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Artisanal and Small-Scale Gold Mining (ASGM): Management and Socioenvironmental Impacts in the Northern Amazon of Ecuador

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Abstract: Mining is one of the oldest economic activities of mankind. Within this activity, artisanal and small-scale gold mining (ASGM) is one of the most studied sectors due to its high level of environmental contamination and the social problems it causes. In recent years, ASGM in the northern Amazon of Ecuador has increased significantly, and studies that describe its current situation and impact are scarce. In this sense, the present study aimed to analyze the current status and socioenvironmental impacts caused by ASGM gold mining activities in the Cascales canton in the province of Sucumbíos in northeastern Ecuador. The methodological tools used in the present study were a literature review of scientific and gray literature, field visits to assess perceived impacts and an expert judgment to discuss the results and establish challenges. The main results indicate that illegal and informal activities continue to be carried out in the upper zone of the Cascales and Duvino rivers; 90% of local miners still use mercury in this activity, although it is legally prohibited. Among the main impacts evidenced are the contamination of water bodies, soil and atmosphere due to the use of mercury and disturbance to flora and fauna due to the use of machinery in the exploration process. Finally, the government should focus efforts on strengthening public policies to socialize the importance of good environmental practices in ASGM and the effects of the impacts on human health and environmental issues, all this with the support of social actors, such as ministries, universities, NGOs, ASGM associations and private enterprise.

Keywords: sustainability; biotic; abiotic; mining; economy; management; geographic information system (GIS); challenges; Sucumbíos; Cascales

1. Introduction

Globally, most of the attention in the gold mining industry is focused on large companies; however, in many parts of the world, especially in developing countries, minerals are extracted by artisanal and small-scale mining (ASGM), a complex and diversified sector [1–4]. It encompasses a wide range of informal independent miners seeking a livelihood to formal small-scale commercial mining entities that produce minerals in a responsible

manner. For many countries, ASGM is both an important source of livelihood and environmental damage [5–7]. There is a growing need to improve the quality of life of miners working outside the formal legal and economic systems and also to optimize the sector's contribution to sustainable development [8,9].

The informal exploitation of minerals, especially gold, has been described as one of the most challenging issues for the southern countries of the globe, due to its social and environmental impacts. In just 15 years, the number of people involved in artisanal and small-scale mining increased from 13 million in 1999 to 30 million in 2014 and 40.5 million in 2017, in Sub-Saharan Africa, Asia, Oceania and Central and South America. Rising unemployment and rising gold prices help explain the phenomenon [10–12]. However, the sector is believed to provide a livelihood for tens of millions of people worldwide [6,13–15]. Many miners practice ASGM seasonally to supplement other forms of income and abandon their farms during periods of drought [6,12]. The ASGM sector comprises all stages of the value chain, including inputs, mining, trade, primary processing, secondary processing and export. It can be carried out at each stage of the mining life cycle, such as exploration, development, operation, closure and postclosure. In addition, it is often carried out in areas adjacent to or within large-scale mining concessions [16,17].

ASGM is a livelihood strategy used mainly in rural areas. The vast majority are very poor people who exploit marginal deposits under extremely harsh and often dangerous conditions, causing considerable environmental impact [8,14,18]. In many cases, mining represents the most promising, if not the only, income-earning opportunity available. However, governments, large companies, environmentalists and other stakeholders often do not approve of ASGM activities [19–21]. Concerns range from the use of child labor and the possibility of environmental damage (especially through the use of mercury in gold mining) to the use of ASGM revenues to finance social unrest and conflict caused by the operations of "gold panners", the high incidence of prostitution and the spread of HIV/AIDS due to the migration of workers [22–26].

Since the 1990s, several Latin American governments with a vast wealth of natural resources began to review and adapt their mining legislation in order to attract foreign investment in large-scale mining. Thus, in recent years, gold mining projects and activity have increased throughout the region [27–30]. However, due to the socioenvironmental risks that have increased and accentuated in recent years, many of them culminating in conflicts, the profits for both parties have been compromised [31–33]. Thus, this activity has been characterized for being vulnerable to socioenvironmental risks, as it usually produces impacts that directly or indirectly affect the populations living in the areas of influence where this activity is carried out. These conflicts can be generated by the use or contamination of resources (water, land, air, etc.) as well as by the displacement of populations or the use of places with special significance for the original inhabitants of the localities [11,34,35]. At the same time, these policies have led to confusion about the role that governments should play in the economic development of the respective countries. In many cases, the affected communities have generated excessive expectations on the part of the mining companies, while on the other hand, governments, particularly local governments, have shown some gaps in the political management of the resources obtained from mining. This has led to the fact that several mining projects are currently being developed with high levels of conflict, as a result of the socioenvironmental impacts they have caused [36–39].

Historically, gold mining in Ecuador has been largely carried out through ASGM, understood in a broad sense as any mining activity with low technology, intensive use of unskilled labor and low production margins per deposit [21,40,41]. Nearly 100,000 people depend directly on this activity and four times that number indirectly. Among Ecuador's strategic mineral resources, gold is the main export product. ASGM produces at least 85% of Ecuador's gold, which corresponds to more than USD 300 million annually in revenues [42,43]. The most vulnerable population, which operates mainly in the informal sector, takes advantage of the opportunities offered by the upward trend in the price of

gold, which explains the growing and accelerated expansion of the sector in recent years as well as its environmental impacts. A worrying aspect of ASGM in Ecuador is the use of mercury (Hg), which is still widespread despite its prohibition since 2015 [5,20,44,45]. This is released into the environment during gold separation and recovery, contaminating air, soil and water and impairing ecosystem services, such as clean air, water and food supply. Metallic mercury reaches food, prior to a transformation to organic mercury. This process is carried out due to bacteria that leave this element bioavailable so that it enters the food chain, and the longer it travels, the greater the bioaccumulation of organic mercury, which, consumed in large quantities by humans, could affect health, presenting symptoms of intoxication [46–48].

It is clear that the intensive exploitation of natural resources can generate a reduction in the services and benefits provided by ecosystems, as well as greater probabilities of risk [49,50], increased poverty and social inequality [51,52]. Various methodologies have been used worldwide to assess the environmental impacts of resource exploitation. Thus, traditionally, the assessment of environmental impacts generally begins with the identification of the components and their pressures, followed by the identification and classification of the impacts. Most studies describing the impacts of ASGM gold mining activities require evidence through physicochemical analysis to determine the impacts and their magnitude [49,53,54]. However, it has been shown that it is also possible to determine environmental impacts in a work, project or activity based on expert consulting, which, based on a review of documented or multimedia information, assigns an impact and its magnitude [9,55,56]. This opens up opportunities for researchers to implement new studies without the mandatory need for physical-chemical laboratory analysis.

In recent years, ASGM gold mining activity has increased in the Amazon region, from being carried out historically in the southern zone in the provinces of Zamora Chinche and Morona Santiago to currently being developed in the northern zone in the Province of Sucumbíos, in the cantons of Sucumbíos Alto and Cascales [15,34–36]. In the absence of information and data that allow us to know the management, the current reality of the area and its impact on the biotic and biotic environment, the objective of this study was to analyze the management and socioenvironmental impacts caused by ASGM gold mining activities in the Cascales canton, applying a technique of bibliographic review and expert judgment to determine the effects perceived by a group of experts with extensive experience in environmental matters.

2. Materials and Methods

2.1. Study Area

The study was carried out in the El Dorado de Cascales Parish in the northern Amazon region of Ecuador. This parish, together with Santa Rosa and Sevilla (Figure 1b), make up the Cascales Canton, in the Province of Sucumbíos (Figure 1a), UTM 17s WGS84 coordinates (254021-9217). The projected population for 2019 is 7574 inhabitants and the territory has an area of 513.1 km^2. The climate is hot and humid and its altitude varies from 365 to 500 m above sea level. The parish conserves a large proportion of natural resources and ethnic groups that strengthen its cultural and natural heritage [57,58]. This area is one of the richest in biodiversity, with well-preserved ecosystems where both flora and fauna species can be found. More than 150 endemic species of mammals, 300 species of birds, 77 species of amphibians and 50 species of reptiles have been recorded [39,40].

This area is characterized by a large number of water bodies, such as rivers, streams and lagoons, with an enormous variety of natural landscapes, highlighting the water component as the resource of greatest use and exploitation for consumption and leisure. In addition, the main economic and traditional subsistence activities are agriculture, livestock, fishing and mining, with most of the agricultural land used for growing coffee, pasture, cacao, sugarcane and bananas, among others. In addition, many of the inhabitants of the parish are engaged in mining to generate an economic livelihood in their homes. The

settlements dedicated to gold mining in the parish are located in the upper part of the microwatershed of the Cascales River [41,42].

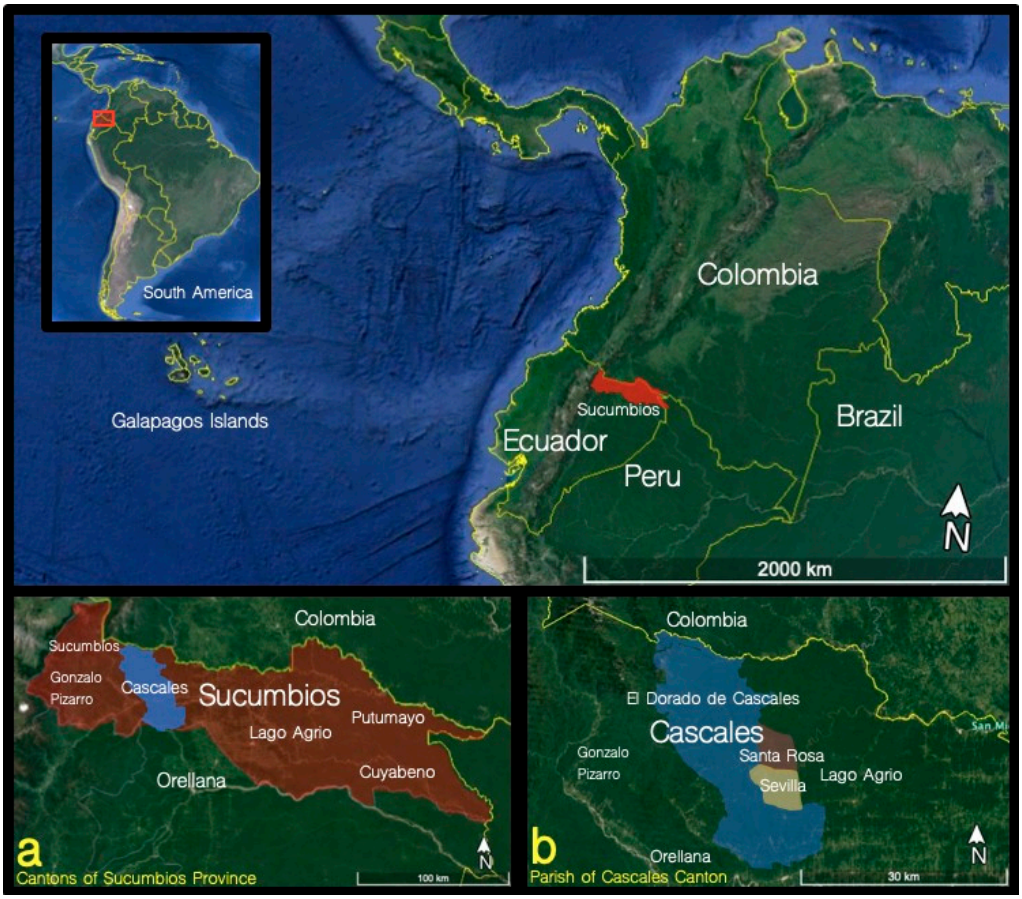

Figure 1. (**a**) Cascales Canton in Sucumbíos. (**b**) In light blue, study area, El Dorado de Cascales Parish.

2.2. Methods

The methodology used in the research employed a set of techniques that responded to each objective. First, for the initial analysis of the current situation of gold mining in the area under study, a bibliographic review of scientific articles and gray literature was carried out, and the information was complemented with interviews and direct observation in the field. Second, a double-entry data collection matrix was used to evaluate socioenvironmental impacts. Finally, to establish the challenges, a technique called expert judgment was applied.

2.2.1. Analysis of the Current Situation

The technique used for the situational study in the parish was based on a bibliographic analysis of papers published in the last 10 years in high-impact scientific databases (Scopus and Web of Science) and regional databases (Redalyc and Scielo) on gold mining in the study area. For this search, keywords were applied to filter the results (artisanal mining + gold + Cascales), in the fields (title, keywords and summary), and the search was complemented with repetitions applying combinations in Spanish and English. Additionally, gray bibliography was used, that is, documents such as plans, laws, reports, ordinances, etc., information that was provided by the authorities of the Decentralized Autonomous Government of the Cascales Canton in charge of the management, control and monitoring of economic activities in the Cascales and the monitoring of economic activities in the El Dorado de Cascales Parish.

2.2.2. Impact Assessment

Environmental impact assessment is based on the identification of external pressures on an ecosystem and its components. The proposed method has been widely used in various environmental impact assessments to identify the main pressures resulting from anthropogenic activities [59,60]. The technique is quali-quantitative and consists of the application of a double-entry matrix, which is a tool that has major advantages over other methods: (i) to carry out the valuation does not require experts, so it is easily accessible; (ii) different impacts caused can be evaluated; (iii) criteria can be taken from several people who have knowledge of the subject; (iv) the criteria or valuation issued must be purely based on the physical environmental conditions present; (v) it is a very easy matrix to apply, adapts to the different impacts, raises a reliable valuation, is very practical in environmental management processes and thus serves to propose means of prevention to its deterioration.

In this section, the methodology is divided into 4 steps. The first step consisted of characterizing the anthropic pressures, for which an interview was conducted with artisanal miners in the area to learn about the processes, activities and techniques used in gold extraction. The second step was to determine the evaluation components, and six components were established, two biotic (flora and fauna), two abiotic (water and soil), economic and social. It is important to note that the difficulty in identifying the ecological and anthropogenic components can be complex, depending on the characteristics of the ecosystem of the study area. The third step consisted of identifying and describing the impacts; in this process, a group of people involved in and knowledgeable about gold mining activities, such as government technicians, academics, local professionals and miners, was built (Table 1). This group of stakeholders was provided with historical evidence of mining activities (photographs and videos), and a field visit to the study area in the parish was scheduled to identify and evaluate the magnitude of the impacts of gold mining activities.

Table 1. People involved in and knowledgeable about ASGM activities in the study area.

Name	Age	Gender	Educational Background	Years of Experience	Relationship with the Area
Hinerth Velázquez	33	Male	Environmental Engineer	8	Environmental Controller in the Cascales Canton
Álvaro Borja	64	Male	Environmental Technician	32	Environmental Technician in Canton Cascales
Juan Carlos López	56	Male	Primary education	25	Local Artisanal Miner
Luis Rivera	45	Male	Secondary education	21	Local Artisanal Miner
María Cango	45	Female	Primary education	16	Local Artisanal Miner
Andrea Chango	34	Female	Environmental Engineer	11	Environmental Technology in Canton Cascales

Finally, in the fourth step, in order to determine the magnitude of the environmental impacts, the expert judgment technique was used, which consisted of forming a technical working group (Table 2), made up of academics and professionals with experience in issues related to the identification of environmental impacts. With the results obtained in the previous steps and identified impacts, this technical committee, as in the previous step, used historical evidence (images and videos) accompanied by a field visit that allowed assigning a magnitude of impact (Table 3). It is important to highlight and clarify that the methodological process to assess the environmental impacts of ASM gold mining activity is based on expert knowledge, a technique called "expert judgment" which focuses on establishing the impacts perceived at the time of reviewing videos and images and prior

to a tour of the mining areas. In other words, the methodology does not consider the geochemical analysis of biotic or abiotic elements.

Table 2. Experts selected to develop the assessment of socioenvironmental impacts generated the ASGM in El Dorado de Cascales.

Name	Age	Gender	Educational Background	Years of Experience	Relationship with the Area
Billy Coronel	41	Male	Master in Management Systems	17	Research Professor in the study area
Carlos Mestanza-Ramón	34	Male	Doctor in Conservation and Management of the Natural Environment	15	Researcher in the study area
Demmy Mora	24	Female	Environmental Engineer	5	Researcher in the study area
Álvaro Borja	64	Male	Environmental Technician	23	Environmental Technician in Canton Cascales
Yader Moreno	35	Male	Environmental Engineer	11	Former Environmental Analyst of the Ministry of Environment and Water of Ecuador in the Province of Sucumbíos

Table 3. Description of the magnitude of impacts.

Magnitude	Description
High	Those that are incompatible with conservation. Their presence would raise the prohibition of use or substantially modify the activities.
Medium	Those that can be compatible with conservation, after implementation of management measures.
Low	Compatible with conservation and susceptible to natural regeneration in the absence of activities.

Three levels (low, medium and high) were used to assign the magnitude of the impacts; these levels (Table 3) consider the pressures and fragility of the components evaluated (step 2). Thus, the severity of the pressures and the vulnerability of the components are directly related to the magnitude of the impact. On the other hand, the magnitude of the impacts depends on the frequency and extent of the processes. It is important to consider that the fragility of the ecosystem components will influence the degree of vulnerability at the time of the assessment. Likewise, it is important to note that once the three levels regarding the magnitude of impacts have been established, the technical team sets one of the three levels considering the type of impact and components affected based on their experience in the environmental and biodiversity fields.

2.2.3. Challenges

To establish challenges, the results of the situational diagnosis regarding gold mining in the parish of El Dorado de Cascales and the evaluation of impacts were used. Based on this, a SWOT (Strengths, Weaknesses, Opportunities, Threats) matrix was developed. In this process, questions were developed to identify various aspects essential to its structure (Table 4).

Table 4. SWOT Matrix (Strengths, Weaknesses, Opportunities and Threats).

Strengths	Weaknesses	Opportunities	Threats
What are the advantages? What is done well?	What is affecting it? What opportunities can arise from the problems?	What is being done wrong? What should not happen?	What do other artisanal ASGM areas do better? What obstacles does artisanal mining have?

3. Results

After explaining the methodological process for conducting the literature review, the socioenvironmental impact assessment and the analysis through expert judgment in the El Dorado de Cascales parish, the results of the analysis and description of the current situation in the area under study, the socioenvironmental assessment and the challenges in the El Dorado de Cascales parish with respect to gold mining activities are presented. The following are the results of the analysis and description of the current situation of the area under study, the socioenvironmental assessment and the challenges in the El Dorado de Cascales parish with respect to ASGM activities.

3.1. Analysis of the Current Situation

Through the bibliographic analysis of different documents, the current situation regarding mining in the El Dorado de Cascales parish was established. The El Dorado de Cascales parish has had constant gold mining activity since 2012, which has caused discomfort for both the indigenous and mestizo population of the parish because settlers invaded their territories to engage in this activity, causing several complaints from the native inhabitants [36]. Gold mining has been characterized by the use of inefficient and obsolete techniques, causing a series of negative impacts on people and the environment. ASGM is characterized by inadequate extraction technology, precarious working conditions, a lack of technical knowledge and little legal and institutional formalization. Currently, mining is still occurring in the main rivers of the parish (Cascales and Loroyaku Rivers), but these activities are carried out informally because there is no environmental registry [35,61].

The Dorado de Cascales parish has the most gold mining activity in the Cascales canton and in the province of Sucumbíos. The main rivers in which this activity takes place are the Cascales and Loroyaku rivers; the coloration of these rivers is a physical indicator that mining activities are taking place. It is estimated that gold production in the study area is approximately 1 kg per week, although it should be noted that this depends a lot on the climatic conditions in the area or zone where there is evidence of gold-bearing material [19,62].

According to interviews with both miners and local residents, they report that in recent years the area has been invaded by illegal and informal mining activities. In addition, the perception expressed by the miners is that one of the main advantages of this activity is the generation of income, which is a great opportunity for local economies. Meanwhile, for the neighboring inhabitants, the development of mining activities causes alterations, disturbances and contamination. All of this is due to the fact that they are not carried out with adequate techniques that do not cause contamination of water sources, soil and biodiversity in general [19,60]. It is clear that these activities have generated a conflict between stakeholders and their inhabitants. If we aspire to raise awareness of the methodology used by miners in order to generate less socioenvironmental impacts, challenges are required where collaboration and integrated work between authorities, stakeholders and citizens is paramount [19,53]. The ASGM in the parish has been characterized by rudimentary techniques. According to information from the canton's municipality, the parish is experiencing a major socioenvironmental problem because gold mining activities do not comply with the Environmental Management Plan [19,48,60].

In addition, there are not enough controls by the competent authorities to verify compliance with the different requirements for their operation without harming the en-

vironment and the nearby population. The citizens of the parish allege that this activity, despite generating more income for the native people of the sector, often causes discomfort because they carry out this activity in an environmentally unconscious manner, causing damage to the bodies of water that are often used by the community for recreational use or as a source of water for their crops and animal husbandry.

3.2. Impact Assessment

The study made it possible to evaluate the main impacts and conflicts generated by gold mining activities in the El Dorado de Cascales parish. Four main activities carried out in the area were identified (Table 5) in the mining process: the classification of gold-bearing gravels and the separation of heavy sediments; the concentration and separation of gold from heavy sediments; gold recovery through amalgamation processes with mercury and the distillation of amalgam for the separation of gold from mercury.

Table 5. Description of mining activities in the El Dorado de Cascales parish.

Activities	Description
Initial exploration	This stage refers to the initial process in which artisanal miners travel long distances in search of an area with indications of gold-bearing materials. In the process, the miners invade so far untouched areas, build paths and roads, clear trees, build houses and camps, use (and spill) fuel, hunt animals, etc.
Gravel classification	This is the first step of exploitation is the mining or excavation of the gold-bearing gravel. This can be done by hand (shovel) or small suction dredges. Classification means the separation of coarse stones from small sand and gravel. This is usually done by sieving.
Preconcentration	This means the separation of light material (sand and gravel) from a mixed heavy minerals concentrate. This is done by "sluicing" in a wooden or metal chute with usually a rough carpet on the bottom, where heavy minerals and gold are held back and light material overflows with the water. The carpet is washed from time to time and the preconcentrate is collected.
Amalgamation	The preconcentrate (also called black sand due to its high content of black iron minerals) is then amalgamated in a pan, where mercury and water are added and the pan is shaken. Fine gold and mercury combine to coarse amalgam flakes, which then are separated from the heavy minerals by panning. The amalgam is collected for further burning.
Burning of the amalgam	Finally, the collected amalgam is then burned. This means that mercury is evaporated by heat (e.g., using a charcoal fire) and enters the atmosphere. It can be inhaled by the operators and leads to their intoxification by metallic mercury. Usually, the largest part of mercury vapor, due to its high weight, settles down around the burning place and contaminates the soil. Some of it may travel a bit further by wind. By rain and erosion, this metallic mercury enters the waterways.

Sixteen socioenvironmental impacts were identified in the three components (biotic, abiotic and socioeconomic) caused by the five main activities carried out by the gold mining process (Table 6). Of the five activities analyzed, the socioeconomic component was the only activity that did not generate substantial impacts on the biotic component. However, the remaining four activities caused negative impacts on the biotic and abiotic components of the ecosystem in the artisanal gold mining areas of El Dorado de Cascales parish. Of the three components studied, water, in terms of the abiotic component, was found to have the greatest number of detrimental impacts from gold mining activities, due to the use of mercury to obtain gold.

The impacts identified in the El Dorado de Cascales Parish generated by artisanal gold mining were shown to be very detrimental during and after mining activities (Table 7). In the study area, sixteen different socioenvironmental impacts were identified, seven with high impact, all related to abiotic components (habitat alteration, disturbance to vegetation, disturbance to vegetation, contamination by chemicals, alteration, contamination and contamination by suspended particles). Followed by eight impacts with medium magnitude, four are related to the biotic component (disturbance by initial exploration, loss of species, contamination by waste and loss by damage or removal), three to the abiotic component (compaction, disturbance and alteration to soil quality) and one to the socioeconomic

component (health). In general, considering all the activities carried out for gold extraction, 54.54% of the activities had a medium impact, 36.36% had a high impact and 9.09% had a low impact on the three components studied.

Table 6. Actual impacts identified, associated with the components identified during gold mining in the parish.

Activities	Components						
	Biotic		Abiotic			Socioeconomic	
	Fauna	Flora	Soil	Water	Atmosphere	Economic	Social
Initial exploration	Disturbance Alteration	Disturbance Alteration Lost	Compaction Contamination	Disturbance Alteration	—	—	—
Gravel classification	Disturbance Alteration Lost	Disturbance Alteration Lost	Alteration	Disturbance Alteration	—	—	—
Preconcentration	Contamination	Disturbance	Compaction	Contamination	—	—	—
Amalgamation	Alteration	Alteration	Contamination	Contamination	Contamination	—	Diseases
Burning of the amalgam	Contamination	Disturbance	Contamination	Contamination	Contamination	Income	Diseases

Contamination: Action when elements or substances that should not normally be in an environment enter it and affect the balance of the ecosystem. Disturbance: Disruption or environmental disturbance to the elements of an ecosystem that over time can regenerate. Alteration: Change in the characteristics, essence or form of the elements of an ecosystem that cannot regenerate over time due to their disappearance. Lost: Elimination of species or part of their individuals. Income: Increase in its economy. Diseases: Any type of impact on human health and quality of life.

Table 7. Main results of the magnitude of impacts and conflicts in El Dorado de Cascales parish.

Component	Impact	Magnitude
Fauna	Initial scanning disturbance	Medium
	Habitat alteration	High
	Loss of species	Medium
	Contamination by waste	Medium
Flora	Disturbance to vegetation	High
	Alteration to vegetation	High
	Loss due to damage or removal	Medium
Soil	Compaction	Medium
	Contamination by chemicals	High
	Alteration to soil quality	Medium
Water	Disturbance	Medium
	Alteration	High
	Contamination	High
Atmosphere	Contamination by suspended particulate matter	High
Economic	Employment	Low
Social	Health	Medium
	Low impact	6.25%
Results	Medium impact	50%
	High impact	43.75%

The results of this assessment of the socioenvironmental impacts generated by gold mining in the El Dorado de Cascales Parish show that artisanal miners did not have the pertinent environmental registration; in addition, they did not extract in a manner that was friendly to the natural environment (Figure 2). The magnitude of the impacts was mostly medium, without discarding the concern of the biotic component. The Cascales and Loroyaku rivers, sources of use for the local inhabitants as sources of daily use for different household activities and also as tourist centers, are now affected by mining activities.

Figure 2. Gold mining. (**a**) Impact on water bodies; (**b**) use of machinery and equipment; (**c**) anthropic impact; (**d**) earth movement and vegetation impact.

It is important to highlight that during the field visit, 31 artisanal miners and 12 small-scale miners were interviewed, 100% of whom stated that they have used mercury at some time in the last few months in activities to extract gold in ASM. In addition, none of them take measures to reduce the impact and risk of using mercury. On the other hand, 100% of artisanal miners finish processing amalgam at home. While 41% of the small-scale group does it in the mining area with the use of torches that generate fire, i.e., high temperatures that separate the mercury from the gold, and 59% do this process in family homes in rural areas. Finally, they state that mercury is easily obtained from intermediaries in local hardware stores or medium-scale miners, but it is known that mercury comes from Bolivia and Peru, and it is also known that much of the mercury that enters Ecuador is sent to Colombia through the San Miguel Sucumbíos–Putumayo border crossing.

3.3. Challenges

Gold mining plays a crucial role in employment production, foreign exchange generation and overall economic activity. Despite the fact that mining activities were paralyzed as a result of the COVID-19 pandemic, gold mining is still evident today. This can be justified by observing the coloration of the main rivers in the parish of El Dorado de Cascales, and these rivers are: Cascales and Loroyaku. The authorities of the study area should focus

their efforts on creating ordinances to regulate these activities in the parish. It is essential to analyze the situation regarding gold mining in general in Cascales in order to take advantage of the potential of the resources in a sustainable manner.

The environmental and health contamination problems caused by the use of mercury are perhaps some of the biggest challenges for the sector and the authorities. According to several interviews with local miners, they state that they use mercury to recover the gold extracted from the rivers. To meet this challenge, not only are strict measures needed to prevent and control environmental contamination and environmental quality in general but also strategies to manage and guarantee a balance between mining activities and the health of workers and residents of the sector are required. New ways of working and understanding the needs and requirements of the workers and citizens of the study area are required.

The incorporation of sustainable methods is essential to ensure that the extraction of this element does not have a negative impact on the environment. To this end, it is necessary to strengthen professional training and establish a change mentality that will allow this sector to adapt to methods that are less harmful to the environment. The state must enact regulatory frameworks in order to manage and promote mining activities to prevent them from being carried out with low technology and precarious working conditions, since the greatest advantage of the artisanal sector is that it is a great source of employment and income for the community.

The challenges of governance and policies for mining resources should focus their efforts on: (i) exercising effective and democratic governance for the sustainable management of natural resources; (ii) mitigating macroeconomic vulnerability to commodity price fluctuations and terms of trade with intertemporal logic; (iii) increasing the progressivity of fiscal revenues, financing public investment and improving the quality and progressivity of public spending at national and local levels; (iv) adding value, deepening local production chains and diversifying production and exports; (v) sharing benefits with communities and guaranteeing economic, social, cultural and collective rights; (vi) protecting the environment, reducing socioenvironmental impact and developing comprehensive policies for the sustainability of natural resources and finally (vii) promoting regional integration in the face of external tensions and protecting competitiveness, without lowering social and environmental standards.

Given the complexity of the issues surrounding ASM, a coordinated and participatory approach is needed to improve its contribution to sustainable development, involving all spheres of government, industry and civil society. The approach considered should be tailored to the particular social, cultural and economic circumstances of Ecuador and the study area. The state should maintain a recognition of the importance of ASM and focus on improving the livelihoods of those involved in ASM and reducing its impacts as part of integrated rural development. ASM activities should also be incorporated into relevant regional and local development programs. The national government has a major role to play in developing appropriate, consistent and transparent policies through a regulatory framework that focuses on ASM facilitation and management. For the framework to be effective, they must ensure that there are sufficient financial and regulatory incentives for small-scale miners to formalize their activities.

4. Discussion

The parish of El Dorado de Cascales is one of the areas with the highest mining activity in the northern Amazon region of Ecuador and, like other regions of the country such as the Andean [63] and Littoral [49,62] regions and other countries in the region [64–66], one of the main problems is the lack of control of mining activities by local, regional and national government authorities. The lack of employment and entrepreneurial opportunities makes people in these areas characterized by high gold concentrations to engage in this activity, so much so that there are even people from other regions and from neighboring Colombia who are tempted by this activity. These social problems of migration and the lack of job

opportunities are very similar to what happens in Africa [16,45] or other Latin American countries [67–70]. Aspects that lead to the generation of conflicts that have been evidenced in the study area are increasing, maintaining the tendency of the countries in the region with important gold mining production. To try to change this reality, it is necessary to implement public policies that involve regulatory, institutional, fiscal and strategic planning, management and the management of socioenvironmental conflicts. All of this requires a long-term vision that allows institutional innovation to maximize social benefit in the present and in the future. It is necessary to consider extraregional experiences that have created public savings and investment funds for specific purposes (education and innovation) or macrofiscal stabilization funds of a counter-cyclical nature. This will make it possible to address effective and democratic governance of mining resources for sustainable development.

It is clear that the ASGM activity of gold in the northern Amazonian area of Ecuador has been a historical reality [50,60,71], present and continuing to expand in the future [42,63,72], due to its high demand and the continuous rise of its market value, all this in response to the war between Russia and Ukraine and the growing distrust of the hegemony of the main world currencies such as the dollar and the euro [73,74]. In view of this, the national government and all the institutions linked to this activity must propose political measures, norms and actions in order to regulate this activity in the economic system, within a framework of sustainable development, focusing efforts on the environmental component and its conservation [75,76], since the polluting elements that are used affect the balance of ecosystems, as evidenced in the results of this study. Thus, proposing solutions to the social and environmental problems of small-scale gold mining in Ecuador is an arduous task that requires the active and coordinated commitment of the government, communities, NGOs, private associations, universities and research institutions. Therefore, the institutions and communities involved in ASM gold mining should form an alliance in favor of sustainable and responsible artisanal and small-scale mining, based on the objectives of sustainable development.

As in other countries worldwide in ASGM mining, mercury is the main pollutant used in the gold extraction process [77,78]. This element is initially used to group gold particles together to form a gold-mercury amalgam. Contamination is produced when the amalgam is poured into water bodies and when the amalgam is left to release the mercury, which dissipates into the atmosphere. This is no different in the study area, where 90% of ASGM miners claim to use mercury clandestinely, causing great harm both to the person performing the procedure and to those living in nearby areas [45,79]. Regarding the origin of the mercury, this element used by illegal miners would have a clandestine origin from Bolivia and Peru through the southern Ecuadorian border [80]. In alluvial mining (river gold), the ratio Hg:Au is usually 1:1. Mercury loss is usually caused by burning the amalgam. Amalgam from river gold consists usually of about 50% gold and 50% mercury, depending on the particle size of the gold [80–82]. On the other hand, there is evidence of higher mercury use ratios when the ore is ground (hard rock mining) and the mercury is ground into small particles and lost in the tailings. In hard rock mining, the Hg:Au ratio can be as high as 10:1 [39,79,83].

5. Conclusions

In the process of the management, control and monitoring of gold mining activities, the authorities and their representatives in the El Dorado de Cascales canton and its parishes, one of the biggest problems is the lack of knowledge of the laws and competencies to be able to apply the laws and their regulations. Local authorities together with provincial and national authorities have not correctly articulated the work in the territory, which has prevented the correct execution of the control and monitoring of activities, facilitating the increase in illegal activities and making it easier to evade them. Local autonomous governments, through their government councils, should focus their efforts on creating ordinances that will allow mining activities to be registered, and then more control over

gold mining activities can be carried out. The creation of management tools will make it possible to evaluate, monitor and control all the processes involved in mining activities.

Gold mining activity in the study area in the El Dorado de Cascales canton has increased in recent years, generating a socioenvironmental impact. It has affected the biotic and abiotic components with high and medium magnitude and the socioeconomic component with medium and low magnitude. The main impacts correspond to habitat alteration, disturbance and the alteration of vegetation at the time of the exploration of territories. On the other hand, contamination and chemical alteration to soil and water, when miners use mercury to form the gold and mercury amalgam, is another important impact. Another strong impact is the atmospheric alteration caused by mercury particles that are released in the process of burning the amalgam to obtain gold. In the socioeconomic aspect, the impact on human health is medium and the economic income for the locals is low, considering that most of the money is taken by the merchants and owners of equipment and machines.

The use of mercury in gold extraction processes can initially be an efficient option due to its effectiveness. However, the results show that there are medium and high socioenvironmental impacts as a direct result of ASGM activities in the parish of El Dorado de Cascales. Upon analyzing the current situation in the parish, it became evident that gold mining is carried out using rudimentary techniques. In addition, there are insufficient controls by competent authorities to verify compliance with the different requirements for operation, without harming the environment and the nearby population. Finally, one of the main difficulties in the development of this study was gaining access to legal and illegal mining areas. The risk is always present due to the social secrecy of this activity. It is recommended to focus efforts on new studies focused on the analysis of heavy metal concentrations in water, sediments and biotic elements. This will allow us to generate a contrast with the results observed in situ by researchers.

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