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# **A Review of Mining Regulations and Environmental Sustainability of Artisanal Gold Mining Sector**

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## **Authors' contributions**

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## **ABSTRACT**

Artisanal and small-scale gold mining imparts on economic development more significantly in developing countries, but it is also responsible for serious environmental deterioration and human health concerns. Despite the robust environmental legislations focused at mitigating the pernicious environmental and human health effects, little attention has been given to integration of environmental sustainability concepts into these regulations. This paper aims at addressing this gap by utilizing a systematic literature review methodology to analyze regulatory gaps and identify areas for improvement for integration of sustainable development. This study employed a systematic review designed to identify published scholarly studies on artisanal gold mining regulations for their effectiveness on environmental sustainability in the ASGM sector. A total of 159 papers were retrieved from the selected databases, 41 passed the inclusion criteria after a conscientious data analysis forming the evidence synthesis. After a rigorous data analysis, we find that the existing literature on ASGM regulations, largely do not systematically integrate critical issues of environmental sustainability. We found that, the regulations have concentrated on effects of chemicals such as mercury and cyanide mining technologies to minimize pollution and environmental assessments, while at the same time failing to address regulatory components of social issues, lack environmental incentives for the poor miners to improve production, lack of

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alternative technologies, lack of social securities, economic incentives and relevant trainings and awareness creation on health and safety which will continue to motivate unsustainable operations. It is thus strongly proposed that environmental sustainability concepts should be systematically and simultaneously integrated into ASGM regulations and policies in order to promote community livelihoods while protecting the environment from its rudimentary activities. The existing literature on ASGM regulations is unsystematic and inconsistent with most of it failing to fully address environmental sustainability challenges

*Keywords: Artisanal gold mining; environmental sustainability; regulations; policy.*

## 1. INTRODUCTION

Artisanal and small-scale gold mining (ASGM) is a highly unregulated field, enshrined on primitive rudimentary processing technics, labor intensive, low recovery, and poor working conditions [1, 2], practiced by small units in remote areas with limited alternative to livelihoods [1]. It is practiced by 40.5 million worldwide benefitting 75 million people globally [3]. However, ASGM is associated with webbed complex environmental degradation, health and social-economic impacts [4] and considered the largest anthropogenic mercury emission globally at 38% [5] [63]. According to [6], ASGM is plagued with environmental sustainability problems which stems from inadequacy of legal and regulatory framework. The impact of ASGM on environmental sustainability has been ignored until recently [2] and has been researched and documented widely [5-10]. The regulation of the ASGM sector is increasing with the need for stringent measures to mitigate negative environmental impacts [12]. The inefficient regulatory regimes are the major contributors of environmental degradation [1,12]. Governments develop laws and policies that are not effective [13], but just to show that appropriate governance is practiced. However, these laws are generally formulated without proper public participation, a global problem signified by poor management and governance [12].

The high cost of compliance to regulations coupled with historical illegal status of ASGM, has made miners avoid dealing with government [14] hence accelerating negative impacts on environment [15]. The problem is with regulations and licensing structures which are developed without proper understanding of the facts in the local mining areas, challenges faced by miners and enforcement agencies [16]. Insufficient resources for government regulatory institutions also hampered enforcement efforts [17]. Many countries have developed most

ambitious mining and environmental laws that are yet to be fully implemented [18]. However, the effectiveness of these laws can be determined by the current degree of environmental sustainability [19] through identification of gaps and key areas for improvement [20]. Sustainable ASGM sector requires both top-down regulatory and bottom-up capacity building activities for development and prosperity [21]. Studies on the environmental impacts of artisanal gold mining for instance in Kenya are not well researched even though much has been studied globally [14-15]. Some studies have focused on the environmental consequences of ASGM activities such as loss of biodiversity, air, water, soil pollution and governance structures [22] [23] but there is need to position together factors of environmental, livelihood sustainability and effective regulatory structures [24]. Despite extensive development of regulations aimed at addressing environmental degradation, inconsistencies of these regulatory systems and weak institutional framework [25], have largely contributed to adverse impacts to environmental sustainability in the ASGM sector [26]

Environmental sustainability entails effective laws and regulations which are key drivers of socio-economic, environmental governance, best available technology and mining practices. These effects call for clear, robust, consistent and sustainable regulatory systems [27] to maximizing benefits and tackle environmental challenges [28]. To fill this knowledge gap, this article considered a systematic review of environmental regulation in existing scholarly data and takes into accounts its implication on environmental sustainability in ASGM sector.

### 1.1 Analysis of Policy and Regulatory Gaps

Robust policies and regulations on ASGM and environmental protection should be formalized to

minimize negative environmental and human health impacts and promote socio-economic activities. In Africa, most of these regulations focus on small groups and individual miners [29]. Very few countries have specified environmental degradation as a crime [30]. One of the main shortcomings is weak enforcement of policies and regulations [31] [16]. This is common to many developing countries whereby governance and administrative structures don't address the problem adequately [22-23]. In Kenya most miners are operating illegally and informally since they are not formally registered, without mining permits and environmental impact assessments as required by EMCA 1999. Environmental licensing for ASGM in Kenya has been difficult due to lack of mining regulations that provided permitting, as both must be integrated for legalization. Furthermore, undertaking environmental impact assessments are quite expensive to many ASGM miners. Policies and regulations must integrate the ASGM sector into economic development and sustainable utilization of natural resources [32] through the principles of sustainable development [33].

Formalization and legalization of ASGM and establishment of environmental standards at community level will improve ecological sustainability [34]. As discussed in this paper, environmental laws in Kenya are very stringent but weak on implementation. This is a common trend globally being adopted by developing countries by developing tough laws but effectiveness is debatable [31], thus demanding simplified ways of implementation at the very local levels [35]. In Kenya, there are no designated areas for artisanal mining making formalization difficult. For sustainability to be realized, ASGM must be formalized [20], improve technology, eradicate mercury systematically and gradually, improve health and safety measures and environmental protection [36] while optimize mineral recovery [37]. In most mining areas in Kenya, illiteracy and lack of training programs prevent miners from building their capacity limiting them from accessing financial credits, incentives and technology transition hence making them continue working illegally and unsustainably. This is an indication that the existing laws are not effective enough to deaden social, economic and environmental problems and hampers efforts to achieve environmental sustainability.

In the present situation, policy and regulatory frameworks in Africa requires reforms to result oriented and inclusivity in policy formulation [38] [39]. Sustainability of ASGM depends on outcomes which includes environmental and natural resource protection, controlled ore extraction, protection of women and children, health and safety standards, use of best available technologies, and legitimate channels of processing and sale of minerals.

Environmental sustainability can also be achieved through a paradigm shift from managing individual miners to managing mining spaces [23] [28], towards socially, economically and environmentally sustainable activities and results [29]. Effectiveness of regulation can be determined by how they are designed to regulates activities rather than individual practitioners [29]. Like in many other developing countries, under articles 31 of the mining Act, 2016, Kenya has created provisions for designated areas for ASGM activities. Tanzania, Democratic Republic of Congo and Mali are some of the countries which created confined areas for ASGM [29]. However, the creation of designated areas for ASGM requires other sustainability components such as spatial planning through environmental impact assessments and linkages with large-scale mining [40].

## **1.2 Overview of Artisanal and Small-Scale Gold Mining in Kenya – (Policy vs practice)**

Kenya has a rich diversity of geological belts including the gold green stone belt which is believed to extend from western Kenya to Tanzania and Mozambique. Gold mining started in 1930s' in the then Migori and Trans-mara Districts [41] leading to introduction of large-scale mining activities after the discovery of new gold deposit in Lolgorian. Artisanal Gold Mining in Trans-Mara is one of the highly relied economic source for the local communities [41]. Most ASGM activities in Kenya occur and intensified in areas which were previously under main colonial mines in Migori, Narok and Kakamega. However, ASGM activities have spread largely to other areas such as Vihiga, Siaya, Turkana, Marsabit, Elgeyo Marakwet, Kisumu and Nandi due to the ore yielding veins along the Archean Nyanza Craton Geological belt [42]. Artisanal gold mining support thousands of local communities as a source of livelihood in developing countries but cheap

hazardous methods of extraction, lack of skills and resources causes risk to miners and environment [35]. The economic value of gold in Kenya has been increasing from Kenya shilling 790.1 million in 2014 to Ksh. 2,021.1 Billion in 2018 [43].

Kenya has developed legal requirements for both large-scale and artisanal gold mining cadres for environmental protection, mineral rights permit, licenses and other related issues such as Occupational Health, Safety Act and Employment Act 2007, to protect minors against child labor and exploitation. Most devolved units of government have no customized laws on environment. However, the actualization and activation of national laws have also not been realized despite the enormous negative impacts of ASGM to environment and human health. Environmental pollution by potentially toxic elements from ASGM activities has been a concern in rural mining areas [44] where high levels of mercury have been detected in environmental, ecological samples [41] and exposure to toxic oxides and sulphides of heavy metals [45]. Gold mining is also attributed to environmental degradation, water pollution, loss of biodiversity and solid waste generation [46]. According to other studies done, people exposed to heavy metal contamination show health symptoms such as metallic taste, night blindness, tremor, gingivitis, neurasthenia, hyporeflexia and sensory [47].

### **1.3 Regulatory Systems and Environmental Sustainability**

In developing countries, ASGM regulations are more observant to small groups and individuals [29] whereby the legislative systems are licensing and permitting ladened by governments bureaucracy ([29]. Based on the technological, processing inputs and governance, mining can have adverse effects to the environment [48]. Regulating the ASGM sector has been a challenge due to government ignorance in incorporating the sub-sector into legal and economic frameworks. It is only important to mainstream the ASGM sub-sector in order to achieve environmental, social and economic sustainability [38]. Overtime, investigation on mercury contamination in ASGM has intensified [39], but emphasis has been given to understanding environmental effects of ASGM activities while minimal studies have been done to identify appropriate legislations and education on impacts of mercury to human

health and for stamping mercury increasing problems [49]. Similar research on the environmental impacts of heavy metals related with ASGM and occupational exposure have been done in Kenya which considered high mercury pollution [41].

Artisanal gold mining is still considered Informal and illegal in some developing countries due to existing regulatory gaps. Formalization of ASGM in Kenya is underway after the development of the Mining Act, 2016, which will manage and monitor the sector by recognizing ASGM as an important economic activity. The Act proposes the decentralization of governance and control of ASGM to county mining offices and devolvement of licensing processes to Multi-Agency County Mining Committees. The use of chemicals for ASGM in Kenya is illegal under the provision of the new mining law and environmental regulations but poor and weak enforcement, lack of licensing and permits systems continue to see this sector striving in growth. Decentralization of licensing, management and monitoring can be a significant contributor to illegal ASGM activities. The regulatory requirement to undertake environmental impact assessment and environmental audits in Kenya is not forthcoming since most miners do not have financial capacity, making more harder for the impacts to be monitored. Weak institutions and lack of technical capacity of the national and county governments hamper enforcement and compliance efforts. In other countries, studies have revealed that legislative inadequacy, lack of appropriate technologies, and lack of awareness are hampering efforts to control chemicals pollution in ASGM [49]. Similar situation is being experienced in ASGM sector in Kenya.

The Constitution 2010 is the Kenya's supreme law which preambles the citizens to be responsible for environmental protection as the heritage and determine to conserve it for intergenerational and intragenerational equity. In Article 42, the Constitution stipulates that "Every person has a right to a clean and healthy environment" and is obligated to have the environment protected for the present and future generations through legislations and other measures. In article 69, the government is responsible for sustainable exploitation, conservation of the environment and natural resources, and promote equitable sharing of the accruing benefits and encourage stakeholder participation in the management and protection

of environment. Most significantly, the Constitution recognizes the establishment of systems and tools such as Environmental Impact Assessment, Environmental Audit for monitoring of the environment and also commands the elimination of processes and activities that pose a risk to the environment. With respect to land tenure, in Article 61 entrust all land to the people of Kenya cleverly as a country, communities and private ownerships. All minerals are categorized as public property in Article 62(1) and transferred all mineral rights to the National Government. It highly protects the rights of aggrieved persons by providing legal action for environmental rights in Article 70. The Environmental Management and coordination Act No. 8 of 1999 takes care of all environmental concerns through environmental impact assessments and audits processes, procedures, guidelines and restoration funds [50] (Economic incentives are also provided by the EMCA Act to support environmental sustainability.

However, despite having robust policies, there is lack of clear mechanisms and structures of coordination for ASGM sector, unrealistic technical procedures, and inadequate legislations on safety of miners, lack of incentives to support best available technology transfer, lack of guidelines on access to credit facilities, rehabilitation of degraded sites, closure of old mines pits, weak enforcement and monitoring agencies are some of the gaps that need to be addressed to support and achieve sustainable mining sector. The use of compliance and enforcement instruments for environmental protection is common in most governments and looks easier as compared to other environmental protection mechanisms such as promoting social incentives and self-regulations.

The formulation of the mining Act of 2016 represents a distinct action to formalize ASGM sector, which has for the recent past shown steady growth with mixed impacts on social, environmental and economic status. Section 92-100 elaborates the management of ASGM operations, which includes establishment of county mining offices, county mining committees and permitting, land and mineral sale compensations. Under section 176-181, the Act provides for health, safety and environmental protection. Formalization will incorporate ASGM activities into national development policies thus creating a universal approach to sustainable utilization of natural resources, community

involvement, environmental management and economic benefits. The application of the pillars of sustainability, which includes social, economic and environmental in the mining laws promote sustainable management of natural resources [33].

The Mining Act classified mining operations into Artisanal mining, Small-Scale mining and Large-Scale mining with clearly defined levels of engagements. It provided for zoning for ASM; established permits and licenses regimes; created local level county mining committees, associations and cooperative groups for ASGM miners. It also provides for protection of environment and health, capacity building and assistance for ASGM, established mineral rights and minerals rights board whose mandate is to vet applications for licenses, as well National Mining Corporation as an investment arm in mining sector.

However, formalization of mining laws in Kenya is yet to be fully invoked, thus the operation is still considered informal and illegal due to absence of the critical structures such as County Mining Committees which are key in licensing and permit processes. In addition, several other regulations to operationalize the Mining Act of 2016 are under development. Environmental Management and Coordination Act (EMCA 1999 covers all aspects of the environment, but there are no specific regulations that prohibit the use of mercury, control of cyanide and other sustainable mining practices and technologies in ASGM. The Water Act, No. 17 of 2016 makes provisions on the regulation, management and development of water resources. The Occupational Health and Safety Act, No. 15 of 2007 make provisions for the safety of workers, the Public Health Act, Chapter 242, Laws of Kenya which make provisions for securing and maintaining health. In terms of mercury use in ASGM, Section 140 (g) of the Mining Act, 2016 prohibits the use of cyanide and mercury. EMCA prohibits the dangerous handling and disposal of waste, introduces a licensing system for waste management, and specifies mercury waste disposal methods.

The Minamata Convention on mercury was established in 2013 with a specific objective to protect the human health and environment from anthropogenic emissions and release of mercury and its compounds. It recognizes mercury as a chemical of global concern due to its significant negative effects to human and environment, its

characteristics of long-range atmospheric transport, persistence in environment, bioaccumulation in the ecosystems. In Article 7 of the Convention, the member states are required to develop and implement a National Action Plan (NIP), promote research on mercury-free alternative practices for sustainable development, provide technical and financial support to miners and prevent diversion of mercury for use in ASGM processes.

## 2. METHODOLOGY

The methodology applied in this research is a systematic review designed to identify scholarly studies on artisanal gold mining regulations for their effectiveness on environmental sustainability in the ASGM sector in the Kenya. A synthesis of published literature on mining and environmental regulations was done based on the evidenced based synthesis approach [51] [26] which according to [52] the best available evidence on practice has shifted from medical to other disciplines as well. Literature search was first conducted using key words relevant to the study topic. Published articles were searched for in Google Scholar, Semantic, Scopus and Science Direct. The search was restricted to publications between 2010-2020. Selected articles were subjected to screening and data extraction stages to identify relevant articles to the research topic.

### 2.1 Literature Identification

An extensive literature search of peer reviewed journals was done to identify relevant articles for inclusion using Google Scholar, Semantic, Scopus and Science Direct for articles that meet the inclusion criteria. The search key words used were artisanal gold mining, artisanal gold mining regulations, artisanal gold mining regulations and sustainability, environmental regulations on ASGM, artisanal gold mining regulations and sustainable development. In the initial search, 159 articles were identified and uploaded to Mendeley citation manager to remove duplicates. The inclusion and exclusion criteria used in the study ensured that articles i) addresses mining and environmental regulations, policies and laws ii) published in peer-reviewed journals ii) written in English only iii) full article accessible from the database and iv) Were published between 2010-2020. The articles were subjected to inclusion and exclusion criteria process above to determine the articles for detailed review. To obtain the

most relevant articles for the study, the titles of the articles were screened by reading through to ensure they are relevant to the research question. The articles were then screened by reading through the abstract in the first stage [53]. Out of 159 articles retrieved, 41 articles were selected and included in the review.

## 2.2 Analysis and Synthesis

The included articles were analyzed and reviewed in details by reading through the full texts and only articles on artisanal mining regulations with respect to environmental sustainability concepts were synthesized.

## 3. RESULTS

A total of 41 articles were included in the evidence synthesis. Of this number, nineteen articles on legal, policy and regulations of ASGM, eleven on environmental sustainability and eleven on other related topics such as social-economic sustainability and technology Fig 1. This could be attributed by the primary research focus on effects of chemicals such as mercury on environment and health and the slip in incorporating the ASGM into legal framework, policies, projects and programmes [20-21].

In addition, 51.2 % of the included articles applied conceptual method, 12.1% were case studies, 17% applied qualitative method, two articles were review studies while cross-sectional and mixed methods had one article each. The descriptive statistics of included studies are shown in Table 1.

The result synthesis indicate that the extant studies are broken, fragmented and focused on specific aspects such as revenue generation, non-participatory with top-down approach with little interest on social-economic aspects while deficient in addressing environmental sustainability. This finding was supported by studies done by [17] who argued that, neglecting some issues during policy formulation will critically affect environmental sustainability in Sub-Saharan Africa. It is thus evidenced from the systematic review that, environmental sustainability of artisanal gold mining requires a coordinated mechanism that effectively links together implementation of regulations, stakeholder and mining communities. Further, we discovered that extant literature concentrated on socio-economic issues in place of environmental issues. According to [54], there is

still a huge gap in environmental regulations particularly in Africa. The effectiveness of regulations is determined by its enforcement but institutional capacity greatly affect effectiveness of the regulations thus straining environmental sustainability in the ASGM sector. This study clearly indicates that there is limited literature in this field as shown by the small sample size obtained.

#### 4. DISCUSSION

The data presented in this study shows clearly that Artisanal gold mining contributes significantly to economic development globally given the adverse effects it poses to the environment [39] [72]. Sustainable development is a concept which integrate five major interdependent pillars of environmental, economic, social, safety and resource efficiency [61] into development agenda in order to achieve a long-term outcome. This indicates that regulations alone cannot be effective to secure environmental sustainability in the ASGM sector [2]. This concept has a strong link with Artisanal and Small-scale Gold Mining which is considered a global economic fulcrum. In this study, we found that, the effectiveness of regulations is determined by its ability to promote result-based outcomes and self-regulation [2] [31] and integrate other components of sustainable development [37]. The extant literature established that most studies focused on the use and effects of chemicals such mercury and other forms of pollution [2]. We

established that, stringent laws are an impediment to achieving environmental sustainability, attributed by high cost of compliance, weak compliance and enforcement mechanisms as well as disconnected governance structures [62]. The existing literature on ASGM regulations proved that they largely do not integrate critical issues of environmental sustainability by failing to address regulatory components of social issues, incentives for the vulnerable miners, alternative environmentally friendly technologies, social securities, and relevant trainings and awareness creation on health and safety which would continue to motivate unsustainable operations. According to Mutemeri et al., 2016, mining and environmental regulations in developing countries are leaned toward managing small groups and individuals rather than mining concessions. This would only add more adverse impacts to the environment, a case already experienced in Kenya [48]. In most cases, poor governance of ASGM sector, contributes to unsustainable activities [38] which calls for mainstreaming of sustainable components into regulatory systems [49]. The application of the pillars of sustainability in the mining laws promote sustainable management of natural resources [33]. These findings clearly identify the literature gap which exist and provides an urge for more studies to understand the impacts of regulatory systems on environmental sustainability in ASGM sector. This is an indicator of an emerging green study area [26]

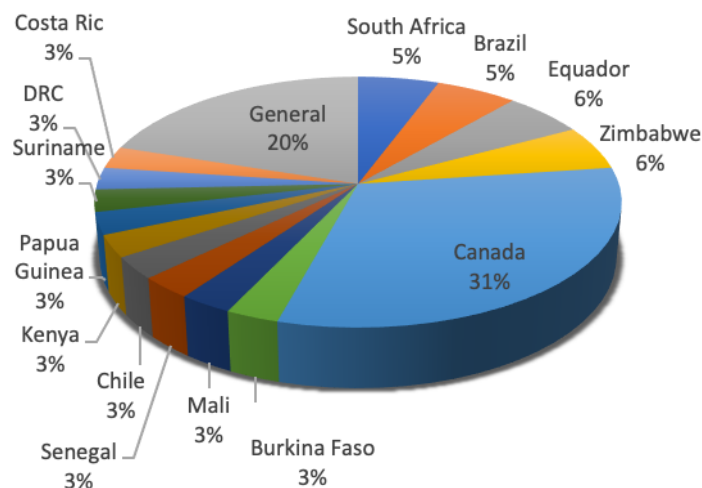


Fig. 1. Distribution of included articles per origin

**Table 1. Summary descriptive characteristics of included studies**

<b>References</b>	<b>Study Type</b>	<b>Origin</b>	<b>Major Objective</b>	<b>Limitations</b>
Aghaei <i>et al.</i> , (2019)	Conceptual	General	Review of mercury pollution in Gold processing, practice and Identify potential gaps	The scope of the study was limited to current practices and technologies of managing mercury pollution without considering other factors of sustainability
Boadi <i>et a</i> (2016)	Conceptual	Ghana	To determine the effects of illegal mining on environment, livelihood and sustainable forestry	The study employed purposive sampling method which can have low level of bias and reliability. The scope of the study was also limited to forest degradation only.
Espana <i>et a</i> 2018	Review	Colombia	To identify the gaps in mining policy and regulations	There is no clear statistical methodology used in the stud
Asamoah <i>et a</i> (2017)	Case study	Ghana	Examine the environmental sustainability of small-scale gold mining activities	The study was limited to qualitative research Quantitative data could have more significant to understand the extend of pollution and streamlining regulatory systems for sustainable mining sector
Asr <i>et al</i> (2019)	Case study	Canada	Integrating mining industry into sustainable development in mining life cycle	No clear methodology outlined indicating study selection
Puluhulawa & Harun, 2019)	Qualitative	Indonesia	Post-ratification of Minamata Convention for sustainability	Data collection was purposive with only 25 respondent This could be bias since the scope of the study covered Gorontalo province
Arma, 2013	Cross-sectional	Ghana, Burkina Faso, Senegal, Mali and Benin	Role of different actors & resistance to regularization of ASGM & environmental pollution and sustainability challenge	The scope of the study was good but it was limited to socio-economic problems only while other sustainability components not included in the study
Gacia <i>et al.</i> , 2015	Quantitative /Qualitative	Colombia	Assessing mercury losses monitoring of health effect and awareness campaign through enforcement of regulations and technology	The scope of the methodology was limited to mercury pollution only
Ghorbani & Kuan (2016)	Case study	Chile	S Sustainability of mining sector in Chile and identify gaps for improvement	The case study could have compared the relationship between mining cultures in the region



References	Study Type	Origin	Major Objective	Limitations
Hennesy et al., 2014	Qualitative	Guyana	Analysis of reforms for socio-environmental regulation and changing mining practices	The scope of the broad without clear research methodology employed
Hilson, (2013)	Case study	Ghana	Informal ASM in sub-Saharan African-Origin of the sector	The research was a case study with unclear methodology. The scope was Sub-Saharan Africa but it was not clear which particular countries
Hilson <i>et al.</i> , 2018	Conceptual	General	Formalization of ASGM in Sub-Saharan Africa	The scope of the study was limited to ratification of Minamata Convention while not giving data on national regulations and sustainability of ASGM sector in the research area
Hilson, 2020	Conceptual	General	Linkages between ASM & SDGs and how to address Environmental and social impacts	Elaborate relationship between ASGM and SDG's was providing. The scope was however narrowed to challenges and opportunities which limits the effectiveness of regulations to provide sustainable ASGM sector
[2]	Conceptual	Indonesia & Ghana	Inadequacy of regulations and their failure to protect Environment	The scope of the study was limited to effective regulations on aquatic ecosystem
Macdonald <i>et al.</i> , 2014)	Conceptual	South Africa	To examine the potential ASGM planning and consideration for as an extension for EIA activity	The relationship between existing regulations and other components of sustainable development was not considered in this paper. The methodology was not statistically applied
(Mutemeri <i>et al.</i> , 2016)	Conceptual	Africa	Change in the policy making process and approach for artisanal and small-scale mining in Sub-Saharan Africa	The study did not show clear research methodology
Asamoah <i>et al</i> (2018)	Qualitative	Ghana	The environmental impacts of ASGM using four parameters (Water, Air, land degradation, and biodiversity loss)	The scope of the study did not provide extensive systematic accounting of social, economic and environmental impacts which are key sustainability concepts
<i>et al.</i> , 2018)	Conceptual	Colombia	Environmental and social impacts of gold mining	Lack of the linkages between the government, scientist, miners and communities and the kind of capacity building of miners for ecosystem

References	Study Type	Origin	Major Objective	Limitations
Cartier and Burge (2011)	Review	Siere Leone	Examines the current dynamics in framing and artisanal mining sector	restoration The study did not highlight specific organizational structures and benefit sharing to support socio-environmental sustainability
[28]	Conceptual	Papua New Guinea	Rationale for use of designated sites and the regulations/key policy issues in artisanal gold mining	The study was limited to regulations of designated mining sites but it did not consider the approach of sustainable mining sector in holistically
Seccatore <i>et al.</i> , 2015)	Conceptual	Brazil	Efficiency and sustainability in small-scale Mining	The scope of the study was limited to efficiency in the mining sector to achieve sustainability but the regulatory aspect was not included
[39]	Conceptual	Brazil	Analysis of mining laws in Brazil focusing on gaps between policies and realities in the field	The study has deeply elaborated the regulatory framework but limited in scope to also integrate environmental, socio-economic and safety issues for a sustaining AASGM sector.
Frækaland Vangsnes, 2018)	Conceptual	Ecuador	Empirically-grounded analysis of mining regulations and practices	The scope was limited to character and regulatory tools only Sustainable development was not articulated broadly in the study.
[24]	Qualitative	Cameroon	Characterization of the mining population and identify socio-economic and environmental impact of ASGM on livelihood sustainability	The aper characterized socio, economic and environmental only while health, safety and resource efficiency in relations to legal provisions were not discussed
[55]	Conceptual	Peru	Sustainable development Challenges and opportunities and collaboration in gold mining	The data collection was short affecting the sample size in respect to target population
Agnes Mwakaj (2012)	Conceptual	Tanzania	Investigate how innovation in the institutional framework of the mineral sector could redress environmental degradation caused by ASGM sector	Regulatory framework and its impact on environmental sustainability was not highlighted
[56]	Conceptual	Ghana	Explore possible strategies for Sustainable small-scale mining small-scale mining in Ghana and Minamata Convention	The methodology of the study is not clearly described Clear linkages of various stakeholders and how it would affect sustainability of ASGM was not captured
	Conceptual	Indonesia	Analyses of the contestation between	No statistical data analysis done and it lacks clear

References	Study Type	Origin	Major Objective	Limitations
(Kakisina <i>et al</i> 2015)			traditional power the power of the state and other powers in the management of mining and its consequences for the sustainability of livelihood patterns	methodological process
(Yego <i>et al.</i> , 2018)	Qualitative	Kenya	To evaluate the impact of artisanal gold mining organizational dynamics on community livelihoods	The research was limited to livelihoods only whereas environmental sustainability and legal context was not mentioned
(Ottenbros <i>et al.</i> , 2019)	Survey	Suriname	How health education affects the levels of knowledge and awareness among local inhabitants and ASGM miners in Suriname	The study iterated on short term effect of knowledge in the community while long term effect could of great importance in reducing mercury pollution
[12]	Qualitative	Zimbabwe	Gold processing in the ASGM sector in Zimbabwe and gaps affecting sustainability	The methodology did not employ statistical analysis of data. The aspect of regulatory systems was not well articulated to support methods mineral processing
(Ledwaba & Mutemeri, 2018)	Conceptual	South Africa	Institutional frameworks that facilitate development of ASGM to identify gaps & challenges in the sector	The study primarily employed secondary data without providing evidence of quotative method of data collection to strengthen the main objective
Marshall <i>et al.</i> , 2020)	Quantitative	Ecuador	To examine cyanide contamination of a river in south eastern impacted by the discriminate discharge of raw gold processing effluents	The scope of the study was limited to chemical pollution This would not give clear position on regulations and sustainability of ASGM
[23]	Conceptual	General	Explore the impact of overlaying mining concession area on existing formal & informal land holding & access right to natural resources	The study in its scope did not provide how regulations can be used to solve mining concessions and integrate all other components of sustainable development into policies
(Moomen <i>et al.</i> , 2019)	Conceptual	Africa	Assess the extent to which Africa Countries enable the creation public geo-information to enhance of sustainable mining policy	The study methodology was limited to geospatial data that support sustainable development in mining sector
Niesenbaum <i>et al.</i> , 2020	Case study	Costa Rica	To explore obstacles and possible solutions to achieve a more sustainable approach to these activities consistent	The methodology including data collection and sampling process was not indicated. The scope of the study is limited to barriers to achieving SD only.

References	Study Type	Origin	Major Objective	Limitations
[57]	Survey	DRC	To characterize existing research on impacts of abandoned mines and ASGM on environment and public health to stimulate research guide policy development and implementation of appropriate intention	The scope of the study was limited to abandoned mines and not active mines which would give bias results towards effectiveness of regulations and environmental sustainability
(Owusu et al 2019)	Conceptual	Ghana	Social and environmental reforms to promote sustainable small-scale mining	The scope of this study was limited to socio-economic reforms while regulatory reforms were not considered hence biased towards providing complete sustainability approaches. The data used was up to 2016 due to unavailability of data which probably affects the accuracy of findings
[58]	Mixed methods	Indonesia	The role of local government in carrying out regional government affairs in the field of environment related to community mining activities	The research was normative-legal using case and conceptual methodologies However, it was limited to environmental impacts while linkage with other sustainability approaches was not discussed
[59]	Conceptual	Colombia	Challenges of formalizing artisanal mining	The study was conceptual which limits a broader understanding of the entire mining value chain which would have been provided qualitatively and quantitatively
[60]	Conceptual	Zimbabwe	Explores the different challenges posed by ASM to sustainable development as well as proactive and unrealistic approach in dealing with these challenges	The study clearly outlined challenges facing sustainability in ASGM sector However, it did not provide how regulatory tools can be used to address such gaps to fully achieve environmental sustainability

Fragmentation of studies in this area was also evidenced by the nature of extant data retrieved with linkages to environmental sustainability. However, the study could have excluded other relevant published data from the evidence synthesis which did not meet the review protocol. These includes articles published in languages other than English, articles published before 2010, and unpublished data which could as well contribute significantly to the research findings. It is thus strongly proposed that environmental sustainability concepts should be systematically and simultaneously integrated into ASGM regulations and policies in order to promote community livelihoods while protecting the environment from its rudimentary activities. The existing literature on ASGM regulations is unsystematic and inconsistent with most of it failing to fully address environmental sustainability challenges

## 5. CONCLUSION

This systematic review considered the existing literature on regulations of artisanal gold mining and its effectiveness in ensuring environmental sustainability. We established that the existing literature on ASGM regulations and its intended objective to protect the environment, is unsystematic and inconsistent with most of it failing to fully integrate and address the concepts of environmental sustainability. Formulation of regulations should adopt a bottom-up approach and inclusive process to give vulnerable mining communities an opportunity to derive solutions for their predicaments. We established that the sustainability of the ASGM sector cannot be achieved by strict enforcement of regulation alone but rather decentralize ASGM governance structures and strengthen the capacity of miners through regulatory and policy frameworks. The regulations require a dynamic community engagement, inter-institutional and multi-agency approach to spurt its effects on the ecosystems. In addition, promotion of self-regulations through management of mining areas rather than individuals would greatly help to resolve such environmental sustainability problems.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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