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RESEARCH ARTICLE

ENVIRONMENTAL IMPLICATIONS OF ARTISANAL AND SMALL-SCALE GOLD MINING ACTIVITY WITHIN THE KOKUMBO DEPARTMENT (CENTRAL CÔTE D'IVOIRE) AND ITS IMPACT ON THE LOCAL POPULATION

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ABSTRACT

Artisanal and small-scale gold mining (ASGM) has emerged as a vital economic activity in the Kokumbo department of the Republic of Côte d'Ivoire, supporting the livelihoods of numerous local communities. This research seeks to explore the environmental impacts of ASGM activities in Kokumbo, including soil and water resource degradation, and their subsequent effects on public health, agriculture, and biodiversity. Through qualitative and quantitative assessments, the study examines how these environmental challenges disproportionately affect vulnerable populations, particularly women and children, who rely heavily on natural resources for daily sustenance. 1631 (90.41% of respondents) adhered to the research to provide information about the situation and stated that ASGM affected the surrounding population's lifes. A total of 21 plant species belonging to 11 families were identified before the mining activity in the Kokumbo area and the family with more species is the *Anacardiaceae* with 7 species. These species become rare or disappear in the mining area and the surrounding village. The results showed that the ASGM activities contaminated the farmland, allowing many animals to be extinct. The most endangered class are mammals including three (3) extinct species in the family Bovidae, two (2) species in the family Suidae, and two (2) in the family Felidae. Our study revealed that the most common disease that affected the local population is malaria, about 49.55%, and 12.49% of people suffered from an intestinal infection. The findings highlight the urgent need for sustainable mining practices, regulatory frameworks, and community awareness programs aimed at mitigating the environmental consequences of ASGM while promoting responsible economic development.

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INTRODUCTION

Natural resources extraction is a cornerstone of human life. Traditionally, people have handled natural resources to acquire the materials they need. These natural resources are broadly categorized as exhaustible, such as minerals, and inexhaustible, such as forests and grasslands (Gutti *et al*., 2012). Numerous nations are achieving economic progress through the extraction of diverse natural resources (Mathe and Phiri, 2016). For example, Côte d'Ivoire is one of the sub-Saharan African countries rich in natural resources. In conjunction with other socio-economic activities such as agriculture, the mining industry is one of the key contributors to the country's socio-economic development. Côte d'Ivoire's geographical location offers it the largest proportion of Birimian formations, i.e. around 35%, which are essentially made up of greenstone. These greenstone belts are therefore potentially rich in economically significant mineral deposits.

Most of West Africa's gold production derives from these formations (Milesi *et al*. 1989). The country's subsoil is overflowing with large sources of gold, which could make Côte d'Ivoire a powerhouse gold-producing nation. Apart from neighboring Ghana, Mali, and Burkina Faso, Côte d'Ivoire is one of Africa's leading gold producers. This potential has been proven by recent discoveries of commercially feasible gold deposits following intensified gold exploration activity in the country. To boost the mining sector, the government of Côte d'Ivoire has drawn up a vigorous development and mining policy. On this basis, deposits of several types of minerals have been unearthed and are being exploited in the country. The increase in these activities is coupled with a deterioration of soils and vegetation cover, resulting in global phenomena of erosion, disturbance of water regimes, loss of soil fertility, and depletion of substantial fractions of biodiversity (Cooke and Johnson, 2002). Mining activities can involve the extraction of minerals, producing several raw materials that have a considerable impact on the environment

and human health (Melodi, 2017). The relationship between the environment and humans has been extensively explored, and the risks can have a significant impact on human health, either through direct exposure of the population to harmful agents, or indirectly, through the disruption of viable ecosystems (Remoundou, and Koundouri, 2009). In the case of the mining sector, rocks are quarried for their richness in ores that can be extracted, but with high concentrations, the ores seldom have sufficient purity to be thoroughly transformed into finished products. This has led people to include the treatment of ores with the use of several gold ore extraction processes including the artisanal way. ASGM refers to a type of informal mining activity that is typically undertaken by individuals or small groups using basic equipment and techniques. Throughout history, ASGM has been a part of human civilization, with individuals seeking to extract this precious metal from the earth using traditional methods. Today, ASGM continues to be a vital sector in many regions, contributing to global gold production while also presenting challenges that need to be addressed to ensure sustainability and responsible mining practices. This type of mining is also associated with a range of social, environmental, and health risks due to the use of rudimentary methods, lack of regulation, and often inadequate safety practices. In Côte d'Ivoire, the first ASGM traces date back to the beginning of the second half of the 18th century. The main objective of this study is to assess how this specific mining activity is affecting the environment and the people living in the Kokumbo area. This involves studying various aspects such as water and soil pollution, deforestation, health risks, socio-economic implications, and possible mitigation strategies. By examining these environmental implications, we aim to raise awareness, propose solutions, and contribute to sustainable development in the affected community.

MATERIALS AND METHODS

Description of the Study Area: Covering an area of around 2847 km², the study zone lies within the central Côte d'Ivoire between longitudes 4° and 5° W, and latitudes 6° and 7° N. It is bordered to the north and south by the District of Yamoussoukro and the Agneby-Tiassa region respectively. The region shares borders with the N'Zi region to the east and the Gôh region to the west (figure 1). Our study site is accessible by road and lies midway between Toumodi (30 km) and Oumé (25 km), on the one hand, and the town of Yamoussoukro (40 km) on the other. It is 200 km from Abidjan.

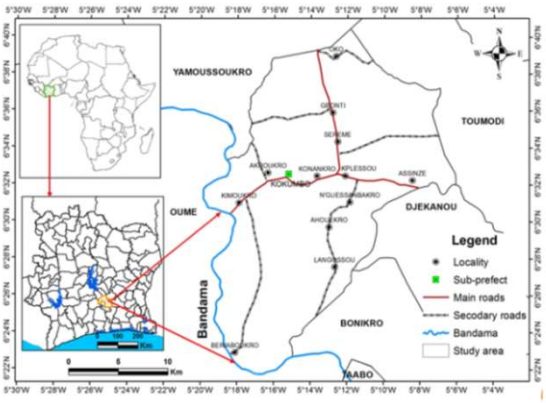

Figure 1. Location of the study region

The region's relief is characterized by two (02) main types of plains. The outer plains, with altitudes of between 200m and 150m, are overlooked by the Kokoumbo (520m) and Diedka (540m) mountains, and the Alébouma range (450m-190m). The inland plains (100m-50m) to the south of Toumodi feature a large erosion zone underlain by isolated peaks of the Boka mountains, such as Orumbo Boka (551m), Sui Boka (470m), Kongoli Boka (211m) and Kwa Boka (262m) (figure 1). The region's climate is tropical and humid (Baoulean), with rainfall reaching 1,200 to 1,300 mm in the 1970s, according to ORSTOM report. It is a high rainfall zone, with an average temperature of 26.4°C and an average rainfall of 1075mm (figure 2). The lowest average rainfall was recorded in January, with just 23 mm. September, with an average of 153 mm, has the highest rainfall (figure 2). Today, as a result of climate change and the destruction of the vegetation cover, rainfall in this region is experiencing a significant drop of 300mm (Climate data center, 2017), which is tending to transform the former climate into a dry tropical one. This region also has transitional vegetation between savannah and forest. It is home to a vast area of savannah including a few islands of dense forest closely related to the geological bedrock. The region's vegetation is made up of wooded savannah, grassy savannah and gallery forests (mesophilic gallery forests along watercourses) characteristic of the "V Baoulé" (transition zone between the southern forest and the northern savannah of the country).

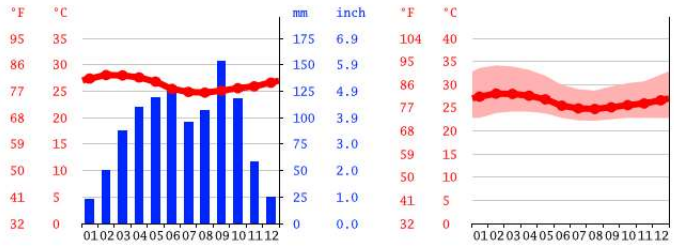

Figure 2. Annual temperature (left) and precipitation (right) in the study region, Source: https://fr.climate-data.org/afrique/cote-d-ivoire/lacs/toumodi-58624/

Study Methods: This study was carried out on the Kokumbo area gold panning site and its surroundings, to assess the environmental and socio-economic impacts of its activities in the region. A question-oriented methodological strategy was particularly suited to assessing the environmental and socio-economic impacts of mining activities. A wider range of data sources enabled us to gather more relevant data to answer all the research questions.

Survey technique: A field survey was conducted from January to December 2023 to involve stakeholders in the purpose of the research and to see the impact of activities according to the different seasons of the year. After identifying the land or a household in the case of residents, before asking questions, we clarify the aim of the study. To gain the interviewees' trust, confidentiality was ensured. Structured and semi-structured interviews were employed to probe their perceptions of the impact of mining activities on the environment and the livelihoods of the local population. The research work took into account prospecting, which consisted in counting and analyzing mine shafts, as well as inventories to ascertain the current state of the flora and fauna.

Target population: The study's target population consisted of two main groups: local gold miners and stakeholders. The involved were those both active and retired gold miners, and who had been working for at least a year. Stakeholders included residents of mining and rural communities and other local authorities, local government representatives, community health services in the area, non-governmental organizations and gold miners' unions. The involvement of the stakeholders was their decision to present a proposal that captured various government positions between the divergences in a consensus-building process. In sum, the study employed stratified, random and practical sampling methods.

Data collection and analysis: Data collection focused on two main sources, primary and secondary information sources (figure 3). Primary data were gained using a number of methods, notably stakeholder interviews with key informants, and field surveys to correlate the information collected and to be sensitive to potential sources of bias in other data. There were also questionnaires aimed at target groups to collect socio-economic and other data on the different ways in which residents interact with their environment and their lives, making up the sample size. Completing the questionnaires took around 20 minutes per person. Secondary data were obtained by consulting mining reports from the region, publications in books, newspaper articles, news on websites, government reports on the region, local files and project reports relating to the subject. The gathered information was analyzed. A Microsoft Excel program was used to enter the information and draw up frequency distribution tables, graphs and diagrams.

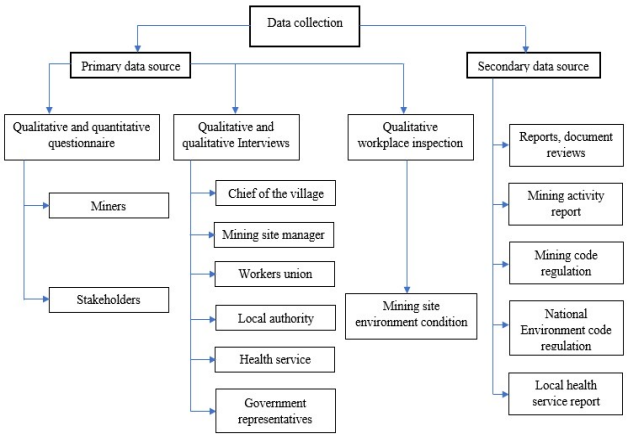

Figure 3. Data collection process flowchart

RESULTS AND DISCUSSION

Socio-Economic Impact: While ASGM can provide short-term economic benefits, it often leads to a cycle of poverty and vulnerability. Communities may become economically dependent on mining, neglecting sustainable agricultural practices, which can jeopardize food security in the long run. It is important to know that mining appropriates land appertain to the local communities and the activities impacts their health, alter the social relationship, destruct the forms of community subsistence and life, cause social disintegration by drastic and curt changes in regional cultures (Samy and Kamaljit, 2014). The competition for land and resources can lead to conflicts within and between communities, undermining social cohesion and stability issues such as land rights and mining ownership can exacerbate tensions.

To identify the major impacts on the socioeconomic of the mining activities in the study area including six villages (Kokumbo, Kimoukro, Konankro, Akroukro, Kpessou and N'Guessanbakro) (figure 1), respondents were asked to talk generally about what changes they have personally observed over the past five years especially and to make a comparison to the existing situation. The respondents affirmed the presence of major changes and impacts which has reduced the arable lands, and the destruction of the forest, activities also decrease the gold panning areas for environment change and population growth, cattle theft, turbidity of waters (Table 1). The impact of mining and quarrying on the environment is obvious: soil degradation, destruction of vegetation and extinction of native fauna are the most significant effects (Rehman *et al*., 2021). From the sample of 1804 interviews, only 1631 respondents either (90.41%,) stated that ASGM affected the surrounding population life. 53.46% (872/1631) of peoples said that landscape degradation had negative effects on the region's vegetation (figure 4), affecting farmland. 41.63% (679/1631) reported the eradication of flora and fauna in the region. Mining can constitute a significant aspect of local livelihoods. Here, 4.91% (80/1631) claim that money earned from their mining activities provides a means of survival Assessing the social impact of activities emerged as a relevant issue in terms of both positive and negative impacts. Finally, mistrust is associated with water-related risks, the source of certain damage to the environment and populations. This mistrust concerns water balance management, water quality, dam failures and site rehabilitation (Pour *et al*., 2016, Biswas and Biswas, 2018)

Figure 4. Soil degradation by small scale gold mining

Figure 5. Mining extraction sites of the study area

Impact on plant species: Mining activities have created a severe disturbance to the land surface through the destruction of the natural ecosystems such as vegetation which refers to plant

Table 1. Socio-economic characteristic of respondents in this survey

Names of village	Responsible	Main socio-economic activities	Mining activity effects	
			Negative	Positive
Kimoukro	Village Chief	Rice growing, maize, sorghum Cassava, farming, hunting Gold Panning Cocoa Coffee, plantain	Reduction of cultivation areas Reduction of gold panning areas Destruction of flora Deviation of the watercourse	Financial gain Business development Jobs generated
Kokumbo	Village Chief and Deputy prefect	Yam cultivation, maize Peanut, Cassava Plantation, hunting, gold panning Cocoa Coffee, plantain	Reduction of cultivation areas Reduction of gold panning areas Scarcity of game Destruction of wildlife	Business development Meeting vital needs Investments Jobs creation
Konankro	Village Chief	Rice cultivation, maize Cassava, yam, peanut Cocoa, Coffee, plantain Gold panning	Turbidity of waters Reduction of cultivation areas Reduction of gold panning areas Rarefaction of game Nesting gaer	Job creation Business development
Akroukro	Village Chief	Rice cultivation, maize Yam, cassava, peanut Cocoa, plantain Gold panning	Turbidity of waters Reduction of cultivation areas Reduction of gold panning areas Rarefaction of game Lack of drinking water The disappearance of almost all game	Business development Financial gain
Kpessou	Village Chief	Rice cultivation, maize Millet, sorghum, peanut Livestock, hunting Gold panning	Destruction of wildlife Cattle theft Reduction of cultivation areas	Business development Job creation Meeting vital needs Market garden crops
N'Guessankro	Village Chief	Rice cultivation, maize Millet, sorghum, peanut Yam, cassava, hunting development Gold Panning	Water turbidity Reduction of cultivation areas	Support to groups Financial gain Business

Table 2. Status of plant species in the study area before and during ASGM acticity, (++): More abundant;(+): Abundant; (-): Threaten, (--): Very threatened

Family	Scientific names	Abundance	
		Before	During
Papilionaceae	*Pterocarpus erinacens*	++	+
Bombacaceae	*Adansonia digitata*	+	-
	Bombax costatum	++	+
	Ceiba pentandra	++	+
Cesalpiniaceae	*Afgelia africana*	++	--
Sapotaceae	*Vitellaria paradoxa*	++	+
	Detarium guineensis	++	+
Anacardiaceae	*Anacardium occidentale*	+	-
	Spondias mombin	+	-
	Cassia siamea	+	-
	Isoberina doka	++	+
	Cassia siberina		
	Danellia oliverii		
	Piliostigma thoningii	+	-
Combretaceae	*Combertum micranthum*	++	-
Meliaceae	*Kaya senegalensis*	++	+
	Carapa procera	+	-
Miosaceae	*Parkia biglobosa*	++	+
Cornaceae	*Lophira laceolata*	+	-
Rubiaceae	*Nauclea latifolia*	++	+
Sterculiaceae	*Cola cordifolia*	+	-

Table 3. Status of plant species in the study area before and during ASGM acticity, (++): More abundant;(+): Abundant; (-): Threaten, (--): Very threatened

Family	Scientific names	Abundance	
		Before	During
Papilionaceae	*Pterocarpus erinacens*	++	+
Bombacaceae	*Adansonia digitata*	+	-
	Bombax costatum	++	+
	Ceiba pentandra	++	+
Cesalpiniaceae	*Afgelia africana*	++	--
Sapotaceae	*Vitellaria paradoxa*	++	+
	Detarium guineensis	++	+
Anacardiaceae	*Anacardium occidentale*	+	-
	Spondias mombin	+	-
	Cassia siamea	+	-
	Isoberina doka	++	+
	Cassia siberina		
	Danellia oliverii		
	Piliostigma thoningii	+	-
Combretaceae	*Combertum micranthum*	++	-
Meliaceae	*Kaya senegalensis*	++	+
	Carapa procera	+	-
Miosaceae	*Parkia biglobosa*	++	+
Cornaceae	*Lophira laceolata*	+	-
Rubiaceae	*Nauclea latifolia*	++	+
Sterculiaceae	*Cola cordifolia*	+	-

species which cover the soil (figure 5). Among the most important impacts on biotic communities are the removal of greenery, which alters the availability of food, water and nutrients (Rehman *et al*., 2021). The study area was covered with various plant species that were victims of human actions as a result of the exploitation. A total of 21 plant species belonging to 11 families were identified before the mining activity in Kokumbo area and the family with more species is the Anacardiaceae with 7 species (Table 2). These species become rare or even disappear in the mining area and the surrounding village. Deforestation is very dangerous for men, animals, and properties, it decreases soil water PH, some soil macro nutrients (Gutti *et al*., 2012). The vegetation in form of natural forest is usually the first casualty to undergo the impact of mineral exploration and exploitation which can cause the elimination of certain plant species and affect certain animals that feed on such plants (Kamga 2018).

Figure 6. Reforestation and flora renewable technique

Table 4. Statistical analysis of fauna of wildlife of the region. Legend: ++: very abundant species; +: Abundant species; Threatened species; 0: Extinct species; R: Reduced species

Class	Family		Scientific names	Abundance	
	Before	**During**		*Before*	*During*
			Cephalophus rufilatus	+	*0*
			Tragelaphus scriptus	++	*R*
	Bovidae		*Sincerus caffer caffer*	+	*0*
			Kobus élipsipryminus	+	*0*
			Erythrocepus patas	++	*R*
MAMMAL			*Cercopithecus aethiopus*	+	*R*
	Cercopithelidae				
			Pantheraleo	+	*0*
	Felidae				
			Phacocerus erytropus	+	*0*
	Suidae				
	Viperniae		*Vipera berus*	+	*R*
REPTILES	*Crocodilidae*		*Crocodylus niloticus*		
	Accipitridae		*Mycrosirtes monochus*	++	*R*
BIRDS	*Ardeidae*		*Ardeala ibus*	++	-
	Psitacidae		*Poicephalus robusta*	++	+
	Bufonidae		*Bufo bulgaris*	+	+
	Ranidae		*Rana esculenta*	+	+
			Tilapia niloticus	++	*R*
FISH			*Clarias dialonensis*	+	*R*
	Cyprinidae		*Malterus electricus*	+	*R*

These cause the disturbance of the ecosystem with a possible consequence on the flora and fauna community (Kamga 2018).

Impact on local fauna of wildlife: As mining expands into previously untouched areas, biodiversity is compromised. The displacement of wildlife and the reduction of available habitats can have cascading effects on the ecological balance in the region. Mining has a wide range of impacts that can affect the abundance and diversity of biotic communities (Rehman *et al*. 2021). An ecological investigation was conducted for understanding the fauna of the study area, especially by listing of species and assessing the existing baseline ecological state in the study area (Biswas and Biswas, 2018). The change created by mining activities to the landscape doesn't allow many animal species to be adapted so that modification reduces their living space. Some impacts are short term and are limited to Mine site but others can have profound repercussion and long-term effects.

Table 5. The main diseases identified within the study area and their probable causes during the March and June 2023

Pathology	The probable source of diseases	Numbers of patients					
		March	Percentage	June	Percentage	Total	Percentage
Malaria	Mosquito bites	321	45.66	401	53.18	722	49.55
Intestinal	Lack of hygiene	98	13.94	84	11.14	182	12.49
Respiratory	Dust, drug, chemical	55	5.5	98	12.99	153	10.5
Dermatoses	Lack of hygiene, drug,	48	4.8	67	8.88	115	7.89
Typhoid Fever	Lack of hygiene,	70	9.95	34	4.5	104	7.14
Anemia	Lack of hygiene,	11	1.56	19	2.51	30	2.06
Acute	Excessive dust, drug,	54	7.68	32	4.42	86	5.9
Gastritis	Excessive dust, drug,	9	1.28	11	1.46	20	1.37
Others	Others	37	5.26	8	1.06	45	3.08
Total		703		754		1457	100%

The region was populated by various animal species that have greatly diminished and currently threatened by the activities (Table 4). The most endangered class are mammals including three (3) extinct species in the family Bovidae, two (2) species in the family of Suidae and two (2) in the family of Felidae. This shows that the species in this area tend to disappear gradually if the attenuation and compensation measures are not taken.

Impacts on the Local Population Health: The use of toxic chemicals, such as mercury, in the gold extraction process poses a severe risk to local water bodies. Contaminated water affects not only aquatic life but also the health of the local population that relies on these water sources for drinking, cooking, and washing. From a health point of view, gold panning can lead to respiratory illnesses (coughs, pneumonia, angina, etc.) due to dust inhalation, and to accidents that are often fatal due to the archaic techniques used to extract the ore. Our study revealed that the most common disease that affects local population is malaria, about 45.66% of people in March and 53.18% in Juin. 13.94% of people suffered from intestinal infection in March, and 11.14% of people in June (Tableau 5). Some people suffered from respiratory infection (5.5%) in March and (12.99%) in June as well as other diseases (3.08%). A total of 1457 people were affected during the monitoring period. Typhoid Fever represents 7.14% of total infected people (104/1457), Dermatoses represents 7.89% (115/1457).

Traditional wells are recharged from surface water and precipitation, mining by its consumptive nature can seriously affect water resources (De Janeiro and Lamego, 2008) which can be a hazard to the surrounding population. Indeed, the diffusion of contamination in the air, water and towards the biosphere, and the chain can potentially subject people to exposure to metals that may present a health risk if the toxicity thresholds established by international health monitoring institutions are exceeded (Wu *et al*., 2018). The result of the extraction of the ore and the process used to get the gold from its ore make mining activities the main cause of environmental pollution and the socioeconomic impact of the study area. The activities affect negatively the environment by polluting the surrounding rivers, air, farmland, landscape degradation but it's also established that the physical health of people living around the area was impacted (Mathe and Phiri,

2016). The use of a toxic substance can affect the close water bodies which are not good for domestic purposes (Joseph 2018).

Mitigation Measures: According to the research described above, a series of actions are foreseen for good management and stewardship following the national biodiversity conservation and sustainable resource use strategy's implementation at two levels of intervention. Make a social impact assessment prior to mining and to assure any major risks identified are appropriately mitigated (Assie *et al* 2024). The first is the conservation of environmental resources in their biodiversity; the second is the sustainable management of environmental resources and international cooperation (Assie *et al*., 2024). The first approach involves conserving biological, physical and human environments by safeguarding species, habitats, ecosystems and the atmosphere. Miners must use renewable and non-renewable natural resources in a sustainable approach (figure 6); collect, store and properly handle all waste likely to cause environmental or health damage, which can help reduce the risk of contamination; backfill extraction pits where possible, or reforest fast-growing species on waste rock or in compensation areas. Government and local authorities must develop comprehensive legal frameworks that regulate ASGM activities, including guidelines for environmental protection and establish local regulatory bodies to ensure compliance with environmental laws and impose penalties for violations. They should conduct education and awareness campaigns to inform local communities about the environmental impacts of ASGM and best practices for sustainable mining, and involve local communities in decision-making processes regarding mining activities to ensure their concerns are addressed. Miner have to cooperate to understand the social, cultural and environmental value of water in mine catchment. By implementing these measures, it is possible to mitigate the negative environmental implications of ASGM while ensuring the well-being of local populations in the Kokumbo department of Côte d'Ivoire.

CONCLUSION

While ASGM in Kokumbo area may offer economic opportunities, it comes at a significant environmental and social cost. The assessment of the impact's activities on the natural resources of the study area has shown that mineral extraction has a greater impact on natural resources and the maintenance works have little impact. This has led to serious ecological disturbances and profound changes characterized by the scarcity of certain animal and plant species, the modification or deformation of the relief; the pollution of the atmosphere by smoke, gases and dust and the surface water and groundwater pollution by chemicals organic such as cyanide, caustic, soda and hydrochloric acid. Sustainable practices and regulations are essential to mitigate the negative impacts associated with ASGM, ensuring that local communities can endure long-term benefits without sacrificing their health, environment, and cultural identity. Collaborative efforts among government, local organizations, and the mining community are crucial to fostering responsible mining practices that prioritize both environmental health and community well-being.

Conflicts of Interest: The authors declare no conflicts of interest regarding the publication of this paper.

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