoods and increased economic stability for their families.

(ii). Challenges

Despite the licensing progress was improved, many artisanal miners still facing challenges due to complex procedures. These procedures must be made simple ensuring broader essential to many miners to have access to legitimate mining opportunities. For particular small-scale operations, ensuring compliance with environmental regulation can be extremely challenge. But, to solve this addressed issue strong enforcement mechanisms and encouragement of sustainable practices support are required. There is still, the area remains need improvement that the early legislation lacked provisions for community rights and involvement. Hence forth, en-

hancing and increasing community encouragement by means of involvement, and participation in the mining sector may help to escalate the transparency and accountability improvement in the mining governance. We expect that the draft new national mining policy developed by the Ministry of Mines endeavor to achieve in addressing these issues by establishing and adopting a strong rules and regulations on environmental protection to promote sustainable mining activity practices. So, the policy and strategy ought to prioritize local community engagement by recognizing the critical role of communities in the success of the ASGM sector development. The government must make great efforts to achieve to setup a mining sector policy and strategy that is more inclusive and equitable through fostering collaboration between miners, and local communities, as well as key stakeholders.

Generally, Ethiopia's mining legislation have taken significant measures in formalizing and supporting the ASGM sector. Even if there is a challenge remained, particularly with regard to licensing complexity procedure and environmental compliance of mining activity, the government's commitment and dedication for sustainable mining practices and community engagement and involvement can perceived as a positive step. The long term successful of the ASGM sector depend on the continuous initiative efforts to restructure an reorganize regulations to provide enhancement support for artisanal miners. By addressing these issues, Ethiopia can harness fully from its ASGM sector, and contributing to sustainable development and economic growth.

3.7. Environmental and Socio-Economic Impacts of ASGM

3.7.1. Environmental Impacts of ASGM

ASGM operations activity is a pillar of economy for miners engaged in it and primarily takes place with minimal capital, poor infrastructure and primitive technologies and has an occasion of opportunity to spur economic growth of the local community. However, this types mining operations activity has a huge significant social and environmental consequence, leading to various adverse impacts [32, 35]. One of the main issues in the mining sector is how to bring the necessary balance between the need to promote sustainable development on the one hand and how to address social and environmental problems that would come along with such operation activity on the other hand because mining itself naturally leads to environmental problems everywhere mining activities are conducted [24, 29].

Basically, the concept of environmental impacts of ASGM includes all consequences that have potential negative impacts on the natural environment and consequently the human environment. Accordingly, ASGM operation activities are one of the anthropogenic activities that change and shape landscapes [29]. ASGM is associated with a number of environmental impacts and the gold produced through ASGM method

was generate pollution. Among the most significant potential environmental impact associated with ASGM operations activities are related to deforestation and habitat fragmentation (destruction), land surface erosion and landscape damage, siltation and pollution of water bodies, dust pollution, air pollution, and noise pollution [33]. The extent to which the landscape is affected by ASGM depends on the scale of ASGM activities. In ASGM, deforestation event happens during land clearance in access to gold deposits and mining activity. The conversions of forests and other natural habitats into mining sites contributes to climate change, fragments the landscape and disrupts ecosystems, reduces biodiversity, and threaten the survival of numerous plant and animal species by isolating and separating wildlife populations [34]. Also, ASGM processes may lead to subsidence and collapsing of mining hole where underground mining excavation were attempted. ASGM operations sometimes encroach upon fertile agricultural land, leading to permanent loss of fertile land. This loss can have severe consequences for local communities that depend on agriculture for sustenance and livelihoods. ASGM activities such as digging and soil displacement can accelerate erosion of valuable topsoil and alter the topography of the land and resulting in the hindering of post-mining land rehabilitation efforts [2, 35].

During the washing and panning steps of the gold production process, ASGMs require water as a vital and indispensable resource. Most ASGM were use running water while others use artificial pod water for panning technique. Because of its high dependence nature on water and location of mining sites close to river basin, this ASGM process has negative effects on water and water compositions. Sediment runoff and improper handling, disposal and discharging of toxic and hazardous chemicals directly or indirectly from mining sites leads to pollution and contamination of nearby soil and streams, rivers, and other freshwater body, reduces water quality, and significantly disrupts habitat of aquatic ecosystems as well as human health [32, 35, 43].

Also, due to ASGM extensive reliance on the amalgamation technique for gold extraction from ore, ASGM considered as main causes of mercury emissions as a primary source to the environment. ASGM emit significant amount of mercury in their attempts to recover gold, into environment during panning and smelting as process so called amalgamation. Therefore, this released out toxic chemical to water resources, soil, air, and can also enter the human body, through inhalation as confirmed by research done in mining sites over the world, poses serious health treats to the miners and surrounding communities or circulates globally and born/create problem in the future [2, 11, 24, 37-39, 53, 54]. However, introducing modern mercury free gold processing technology such as gravity method, borax techniques gold extraction can drastically reduce and eliminate the mercury from ASGM sector [40-44].

Many areas where ASGM activities were conducted show

significant attention for the natural environment and social concerns [15, 34, 36]. The Ethiopian mining law has different comprehensive provisions that are intended to protect social and environment from mining activities impacts. In the current Ethiopian regulatory systems, environmental impact assessment process and management requirements for ASGM are often too difficult and are not realistically attainable by governments or miners [33]. Moreover, the issuance of ASGM licenses occurs without adequate regulatory guidance regarding environmental responsibilities, leading to a lack of financial and technical support for raising awareness and building the capacities of miners in terms of rehabilitation efforts. This situation poses significant risks, as abandoned mining pits endanger human life, livestock and wild life. Additionally, the pits and trenches often collect and accumulate standing pond water, which contribute increased possibility of malaria outbreaks and creates health hazards [8].

As per the Mining Operation Proclamation No. 678/2010, environmental impact assessment or environmental management plan documents are exempt for holders of artisanal mining licenses as a first requirement condition in order to license granting. Based on mining operations regulation No. 423/2018; the artisanal mining license holders shall fill pits they dug and plant instead of trees they chop down, observe other obligations stated under proper environmental laws and shall not be allowed to use mercury or similar hazardous materials in their operations. The artisanal gold miners have responsible on environmental management in effective and sustainable manner. A licensee shall be obliged to conduct mining operations in compliance with the environmental, health, and safety requirements set forth in the relevant laws for artisanal mining. The mining law requires rehabilitation of mined-out sites. Land from which miners have extracted minerals require clear recognition rights of miners to convert and rehabilitate the land from which they mining. However, a significant proportion of ASGM remains unaware and uninformed about laws and regulations govern and control mining operations and its effects on the environment.

Therefore, there is a significant real evident environmental damage of the ASGM operations (Figure 5). In particular, ASGM operations in Ethiopia are causing high level of physical land degradation and deforestation where in many places rehabilitation efforts are not made (Figure 5). Furthermore, there are no specific environmental laws that govern the particular challenges of the ASGM sector. The mining regulation which is currently in force does not also provide guidelines or any other rules how ASGM's may be involved in community development because of their impact on the environment. Generally, there is a lack of an effective environmental impact assessment and management. The condition of ASGM at ground levels not governed by or does not consider the issues of environmental rules, regulations, proclamations, and directives.



Figure 5. Few ASGM Impact on the Environment.

3.7.2. Socio-Economic Impacts of ASGM

ASGM is an important source of employment for youth, especially in rural areas. Millions of people in over 70 low-income countries and middle-income countries depend on artisanal gold mining for their livelihoods, producing around 20% of the global gold production [24]. The gold produced by ASGM activities can be used as economic indicators in which it boosts national growth and increases employment opportunities. ASGM plays a crucial role in sustaining the livelihoods of mining communities and serving as a primary source of income for community depend on it both directly and indirectly and it is a difficult risky occupation operate without guarantee within legal frameworks or informal engage practice [36].

The practice of artisanal mining has been associated to

adverse numerous undesirable socio-economic impacts on mining communities and may not give any benefits at all while or after mining [29, 32]. ASGM contributes to the employment of more than 1.26 million miners directly and supports and sustains over 7.5 million populations indirectly from income of gold sold and stands out as the primary source of income, and plays a significant role by contributing approximately 74% to the overall livelihood of mining communities [6, 19]. While recognizing the significance of ASGM in supporting livelihoods of miner's community, it is essential to address various challenges to improve the conditions of artisanal mining communities.

ASGM method of operations activities are potentially harmful to the human health which occur as a result of human intervention and poses serious health treats to humans. ASGM operation frequently associated with factors such as toxic

chemical pollution, dust and noise pollution which can cause health problems to human during mining activity. [11, 39, 53, 54]. Where ASGM activities exist, there is a low level of hygiene, occupational health problems and frequently lack basic health care and sanitation, as a result, transmittable diseases often increase [45, 46]. Most of ASGM don't use personal protective equipment during mining operations and illness such as malaria, waterborne diseases, and respiratory diseases are broadly occurred [6]. Massive ASGM operate informally, and connected with low levels of worker safety measures, health care or environmental protections [45, 47, 48]. This occupational difficulty facing the ASGM community is due to lack of training, inadequate ventilation system, a lack of safety equipment, inappropriate handling and use of chemicals, obsolete equipment [49].

Generally, ASGM sector is highly associated with occupational health issues, particularly when practiced informally or with limited technical and material resources. The healthiness of physical conditions and welfare safety of miners, family members and surrounding communities are most of the time negatively affected [49]. Understanding occupational health risks in the ASGM sector is an important precondition for miners to protect themselves and their communities, and shift to environmentally sound and safe practices [24]. Furthermore, the issuance of ASGM licenses occurs without adequate regulatory guidance regarding environmental responsibilities, leading to a lack of financial and technical support for raising and capacity building and awareness creation of miners on the rehabilitation of mining sites. This situation presents a serious concern, because the abandoned mining pits endanger human life, livestock and wild life [2, 29, 36].

Moreover, these pits often accumulate standing water, which increase the malaria outbreaks and poses health hazards [8]. In some Ethiopian regions, ASGM occurs in areas affected by conflict and/or social instability. disagreement on land, violence, and abuses of human rights can make worse by contribute to social tensions in the competition for mineral resources. Inadequate governance, management and regulation can further intensify the issues within ASGM, making it more challenging to ensure responsible mining practices and equitable resource distribution. The conflicts among ASGM arises from lack of clear delineation of mining sites. [6, 36, 49].

ASGM often exhibits gender inequalities, in which women are typically facing greater socio-economic challenges (8). Majority of artisanal miners are men and women are participating less and they are less profitable from gold mining, processing and trading. Women are participating on open surface and shallow depth mine, washing and processing while men dominate the whole process starting from extraction activities to final pure gold sale. Due to surface mining are become almost all depleted now they shift to underground mining. This gender imbalance can limit women's economic empowerment, access to resources, and decision-making power within mining communities [9]. According to the re-

cent study conducted the local negative norms/ belief is one of the factors which limit and affect the participation and involvement of women in mining and processing operation activities and decides women's roles. These norms are a universal belief that women's roles should be confined to domestic matters, thereby limiting their involvement in the mining industry [6].

In some instances, children are engaging and involved in ASGM activities and exposed to hazardous mining processes like physical and psychological dangers risks, sacrificing their education [50]. However, this child labor activity situation in ASGM hinders children's growth and development and darkens their future opportunities and prospects by perpetuates intergenerational poverty. The physical damage as well as increasing school dropouts due to children participation in mining activities was increased [6]. Hence it is important to provide support for women and children by addressing issues that hinder them from fully partaking and beneficiaries in ASGM.

Most of ASGMs don't use personal protective equipment during mining and processing operations and exposed to illness such as malaria, waterborne diseases, and respiratory diseases (6). Silicosis is one of the widespread occupational illnesses affects ASGM operations which characterized by dusty environments. During the ASGM operations such as mining, crushing and milling, continuous dust inhalation results in the accumulation of fine silica particles in the lungs. This accumulation causes lung irritation (pneumonitis) and the formation of scar tissue, resulting in airway obstruction [12, 45, 51]. Breathlessness, coughing, increased mucus production are common respiratory symptoms of silicosis including indicators of acute silicosis like fever and chest pain. The severity of these symptoms depends on the dose and duration of exposure, as well as individual factors like smoking habits and pre-existing lung conditions that may have compromised lung function [24, 38, 47, 48]. To prevent and mitigate dust inhalation problem during mining and processing in ASGM operations, can be solved through two crucial interventions such as proper use of respiratory masks and adoption of wet processing techniques with water to control and minimize the dust generation.

3.8. ASGM Environmental Impacts Reduction Strategy and Mitigation Measures

Addressing the issues related to environmental, social and health impacts of ASGM requires a collaboration program among stakeholders, including ASGM miners, local communities, federal and regional governments, and non-governmental organizations. Therefore, the improvement of ASGM negative activities on environment only achieved if all concerned body committed to support with specific environmental management tools and strategies designed and implemented to practice in the ASGM operations.

The mining proclamation does not impose obligations on

ASGMs to train and skill-up themselves with a view of increase their skills from time to time. Thus, the law governing mining sector should consider and introduce the law that enforces artisanal miners to upgrade their skills up to date. Lack of awareness and technical training of the ASGMs contribute to the environmental issues. International scientific discussions, debates, and numerous studies have examined and addressed most effective strategies and approaches for the sustainable management of natural resources. So, environmental impact of the ASGM can be minimized through closing illegal and unregulated mine sites by enforcing regulations, legislation and follow-up of legal and formal mine sites. Eventually, restoring mine sites also will reduce the negative environmental impacts and effects of mining.

The better understanding of all mining activity related mineral processing will lead to a sustainable mining industry and mitigation of environmental impacts. Therefore, mitigating adverse environmental impact of ASGM requires technically educating and training of miners, regulatory and policy enforcement, involve participation of local communities and miners in decision making. Mitigation of the adverse effects of mining can be possible through critical decision-making and community participation, planning and implementation of manageable strategies in mining area, and sometimes environmental development aid from concerned donors. Mitigation measures of land, soil and water entail the reestablishing of the original affected areas as a result of ASGM activity. Appropriate approaches of environmental management methods and techniques entails use of natural resources effectively as possible for economic growth and preserving the natural resources without irrevocably harming the environment.

First of all, it is better to address proactive steps to mitigate anthropogenic effects of ASGM operations impacts on environment. By systematically examining environmental impacts and adopting suitable mining practices to mitigate environmental impacts, it is possible to make mining a fewer environment destructive and improve environmental performance. Strong governance and management of the ASGM sector will help to gain the positive benefits of ASGM by minimizing or eliminating any negative environmental, social and economic impacts. Accordingly, the things thought to be considered and expected to reduce the impact of ASGM have been attempted to mentioned and described as follows.

Launching and Promoting of a comprehensive initiative programs focused on reforestation and sustainable land management in areas affected by mining activities. This initiative may include activities such as tree planting campaigns, sustainable land management practices, and the promotion of alternative livelihoods to reduce dependence on mining. The forests conservation and plantation were a great concern in many ASGM areas because miners are cut down trees for site clearance, coal preparation for additional income. Designing and promoting alternative mercury-free gold mining and processing technology such as gravity separation techniques

and Borax in separation of gold from ore without mercury usage. Collaborate to work together with organizations and environmental specialist experts to plan and develop training programs, and organize workshops to buildup capacity of miners on promoting the adoption of safer and more environmentally friendly techniques, distribute educational materials for effective technical support on the rehabilitation techniques and best mining practices. Develop and establish proper waste management practices to reduce pollution beyond the mine site. Educate miners on the reclamation process to enhance miners concept on the proper handling and storage of topsoil for future reclamation activities.

Create a mechanism that tracks and monitors the enforcement of existing regulations related to environmental issues in mining operations. Develop personal protective equipment (PPE) promotion program and establish partnerships with local suppliers to easily access this PPE such as masks, gloves, and eye goggles at affordable prices. Promote mine safety and ventilation enhancement program that focuses on improving mine safety by addressing inadequate pit aeration. This can involve the installation of ventilation systems, development of safety protocols, and training for miners on proper ventilation practices to mitigate the risk of suffocation. Implementing gender equality and women empowerment initiative to promotes gender equality and women's meaningful participation in ASGM is one main issue need touch. Another main issue that needs focus is protect children from physical harm and prevent their involvement in ASGM activities. This may achieve only through identifying the risks associated with child labor, interventions to support school attendance and retention, and alternative livelihood opportunities for families involved in ASGM. Also, provide specialized occupational health services targeted to the needs of ASGM miners, including regular health check-ups, screenings for occupational diseases (such as silicosis and mercury poisoning, diarrhea), and occupational safety training.

Suit condition to conduct comprehensive strategic environmental impact assessment (SEIA) program at the scale of ASGM zone to assess the cumulative environmental impacts and based on SEIA findings, collaborate with government agencies, environmental experts, and stakeholders to develop guidelines and regulations to provide technical support and resources which assist ASGM operators in complying with the SEIA requirements.

3.9. Current Challenges and Obstacles of Ethiopian ASGM Sector Towards Sustainable Development

Artisanal and small-scale mining operations can be promised to boost communities from poverty. However, the most ASGMs involved in ASM operation activity are often poses a significant number of dangerous risks (hazards) during their mining activities both to the miners themselves and to their surrounding communities and environments. The continuous

legal enforcement level of proclamations law is weak. Typically, the most artisanal and small-scale mining operations are undertaken outside of the law and without compliance with mining industry standards. The informality of artisanal and small-scale mining operations was commonly seen by working without license, legal protection, support of the government and not complying with government regulations and environmental mitigation matters.

In an effort to improve the washing process and increase productivity, advanced machine should be introduced to this sector either by technology adoption techniques from other successful country or by importing from Manufacturer Company. This will facilitate the process of washing minerals, particularly for artisanal miners. Most ASGMs don't know how to treat water or the reusability of it and most of them are lack latrines. One of the major challenge/ problems is lack of sufficient/ adequate water sources in most mining sites. As a result, washing process cannot be effectively carried out. This obstacle and delays the process of mining operations efficiency and exposes miners to high costs to buy water. ASGM operations often lack compliance with safety regulations and standards.

In summary, there are a number of risks associated with artisanal mining such as miners personal injuries, infrastructure damage, economic losses, and environmental contamination and pollution. Implementing safety regulations, encouraging and promoting responsible and sustainable mining practices, and providing support and alternatives substitutes for artisanal miners are all mandatory to mitigate these dangers and guarantee safer and more sustainable mining operations.

ASGMs accidents relate to poor mining practices or collapse of tunnel/shaft. As occasional artisanal mining activity occurs beyond the country's law, these activities may not fulfill minimum standard quality of tools and equipment, or safety practices. As a result, miners are less likely to be equipped with effective safety materials and work with these backward materials. An artisanal mining operation frequently takes place without appropriate and adequate infrastructure. This may prevent miners from access to proper safety equipment by increasing the risk of accidents and injuries. Malfunctioning or dangerous machinery can further contribute to hazardous working conditions. For example, such circumstances happened when a roof of routine blasting operation tunnel collapsed and resulted in the death of miners die at Nedjo gold mine western Ethiopia, Guji in Seba Boru Woreda, South Western Ethiopia <https://www.ethiopiaobserver.com/>, <https://www.africanews.com/2022/02/23/seven-killed-in-ethiopia-mine-collapse/>, and Zimbabwe. Similarly, a landslide in an unlicensed gold mine in Indonesia trapped approximately 100 miners, highlighting the dangers faced by artisanal miners (<https://www.bbc.com/news/world-africa-66968026>). Small-scale artisanal mining can negatively impact a country's mining sector and economy in various ways. Firstly, it can deplete valuable mineral resources at a faster rate. Addi-

tionally, as these operations often operate outside the law, they may not pay taxes on their mineral extractions, leading to revenue losses for the government. Moreover, the presence of illegal mining can make it challenging for licensed stakeholder to operate profitably. The sale of artisanally mined minerals at lower prices in illegal ways can also undermine the profitability of the mining sector. The sale of artisanally mined minerals at lower prices compared to those sold by international corporations can also undermine the profitability of the small-scale artisanal mining community.

Artisanal mining is a significant source of environmental pollution, particularly due to the use of toxic chemical (mercury) in gold extraction. The used mercury extraction processes are often inefficient and hazardous method. This leads to the release of large quantities of mercury into the environment. The UN has reported that artisanal mining is responsible for 40% of the world's total mercury emissions, with approximately 1,000 tones being released annually. The use of mercury in extraction methods poses health risks not only to miners but also to individuals residing in mining areas. Furthermore, illegal mining operations, including those associated with artisanal mining, have caused significant environmental damage [37].

Conflicts among the artisanal and small-scale gold miner (ASGM) communities are rare while a significant conflict issue arises seriously between artisanal miners and larger private mining companies as they gain rights to develop deposits that are already worked by artisanal miners due to overlapping of mining areas as a result of poor licensing and area delineation problems or as the area transferred for in special manner.

ASGM in Ethiopia practices a long years of poor mining experiences having Unexplored and untapped resources. This is due to factors such as lacks appropriate technology, government late focus on ASM sector, lack of skilled man power for technology usage, poor OHS practice, lack of continuous support and coordination from related body, lack of competent trainers within the intuitions, lack of sufficient training, in adequate training centers.

Other challenge facing ASM sector includes in the major ASM activities that production and marketing are informal.

Some of the challenges and obstacles that encountered to prevent ASGMs from achieving sustainable development include high levels of miner's mobility, illegal and informal mining activity, use of obsolete/inappropriate equipment, low level of legal framework and regulations enforcement.

When we analyze the current situation status of ASGM operation in the Ethiopia, generally this sector was characterized by a widespread challenges like low productivity, illegal trade, informality and illegality, lack of clear guiding policy and guiding prices, lack of clear geological information and mapping out the area, lack of suitable access to financial credit situation, awareness and enforcement of mining regulations, ground-level voices in decision making processes, coordination between government agencies.

However, ASGM could be presents an additional financial challenge to the government in the regulating financial transaction process in which miners itself can participate in the informal gold transaction and do not pay tax by concealing their earnings and leaving revenue of government, which will limit the capability of government to provide services or enforce application of laws in this sector.

The current ASGM practices in Ethiopia can be described and characterized by primitive and lacking efficiency, low degree of capitalization or mechanization, low level of productivity and recovery, unrecyclable wastes, use inappropriate obsolete technologies, poor information, low levels of environmental awareness.

The information and data regarding formal engagement of country's ASGM has not been properly recorded. improving information status on ASGM from time to time is essential to understand the ASGM's situational status such as social, economic, governance, environmental, technological facets and their potential in fighting against poverty. Additionally, improving and updating data recording system on ASGM will provide basic data and knowledge needed to create and carry out support and policy initiatives and assist in determining a set of appropriate indicators for tracking and evaluating the advancement of the ASGM sector.

3.10. The Role of Government and Private Sector in Technology Advancement in Supporting ASGM

The technology should aim to provide a simple and efficient tool for ASGMs mining and processing. Developing and promoting mining and processing technologies would help for the advancement of the ASGM sector in Ethiopia, by fostering sustainable mining practices and enhances productivity and production quality. A government sector and related organizations plays a crucial role in technological advancement within the mining industry sector, particularly in the artisanal and small-scale gold mining (ASGM) sector [35, 52].

An organization can focuses on identifying the needs and challenges within the ASGM sector and develops appropriate solutions to address this problem through:

Applying knowledge-based approaches, both directly and indirectly, to the mining industry sectors.

Engaging research activity aims to develop innovative techniques and technologies that can enhance the efficiency and sustainability of mining operations.

Conducting supportive research efforts aimed at improving the production and productivity of ASGM communities.

Additionally, the organizations can facilitate technology transfer programs and training initiatives to promote the adoption of flexible and simple technologies and practices within the ASGM.

Also build educational and technical training centers for fostering collaboration and knowledge exchange which acts as a bridge between stakeholders and the mining sector.

Focusing on the development and adoption of specific mining technologies relevant to artisanal mining activities.

In this article, despite those mentioned above, I have tried to touch on a few strategies to help Ethiopian ASGM sector in the following topic.

4. Methods to Support the ASGM Sector in Ethiopia

Although there are many widespread problems with ASGM, through various level of support, the ASGM sector can be improved and its potential harnessed. The measurement approaches to support and improve the current existing situation of ASGMs are discussed/ presented as follows.

First of all, focus on formalization and legalization of ASGM communities to enhance the production performance, through trough assessment. This will require legal framework and regulations enforcement to organize them and performed by registration of ASGM to legalize and administer. It will require high commitment to developing conducive policy, legal framework and regulations to encourage ASGM in the mineral policy of country.

Then focus to train miners to adopt more responsible and environmentally friendly methods of gold mining and processing. By focusing on chemical-free methodologies that forego the use of mercury and other toxic chemicals, the miners are able to work in a safer and healthier environment, and responsibly and positively produce gold and generate long-term benefits for their economy.

Focus on improving working conditions of ASGM. This will include technical assistance that increase their productivity with standard social protection, promoting better integrated rural development strategies by interplaying mining with other aspects of local economies and emerging gold fair trade or clean supply chains model pilot effort to increase responsibility across the supply chain and certify gold they provide to incentivizes them for their contribution to both global gold industry and to local economy of a given community.

On the other hand, they can be supported by introducing /providing/promoting modern technology or by connecting with manufacturers. Similarly, start to suit situations how they acquire access to underground mines existing in the vicinity of the potential area either by self or make collaborations with similar ASGM to share existing resources and the company will support through technology, financial experience and marketing from the company stakeholder. Building market center was support effort made to control illegal market. This creates conducive working environment and market link between them by creating modern market system from mine to market. Establish ASGM cluster zone through reform to solving the exiting problems step by step and for technology intervention. In parallel to this creating modern mining and processing center is necessary for intervention of simple,

mobile beneficiation technology to give services at one center.

This entails conducting qualitative resource evaluation of existing high potential gold area by integrate methods.

Proper ASGM transformation to next production level is necessary to increase their productivity. This ASGM mining and possessing technology transformation entails creation of ASGM zone around gold potential areas by demarcating mining areas for ASGM. This plays an important role in creating/providing accessible basic extension services for local community. One can develop training, knowledge sharing and awareness raising/ creation forums /platforms for ASGM by creating government-university- industry – linkage opportunity ASGM.

Financing ASGM can help miners to obtain advanced technology that better comply with environment. This will gradually decrease and ultimately eliminates the use of mercury, and often increases the gold yield for miners. Focus on preparing proper environmental monitoring and mitigations measures to proactively work on it and Prioritizing/emphasizing women's activity in the ASGM sector.

5. Opportunities and Recommendations for the ASGM Sector

Supporting ASGM has many benefits. Some of the benefits that will gain from supporting ASGM includes, easy to provide extension services, credit services, depending on their convenience the miners can produce high quality product, increase quality and quantity of productivity, save time, reduce adverse environmental impact and helps to rehabilitate degraded mining areas and environmental, expanded and implemented procedures of environmental management and mitigation practices, through a process ASGM transformation can be achieved, create market link among ASGM and also ASGM between large scale, help to smoothly transfer technology by implementing modern equipment to increase government revenue and reduce illicit/ illegal gold trafficking/ trading through strategic incentives. The right measures taken to improve ASGM challenges in Ethiopia were include formalization, legalization and modernization of the ASGM sector, deliver financial support and the way access to capital, and extensional services for ASGM community, capacity building and technology intervention with best practices among ASGM community, reforming ASGM community through cluster zone for better deliverance of conducive and comprehensive legal frameworks, access to geological data and equipment, dialogue between ASM stakeholders and stretch-out environmental monitoring, evaluation and mitigations measures system. The ASGM sector monitoring and evaluation mechanisms my include, Improving the competitiveness and productivity of the ASGM, develop competitive marketing strategy of the ASGM, create conducive environment, sustainability and inclusiveness among ASGM community, develop capacity building training program for

ASGM community, ensure the availability and accesses to the required finance and financial product and market.

Implementation of the ASGM cluster zone requires the work of determination and effort. These efforts and commitment include the work of such as gather basic geological information and data on resource; manpower, technology through data collection assessment, identification of potential mineral area, to map and delineate potential mine site, check out tonnage and grade of deposit, support and enforce to monitor on licensing/ formalizing and regulation in bringing sustainable mining, identify number of miners and amount of production, identify current existing problems, i.e. related to environment, mining and processing methods, identify market center area for linkage with buyers, provide extensional services and technical assistance to ASGM workers.

6. Conclusion

Even though, Ethiopia experienced ASGM activity for a long year of history, the mining status is at infant stage due to available low level of experience, knowledge, technology, finance, market and it has not been able to avoid hunger and poverty from community engaged in it. There is also lack of proper documentation, legal protection, and continuous government support on the ASGM sector. In this paper, we recommend on information collection and data gathering regarding the equipment used in mining and processing, ore recovery status, ore reserves and the accurate ways of deposit delineation. The performance of assessment work so far done concerning ASGM should be evaluated, gaps were identified and miner's access to finance services, gold supply chain and smuggling issues, alternative income sources for local community are the area which require further assessment. The issues related to production, technology, limited access to finance, markets and information gaps, illegality, social and environmental matters areas must be corrected and require policy for effective management and regulations of the sector. A commitment work was necessary to train and arm miners with modern equipment that comply with local ore along with best practices. Also, it is necessary to quantify the significant degree of illegality in the ASGM sector to make it easy for formalization and legalization process for informal and illegal artisanal miners. The two most important critical and essential issues were the equal participation and benefits of women and the use of local knowledge in the ASGM sector might be verified and confirmed.

Therefore, government may adopt coordinated strategy approaches that reduce the main challenges of ASGM to deliver foster environmentally and socially responsible ASGM sector in the country. Government may take action like strengthening ASGM governance, formalization, legalization and ASGM transformation, establish ASGM cluster zone, improve the skills of ASGM through training and experience sharing, work on barriers identified as aforementioned by many research and assessment, make continuous follow-up of

ASGM. This comprehensive review will serve as a valuable source for policymakers, researchers, and stakeholders interested in the supporting sustainable development of the artisanal and small-scale gold mining sector in Ethiopia on how to increase its productivity and economic impact. It provides a necessary future strategies and interventions that initiate a government to work on the promoting both economic growth and environmental preservation and conservation with relevant body who interested to support the development of the ASGM sector.

Abbreviations

ASGM	Artisanal and Small-scale Gold Mining
GDP	Growth Development Production
G.C	Gregorian Calendar
UNDP	United Nations Development Program
GSE	Ethiopian Geological Survey
GIE	Ethiopian Institute of Geology
NBE	National Bank of Ethiopia
UN	United Nations
ASM	Artisanal and Small-scale Mining
OHS	Occupation and Health Safety

Author Contributions

Misganu Kabeta: Conceptualization, Data curation, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

References

- [1] Proclamation No. 678/2010: A Proclamation to Promote Sustainable Development of Mineral Resources, 2010, ministry of mines and energy, Ethiopia.
- [2] Thomas Hentschel, Felix Hruschka, Michael Priester, 2003, Artisanal and Small-scale Mining. Challenges and Opportunities.
- [3] Hailu Elias & Atlaw Alemu, 2022, Formalizing and enhancing performance of artisanal and small-scale gold mining in Ethiopia.
- [4] Andrew Keili, Hailu Elias, and Kebede Bekele, 2021, Artisanal and small-scale mining in Ethiopia: Scoping study for a comprehensive survey.
- [5] World Bank, 2021, Artisanal and Small-Scale Gold Mining: A Framework for Collecting Site-Specific Sampling and Survey Data to Support Health-Impact Analyses.
- [6] Addis Ababa University, AAU, 2022, Analysis of Challenges and constraints Facing Artisanal and Small-Scale Gold Mining sub-sector in Ethiopia: ways forwards and technology interventions; unpublished paper.
- [7] Jacopo Seccatore, Marcello Veiga, Chiara Origliasso, Tatiane Marin, Giorgio De Tomi, 2014, An estimation of the artisanal small-scale production of gold in the world: <https://doi.org/10.1016/j.scitotenv.2014.05.003>
- [8] Priya Bala-Miller, Rahel Getachew, Munisha Tumato, 2020, Supporting the Ethiopian Ministry of Mines to Develop ASM, CASE STUDY #3; State of the Artisanal and Small-Scale Mining Sector.
- [9] Canadian International Resources and Development Institute, CIRDI, 2019, Ethiopian Artisanal, Special Small-Scale Mining Strategy Roadmap Final Draft.
- [10] Proclamation No. 52/1993: A Proclamation to Promote the Development of Mineral Resources, 2018, ministry of mines and energy, Ethiopia.
- [11] Gavin Hilson, 2002, Small-scale mining and its socio-economic impact in developing countries, <https://doi.org/10.1111/1477-8947.00002>
- [12] World Gold Council, ASGM report Press Release, 2022, New World Gold Council report looks at lessons learned on managing the interface between large-scale and small-scale and artisanal gold mining, <https://www.gold.org/news-and-events/press-releases/asgm-report-2022-press-release>
- [13] Anwar Endris Hassen, 2022, Competency oriented management for sustainable artisanal and small-scale mining sector development in Ethiopia: <https://doi.org/10.1111/1477-8947.12246>
- [14] Mark Freudenberger, Timothy Fella, Sebastien Pennes, 2013, Property Rights and Artisanal Mining: Clarifying and Strengthening Rights: Options for Policymakers.
- [15] Hentschel, T., Hruschka, F. and Priester, M. 2004, *Artisanal and Small-Scale Mining: Challenges and opportunities*. Available at <https://www.iied.org/9268iied>
- [16] Intergovernmental Forum on Mining, Minerals, Metals, And Sustainable Development, 2017, Strategy for Managing Artisanal and Small-Scale Mining.
- [17] Yared Hailemariam, 2023, Legislative Power over Mineral Resources in the Ethiopian Federation: Legal and Practical Challenges: <http://dx.doi.org/10.4314/mlr.v18i1.4>
- [18] Tamrat Mojo Beyene, 2013, ASGM sector formalization and sustainable development, case study of Ethiopia.
- [19] Ethiopian Extractive Industries Transparency Initiative, EEITI, 2016, Artisan Mining Operation and Its Economic Values, Ethiopia, A Final Draft Report https://eiti.org/sites/default/files/attachments/artisana_mining_3.pdf
- [20] Ethiopian Geological Survey, 1996, Over view of Ethiopian Geology, <https://www.collegesidekick.com/study-docs/12840647>

- [21] Solomon Tadesse, Jean-Pierre Milesi, Yves Deschamps, 2003, Geology and mineral potential of Ethiopia: a note on geology and mineral wealth of Ethiopia: [http://dx.doi.org/10.1016/S0899-5362\(03\)00048-4](http://dx.doi.org/10.1016/S0899-5362(03)00048-4)
- [22] Assefa Getaneh, 1991, The Mineral Resources Potential of Ethiopia.
- [23] Ernesto Abbate, Piero Bruni and Mario Sagri, 2015, Geology of Ethiopia: A Review and Geomorphological Perspectives, https://doi.org/10.1007/978-94-017-8026-1_2
- [24] Artisanal Gold Council, AGC, 2022, Chemical hazards in the artisanal gold mining sector: Impacts of mercury, cyanide and silica dust on human health and environment.
- [25] Binnyam Ahmed, 2023, Legal History of Extractive Industry Governance in Ethiopia, Bahir Dar University Journal of Law Vol. 13, No. 2 (June 2023).
- [26] Tilahun Weldie Hindeya, 2012, An Overview of the Legal Regime Governing Minerals in Ethiopia, Bahir Dar University Journal of Law, Vol. 3, No. 1 (2012).
- [27] Ethiopia's mining proclamation and legislation with their corresponding amendments: 1943, 1944, 1951, 1971, 1975, 1994, 1996, 1998, 2002, 2006.
- [28] Estelle Levin Limited (ELL) and Sudca Development Consultants (Sudca), 2016, GOLD TECHNICAL TRAINING MANUAL.
- [29] Rao Cheepurupalli., Hagos Abraha., Mearg Belay., & Anura-dha, B. 2022., Impacts of Artisanal Gold Mining on Miners and the Environment in the Asgede Tsimbila Woreda of Northern Tigray, Ethiopia. <https://doi.org/10.48047/NQ.2022.20.1.NQ22381>
- [30] Proclamation No. 816/2013 A Proclamation to Amend the Mining Operations Proclamation, 2013, ministry of mines and energy, Ethiopia.
- [31] Regulation no. 423/2018: Council of Ministers Regulation to provide for Mining Operations, 2018, ministry of mines, Petroleum and Natural Gas, Ethiopia.
- [32] Siduduziwe Ncube-Phiri, AliceNcube, lessing Mucherera, khululi Ncube, 2015, Artisanal small-scale mining: Potential ecological disaster in Mzingwane District, Zimbabwe, <https://doi.org/10.4102/jamba.v7i1.158>
- [33] Canadian International Resources and Development Institute, CIRDI, 2017, Environmental Assessment and Management for Artisanal and Small-scale Mining.
- [34] Vijayan Gurumurthy Iyer, 2017, Strategic Environmental Assessment (SEA) Process for Sustainable Mining and Mineral Management Development, <https://doi.org/10.4236/oalib.1103422>
- [35] Pollution Prevention and Waste Management, TRI National Analysis 2016, www.epa.gov/trinationalanalysis/ January 2018.
- [36] 2025, Degfie Teku, Geo-environmental and socio-economic impacts of artisanal and small-scale mining in Ethiopia: challenges, opportunities, and sustainable solutions, <https://doi.org/10.3389/fenvs.2025.1505202>
- [37] Minamata Convention. 2019. *Minamata Convention on mercury text and annexes*; <https://minamataconvention.org/en>
- [38] Rajae, M., Long, R. N., Renne, E. P., & Basu, N. 2015. Mercury exposure assessment and spatial distribution in a Ghanaian small-scale gold mining community, <https://doi.org/10.3390/ijerph120910755>
- [39] Israel, Danilo C. & Asiot, Jasminda, 2002, Mercury Pollution Due to Small-Scale Gold Mining in the Philippines: An Economic Analysis, <https://doi.org/10.62986/rps2002.02>
- [40] Zeryihun Hailu, 2025, Evaluation of Borax as an Alternative to Mercury in Gold Recovery: A Case Study of Benishangul Gumuz Region, Assosa Area, Western Ethiopia, Unpublished MSc Thesis, Addis Ababa University, Addis Ababa, Ethiopia.
- [41] JF Thomsen, 2018, The mercury-free gravity borax method in artisanal small-scale gold mining, <https://doi.org/10.1136/oemed-2018-ICOHabstracts.692>
- [42] Peter W.U. Appel, and Leoncio Na-Oy, The Borax Method of Gold Extraction for Small-Scale Miners: <https://doi.org/10.5696/2156-9614-2.3.5>
- [43] Nadine Steckling, Stephan Bose O'Reilly, Dennis Shoko, Stefan Muschack, Rudolf Schierl, 2014, Case Study: Testing Local Conditions for the Introduction of a Mercury-free Gold Extraction Method using Borax in Zimbabwe, <https://doi.org/10.5696/2156-9614-4-7.54>
- [44] Misganu Kabeta, Mulugeta Sisay Cheru, Goitom Gebreyohannes Berhe, 2024, Applicability of Gravity Separation Method on The Ashashire Gold Ore Deposit from Benishangul Gumuz Region, Ethiopia, <https://doi.org/10.4236/ijnm.2024.112002>
- [45] WHO. 2016, Environmental and Occupational Health Hazards Associated with Artisanal and Small-Scale Gold Mining, <https://iris.who.int/handle/10665/247195>
- [46] Melaku, E. 2018, ASGM formalization and its environmental and social impacts in Ethiopia. Presentation.
- [47] CDC, 2014, Preventing Silicosis and Deaths in Construction Workers: <https://www.cdc.gov/niosh/docs/96-112/default.html>
- [48] Katelyn M Kowalewski, 2020, Prevalence of Silicosis in Industry Workers: A Rising Public Health Crisis, Unpublished MSc Thesis.
- [49] Getachew, R. 2018, Factors Influencing the performance of artisanal small scale gold miners: The case of Menge Woreda, Benishangul-Gumuz National Regional State, Unpublished Master's Thesis.
- [50] Kumar, D., Wata, C., & Muthuraman, M. 2020, A Review of Status and Challenges of Child Labor in Artisanal and Small-Scale Mining in Sub Saharan Africa: A Look Through Ethiopian Context.

- [51] Hikmat, 2024, Determination and contamination status of mercury and other heavy metals in artisanal and small-scale gold mining at Banyumas region, Central Java, Indonesia, using ICP-OES,
<https://doi.org/10.1080/03067319.2024.2390149>
- [52] Alejandro Delgado Jiménez, Nicole M. Smith, Elizabeth A. Holley, 2024, Towards sustainable ASM-based livelihoods: The role of institutional arrangements in the formalization of artisanal and small-scale mining,
<https://doi.org/10.1016/j.resourpol.2024.105129>
- [53] World Health Organization (WHO), 2016, Artisanal and small-scale gold mining and health: Environmental and occupational health hazards associated with artisanal and small-scale gold mining.
- [54] Kevin Hutchings Telmer, MM Veiga (2009), World Emissions of Mercury from Artisanal and Small-Scale Gold Mining, in Mercury Fate and Transport in the Global Atmosphere: Measurements, models and policy implications.