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Environment risk and impact assessment of the use of mercury for gold mining in the Santurban Paramo area, Colombia

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ABSTRACT

Gold mining in the Santurban Paramo in Colombia contributes to the development and growth of the region by generating employment and income for the inhabitants. However, the benefits of this activity may be offset by the use of mercury in the amalgamation stage of gold production. Mercury is a heavy metal that is highly toxic and harmful to the health of people who are directly or indirectly involved in gold mining and causes damage to the environment, such as deterioration of vegetation cover, harmful effects to flora and fauna in the Paramo, disappearance of endemic species, and reduced quality of natural resources (water, soil, and air). This research seeks to analyze the different environmental impacts and risks of inadequate handling of mercury in gold mining. To do so, the mining activity process and the area of influence were first characterized and evaluated. Next, soil and air mercury concentrations were measured in the mining areas considered under this study. In the municipalities of California and Surata in the Santurban Paramo, values between 160–226 g/t of mercury were measured in the production plants. Finally, the environmental impacts were evaluated with the help of an environmental risk matrix, obtaining higher risk indexes in natural resource quality and effects on flora and fauna of the Santurban Paramo.

Contribution/Originality: A health and environmental risk assessment in areas of mercury mining activities is a very important and innovative tool to address these problems because it allows to quantify the most important and relevant hazards of the process, which will be an option to make decisions to address these problems.

1. INTRODUCTION

Colombia is recognized worldwide for its diversity in nature reserves and natural resources and is a major tourist destination due to the biotic and abiotic factors that characterize the country such as emblematic fauna and flora species, waterfalls, canyons, and more.

An especially important habitat in Colombia is the Santurban Paramo, located in Santander and North Santander, whose water resources provide for the needs of approximately 2,200,000 inhabitants (CDMB, 2015). The area is incredibly biodiverse, with more than 700 species, including 450 plant and fern species, 17 reptile species, 201 bird species, 58 mammal species, and 17 amphibian species (Lopez, Biotic, Avellaneda, Physicist, & Paez, 2012). Due to this biodiversity and the strengthening of the agricultural sector by 26% (Caracol, 2019) the region represents high economic and environmental potential. It is also recognized for foreign investment in goods and services focused on artisanal mining as sustenance for the needs of Santander and North Santander (El Tiempo, 2017).

Artisanal mining is a widespread economic activity in the Santurban Paramo. For example, in the community of Vetas, artisanal mining contributes directly or indirectly to 80% of the economy (Quintero, Ríos, Monroy, & Londoño, 2021) fulfilling an essential role in supplying the raw material of gold for different industrial sectors (Quintero et al., 2021).

However, in most cases, the benefits obtained by mining in the region are at least somewhat offset by the negative outcomes of obtaining gold. Approximately 200 L/s of groundwater become contaminated by contact with mercury and other chemicals used in gold mining, creating acidic water mixed with cyanide and mercury (Peña, 2020). This contamination is a result mainly of lack of knowledge and mismanagement of resources; those affected include those who are in direct contact with mercury and mercury-contaminated water as well as the environment as a whole. This alteration of the ecosystem is generally done to meet the economic needs of the region without contemplating the environmental impact generated (El Tiempo, 2020). More than 80,000 native trees in the area have died due to lack of nutrients and water resources necessary for their survival (France 24, 2020).

Mercury, the highly toxic heavy metal used to form an amalgam with gold, is a silver liquid at room temperature and can be found in water, soil, and air as well as can be absorbed or ingested by living beings (Balali-Mood, Naseri, Tahergorabi, Khazdair, & Sadeghi, 2021). Its melting point is -39°C while its boiling point is 357°C; its solubility in water increases 1.3x for every 10°C increase in temperature in the environment. Mercury has a high environmental impact on organisms, which use natural resources for their survival (Gaffney & Marley, 2014).

Mercury is considered one of the 10 chemical elements of most significant concern worldwide (Wang et al., 2020) due to its transformation from elemental mercury to organic mercury,, a highly toxic substance when released into the atmosphere and into the trophic chain of living beings (Zaferani & Biester, 2021), causing impacts on organisms when in contact with amounts even as low as 0.05 µg/g (Zulkipli et al., 2021). Among the problems caused by mercury contamination in water is the accumulation of the heavy metal in fish, causing severe damage to their tissue as it becomes methylmercury (Ghezzi et al., 2022). This form of mercury accumulates over time and can enter humans through consumption of this contaminated fish, which can cause tissue and eye damage, respiratory and circulatory issues, muscle pain, potentially cancerous tumors, and even death (ATSDR, 2022).

The Portable X-ray Fluorescent Spectrophotometer (XRF) is a device which can be used to detect mercury. This device is currently used for real-time field analysis, preliminary analysis to be corroborated by laboratory analysis, soil detection, Air Core, diamond drilling cores on a macro scale in geochemistry and micro scale in structure, alteration, mineralogy, and fluid flow. Not only can the equipment detect heavy metals such as mercury, lead, arsenic, and chromium, but also minerals like copper, gold, molybdenum, silver, and zinc. The use of the XRF is essential in environmental licensing studies or when studying inadequate and illegal mining processes because it allows for the rapid detection of heavy metals of interest and the analysis of raw ore, concentrate, and alloys, which leads to real-time on-site soil and filter analysis, instant project delineation and cost reduction, and fast, interactive monitoring.

Mercury contamination can reach ecosystems through rainfall and mining practices, which cause erosion and seepage; this mercury contamination, as mentioned above (Ebadian, 2001) can contribute to the disappearance of endemic species and alteration of ecosystems. Poor management of this heavy metal has resulted in an increase of more than 460% of mercury concentration in the atmosphere (Meneses et al., 2022). Authorities and residents of the region have begun to implement remediation strategies to minimize environmental impacts caused by gold mining, which introduces an opportunity for growth and sustainable development by recovering mercury and designing educational and training strategies to avoid falling into a vicious cycle of mercury use, release, accumulation, and damage to the environment, local flora and fauna, and residents.

2. METHODOLOGY

The research methodology is divided into 4 important aspects: characterization of the area of influence, explanation of the gold mining process in the Santurban Paramo, characterization of mercury, and the environmental risk and impact in the area of influence Figure 1.

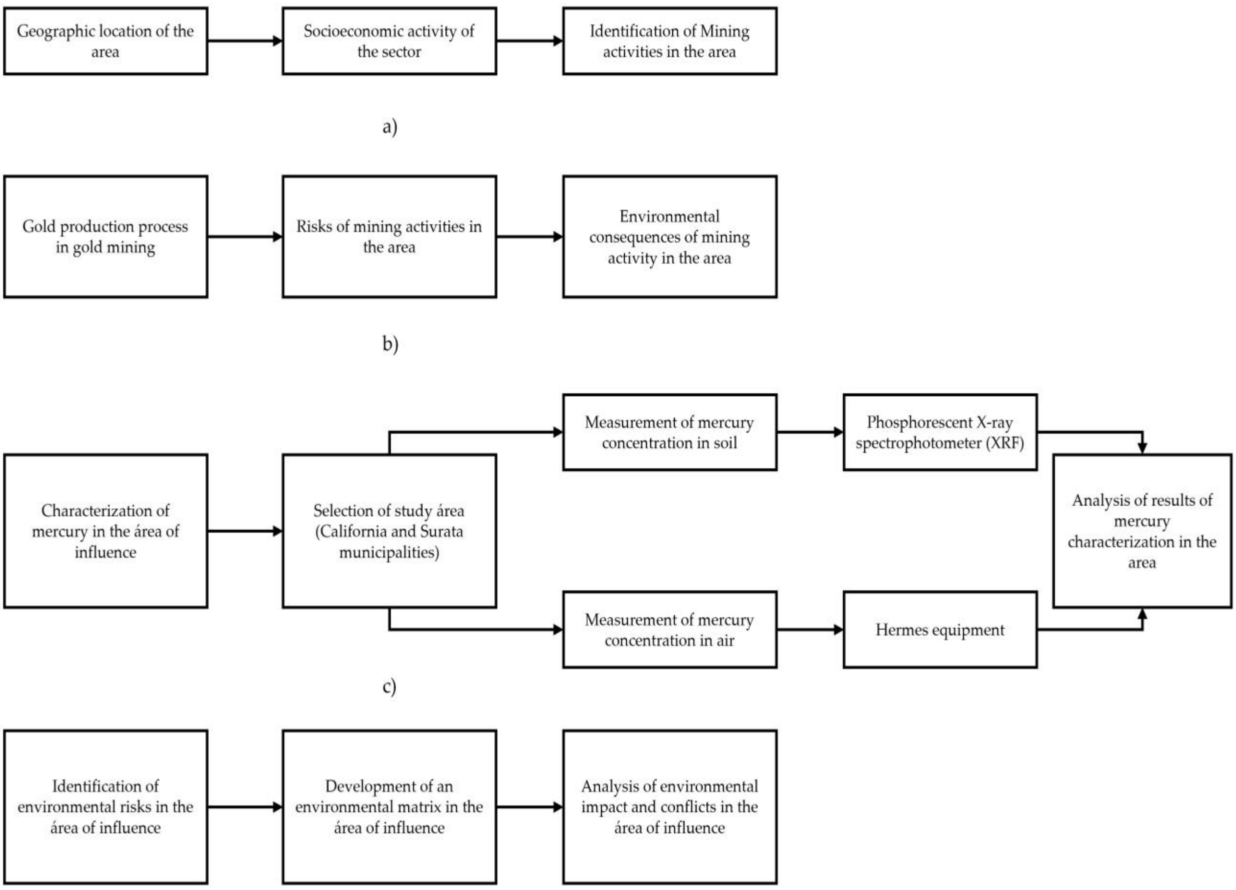

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Figure 1. a) characterization of the area of influence; b) gold mining process in the Santurban Paramo; c) characterization of mercury in the area of influence; d) risks and environmental impact of the area.

To detect and measure mercury, the XRF is used. The XRF is an instrumental analytical technique that measures the elemental composition of a solid substance exposed to X-ray radiation. The qualitative analysis is obtained from the energy and emitted x-ray wavelength. The sample exposure time is approximately 30–600 seconds. However, detection limits are affected as time is prolonged.

When used in situ on tailings contaminated by illegal mining, heavy metals and other contaminants that may be found in the studied sediment are immediately analyzed. During this research, the XRF was calibrated prior to performing soil measurements, using the calibration factors determined by the equipment (see Table 1).

To detect mercury in mining tailings, the following factors should be considered: the measurement time of 30–40 seconds to detect heavy metals, repeatability in each study area with the determination of measurement points, the standard deviation of each point, and the detection limit based on the calibration curve Table 1 and Figure 2.

Likewise, the following factors are considered when evaluating the risks and environmental impact generated by gold mining activities in the Santurban Paramo (see Table 2).

Table 1. Equipment calibration data.

Standard	Standard description	Element	Min (%)	Max (%)	Reading (%)
2711a	NIST standard reference Material 2711a Montana II soil	K	2.380	2.660	2.630
		Ca	2.300	2.640	2.590
		Ti	0.300	0.400	0.320
		Pb	0.130	0.150	0.130
		Mn	400.000	700.000	428.000
		Zn	300.000	500.000	356.000
		Sr	210.000	250.000	234.000
		Cu	130.000	150.000	131.000
		As	10.000	100.000	68.000
		Cd	40.000	60.000	42.000
		Ni	10.000	50.000	42.000
		Sb	10.000	50.000	37.000
		Hg	0.000	<9.000	None detected
Bank	Silica XRF standard SiO_2	Si	52.600	56.700	None detected

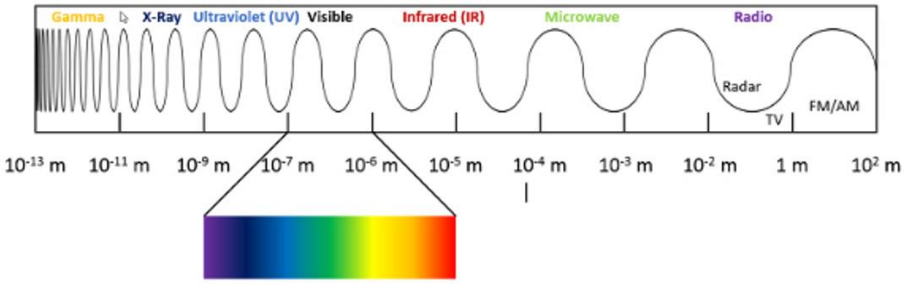

Figure 2. Limit detection of portable X-ray fluorescent spectrophotometer (XRF).

Table 2. Environmental impacts of gold mining in the Santurban Paramo.

Impact	Description
Financing of public management	Increase or decrease in the consumption of laws, organizations, systems, and procedures that the government or the region has to ensure and use public resources effectively and efficiently.
Employment generation	Increase in the employed population for the development and economic growth of the sector.
Change in air quality	Produced by the emission of greenhouse gases (GHG), mainly carbon dioxide, due to human activities such as deforestation; negatively or positively affects activities that favor the flora and fauna of the sector.
Increase in the quality and supply of goods and services	Increased supply and demand for goods by having focus and entry points for the production of gold and other minerals in the area.
Changes in community organizational dynamics	Positive or negative change of the inhabitants or communities by creating another source of economic income to the territory.
Cover and terrestrial habitats	Increase or decrease of flora and fauna in the area, especially endemic or endangered species.
Alteration of the physicochemical and biological properties of the soil	Increase or decrease in soil quality: nutrients, microorganisms, carbon, and energy source.
Alteration of communities of terrestrial fauna	Increase or decrease in Paramo fauna.
Reconfiguration of the relationship with the territory	Empowerment of the territory with new manufacturing practices and economic, social, and environmental development to meet the needs of the sector.
Alteration of hydrobiological communities	Increase or decrease in aquatic ecosystem communities of the consisting of plants and animals that are microscopic and macroscopic.
Changes in population dynamics and in the demand for public and social services	Increase or decrease in the area's population growth in relation to the goods and services offered with economic and social activities.
Alteration of populations of endemic flora with special conservation status	Increase or decrease in endangered or endemic flora and fauna, known for their role in the preservation and protection of the culture and coverage of the Paramo.
Change in land use	Increase or decrease in land for agricultural, livestock, or conservation use.

Impact	Description
Change in the physicochemical and bacteriological quality of surface water	Increase or decrease in water quality, especially the rivers, basins, and streams of the Paramo, which are the subsistence ecosystems of aquatic organisms.
Generation of expectations and potentiation of conflicts	Increase in conflicts in the region, whether by armed groups or ancestral communities for the preservation and protection of natural resources or their exploration or extraction.
Changes in sound pressure levels	Increase or decrease in sound pressure that is generated from economic, social, or environmental activities.
Lowering of the water table	The exhaustion of a sealed enclosure to work reduces water pressure on structural elements and soil resistance.
Affectation of the infrastructure for community use	Increase or decrease in communities of small basic structures or settlements in the area.
Impact on local mobility	Positive or negative impact on mobility in the region in daily commutes to work or residential mobility.
Alteration in the surface water flow regime	Increase or decrease in water quality in the availability and flow of the resource.
Involuntary transfer of social units	Displacement of ancestral communities or the inhabitants of the sector for economic practices.
Habitat fragmentation and loss of visual connectivity of ecosystems and visual quality	Increase or decrease in Paramo ecosystem coverage for the subsistence of flora and fauna.
Variation in vibration level	Increase or decrease in the oscillating movement concerning a reference position.

These 23 identified impacts are evaluated according to an environmental rating scale where a low impact will have a value of 1, a regular impact will have a value of 2, a medium impact will have a value of 3, and a high impact will have a value of 4 (see Table 3).

Table 3. Environmental impacts assessment scale.

Low impact	Regular impact	Medium impact	High impact
1	2	3	4

3. RESULTS AND DISCUSSION

3.1. Characterization of the Area of Influence

The Santurban Paramo is in the departments of Santander and Santander North and corresponds to Corponor's area jurisdiction in 10 municipalities: Chitaga, Salazar de las Palmas, Arboledas, Villacaro, Pamplona, Cacota, Silos, Cucutilla, and Mutiscua. The Paramo has an altitude of 4,200 meters above sea level (CORPONOR, 2009) Figure 3.

One benefit of the Paramo lies in the birth of rivers and streams; in the Santurban Paramo, the Chitaga, Cucutilla, and Cachira basins are formed (CORPONOR, 2009). In these basins, medicinal flora are studied for their potential prevention of various diseases. The Santurban Paramo is also known for being a dynamic ecosystem, producing natural resources such as water and soil. However, the Paramo has been affected over the years by the following:

- Agricultural activities.
- Gold mining.
- Climatic variations.
- Alterations due to natural phenomena.
- Sedimentation rates in the soil resource.

The socioeconomic activities of the sector mainly include (CDMB, 2010):

- Agriculture, livestock, hunting, forestry, and fishing.
- Mining and quarrying.
- Manufacturing industry.
- Electricity, gas, and water.
- Construction.

- Trade, repair, restaurant, and hotels.
- Financial establishments, insurance, real estate activities, and services.
- Social, community, and human service activities.

An important activity in the Santurban Paramo for local development and growth is gold mining, an ancestral activity that is the economic livelihood of many residents. However, the region's ecosystem services and demographics have been affected by the indiscriminate use and misuse of water and soil resources. This is mainly due to a lack of the necessary tools for the correct management and disposal of mercury, used in the gold amalgamation process.

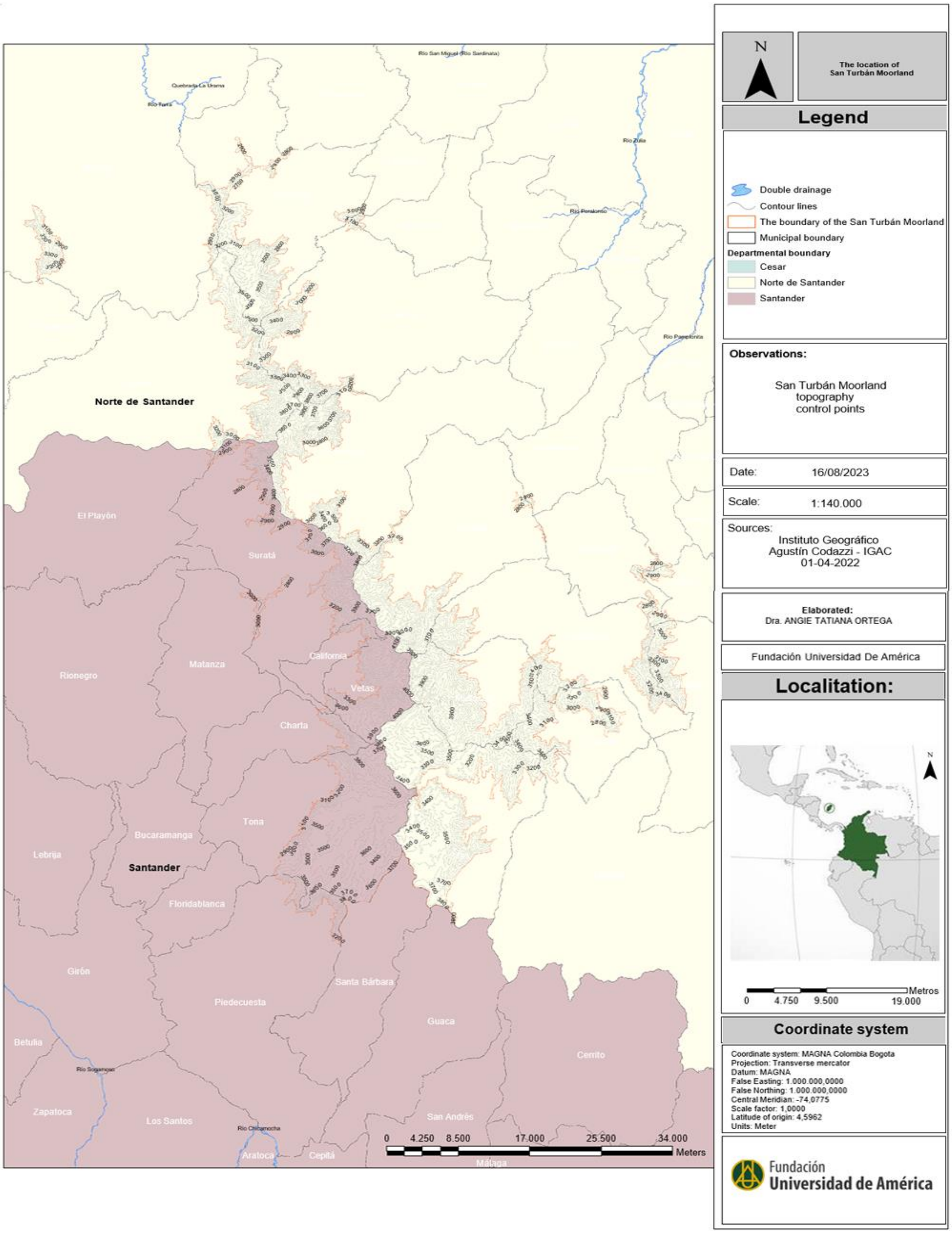

Figure 3. Topography of the Santurban Paramo.

While it is true that gold mining has been catalogued as an important social and economic activity in Paramo, the negative consequences of this activity have yet to improve. One consequence that has been of interest is the accumulation of mercury in natural resources. Mercury is used in the amalgamation process, and traces of this material enter the pure streams formed in the highlands and river basins, causing ecosystem alteration and the disappearance of endemic species of flora and fauna, ancestral species used by the region's inhabitants who have dwindled in number due to lack of optimal livelihoods for their survival (Acevedo Tarazona & Correa Lugos, 2019).

Mercury affects people's health in two different ways. First, mercury accumulates in the trophic network by accumulating in the tissues of aquatic species used as food and commerce by the residents of the area. By not having proper management of mercury use in gold mining, the mercury enters aquatic ecosystems and contaminates these fish species and therefore enters the human system of those who eat the fish. Second, those who are directly engaged in mining activity can have direct dermal and respiratory exposure to mercury. Not having the necessary safety equipment releases mercury emissions into the atmosphere, exposing miners. Mercury exposure causes respiratory, reproductive, circulatory, muscular problems and even death as a long-term consequence.

3.2. Gold Mining

The gold mining process in the Santurban Paramo is performed first by obtaining mining ore. This material is passed through a crushing and milling process to obtain smaller particles of gold and is then subjected to a flotation process to remove traces of material left over from the previous process that could modify the properties of the final product. The material then goes through a roasting and leaching process and then the gold amalgamation process (Wotruba & Vasters, 2002) a stage that is worrisome to the sector's residents and environmental authorities due to the use of mercury. This stage is important for obtaining pure gold; however, using mercury is detrimental to human health, the ecosystem, and the area's natural resources. Finally, the gold amalgamated with mercury goes through sedimentation, removing the mercury by steam without prior treatment to obtain liquid gold (Poveda Ávila, Nogales Vera, & Calla Ortega, 2015) Figure 4.

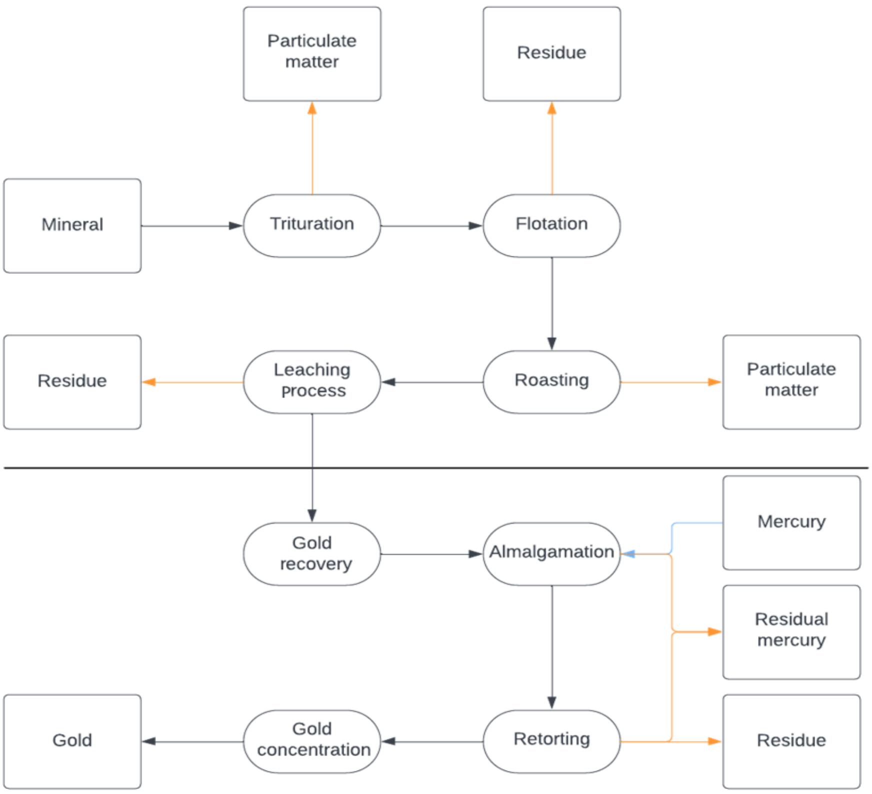

Figure 4. Artisanal mining process in Colombia.

The main stakeholders in the Santurban Paramo gold mining process were evaluated according to the Mitchell, Agle, and Wood (1997) typology, classifying stakeholders as Latent, Expectant, and Definitive. The Definitive type have three attributes (Power, Legitimacy, and Urgency), which could represent an opportunity or a threat based on the importance they hold in performing the mining activity, as is the case of Community, Civil Society, Regional Corporations, Media, Clients, Financial Entities, and Suppliers Figure 5.

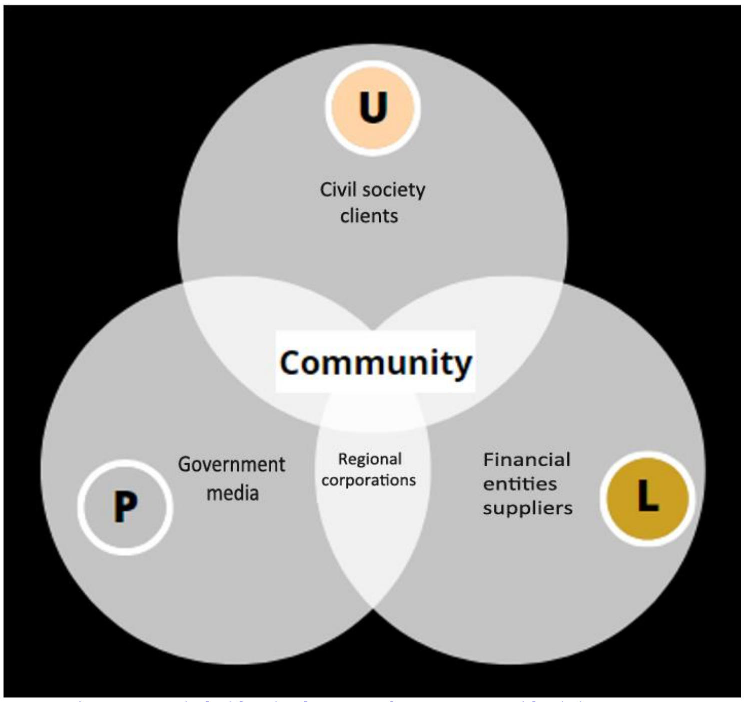

Figure 5. Stakeholders in the Santurban Paramo gold mining process.

According to local residents, the depth of the open pits for gold mining does not measure more than 100 m (Acevedo Tarazona & Correa Lugos, 2019). The gold is used for ritual, cultural, industrial, and economic purposes as currency. The gold represents the culture of the region's farmers transcending as a means of livelihood and development of Santander.

Mining does not represent an inherent risk to its surroundings; what can be dangerous is how the activity is developed (Cañon & Mojica, 2017). Artisanal gold exploration and extraction processes can generate toxic pollutants such as mercury, copper, lead, zinc, and arsenic, which can deteriorate both the short- and long-term health of people and the environment. To perform mining activities, ecosystems are sometimes altered or even destroyed due to poor environmental practices, where only the satisfaction of the sector is sought and not concern for natural resources.

With the use of these polluting materials, ecosystems around these mining activities are often increasingly deteriorated, not because of the gold mining process itself, but because of the use of the amalgamation method without preventing the risks that mercury use and inadequate disposal can bring. By not providing adequate mercury management, the mercury used becomes toxic to human health by accumulating in the lungs and in the tissues of fish that could be caught and consumed. Fishing activity is therefore significantly affected by the accumulation of mercury in the tissue (Guerrero-Martin et al., 2023; Ortega-Ramírez, Angulo-De Castro, Becerra, Gómez Caipa, & Huerta-Quiñones, 2022; Ortega-Ramírez et al., 2020; Ortega-Ramirez, Torres-López, Silva-Marrufo, & Moreno-Barriga, 2023; Ramírez et al., 2022). There is a need to carry out mercury remediation and recovery activities to reduce the spread of mercury in the environment and thus improve the state of the nearby ecosystem and restore territory deteriorated by the gold mining process in the Santurban Paramo. The positive and negative impacts of artisanal mining include Figure 6:

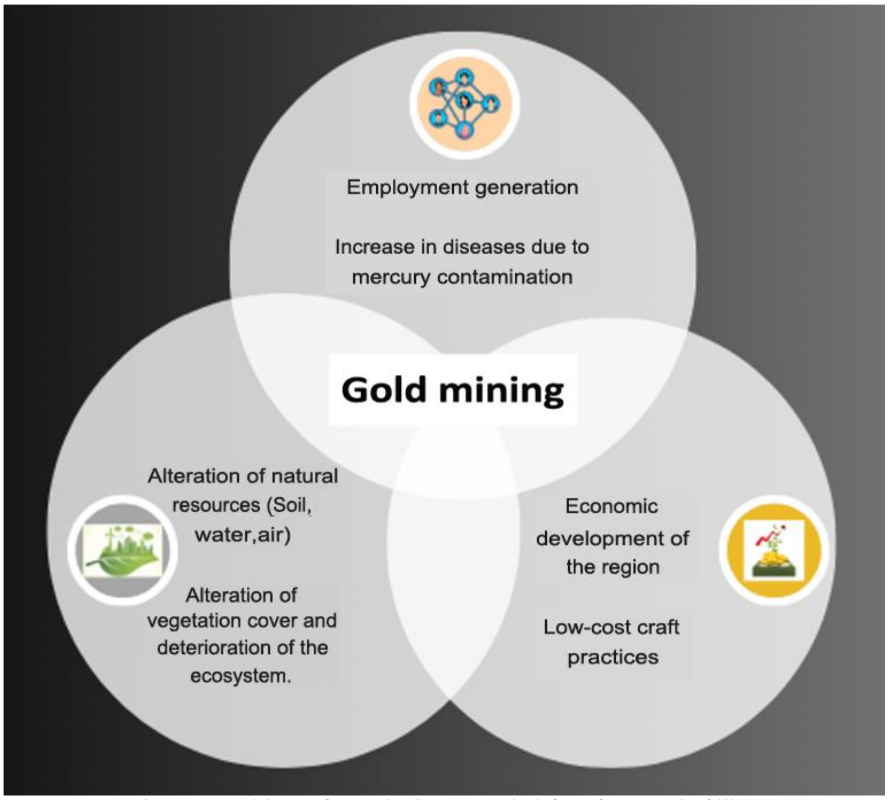

Figure 6. Positive and negative impact analysis based on sustainability.

3.3. Mercury Characterization in the Area of Influence

The mercury measurements in the Santurban Paramo were performed using an XRF for soil measurements and Hermes equipment for air measurements (see Table 4 and Table 5).

Table 4. Measurement results in California, Santander.

Zone	Date	Latitude	Length	Mercury in soil (g/t)	Mercury in air (ug/m³)	Description
1	13-10-2022	7.379	-72.897	226.000	1.000	Measurement on sacks of tailings
		7.379	-72.897	49.000	1.000	
		7.379	-72.897	79.000	0.6.000	
		7.379	-72.897	102.000	4.2.000	
		7.379	-72.897	17.000	1.000	Measurement in mine water sediments
2	13-10-2022	7.369	-72.915	56.000	0.100	Beneficiation plant, La Baja mine
		7.369	-72.915	40.000	0.500	
		7.369	-72.915	0.000	0.300	
		7.369	-72.915	220.000	0.300	
		7.369	-72.915	193.000	0.100	
		7.369	-72.915	58.000	0.100	
		7.369	-72.915	66.000	0.100	
3	13-10-2022	7.360	-72.928	152.000	0.000	Coconuts in residential area/La Plata
		7.360	-72.928	160.000	0.000	
		7.360	-72.928	120.000	0.000	
		7.360	-72.928	85.000	0.000	
4	13-10-2022	7.350	-72.935	38.000	3.700	Thunderer
		7.350	-72.935	50.000	0.400	
		7.350	-72.935	56.000	0.200	

Table 5. Measurement results in Surata, Santander.

Zone	Date	Latitude	Length	Mercury in soil (g/t)	Mercury in air (ug/m³)	Description
1	10-14-2022	7.452	-72.943	0. 000	0. 000	Mercury-free processing plant
		7.452	-72.943	0. 000	0. 000	
		7.452	-72.943	0. 000	0. 000	
		7.452	-72.943	0. 000	0. 000	
		7.452	-72.943	0. 000	0. 000	
		7.452	-72.943	0. 000	0. 000	
		7.452	-72.943	0. 000	0. 000	
		7.452	-72.943	0. 000	0. 000	
		7.452	-72.943	99. 000	0.400	
		7.452	-72.943	60. 000	0.200	
2	10-14-2022	7.431	-72.935	0. 000	0.100	Hope mine
		7.431	-72.935	0. 000	0.100	
		7.431	-72.935	55. 000	0.100	
		7.431	-72.935	0. 000	0. 000	
		7.431	-72.935	0. 000	0. 000	
		7.431	-72.935	0. 000	0. 000	
		7.431	-72.935	0. 000	0. 000	
		7.431	-72.935	0. 000	0. 000	
		7.431	-72.935	0. 000	0. 000	
		7.431	-72.935	0. 000	0. 000	
		7.431	-72.935	0. 000	0. 000	
		7.431	-72.935	0. 000	0. 000	
		Oquenda		0. 000	0. 000	
		Reform		24. 000	0. 000	

19 measurements were made on tailings from 4 zones (see Table 4). The first zone was an area where the material was packed in sacks. Mercury had been used on this material for gold extraction, and a maximum concentration of 226 g/t of mercury was found. The 17 g/t results were found in the sediments of other mine waters found in California, a municipality in Santander. The second zone corresponded to a processing plant, where a maximum concentration of 220 g/t of mercury was found. In zone 3, a maximum concentration of 160 g/t was found. However, it should be noted that this plant is located on residential land, for which the Environmental Protection Agency suggests that the allowable limit is 11 g/t of mercury. Finally, at the Tronadora mine, soil measurements between 38–56 g/t and air concentrations of 3.7 µg/m³ were found, above those allowed in Resolution 2254 of 2017 for mercury in air (Ministerio de Ambiente y Desarrollo Sostenible, 2017).

A sample was taken at the first site in zone 3, which showed a result of 152 g/t of mercury with the XRF. In the tailings studied in California, there was a high presence of inorganic mercury in both air and soil, exceeding values suggested by the Environmental Protection Agency (EPA)and those established by Resolution 2254 of 2017 (Ministerio de Ambiente y Desarrollo Sostenible, 2017).

Mercury was not detected in zone 1 except in the last two measurements (see Table 5). These two are not georeferenced because they are not samples from the studied mine but from other neighboring mines where it is assumed that mercury is used. Inside the studied mine, measurements were taken in locations representing different parts of the process to obtain gold, such as the entrance, the shaking table, the tailings machine, and a mixed equipment, where it was assured that in general an amalgam is made, but no traces of mercury were found (Hernández, Maldonado, & Rodríguez, 2019).

In zone 2, measurements were made on tailings older than 7 years, which the La Esperanza mine personnel claimed were material worked with mercury. However, of all the measurements, only one showed a mercury concentration of 55 g/t, and this may be because the measurement was conducted on the floor of the place where the coconuts were previously used. The personnel asserted that the equipment is currently inactive. At the end of the day, the miners requested for the researchers to analyze the material from the Oquenda and La Reforma mines;

of these materials, only the one from La Reforma contained mercury with a value of 24 ppm. Mercury measurements performed in the municipalities of California and Surata are shown in Figure 7.

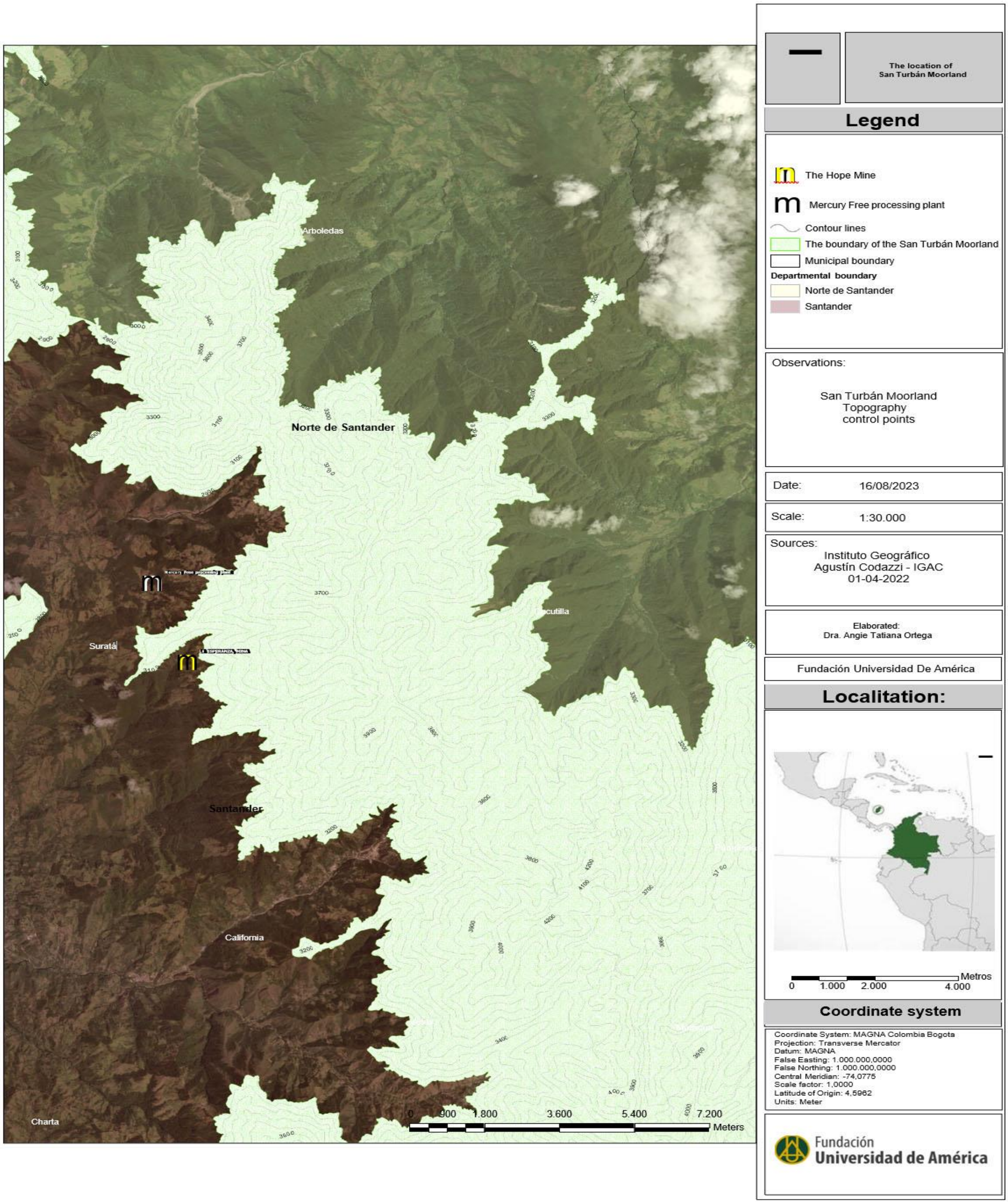

Figure 7. Control point in Santurban Paramo.

3.4. Risks and Environmental Impact

The impacts of gold mining in the Santurban Paramo were evaluated, involving such elements as poor management in the use of mercury to obtain gold, ecosystem degradation, and economic and social practices in the area (see Table 6).

Table 6. Risk and environmental impact matrix prior to mining activity in the Santurban Paramo.

Impact	Activities that generate complex environmental impact	Value impact	Classification
Financing of public management	Lack of environmental regulations for the protection and preservation of natural resources in the area	2	Regular
Employment generation	Gold mining represents a source of development and economic growth in the area	2	Regular
Change in air quality	Mining, deforestation, deterioration in vegetation cover, presence of mercury in the air	3	Medium
Increase in the quality and supply of goods and services	Gold mining activity as a good and service for the development and economic growth of the sector	2	Regular
Changes in community organizational dynamics	Displacement of ancestral settlements in the area, reduction of endemic species for the cure of diseases	2	Regular
Vegetation cover and terrestrial habitats	Deforestation, alteration in vegetation cover due to mercury contamination, alteration in soil quality, absence of nutrients for the subsistence of living beings, alteration in air quality, deterioration of the natural reserve	4	High
Alteration of the physicochemical and biological properties of the soil	Mercury concentration in areas of mining activity, presence of heavy metals in the soil, lack of quality in vegetation cover, deforestation, changes in soil properties, decrease in nutrients	4	High
Alteration of communities of terrestrial fauna	Affectation in vegetation cover, deterioration of the terrestrial ecosystem, deforestation, lack of food and resources, change in the quality of water and soil, disappearance of endangered species, loss of the identity of the Paramo	3	Medium
Reconfiguration of the relationship with the territory	Employment generation, ancestral practices, economic and social development	2	Regular
Alteration of hydrobiological communities	Impact on vegetation cover, deterioration of the aquatic ecosystem, deforestation, lack of food and resources, change in water and soil quality, the disappearance of endangered species, loss of the identity of the Paramo, contamination of water resources, disappearance of microscopic species, the appearance of species immune to mercury concentrations	4	High
Changes in population dynamics and the demand for public and social services	Gold mining activity as a good and service for the development and economic growth of the sector	2	Regular
Alteration of populations of endemic flora with special conservation status	Affectation in vegetation cover, deterioration of the terrestrial ecosystem, deforestation, lack of food and resources, change in the quality of water and soil, disappearance of endangered species, loss of the identity of the Paramo, disappearance of endemic species	3	Medium
Change in land use	Mercury concentration in areas of mining activity, presence of heavy metals in the soil, lack of quality in vegetation cover, deforestation, changes in soil properties, and decrease in nutrients	4	High
Change in the physicochemical and bacteriological quality of surface water	Presence of mercury in the water affects the aquatic ecosystem, the health of organisms, and the vegetation cover, and facilitates the appearance of diseases, alteration in the quality of natural resources	4	High
Generation of expectations and potentiation of conflicts	Appearance of forced displacement, territorial conflicts, conflict over identity rights and respect for the ecosystem	2	Regular
Changes in sound	Mining, deforestation, deterioration in vegetation		

Impact	Activities that generate complex environmental impact	Value impact	Classification
pressure levels	cover, presence of mercury concentrations in the air, noise generation from mining activities	2	Regular
Lowering of the water table	Floods, excavations in the area, exploitation of resources, exploration of resources, alteration in vegetation cover	2	Regular
Affectation of the infrastructure for community use	Alteration of the Paramo ecosystem, affectation of natural resources, affectation of economic development	2	Regular
Impact on local mobility	Floods, earthquakes, deterioration of roads	1	Low
Alteration in the surface water flow regime	Mercury in the water affects the aquatic ecosystem, the health of organisms, the vegetation cover, the appearance of diseases, and the quality of natural resources	3	Medium
Involuntary transfer of social units	Appearance of forced displacement, territorial conflicts, conflict over identity rights, and respect for the ecosystem	2	Regular
Habitat fragmentation and loss of visual connectivity of ecosystems and visual quality	Deforestation, alteration in vegetation cover due to mercury contamination, alteration in soil quality, absence of nutrients for the subsistence of living beings, alteration in air quality, deterioration of the natural reserve	3	Medium
Variation in vibration level	Mining, deforestation, deterioration in vegetation cover, presence of mercury concentrations in the air, noise generation from mining activities	2	Regular

Being not directly related to the handling of mercury in artisanal mining, the impact of mining activities on local mobility is considered low. However, due to the poor condition of roads in Colombia and natural phenomena in the area, such as floods, landslides, or earthquakes, the transportation and distribution of goods and services for gold production could be affected, causing economic losses because import and export needs will not be met quickly and efficiently.

Most impacts evaluated at the social level are considered regular impacts; these are involuntary relocation of social units, variation in the level of vibrations, generation of expectations and empowerment of conflicts, changes in sound pressure levels, lowering of the water table, affectation of infrastructure for community use, changes in population dynamics and demand for public and social services, reconfiguration of the relationship with the territory, increase in the quality and supply of goods and services, changes in community organizational dynamics, funding of public management, and generation of employment. In contrast, one of the benefits of gold mining in Santurban Paramo is local development and economic growth based on the generation of employment as a form of subsistence for the communities when producing minerals such as silver, coal, and mainly gold. However, inadequate practices can lead to the degradation and alteration of local lifestyles through armed conflicts or territorial conflicts when conserving and protecting the natural reserve, as well as the alteration of infrastructure and vegetation cover by polluting the environment, the disappearance of endemic species as natural methods for curing disease, or the deterioration of the communities' health with the presence of mercury in the environment.

Likewise, the impacts considered to have a medium impact level are: alteration in the surface water flow regime, habitat fragmentation and loss in visual connectivity of ecosystems and visual quality, alteration of endemic flora populations and with special conservation status, alteration of terrestrial fauna communities, and change in air quality. The use of mercury in mining activities leads to a gradual weakening of the vegetation cover, making the environment vulnerable to the spread of contaminants from tailings to the atmosphere, water, and other natural resources, thus deteriorating the entire ecosystem. Reduction in conservation and protection of the Paramo in terms of endemic flora and fauna will diminish its capacity to resist changes, causing the disappearance of important species and, with it, the alteration of the ecosystem and the protected area of the Paramo, an important reserve in Colombia.

The change in the physicochemical and bacteriological quality of surface water, the alteration of hydrobiological communities, vegetation covers, and terrestrial habitats, and the alteration of the physicochemical and biological properties of the soil have the highest impact from gold mining activities in the Santurban Paramo. Natural resources (water, soil, and air) are the most affected by being in direct contact with mercury since mercury without adequate management and disposal accumulates in the water systems, soil, and atmosphere. These natural resources are the means of survival for terrestrial and aquatic organisms and upon being contaminated, the spread of mercury and its health effects become significant, causing damage to the vegetation cover, deterioration of the environment, and deterioration of the quality of natural resources and, therefore, affecting quality of life in the region.

4. CONCLUSION

Gold mining represents the most significant source of income and economic and social development in the Santurban Paramo. Artisanal gold mining is an activity in which the ancestral and traditional techniques of the community are tested by using mercury with material for the amalgamation process to obtain the gold.

However, the use of mercury in gold mining leads to the deterioration of the environment in municipalities such as California and Surata, where mercury measurements were conducted in the soil and air representing different areas of collection, production, and disposal of the mining activity. Concentrations in soil varied between 160–226 g/t in the production plant.

The environmental impacts and risks caused by mining activities in the Santurban Paramo were evaluated, which showed a regular level of social and economic impacts; a regular level of impacts on employment generation, goods, services, and infrastructure; a medium level of impacts related to habitat of endemic species, affectation of endemic populations, and conservation of the territory; and a high level in the alteration of natural resources directly related to mining and therefore triggering issues in vegetation cover; alteration of the ecosystem of aquatic organisms and land; and people's health by consuming contaminated species or exposure to high concentrations of mercury in the environment.

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