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Research Article

Assessing Social and Environmental Impacts of Artisanal and Small-Scale Gold Mining Practices in Lolgorian, Kenya

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ABSTRACT

The environmental implications of artisanal and small-scale gold mining (ASGM) practices have significantly grown, particularly on environment, socio, and livelihoods of the mining communities. The study aims to investigates the environmental and socioeconomic consequences of these practices. A survey research design including primary data as well as a random sample process were employed in the study. A total of 250 questionnaires were distributed to randomly selection respondents across the artisanal mining and processing areas. The statistical package for social sciences version 26.0 was used to analyze the data, which included frequency distribution tables, pie charts, bar graphs, percentages, regression, and correlation analyses. According to the data, 97% of gold miners use the mercury amalgamation process, 95.5% operate illegally, and 94.3% do not conduct environmental impact assessments for their mining activities. In terms of ASGM formalization, 68.1% say that poor governance has had an influence on the process, hampered sustainable practices and operations. According to the data, 91.4% of respondents strongly agreed that ASGM provides livelihoods for both women and children, while 73.1% strongly felt that ASGM is more profitable than other forms of livelihoods. The total health implications of hazardous chemical exposure linked with ASGM activities are that 75.5% are aware of major health consequences. Unfortunately, 83.2% of individuals surveyed said they continued to burn amalgam without protective equipment. The environmental implications of ASGM operations have significantly grown, particularly in terms of forest destruction and soil and water contamination (60.4%). The data from model fitting revealed that, at p=0.05, trends, practices, and governance structures were statistically significant with independent variables (X_1, X_2, X_3, and X_4) in predicting ASGM environmental sustainability. According to the data, Nagelkerke=0.198, or about 20% of the variance in mining operations in the ASGM sector, may be attributed to the four independent variables. According to the findings of the study, ASGM's current practices and governance structures have a major influence on the sector's environmental sustainability. The study suggests that ASGM formalization be accelerated and decentralized, and that governance mechanisms be operationalized in order to improve miners' skills and knowledge through education and socioeconomic development. Promoting miners' self-regulation is also essential for ensuring environmental sustainability.

Keywords: artisanal gold mining, practices, sustainability, heavy metals

INTRODUCTION

Artisanal and small-scale gold mining (ASGM) is a significant economic activity in most rural areas of developing countries (Agwa-Ejon and Pradhan, 2018). It is defined as a labor-intensive, inefficient, and dangerous gold mining operation that generates 10,000 to 100,000 tons of gold per year (Seccatore et al., 2015). As stated by Mantey et al. (2020), with a positive economic growth trajectory, ASGM continues to be one of the most widely practiced subsistence and informal economic activities in the world. This sector not only provides a source of income for the underprivileged local community who have few other alternatives for employment, but also has major social and environmental effects (Corbett et al., 2017; Peša and Ross, 2021).

Due to limited livelihood options and unemployment in Africa, ASGM has witnessed great expansion, but it has subsequently created work possibilities and increased tax income (Hilson and Maponga, 2004). Mining operations involving ASGMs have the potential to impact the environment, human health, and community livelihoods. The preponderance of the environmental damage caused by ASGM is the result of unsustainable mining technologies. Despite substantial health effects, underground mining is the most widespread method in the Lolgorian mining area (Achuora et al., 2020; Anderson, 1991). The environmental performance and sustainability of underground mining indicate considerable negative environmental implications (Asamoah et al., 2017).

Because of its easy availability and affordability to poor miners, mercury is commonly used in gold processing in ASGM around the world (Hilson et al., 2018). Lack of alternative technology (Ottenbros et al., 2019; UNEP, 2018), awareness and capacity for sustainable mining practices are other factors (Calao-Ramos et al., 2021). Mining activities that are environmentally, socially, economically, and resource-efficient can contribute to improved environmental quality (Laurence, 2011). Due to financial constraints, cleaner technologies have proven unaffordable to the bulk of artisanal miners. Uncontrolled ASGM activities are frequently related with environmental degradation and economic livelihood loss as a result of inappropriate mining procedures (Boadi et al., 2017; Isung et al., 2021). ASGM operations, according to the United Nations Environment Programme (UNEP), emit the most anthropogenic mercury into the environment (Agwa-Ejon and Pradhan, 2018; Anderson, 1991; Swenson et al., 2011).

Mercury is one of the top ten most harmful pollutants to human health (Bose-O'Reilly et al., 2017; Ottenbros et al., 2019), and it is primarily released by small-scale gold mining (Calao-Ramos et al., 2021; Carrasco-Rueda et al., 2020). The toxicity of these compounds is a major source of occupational exposure concerns and environmental damage (Charles et al., 2013). The intake of polluted fish by persons living far from mining areas has been connected to the risk of dietary mercury exposure (Diringer et al., 2015).

According to Calao-Ramos et al. (2021), mercury exposure is inextricably linked to unsustainable mining practices. The lack of alternative technology is a major factor in this (Ottenbros et al., 2019). Some of the problems contributing to unsustainable ASGM practices include a lack of well-structured operational governance structures and a lack of legal framework implementation (Adu-Baffour et al., 2021). The effects of ASGM have had a significant impact on ecosystems, including land degradation, the development of hazardous tailing waste that pollutes streams and biodiversity loss (Djibril et al., 2017).

The agricultural industry has also been threatened by mercury-contaminated tailing waste from ASGM, which bio-accumulates in the soil, degrading soil quality and fertility (Hindersah et al., 2018). The rising health and environmental implications of mercury pollution motivated the international community to draft the Minamata Convention on Mercury, which entered into force in 2017 after three years of intensive talks involving 140 member states (UNEP, 2009), with the goal of decreasing and monitoring mercury emissions and formalizing the ASGM industry.

Although formalizing ASGM will not ensure cleaner production, basic measures combined with education and awareness can be more effective (Veiga et al., 2014). Current ASGM practices and trends are not only ineffective for sustainable chemical usage and management in mining, but they also pose major environmental, social, and economic risks. The effects of ASGM on the environment and human population have been studied extensively (Macdonald et al., 2014), but the effects of mercury and the danger of heavy metal exposure have received special attention.

Similar studies in Kenya are not well-researched. The focus has generally been on water, soil, and air pollution, as well as bio-diversity (Asamoah et al., 2018; Mitchell, 2016). However, no studies on the socio-economic and environmental implications of ASGM practices in Lolgorian have been conducted. This study intends to examine the environmental and social-economic repercussions of ASGM practices in Lolgorian, South Western Kenya, and offer policy interventions for long-term management of this critical sub-sector.

MATERIALS AND METHODS

This study used a qualitative method and a random sample technique, as well as a descriptive research design that focused on ASGM practices and field observations. The study also drew on secondary data from a review of published articles on ASGM, with an emphasis on the effects of ASGM practices on the environment, as well as the social and economic implications for miners. The data was collected through unstructured questionnaires distributed to artisanal gold mining villages in order to evaluate the consequences of ASGM practices on the ecological, social, and economic elements of the mining communities. Direct field observation of mining methods, activities, and tools, as well as mine waste management, gold processing, and amalgamation processes, were employed. The data was collected between December 2019 and February 2020. The responders were given enough time to consider and react appropriately. A total of 245 respondents were sampled. The number of respondents was reduced by five owing to the impact of COVID-19, which caused mines to close prematurely before data collection could be finished.

The researchers also employed the common national language (Kiswahili), which the majority of the respondents understood, as well as translators to the miners' local languages. This gave respondents confidence in their ability to participate. To maintain quality control and minimize bias, the researchers made a point of distinguishing between the participants' perspectives and the researchers' interpretation of the information communicated.

Study Area

Narok County is situated at South Western Kenya lying between coordinates (S1°.13.854', E34°48.5986'), **Figure 1** along the great rift valley and border Tanzania. It covers an estimated area of 17,933 km^2, which is 3.1% of Kenya. According to Kenya National Bureau of Statistics, Narok County has a population of approximately 1,130,703 in 2019. It is endowed with rich natural resources including the world famous Maasai Mara National Game Reserve, gold mining and indigenous forests. Lolgorian mining area is part of Migori gold complex consisting of Archean Nyanza greenstone of proximal, central and distal facies. The gold deposits occur in quartz veins of sulphides.

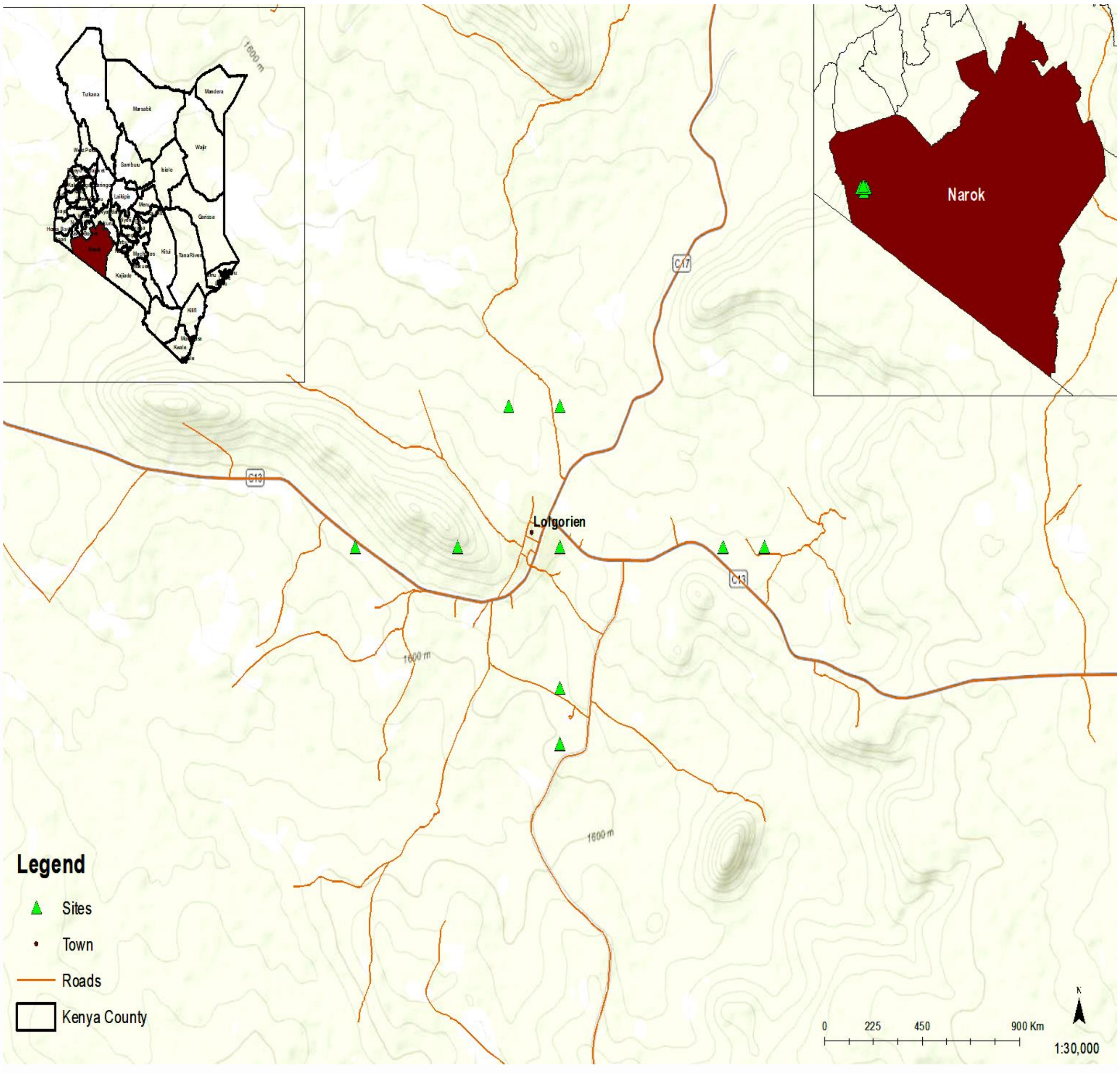

Figure 1. Map showing research area (Tampushi et al., 2021)

Sample Size Determination

The sample size (n) was determined using Fischer sampling technique (Fischer et al., 1998), as follows:

$$n = \frac{z^2pq}{d^2},$$

where n is the sample size for target population greater than 10,000, z is the standard normal deviation at the 95% confidence level, p is the proportion in the target population estimated to have characteristic being measured, d is the level of statistical significance set, and q=1-p. Assuming that there is no estimate of the proportion of target population assumed to have the characteristics of interest 50% should be used (Fischer et al., 1998).

$$n = \frac{(1.96)^2(50)(50)}{(0.5)^2} = 384.$$

Since the population of artisanal and small-scale miners is less than 10,000, the sample size adjustment was done using the following formula:

$$nf = \frac{n}{1+\frac{n}{N}},$$

where nf is the desired sample size for population <10,000, n is the calculated sample size, N is the total population.

$$nf = \frac{384}{1 + \frac{n384=250}{1,000}}$$

Data Collection Tools

The questionnaire was divided into five sections, each with a different number of unstructured questions built on a five-point Likert scale (1=strongly disagree, 2=disagree, 3=neutral, 4=agree, and 5=strongly agree). The topics include demographic statistics, trends, and practices in ASGM. The implications of ASGM practices on miners' social-economic and livelihoods; knowledge and perception of the impacts of ASGM practices on health and the environment; and the efficacy of legislation in managing chemicals in ASGM.

The open data kit (ODK) tool was used to administer the survey and collect the data, which was then transferred to the statistical package for social science (SPSS) version 26.0. for statistical analysis.

Statistical Analysis

The information gathered was analyzed with the SPSS version 26.0. Descriptive statistics were used to examine the demographic profile of the respondents, which included gender, age, origin, marital status, education, years of mining experience, and mining category. Regression analysis, including tests for normality, goodness of fit, and model fitting, was done, and the results of hypothesis testing performed using Ordinal Regression analysis were also reported. The analysis findings were presented using frequency distribution tables, pie charts, and bar graphs.

THEORETICAL FRAMEWORK

Classical Theory of the Informal Sector

Informal sector activities are believed to have no significant average returns (Manara, 1980; Straffa 1960). According to Straffa (1960), classical theory, informal sector is defined by methods that will not provide the average rate of profit at the existing level of wages and prices, and hence capitalists will not operate since they demand average returns. Due to a lack of alternatives, the informal sector employs flawed practices. Economic constraints drive jobless people into the informal sector, such as ASGM, which creates a unique social stratum, such as mining villages. However, the global economic crisis is to blame for the growth of the informal sector in developing countries.

The informal sector is distinguished by the use of primitive equipment, labor intensiveness, poor productivity, and low fixed capital and profitability, all of which are typical of ASGM. Various researchers have explored informal sector theories from historical and empirical perspectives, and they have discovered that they are scant (Gibson and Kelley, 1994).

The classical theory agreed with other researchers who discovered that ASGM is an informal and illegal industry that is operated by impoverished (Agwa-Ejon and Pradhan, 2018; Mantey et al., 2020). According to this theory, the informal sector's wage is exogenous, and the profit rate is lower than the formal rate. The technology utilized is primitive and poor in productivity, has little fixed capital, and requires intermediate inputs such as imports, which are not feasible in the formal setup.

These situations differ from the overall features of an ASGM sector, which employs primitive technology, low resource recovery, low income, and the use of toxic chemicals such as mercury and cyanide (Hilson et al., 2018). Most developing countries currently lack or have insufficient regulatory frameworks for ASGM, resulting in the sector being illegal (Adu-Baffour et al., 2021). Classical theory outlines five main criteria that have been used to define the informal sector in the literature. These include the land size, types of employment or responsibilities of different actors, technology used or capital level, legal status, and income level.

RESULTS AND DISCUSSION

Demographic Characteristics

According to **Table 1**, males made up 67.35% of the study population, while females made up 32.65%. This is owing to the fact that in Sub-Saharan Africa, women face barriers to obtaining employment, forcing them to engage in the informal sector, such as ASGM, which is deemed dangerous (World Bank, 2021). This has been compounded further by the movement to legalize the sector (Hilson et al., 2018). In these settlements, women are only involved in minor duties such as amalgamation, ore crushing, and sluicing.

Table 1. Socio-economic characteristics of respondents

Variables		Frequency	Percentage (%)
Sex	Male	165	67.0
	Female	80	33.0
Age	18-30 years	109	44.5
	31-40 years	67	27.3
	41-50 years	45	18.4
	51-60 years	19	7.8
	>61 years	5	2.0
Marital status	Married	188	76.73
	Single	43	17.55
	Widowed	14	5.71
Number of children	0-3	124	50.6
	4-6	79	32.2
	7-9	19	7.8
	More than 9	23	9.4
Education	Primary	143	58.4
	Secondary	51	20.8
	Diploma	8	3.3
	Degree	3	1.2
	Postgraduate	2	0.8
	No formal education	38	15.5

Approximately 58.4% of miners received basic education, 20.8% received secondary/vocational education, 3.3% received tertiary education, 1.2% received undergraduate degrees, 0.8% received postgraduate education, and 15.5% had no formal education (**Table 1**).

Individual/family miners had 31% of the respondents in the category of miners, while 5% and 4% represented small groups and traders, respectively (**Figure 2**).

The research also indicated severe socioeconomic repercussions of ASGM, such as a substantial influx of miners from other places, including 38% from Migory, 22% from Narok, and 20% from Tanzania (**Figure 3**). A similar study suggests that miners migrate from one place to the next and even cross borders (Otoijamun et al., 2021).

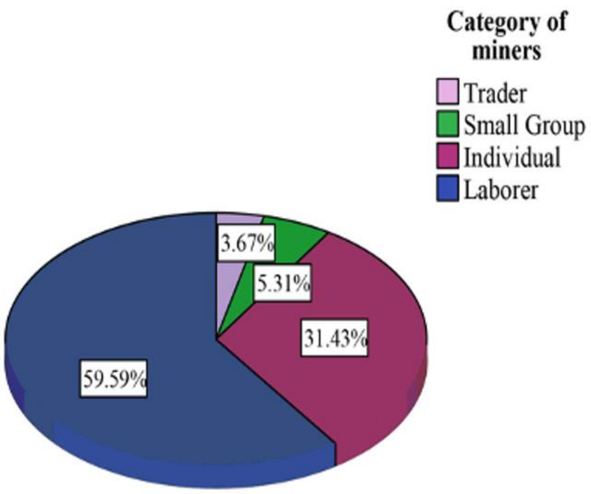

Figure 2. Category of the miners

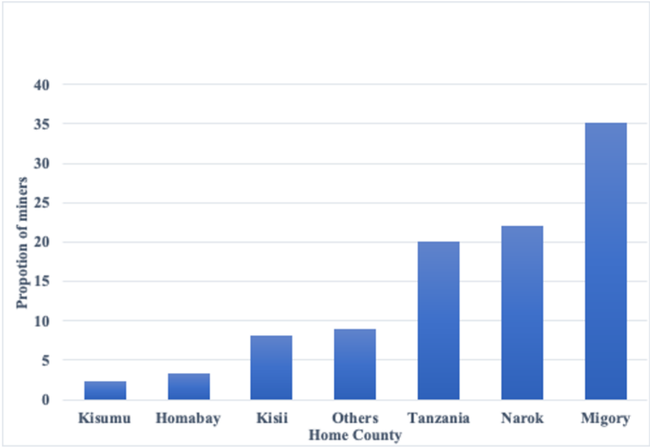

Figure 3. Distribution of the respondents by their origin

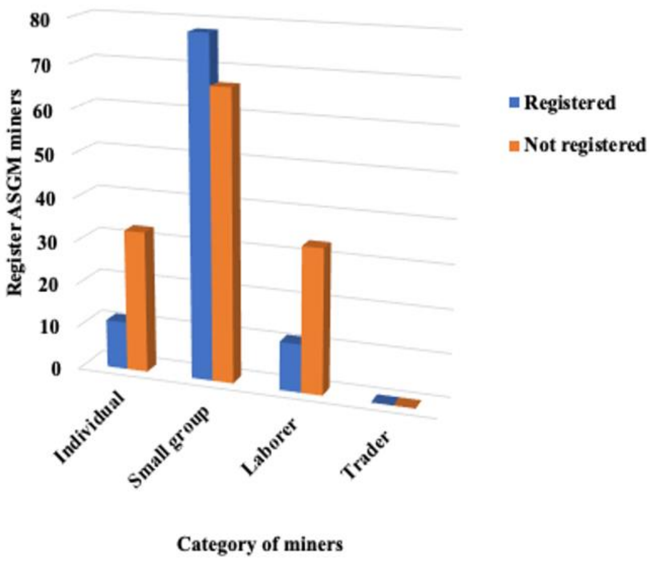

Figure 4. Group registration by Department of Social Service cross tabulation

Individual/family mining is connected with significant health and safety concerns, as well as the use of ecologically harmful mineral extraction and waste management technologies (Mining and Minerals Policy, Kenya, 2016). This is explained by their failure to follow mining rules. In terms of social services department registration, roughly 77.78% of small group miners were registered (**Figure 4**).

This necessitates raising awareness about the need of acquiring mining rights and permits. Miners' legal rights are aligned with proper safety measures and fiscal regimes such as taxes and incentives.

Preference of Mining Method

One of the goals of this research was to look at artisanal miners' preferences for artisanal mining methods and practices in the Lolgorian mining area. According to the survey, underground mining is the most common method of mining in this area. Similar results were obtained in other studies in Kenyan where the majority of miners (38.1%) work underground (Achuora et al., 2020). According to the research findings, amalgamation with mercury is the most popular gold extraction procedure, with 97.6% of respondents highly liking this method.

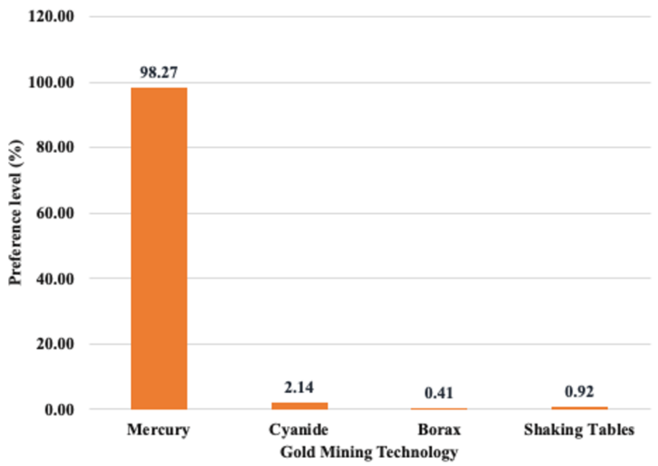

Figure 5. Preferred methods of gold extraction

According to the survey findings, amalgamation with mercury is the most favored technique of gold extraction, with 97.6% of respondents strongly favoring this approach. According to (Duijves and Heemskerk, 2014) case study, 97.8% of artisanal miners choose and use mercury in gold processing. As per the study findings, the most preferred method of gold extraction is amalgamation using mercury with 97.6% of the respondents highly preferring this method. In a case study by (Duijves and Heemskerk, 2014), it was found that 97.8% of artisanal miners prefer and uses mercury in gold processing.

This is due to a lack of alternative technologies (Ottenbros et al., 2019). Mercury usage and trade are also influenced by an inefficient legal framework, as well as economic and complicated political bureaucracy (Hilson et al., 2018). Despite the fact that it has been linked to catastrophic health consequences, the majority of miners favor this practice (Anderson, 1991).

As shown in **Figure 5**, borax is the least preferred technique in artisanal gold mining, with 99.6% of replies indicating "not preferred," followed by shaking tables with 98.8% non-preference, and finally usage of cyanide with 97.6% non-preference. Despite minimal attempts to promote cleaner ASGM technology, the use of mercury is necessitated by miners who do not believe new methods can increase gold recovery (Hilson et al., 2018). Poor governance mechanisms also impede knowledge and awareness in the ASGM industry (Ottenbros et al., 2019). As a result, it is critical to enact policies that will help reduce, manage, and mitigate the dangers associated with mercury usage. Fines, public awareness efforts on more efficient gravity separation techniques, and waste containment systems with more environmentally acceptable standards are among them.

Trends and Practices in Artisanal Gold Mining Lolgorian

In investigating the trends and practices in ASGM, it was observed that 44.1% of the population strongly agree that they have no problem with using mercury in their residential area. Globally, 1,400 tons of mercury are released into the environment each year (UNEP, 2018). 87% of the respondents, did not prefer to burn mercury amalgam in the presence of children. It was discovered that children, breast-feeding mothers, and women of reproductive age are all involved in artisanal mining. More than two-thirds of respondents (76.3%) stated that they have not implemented basic technology, such as the use of retorts, to reduce the occupational and health consequences of mercury vapors. However, although being well aware of the situation, most miners lacked retorts.

Mercury exposure is intimately linked to mining methods, involving amalgamation (Calao-Ramos et al., 2021). Adoption of cleaner technology may be more difficult for impoverished miners, since the survey found that 76.3% of respondents practice safe occupational health and safety measures. Similarly, 82% did not adopt cleaner gold processing technologies. This could be because of high cost of alternative mercury-free methods. Although ASGM formalization cannot guarantee cleaner operations, basic procedures combined with education and awareness can be more successful, in ensuring sustainable production models (Veiga et al., 2014). Current ASGM procedures and trends are not only ineffective for the long-term use and management of chemicals in mining activities, but also pose major environmental and occupational health and safety risks.

Social and Economic Implications of ASGM

ASGM impacts on the livelihood of miners both positively and negatively (Isung et al., 2021). ASGM is characterized by poverty, diseases, poor social service and child labor (Hinton, 2007). In order for the mining communities to cope with the challenging economic implications of ASGM, regulatory frameworks should introduce alternative livelihood mechanisms. In this study, it was discovered that 91.4% of respondents highly agreed that ASGM provides livelihood options for both women and children, while 73.1% strongly agreed that ASGM is more profitable than other forms of income, such as agriculture. This conclusion is corroborated by research conducted in the "Osiri" mining region in Migori, Kenya by (Buss et al., 2020) in which it was demonstrated that, women navigate through gender norms and structures that delimits there mining roles. In Africa, ASGM directly supports the livelihoods of almost four million people and indirectly supports the livelihoods of another 20 million (Hilson and Maponga, 2004). 78% of those polled strongly agreed that cooperative formation improves better practices in ASGM increasing the efficacy of the legislation by facilitating self-regulation and recognizing the need for support and inclusion in policymaking (Mutemeri et al., 2016). It was also established that, that the formation of cooperatives would facilitate an increase in mining's socioeconomic benefits while promoting good environmental practices, improving tax compliance, savings accumulation, acquisition of relevant skills through workshops, and accessing government-supported concessional lending, among other economic advantages. This is a vital economic sector on which local population depends.

Mining contributes around 1% of GDP to the Kenyan economy, despite its theoretical capability of 4% to 10% of GDP (Handbook, 2015). This is due to insufficient optimum utilization of accessible mineral resources. However, 92.2% of respondents stated that county/national governments do not provide incentives to support their livelihoods and gold mining operations. Similarly, 96.7% strongly disagreed that the government had supplied artisanal miners with financial facilities. According to these findings, the government should give financial support, establish credit facilities and incentives to artisanal gold miners.

Knowledge and perception on effects of ASGM practices on health and environment ASGM makes a substantial contribution to Kenya's expanding economic graph. However, its actions endanger the environment and human health through multiple exposure routes (Owusu et al., 2019). Exposure to hazardous heavy metals such as mercury, cadmium, lead, and arsenic, as well as occupational exposure to dust, fumes, and physical accidents, all pose serious risks (Corbettet et al., 2017). ASGM miners in Lolgorian are reasonably aware of the overall health implications of exposure to hazardous chemicals linked to ASGM activities; 75.5% strongly believe that these chemicals have major health consequences and pollute the environment. 77% of miners were aware that mercury vapors emitted by mercury amalgam pose serious health risks.

According to Odumo et al. (2018), the Transmara-Migori mining environment is heavily contaminated by heavy metals. Mining trends and practices have an impact on the level of environmental degradation in Lolgorian, with 60.4% agreeing that present mining activities have increased deforestation and environmental degradation. ASGM is strongly linked to environmental deterioration, such as air pollution, deforestation, land degradation, open pits, and heavy metal poisoning of soil and water (Kamga et al., 2018). Although significant efforts have been made to raise community awareness about the impacts of mercury on health, little progress has been made in changing knowledge toward more sustainable mining operations (Aram et al., 2021). The level of education and experience gained from working in the industry improved knowledge and awareness of the impacts of ASGM activities.

Despite being aware of the risks to health and the environment posed by practices such as open burning of amalgam, 83.2% of respondents continued to engage in unsustainable mining practices. This suggests that comprehending problems does not always result in behavior change, indicating a nonlinear link between knowledge and behavior change (Aram et al., 2021). Low compliance with the use of PPEs was noted and is typical among ASGM miners. Observations of miners burning amalgam without retorts or PPEs have been made all across the world (Afrifa et al., 2019). This is due to a lack of capacity building and training for miners, as well as a lack of legal knowledge. Other studies have found that exposure to Hg vapor might induce neurological symptoms, kidney damage, and reduced cognitive abilities (Esdaile and Chalker, 2018).

Other studies have found that miners who burned amalgam had high Hg concentrations in their urine, blood, and hair, as well as indications of chronic Hg poisoning (Bose-O'Reilly et al., 2017). The study discovered that formalizing ASGM in Kenya and enforcing laws effectively will minimize human exposure to Hg in the ASGM industry. It is critical to increase their ability, knowledge, and understanding of the consequences of ASGM operations on health and the environment in order to mitigate the effects of unsustainable mining practices (Ottenbros et al., 2019). It is still in its early stages of transmit information on sustainable production patterns in ASGM in order to encourage behavior toward cleaner and more ecologically friendly technology.

Effectiveness of the Regulations in Management of Chemicals in ASGM

Two critical issues must be addressed through effective regulations. First, effective regulatory systems should be outcome-based, and second, they should aim to conserve natural resources, health and safety, skill development, and open and transparent mineral trading (Mutemeri et al., 2016). With 38% of the world's total ASGM mercury emissions, it is the major anthropogenic mercury polluter (Fritz et al., 2018). This industry is still informal and mostly uncontrolled in Kenya. The inadequacy and constraints of mining and environmental legislation are primarily to blame for the unsustainable ASGM sector (Hilson and Potter, 2005). The Minamata Convention was designed to safeguard, decrease, and monitor mercury levels in the environment, but Kenya has yet to ratify it five years after it entered into force.

The ASGM law in Kenya is very new and has a long way to go before it is properly implemented. We propose in this paper that present regulations are insufficient to adequately address the environmental degradation and health risks caused by ASGM operations. This is due to the government's failure to integrate ASGM into the development framework, weak institutional capacities, and poor inter-agency coordination mechanisms. Integrating the ASGM industry into the development agenda would result in environmental, social, and economic sustainability (Maponga and Ngorima, 2003).

According to the findings of this study, 95.5% of miners are working illegally without mining permits, and 94.3% of them did not conduct environmental impact assessments and audits as required by legislation. This will make environmental sustainability more challenging because the lack of environmental impact assessment studies will limit other components such as environmental monitoring and spatial planning for specified ASGM areas (Morrison-Saunders et al., 2015). Despite having strict rules, this is an indicator of insufficient institutional capacities in charge of enforcement (Tampushi et al., 2021).

Despite the fact that 68.1% of respondents believe that regulations assist formalization, they also believe that they are not being properly implemented at the moment. Most miners, according to (Achuora et al., 2020). lack appropriate knowledge and skills in best mining practices, and current regulatory mechanisms are ineffective. In this research 73.9% of respondents indicated that the government presently does not provide extension services personnel to give technical assistance to ASGM miners. Due to legislative and governance shortcomings, the formalization of ASGM is still yet to occur.

Table 2. Descriptive statistics of log transformed variables

Variable	Mean	Skewness statistic	Kurtosis statistic
LogY	0.46	-1.50	1.42
LogX1	0.22	0.16	-1.26
LogX2	0.54	-3.04	2.86
LogX3	0.59	-1.92	3.52
LogX4	0.01	9.28	97.39

Inferential Statistics

In this study, Kolmogorov-Smirnov test was used to determine the normality of the sample distribution which indicated that all the variables are statistically significant, that is, $p<0.05$. This implies that the data set is not normally distributed as showed by skewness $\geqslant 1$ with standard error of 0.16 and kurtosis statistics <-3 or $\geqslant 3$ and standard error of 0.31 (**Table 2**). To normalize the data set, log10 transformations were made on the variables, the kurtosis and skewness statistics were still observed to be extreme. For this reason, the null hypothesis was not rejected.

H0: The data set does not originate from a normally distributed population.

Ordinal Regression

For inferences, the study employed ordinal regression of the collected data. This was preferred since the variables of interest were qualitative in nature with ordinal scale. The model employed composite variables constructed from respective sub-items. The response variable in this case was environmental and social-economic effects of ASGM mining practices while the predictor variables were: trends and practices in chemical use and management, socioeconomic impacts of ASGM, knowledge and perception of ASGM effects on health and environment, preference of mining method. As such the regression equation is represented, as follows:

$$Y=\beta_0+\beta_1X_1+\beta_2X_2+\beta_3X_3+\beta_4X_4+\varepsilon,$$

where Y is the environmental and socio-economic effects of ASGM practices, β_0 is constant, X_1 is the trends and practices in chemical use and management, X_2 is the socio-economic impacts of ASGM, X_3 is the knowledge and perception of ASGM effects on health and environment, X_4 is the preference of mining method.

From the parameter estimates (**Table 3**) the regression model can be summarized, as follows:

Table 3. Parameter estimates

		Estimate	Standard error	Wald	df	Sig.	95% confidence interval	
							Lower bound	Upper bound
Threshold	[Y = 1.00]	3.129	1.254	6.225	1	0.013	0.671	5.586
	[Y = 1.17]	3.523	1.244	8.019	1	0.005	1.085	5.961
	[Y = 1.33]	3.752	1.241	9.146	1	0.002	1.320	6.184
	[Y = 1.50]	4.002	1.238	10.443	1	0.001	1.575	6.430
	[Y = 1.67]	4.515	1.238	13.303	1	0.000	2.089	6.942
	[Y = 1.83]	4.771	1.239	14.820	1	0.000	2.342	7.200
	[Y = 2.00]	4.936	1.240	15.830	1	0.000	2.504	7.367
	[Y = 2.17]	5.148	1.242	17.167	1	0.000	2.713	7.583
	[Y = 2.33]	5.365	1.245	18.574	1	0.000	2.925	7.804

Table 3 (continued). Parameter estimates

		Estimate	Standard error	Wald	df	Sig.	95% confidence interval	
							Lower bound	Upper bound
Threshold	[Y = 2.50]	5.466	1.246	19.247	1	0.000	3.024	7.908
	[Y = 2.67]	5.541	1.247	19.747	1	0.000	3.097	7.985
	[Y = 2.83]	5.686	1.249	20.730	1	0.000	3.238	8.133
	[Y = 3.00]	6.259	1.257	24.800	1	0.000	3.796	8.722
	[Y = 3.17]	6.414	1.259	25.947	1	0.000	3.946	8.881
	[Y = 3.33]	6.509	1.260	26.670	1	0.000	4.039	8.980
	[Y = 3.50]	6.643	1.262	27.690	1	0.000	4.169	9.117
	[Y = 3.67]	9.984	1.347	54.960	1	0.000	7.345	12.624
	[Y = 3.83]	10.198	1.360	56.247	1	0.000	7.533	12.863
	[Y = 4.00]	10.323	1.369	56.905	1	0.000	7.641	13.006
	[Y = 4.33]	11.843	1.580	56.149	1	0.000	8.745	14.941
	[Y = 4.67]	12.704	1.805	49.533	1	0.000	9.166	16.242
Location	CompX1	-0.164	0.148	1.237	1	0.266	-0.453	0.125
	CompX2	0.576	0.289	3.969	1	0.046	0.009	1.143
	CompX3	0.545	0.109	24.909	1	0.000	0.331	0.759
	CompX4	2.754	0.752	13.399	1	0.000	1.279	4.228

Table 4. Test for correlation

Variables	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ASGM chemical management effectiveness	0.27	250	0.00	0.84	250	0.00
Trends and practices in chemical use & management	0.22	250	0.00	0.86	250	0.00
Socioeconomic impacts of ASGM	0.30	250	0.00	0.79	250	0.00
Knowledge and perception of ASGM effects	0.28	250	0.00	0.78	250	0.00
Preference of mining methods	0.51	250	0.00	0.12	250	0.00

Table 5. Multi-collinearlity test

Model	Collinearity statistics	
	Tolerance	VIF
Trends & practices in chemical use & management	0.92	1.09
Socioeconomic impacts of ASGM	0.90	1.11
Knowledge & perception of ASGM effects on health & environment	0.91	1.10
Preference of mining method	0.91	1.10

$Y=4.67-0.16X_1+0.58X_2+0.55X_3+2.75X_4$

The model shows that X_2, X_3, and X_4 are statistically significant ($p<0.05$) in predicting effectiveness of chemical management in ASGM at 95% confident level and alpha=0.05. However, X_1 was not statistically significant in determining the environmental and socio-economic effects of ASGM practices.

The regression coefficients translate that, for every one-unit increase in trends and practices in ASGM for instance from 1 to 2, there is predicted decrease of 0.16 in the log odds environmental and socio-economic effects of ASGM practices. The analysis also shows that for every one-unit increase in Socio-economic impacts of ASGM there is a predicted increase of 0.59 in the log odds environmental and socio-economic effects of ASGM practices, while for knowledge and perception of ASGM effects on health and environment there is expected increase in the log odds environmental and socio-economic effects of ASGM practices by 0.54. For every one-unit increase in preference of mining method there is predicted increase in the log odds of effectiveness of chemical management by approximately 2.8.

The goodness of fit test indicated that at $p<0.05$, the trends and practices in chemicals use and management, socio-economic impacts of ASGM, knowledge and perception of ASGM effects on health and environment, preference of mining method were statistically significant in predicting the effects of ASGM mining practices. It was evident that estimated regression model fit the data well at a defiance Chi-square (χ^2=780.11, df=2,663).

The Nagelkerke statistics in pseudo-R-square is analogous to R-square statistics in ordinary linear regression models, the results indicated that Nagelkerke=0.20. This implies that approximately 20% of the variation of effectiveness of chemicals management in ASGM is attributed to the selected four independent variables (**Table 4**).

Multi-Collinearity

For credible regression analysis it is assumed that the predictor variables in a multiple regression model exhibit no high correlation (Hair et al., 2013). To evaluate this assumption, variance inflation factor (VIF) was used (**Table 5**). Multi-collinearity is present when tolerance value is ⩾0.01 and similarly when VIF is greater than 10. The dataset for this study showed that the tolerance values for all predictor variables were above 0.01 and the respective VIF values were less than 10. This implies that the in this study, the multi-collinearity assumption was not violated.

CONCLUSION AND RECOMMENDATION

This study was aimed at assessing the impacts of ASGM practices on human population and the environment in Lolgorian. The results obtained show that high proportion of miners (45%) are youths thus providing employment opportunities for them. However, most of the miners are have attained only primary education or not attended school at all. It was also revealed that almost all miners still use inefficient mercury amalgamation method and the absorption of mercury free technologies is lacking resulting in low productivity, environmental risk and socio-economic implications. The adoption of efficient and effective technology will improve gold recovery, minimize environmental impacts, sustain community livelihoods and leverage on global practices.

The study further underlines poor governance of ASGM sector and weak implementation of the recently established mining laws. There is no clear unidirectional policy on mercury use, sale, and storage. The cheap mercury prices, readily available and lack of control measures exacerbate its consumption thus continuous release into the environment.

The study proposes that the process of formalization should be fastened to improve environmental and socio-economic practices. The artisanal miners should also be empowered to form cooperatives, create awareness and educate miners on the possible health risk of heavy metals and provide incentives for adoption of mercury free technologies. The government should also facilitate financial and credit facilities for the miners to eliminate worst practices such as whole ore amalgamation, open burning of amalgam, avoid burning of amalgam in residential area and cyanide leaching of contaminated sediments.

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