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Review of the environmental and human health impacts of mercury use in gold mining in the Santurban Paramo area

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ABSTRACT

Illegal mining is a problem that currently affects the vegetation cover of Colombia due to the environmental liabilities and the damage it causes to the environment in the eagerness to obtain gold in an easy way by using mercury. For this reason, this article presents a detailed bibliographical review of the environmental, social and economic problems of artisanal mining in the Santurban Paramo due to the inappropriate use of mercury and its impact on both the environment and the health of the people who perform this activity, describing first of all the importance of the Paramo in relation to the protection of its ecosystem and biodiversity; secondly, mercury as an imminent danger due to its use and the effects of the activity taking into account the policies and regulations carried out for the preservation and reduction of environmental contamination generated by the bad practices of artisanal mining and finally, the environmental and human health impacts due to direct and indirect contact with mercury. As a result of this research, although artisanal mining represents an important role for the survival of the community, it is necessary to implement continuous improvement strategies to reduce the use of mercury due to the problems caused by this dangerous metal both for the environment and the water source fundamental for the life of the Santurban Paramo and for the health of the people, where education and environmental awareness gain more strength for the protection and preservation of this natural reserve in Colombia.

Contribution/Originality: This article presents a detailed bibliographical review of the environmental, social and economic problems of artisanal mining in the Santurban Paramo due to the inappropriate use of mercury and its impact on both the environment and the health of the people who perform this activity.

1. INTRODUCTION

The Santurban Paramo, located in the middle of the Cordillera Oriental in the departments of Santander and North of Santander (El Tiempo, 2020) supplies water resources to approximately 2.3 million people (Colparques, 2022) being the refuge of more than 700 species (Avellaneda, 2019). The majority of the population lives from agriculture and livestock, causing the Paramo to present a degree of transformation of 26% (Caracol Radio, 2019). Similarly, in the Santurban Paramo is one of the largest gold reserves in Latin America, calculating the existence of 7.7 million ounces of gold (about 16 tons per year) and about 80 million ounces of silver (about 72 tons per year) (Bacca Contreras, García Mantilla, & Pinto Mantilla, 2018). While it is true, artisanal mining in the Paramo is the sustenance and economy of the region as it is in the ACSe of Vetas where 80% of the population is dedicated to artisanal mining (PaisMinero, 2020) since it plays an important role in the supply of basic raw materials in different sectors of the application for the strengthening of urban and colonial development of the region, being used as important investments in times of crisis (Quintero, Ríos, Monroy, & Londoño, 2021). These advantages are being overshadowed by the method of its extraction, this being in many ACSes the amalgamation with mercury, a highly dangerous and toxic element for the water resource (Torrado, 2017) where 224 liters / second of groundwater that is filtered by artisanal mining, being in contact with sulfur rocks causes the propagation of acidic water mixed with cyanide and mercury from this practice (Peña, 2020) causing serious environmental problems. Likewise, problems are evident for people who are directly related to the activity (Irenge, Bushenyula, Irenge, & Coppieters, 2023) the environment being the habitat where fish inhabit which feed indirectly on this component and the ecosystem by damaging the flora of the place in order to meet their needs (France 24, 2020) which so far have deforested more than 88,000 native trees and found approximately 360 tons of contaminated sand in the water resource Santurban Paramo (El Tiempo, 2017) which indicates that Colombia is going through an imminent danger due to mercury. However, today strategies and contingency plans have been developed in which both sides of the coin benefit, on the one hand, the population and on the other hand the ecosystem, looking for other mining methods that do not put at risk the health of those who carry out the practice or damage the ecosystem, water and soil resources that are essential for nearby municipalities and regions, being necessary for their subsistence.

For this reason, this article seeks to identify the environmental impacts on the environment and the ecosystem and impacts on the health of people directly or indirectly involved due to mercury contamination in the Santurban Paramo by illegal mining, in order to identify the risks of human activity and how this entails environmental education to safeguard the quality of life in the region.

2. METHODOLOGY

To carry out this research, it was necessary to implement bibliographic analysis, reviewing a total of 703 documents based on bibliometric tools such as: Mendeley, Scopus, Refworks and Word Cloud, in order to collect the relevant information in this study. First, documents were identified with artisanal mining with mercury contamination by year of publication, types of documents with greater search and the area of research. The search equation used for the execution of the bibliometric analysis carried out in January 2023 was: "(("environmental contamination" OR "artisanal mining") AND mercury AND health)".

First shows that the largest number of publications were made in 2021 and 2022 with a total of 61 and 64 documents respectively (Figure 1), while in 2023 a total of 3 documents have been published (Scopus, 2023) indicating that the topic of study of artisanal mining and environmental pollution from mercury is a topic of great interest due to the influence it has on the preservation of the Paramos and ecosystems at a global level.

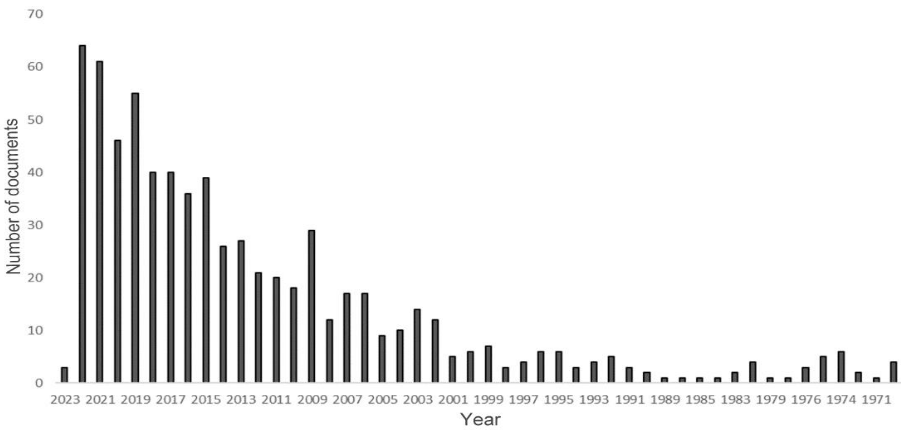

Figure 1. Results per year vs number of documents.

On the other hand, identified that the types of documents published with greater relevance are articles with 81.1%, reviews with 9.7%, conferences with 4.3% and book chapters with 2.8% (Figure 2) (Scopus, 2023). Likewise, represents the research areas with the greatest interest in environmental pollution of artisanal mining due to mercury, with environmental sciences with 38.4%, medicine with 12.9%, land and planet with 7.0%, culture and technology with 5.6% and chemistry with 5.1% (Figure 3) (Scopus, 2023).

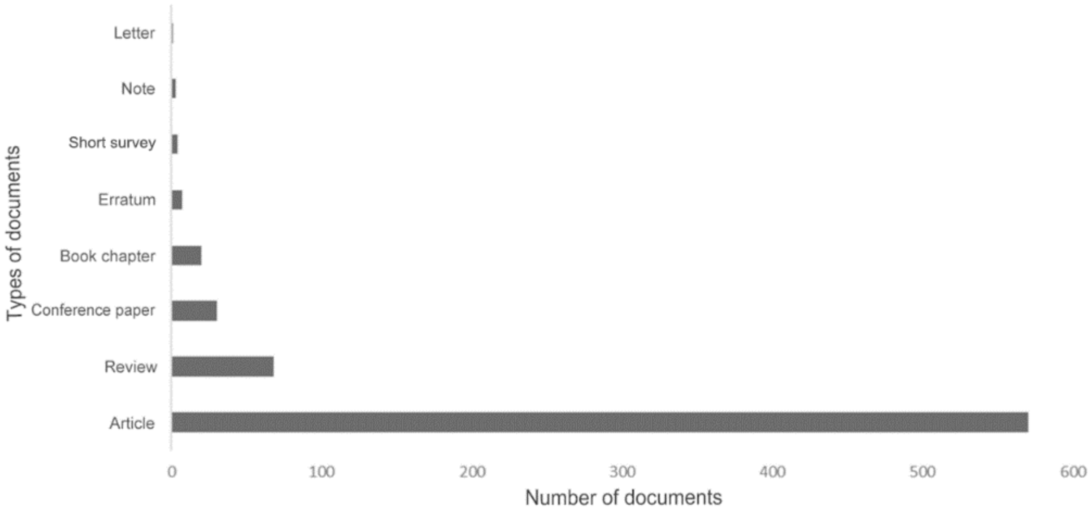

Figure 2. Results per types Vs number of documents.

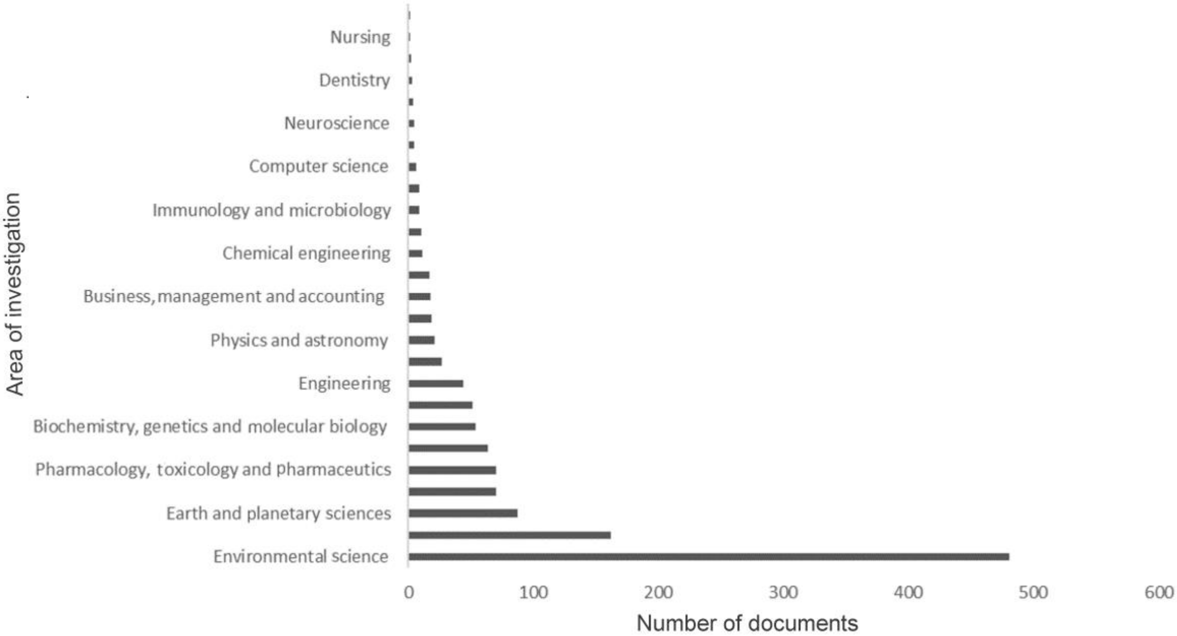

Figure 3. Results per area Vs number of documents.

Based on the analyses carried out previously, a second bibliometric analysis is carried out taking reference to the same search tools delimiting the years of publication between 2019 and 2022 in the area of environmental sciences, finding a total of 173 documents using the following search equation: "("environmental contamination" OR "artisanal mining") AND mercury AND health) AND (LIMIT-TO (PUBYEAR, 2022) OR LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR, 2020) OR LIMIT-TO (PUBYEAR, 2019)) AND (LIMIT-TO (SUBJAREA, "ENVI"))".

From the new bibliometric review, the countries of America and Europe were identified as the ones that have had the most interest in this environmental problem where the United States is in first place with a total of 37 documents, followed by Brazil with 26 documents, Japan with 20 documents, Germany with 13 documents and Indonesia with 12 documents. And finally, within the authors with more publications stand out Sakakibara with a total of 9 documents focused on mining, bioremediation and final disposal of mercury, while Kimijima, Shoko, Stecking-Muschack and Veiga have published a total of 4 articles each focused on environmental pollution.

3. RESULTS AND DISCUSSION

The results obtained in the bibliographic review of mercury pollution in the Santurban Paramo are evidenced based on the main problems in the Paramo due to the implementation of mercury for artisanal mining, as well as the environmental conflicts of the people involved in this economic activity, healthy impacts and how from a social aspect the problem in the region is addressed by carrying out environmental education as an axis sustainability and protection of resources and the environment.

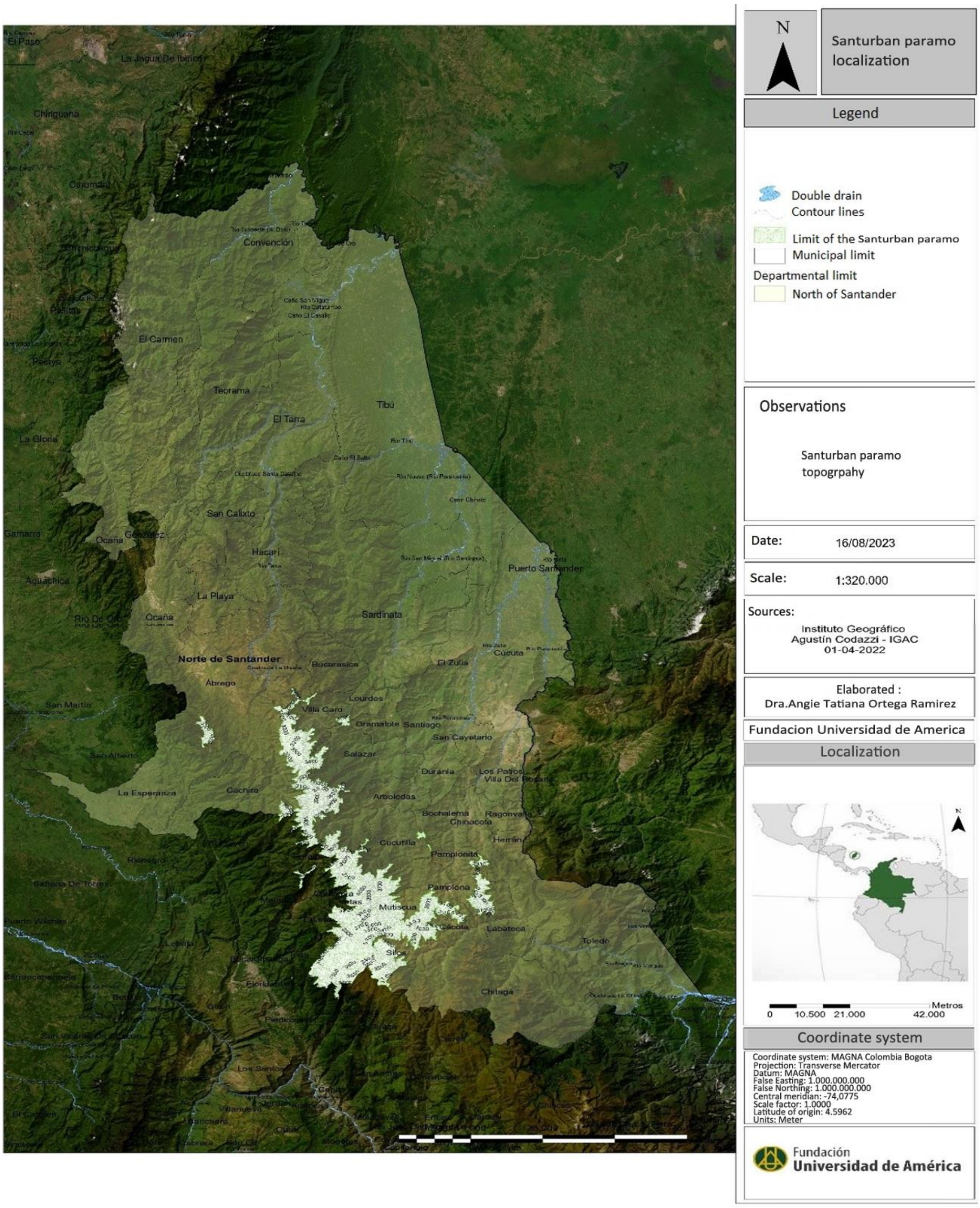

Figure 4. Localization of the Santurban Paramo.

3.1. General Contextualization of Santurban Paramo

Colombia is characterized by its diversity in resources and natural reserves, where its fauna, flora and landscapes make it a tourist place (García-García & Díaz-Timoté, 2022).

Its fundamental axes of preservation are the Paramos, among them the Santurban Paramo located in the departments of Santander and North of Santander (CDMB, 2015) (Figure 4), having as its greatest resource water, which satisfies approximately 2,200,000 inhabitants. Thanks to its biodiversity, the Santurban Paramo has been recognized as a geological potential in foreign investment, based on artisanal mining in terms of production and employability (Externado of Colombia University, 2019).

The Santurban Paramo is considered a complex finding in its interior ecosystem of humid Paramos and Andean jungles, having registered approximately 450 species of vascular plants and ferns, 17 species of reptiles, 17 amphibians, 201 birds and 58 mammals (Lopez, Biotic, Avellaneda, Physicist, & Paez, 2012).

It covers around 100,000 hectares equivalent to 30 municipalities. It is under the jurisdiction of three regional autonomous corporations: Regional Autonomous Corporation for the Defense of the Bucaramanga Plateau (CDBP), Regional Autonomous Corporation of the North Eastern Border (CORPONOR) and Autonomous Corporation of Santander (ACS) (Cañón & Mojica, 2017).

Years ago, the Santurban Paramo has been the subject of debate due to the artisanal mining that takes place there, having gold and water as fundamental axes achieving a balance between the sustenance of the region and the protection of the ecosystem, however, from the arrival of foreign capital and liberalism, the practices became an imminent damage to the Paramo (Rozo Jaimes, 2022).

3.2. Mining process in the Santurban Paramo

Mining is the base of the population near the Santurban Paramo, generating income and environmental sustainability in the region, however (Kosai, Nakajima, & Yamasue, 2023) these practices bring with them unfavorable consequences for the environment such as: the deterioration of water resources, conflict in ecosystem and soils, affectation to the ecosystem (Casso-Hartmann et al., 2022) conflict of surface and groundwater, affectation of air and public health, social problems derived from mining and ignorance of ethnic groups (García & Ruiz, 2013).

The artisanal mining process in Colombia begins with the extraction of the mineral with the implementation of dynamite and crushing and milling processes with the help of hammer mills or balls (Lopez Jimenez, Velasquez Bonilla, Mejía Restrepo, & Mesa Giraldo, 2022) in this step particulate matter different from the ore comes out and the crushed gold of 5 cm is subsequently transferred to a flotation process, roasting and leaching to finish removing traces of residues and materials that are not relevant in the process and may alter the desired product (Wotruba & Vasters, 2002). After this, the gold is recovered and disposed of mercury-coated copper plates, being the amalgamation stage where the crushed material is introduced with mercury producing an amalgam at the same time that the grinding process is carried out (Costa, Alfonso, & Palacios, 2009). At the end of this stage, a sedimentation process is passed where the water is separated from the material by means of steam to remove the mercury from the surface of the mineral and thus obtain the liquid gold (Poveda Ávila, Nogales Vera, & Calla Ortega, 2015). In some processes to prevent mercury from being released into the atmosphere without prior treatment, the "retorting" process has been implemented, in which evaporated mercury is collected in burning chambers, cooling tanks and mercury gas recovery zone to avoid environmental pollution that this metal generates (Tovas Jumpa, Sánchez, & García Alvarez, 2005) however, this stage is still being tested and unfortunately the concern for the environment in artisanal mining is almost nil.

3.3. Mercury, an Imminent Risk

Mercury is a heavy silvery fluid at room temperature found in air, water and soil in three forms: elemental mercury, inorganic mercury and organic mercury known as methylmercury (Balali-Mood & Sadeghi, 2021). It has one of the narrowest temperature ranges of all metals with a melting point of -39°C and boiling point of 357°C. Their behavior is similar to that of noble gases, forming weak bonds and melting rapidly at relatively low temperatures. Its solubility in water increases by a factor of 1.3 for every 10°C increase, causing serious environmental problems (Gaffney & Marley, 2014).

It is considered one of the ten chemicals of concern (Wang et al., 2020) being found in both marine ecosystems and freshwater from atmospheric arrangement that reduces mercury to elemental mercury, being released into the atmosphere or extracted from the water column by particles buried as sediments (Zaferani & Biester, 2021). This causes serious problems in organisms with a minimum concentration of 0.05 μg/g (Zulkipli et al., 2021) such as skin, respiratory and nervous problems resulting in cancer or even death in the worst ACSe (Mallongi, Rauf, Astuti, Palutturi, & Ishak, 2023).

Mercury contamination is declared a hazardous environmental pollutant as it can accumulate in aquatic food chains with a serious threat to living beings (Gworek, Dmuchowski, & Baczewska-Dąbrowska, 2020) to people's health and to the water resource of a region or country (Al-Saleh et al., 2020).

This contamination is reflected in different living beings, such is the ACSe of fish, where mercury enters their body through food circulation in fresh or salt water (IPEN, 2016) transforming into a highly dangerous form through microbial activity because the mercury that accumulates in fish is monomethyl mercury (Ghezzi et al., 2022) constituting 85% of total mercury. Fish at the top of the food chain can harbor mercury concentrations in their tissues of more than a million times the concentration of mercury in the water they inhabit (Jones, 1996).

But mercury not only affects living beings but also the community, especially children, bringing with its neurological disorders such as learning disabilities, dyslexia, mental retardation, attention deficit disorder, imperactivity and autism in adulthood (Cheng et al., 2022). Likewise, at high levels it can damage the brain, heart, kidneys, lungs and immune system. Likewise, people between 40 and 60 years old are also violated by these levels of pollution since their defenses decrease, causing even greater problems such as the activation of cancer and even death (Meneses et al., 2022).

These damages can be determined by the early exposure of the community to be in direct or indirect contact with mercury due to contaminated intake as mentioned above or by bad practices in the sustainable activity of a region or country such as the oil industry or artisanal mining that occurs in the Santurban Paramo (Beckers & Rinklebe, 2017).

But many times, these mercury contaminations reach the ecosystem, a place that is often abandoned by the bad practices of people with the sole purpose of satisfying their needs. This change is evident since rain drags mercury to river sources, causing filtration in groundwater systems (Ebadian, 2001) bringing with it over the years an increase of 450% above the natural levels of mercury concentration (Pabón, Benítez, Villa, & Corredor, 2022).

This ultimately leads to the aquatic environments where methylation occurs, generating an imminent danger to the health of communities due to direct inhalation of contaminated vapor and dust, dermal exposure and food sources as mentioned above (Bansah, Acquah, & Assan, 2022).

3.4. Environment Impacts

Environmental conflicts in Colombia are affected in the first place by territorial regulations and the delimitations of environmental protection with the use of natural resources. Secondly Velez-Torres and Vanegas (2022) because of the disputes over the use of conservation of ancestral territory by ethnic peoples and communities. Thirdly, the overlap between extractive and agricultural activities and finally related to the demand for justice and reparation from victims of forced displacement (Hincapié Jiménez & López Pacheco, 2016).

One of the controversies that the Santurban Paramo hosts daily is the decision to exploit or not to exploit the place with gold mining because of water regulation services provided to the capital cities and municipalities of Santander and North of Santander, obeying a global economic context (Montenegro, 2015) opening the gap of duality between gold vs artisanal mining with social disputes and satisfaction of interests (Méndez-Villamizar, Mejía-Jerez, & Acevedo-Tarazona, 2020) from an environmental political contest on the national stage.

This is because gold becomes a sustenance, a good in global markets because of the reserves they have of the metal (Argüello Ramón & Sierra Díaz, 2022). However, the problems of currency exchange and price growth bring with them a bad activity of exploitation of deposits, having as their purpose an ambiguous idea of the rise of the peso and a satisfactory profit in relation to their activities (Morante-Carballo, Montalván-Burbano, Aguilar-Aguilar, & Carrión-Mero, 2022).

This process brings with it problems in the water resource with the change of flow of the rivers, flood hazards and variation in recharge regime and change of Flow (Parra Romero, 2019) and soil resource of the Paramo with the loss of fertile soil, modification of relief, dynamic alteration, soil subsidence, among others and health problems for people who are directly related to mining causing brain death when mercury accumulates in living organisms (Perez & Betancur, 2016).

On the other hand, socioeconomic problems are evidenced by the concern around private property, the right to exercise economic activities and citizen participation where the general interest and the particular interests of the population are reconciled, guaranteeing the minimum vital and human dignity of ethnic communities (Jimenez Castiblanco, 2022).

In relation to this situation, the operation of mining in the Santurban Paramo, although it is a good for the communities that carry out this activity, brings with it environmental problems without return such as: the uncertainty of the effects of mining projects on water at the ecosystem level, desertification due to the change of water cycles, conflicts over land use in strategic areas such as Paramos, increases in solids and particles in the water of the rivers used by populations (Abadia & Avendaño, 2014) proliferation of particular in the air that affect people's health due to the release of mercury generated by artisanal mining, cycles of local price inflation as a result of the arrival of mining personnel of goods and services, speculation of potential gold reserves without empirical material, applications for environmental licenses for exploitation in closed areas and forest reforestation practices in relation to the restitution of environmental services, causing the displacement of endemic animals from the areas, loss of biodiversity, destruction of migration landscapes, destruction of fauna, erosion by intervention, destruction of fragile ecosystems and detriment of land suitable for agriculture.

For this reason, given the environmental conflicts mentioned above, in preservation areas such as the Santurban Paramo it was ordered by the Ministry of Environment and Development that no mining activities will be carried out since the scenarios where mining is carried out are already affected by mercury (Duran Castellanos, 2018) together with Law 1450 with the National Development Plan 2010-2014 with the delimitation of Paramos through practices sustainable (Cubillos, 2021) with the purpose of repairing degraded biotic components and areas of sustainable use as an economic activity as long as the biodiversity of the place and long-term damage are not altered (Acevedo & Correa Lugos, 2019). However, the communities of the Santurban Paramo ignore this problem by caring only about their own economic benefit and not about the environmental damage to the ecosystem that is deteriorating more and more.

Other impacts that occur in gold mining activities in the Santurban Paramo are the social impacts, which by generating employment with the implementation of these activities in the region, there are serious problems for people who are directly or indirectly related to mercury, bringing with it negative impacts related to diseases from mercury contamination and health damage that will be shown later in the research, the exploitation of labor since in most ACSes minors are used to carry out this activity without any protection whatsoever (Aranoglu, Flamand, & Duzgun, 2022; Espin, 2023; Malca, Dunin-Borkowski, Bustamante, Reaño, & Armas, 2023).

Similarly, there are negative economic impacts such as tax evasion or interference in areas destined for research or preservation of the ecosystem, affecting ecotourism, agriculture, and forestry activities, which aggravates the situation in the Santurban Paramo (Karzanova & Cordova, 2022).

This generates impacts on security and tourism in the Santurban Paramo and surrounding regions due to informality and illegality caused by the involvement of armed groups or illegal mining, resulting in the degradation of protected areas, damage to the ecosystem of endemic species native to the Paramo, and the deterioration and destruction of natural resources for the subsistence of the species and the inhabitants of Santander.

The following is a compilation of the environmental, social and economic impacts of gold mining in the Santurban Paramo (Achina-Obeng & Aram, 2022; Alonso, Pérez, Okio, & Castillo, 2020; Basu et al., 2022; Dobler, 2019; Eckley et al., 2020; Garcia, 2013; Guerrero-Martin et al., 2023; Ibañez-Gómez et al., 2022; Mallongi et al., 2020; Mestanza-Ramón et al., 2022; Ministerio de Ambiente y Desarrollo Sostenible, 2017; Ngom et al., 2022; Oliveira et al., 2021; Quarm, Anning, Fei-Baffoe, Siaw, & Amuah, 2022; Rakhshan, Mansournia, & Kashi, 2023; Ramírez, López, Marrufo, & Barriga, 2023; Ramírez et al., 2022; Salomão et al., 2023; Sousa & Zaitune, 2022; Tampushi, Onyari, & Muthama, 2022) (Table 1 and Figure 5).

Table 1. Risk and environmental impact matrix prior to mining activity in the Santurban Paramo.

Impact studied	Component	Impact involved	Description of impact
Environment impact	Biotic	Changes in endemic flora populations	When gold mining activities are carried out, damage is caused to the vegetation cover and within the destruction of species endemic to the ancestral population.
		Changes in endemic fauna populations	Gold mining activities cause damage to the vegetation cover, thus altering the subsistence ecosystem of the fauna of the Santurban Paramo.
		Alteration of the habitat of conservation species	Mercury contamination, as it accumulates in the soil, causes the deterioration of the ecosystem of the species under conservation in the Santurban Paramo.
	Abiotic	Alteration of nutritional properties present in soil, water and air resources for the subsistence of species	When traces of the material (Mercury) accumulate in the environment, the nutritional properties of the ecosystem are altered, causing the disappearance of the flora and fauna of the Paramo.
		Mercury contamination	Gold mining, when carried out with mercury, causes direct impacts on soil and water resources by altering the cover and ecosystem of the Paramo species, which causes traces and material to accumulate in the environment.
Environment impact	Abiotic	Forest destruction	Need for space to operate machinery for gold mining in the Santurban Paramo.
		Destruction of alluvial agricultural lands	Source of soil impacts and thus crop deterioration.
		Destruction of the vegetation cover	Alteration of the agricultural ecosystem, conservation and protection of the Paramo to carry out illegal gold mining.
		Deterioration of the physicochemical properties of the soil	Gold mining in the Paramo causes damage and alterations to the physicochemical properties of the resource due to vegetation cover and soil erosion.
		Appearance of soil erosion	Alteration of the ecosystem and vegetation cover due to mercury contamination and traces deposited in the soil.
		Deterioration of land use	Gold mining in the Paramo causes damage and alterations to the physicochemical properties of the resource due to vegetation cover and soil erosion.
		Alteration of river channels	The habitat of aquatic species is reduced as sediments alter their ecosystem, resulting in a change in the morphology of the channel and an increase in flooding.
		Change in the physicochemical quality of	The habitat of aquatic species is reduced as sediments alter the ecosystem of these, bringing

Impact studied	Component	Impact involved	Description of impact
		the water resource.	with them a change in the morphology of the channel and an increase in flooding and therefore the properties of the resource.
		Alteration in air quality	As an indirect factor due to mercury pollution, emissions and the destruction of the ecosystem lead to the deterioration of the ozone layer and therefore to the generation of greenhouse gases.
		Proliferation of air pollution	As an indirect factor due to mercury pollution, emissions and the destruction of the ecosystem lead and the deterioration of the ozone layer and therefore to the generation of greenhouse gases.
Social impact	Social	Disease generation	Due to mercury contamination by gold mining, different diseases and health problems are generated in people who are directly or indirectly related to the activity.
		Labor exploitation	By using minors to carry out the mining activity without any type of safety or protection in the handling of mercury.
		Armed conflict	Being in a preservation and conservation zone, there may be problems with armed groups that want to profit from mining in the Santurban Paramo.
Economic impact	Economic	Tax evasion	In most ACSes, as mining activity is illegal, taxes are evaded before the environmental authority and national regulations.
		Interference from preservation zones	When mining activity prevails over the preservation of the Paramo, it interferes with environmental protection zones, deteriorating the ecosystem, natural resources and the species that live there.

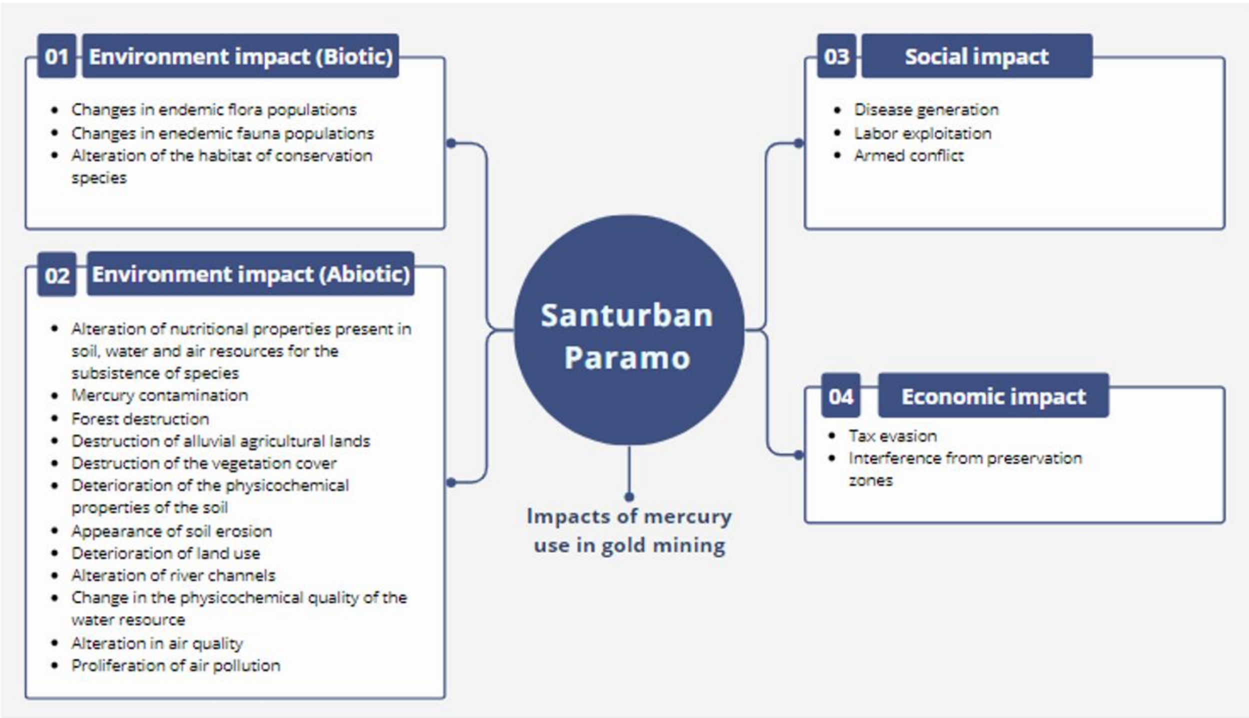

Figure 5. Results of environment impact in Santurban Paramo.

3.5. Human Health Impacts

Mercury represents a danger to human beings due to its high degree of toxicity and harmful effects on health. This metal enters the body through: digestion (due to the ingestion of food in direct contact with mercury contamination such as fish), inhalation (particles dispersed in the air) and skin contact (when handling soil and water resources contaminated by mining waste). Exposure levels for each type of mercury (elemental, organic and inorganic) are shown blow in relation to the exposure routes mentioned above (Dolibog, Pietrzyk, Kierszniok, & Pawlicki, 2022; Elumalai, Sujitha, & Jonathan, 2022; Fallatah et al., 2022) (Table 2):

Table 2. Exposure levels for each type of mercury.

Exposure levels	Elemental mercury	Organic mercury	Inorganic mercury
Inhalation	High for vapor (~85%)	High (~80%)	Medium and low (40%)
Oral	Low for liquid (0.01%)	High (~95%)	Medium and low but high for babies (~15%)
Skin	Medium for vapor (3%)	Medium and low (~5%)	Medium and low (~3%)

Due to the exposure levels shown in the Table 2, when humans are in contact with elemental mercury, it is rapidly absorbed through the respiratory tract, being highly soluble in lipids when it enters the circulatory system, causing serious problems in the functioning of red blood cells in 95% de tot eh presence of hydrogen peroxide. Likewise, when it enters the circulatory system, elemental mercury alters the organs it passes through until it accumulates in the brain in mercuric forms. The half-life of elemental mercury is 60 days, being expelled in the feces or upon exhalation. However, traces and formations of mercuric ions cause irreparable damage to the organism with short-, medium- and long-term consequences (Al-Sulaiti, Soubra, & Al-Ghouti, 2022; Aquino, Malone, Smith, & Zúñiga, 2022; EPA, 1997).

On the other hand, there is inorganic mercury, which enters the body through the respiratory tract and the ingestion of contaminated food, leading to a daily absorption of between 37 μg/kg to 44 μg/kg, with low solubility in lipids. This mercury does not enter the circular membrane, but when the mercuric salt is absorbed in the organism, it brings to protein, which are transported through cell membranes without being detected, causing the formation of methylmercury in the digestive system or being reduced to elemental mercury by the mitochondria and thus being able to enter the circulatory system until it reaches the brain mercury in the body is 40 days (Al-Sulaiti et al., 2022; Das, Kumari, Kumar, & Kush, 2023; Nguyen, Hien, Truong, Chi, & Sheu, 2022; Saalidong & Aram, 2022).

Finally, there is the route of exposure of organic mercury, this being through the ingestion of mercury-contaminated species from artisanal mining in 95%. This form of mercury is highly lip soluble, binding to the cysteine group of proteins. It is a stable metal and decomposes slowly since its half-life in the organism is to 32 to 164 days. It is main cause of problems in gestation and in the development and growth of babies, since it is secreted through breast milk, causing immunological problems to the newborns and the mother. In addition, it can enter the placenta, causing alterations in the amniotic fluid and problems in the fetus, causing premature birth with immunological, learning and behavioral deficits (Al-Sulaiti et al., 2022; Dack, Fell, Taylor, Havdahl, & Lewis, 2022; Houde et al., 2022; Parker, Gillie, Miller, Badger, & Kreider, 2022).

Among other health problems caused by exposure to organic mercury are: affectation of the central nervous system, causing hearing, sight and speech problems, cardiovascular problem with fatal heart attack, dementia, muscular problems, bone and nervous system problems and decrease in the Intelligence Quotient (IQ) of the newborn.

The following are the human health effects of the types of mercury by route of exposure (Al-Yaari & Saleh, 2022; Emmanuel, Chukwudi, Monday, & Anthony, 2022; Gheitasi, Ghammamy, Zendehdel, & Semiromi, 2022;

Mitra et al., 2022; Nejad & Sheibani, 2022; Pang, Gu, Wang, & Zhang, 2022; Taux, Kraus, & Kaifie, 2022; Zhao & Bergmann, 2023) (Table 3):

Table 3. Effects of type of mercury in human health.

Effects	Elemental mercury	Organic mercury	Inorganic mercury
Nervous system	Dysfunction, insomnia, impaired motor skills, memory loss, immune deficit	Dysfunction, malformations in fetus, immune development, seizures, altered senses, memory loss, language disorders, spontaneous abortion, alteration of menstrual cycles, change in the properties of breast milk, infertility	Nervous pain, irregular movements of the extremities
Digestive system	Dysfunction	Nausea, abdominal cramps, diarrhea, corrosive in the intestinal tract	Nausea, abdominal cramps, diarrhea, corrosive in the intestinal tract
Urinary system	Dysfunction	Renal insufficiency, alteration of urine properties	Renal insufficiency, alteration of urine properties

Different studies have been carried out on the populations immersed in gold mining activities with mercury exposure; such is the ACSe of the study conducted by Bastiansz, Ewald, Rodríguez Saldaña, Santa-Rios, and Basu (2022) who conducted research with 832 people from Kenya, United States, Jamaica and Hong Kong, finding that 9 people presented symptoms related to tremors, lassitude and vertigo; about 139 people in Jamaica presented itching, irritability, headache, depression and scars; 52 people from United States and 49 people from Hong Kong presents fatigue, nervousness, irritability, severe headache, weakness, insomnia, anxiety, depression, memory loss, tremors and body pain. The points with the highest mercury concentration levels were: blood, hair, urine and feces, with levels of 1,762 µg/g and 56,000 µg/g at ages 10 month to 50 years. Additionally, individuals between 6 weeks and 10 years presented mercury levels in blood of 2,620 µg/L, in urine of 170 µg/L and in hair of 5,617 µg/g and individuals younger than 5 years presented signs of mercury intoxication upon contact with their mothers (Bastiansz et al., 2022).

Likewise, the study conducted by Saldaña-Villanueva et al, where the impacts on the health of mine workers are evaluated based on the lack of social security as the main factor for the lack of access to medical care, is also analyzed. The workers in this study showed a median mercury concentration of 6 µg/g to 101 µg/g, showing deterioration of neurodevelopment and language in children in blood and urine samples from 6 to 12 months of age and in adults the health effects presented were symptoms in the nervous and digestive system, tremors, vision fields, sensory alterations, sensory alterations, sensory imbalances, imbalances of the nervous and digestible systems, dyspnea, headache, reduced appetite, hair loss and excess saliva. It is necessary to implement strategies in health plans in mercury mining areas, carrying out environmental evaluations of mercury exposure levels to guarantee work opportunities and impact the wellbeing and quality of life of the population (Saldaña-Villanueva et al., 2022).

The study by Dahmardeh Behrooz, Tashakor, Asvad, Esmaili-Sari, and Kaskaoutis (2022) assesses human health risks based on the degree of non-carcinogenic risk associated with mercury particles by studying respiratory exposure in adults (up to 70 years) and children (up to 15 years), showing that inhalation results in adverse health effects due to dust emissions and environmental impacts on soil, air and water resources (Dahmardeh Behrooz et al., 2022). Similarly, a study by Issifu, Alava, Lam, and Sumaila (2022) evaluated the adverse effects of mercury contamination in fisheries, estimating that the concentration of mercury is 50% higher than the permissible thresholds for fishing capacity and consumption. People who are exposed to these contaminated species are at risk of exposure to highly toxic methylmercury for human health and with it the deterioration of the quality of life of the region and the subsistence by not having the tools, controls and management of mercury and with it the non-guarantee of the exposure limits from the mining activity (Issifu et al., 2022).

Research by Soe, Kyaw, Arizono, Ishibashi, and Agusa (2022) present a general review of the risks of mercury on human health and the environment based on the tragic mercury era in stages of poisoning due to ingestion of mercury contaminated species or grain seeds treated with methylmercury leading to loss of consciousness and even death; toxicological studies on populations exposed from gold mining activities leading to neurological problems; and research on various sources of exposure scenarios such as food ingestion, need for site-specific data, cultural considerations, small-scale gold mining, global change considerations, skin lightening products, dental amalgam, contaminated sites and e-waste recycling (Basu et al., 2023; Soe et al., 2022).

Finally, there is the study by Kumar, Sharma, and Sedha (2022) where male reproductive health is exposed in terms of mercury contamination, especially in the quality of semen, which, having high levels of mercury in the blood, alters the morphological percentage of spermatozoa. In the ACSe of women, there are problems in pregnancy, complications in the development of babies, alterations in the menstrual cycle and miscarriages (Kumar et al., 2022). In the study carries out by Diwa, Deocaris, Geraldo, and Belo (2022) the ecological and health impacts of heavy metals from a mercury mine are evaluated, in which the probability of adverse effects for adults and children is suggested, with an average contribution of heavy metals of 38.8% for adults and children (Diwa et al., 2022).

Despite the consequences of the use of mercury for mining in the Santurban Paramo, miners and peasants defend their right to continue in a territory in which they have reproduced life for generations, from ancestral activities and through their level of production they provide food and minerals to the communities of the region, in order to determine ancestral zones and ecosystem preservation.

For them, the Paramo is sacred along with all the biodiversity found there, as well as with the knowledge and relationship of care for water as a water source and sustainability for mining practices and their improvement (Parra-Romero, 2022; Parra-Romero & Gitahy, 2017) for the development of management and conservation strategies of the Santurban Paramo in the ACSe of already established instances of local participation (Sarmiento Pinzon et al., 2014).

That is why Colombian legislation and policies such as Law 1930 of 2018 begin to involve all actors working with mining in the Santurban Paramo (Avella, Sosa, Marin, Galvis, & Trujillo, 2021; Vargas-Chaves, Gómez-Rey, & Rodríguez, 2020) creating awareness not only of the problems that the use of mercury entails in these practices, but also in the care and protection of water and soil in article 111 of the Political Charter, Law 373 of 1997 (Zapata-Cardenas & Pinto-Arboleda, 2022) and Resolution 0839 of 2003 with the environmental management of the Paramos in relation to the ecosystem approach of the region with the use of biodiversity, home activity, fishing and artisanal mining (Abadia & Avendaño, 2014). Similarly, Resolution 1015 of 2011 establishes the rigorous studies of the control institutions for the mining activity of the Paramo together with environmental impact studies in defense of water and surrounding populations in relation to the environmental licenses established there (Parra-Romero & Gitahy, 2017).

Likewise, the agricultural sector is involved together with the National Environmental System (NES) in the management and management challenges of Paramos with needs for convergence, concurrence and articulation between public and private actors (Vargas-Chaves et al., 2020).

Additionally, for the protection of the Paramos against chemical pollutants, the Regional Autonomous Corporations in compliance with the SDGs establish environmental management plans based on communication and education (Gutierrez & Calderón, 2020) where lines of research are established for:

- Illegal mining characterizes environmental impacts in the prioritization of protected areas.
- Deforestation with the identification of vulnerable areas and minimization of this problem.
- Cleaner production and sustainable management with the characterization of logistics processes for the preservation of the ecosystem.

- Ecological conservation and protection of biodiversity with the conservation of the environment and natural resources (Vergel, 2021).

However, the relationship between society and nature has also brought contingency plans in terms of water resources, this plan contains elements of infrastructure and management Electronic Stability Program (ESP), Bucaramanga Metropolitan Area (BMA) and Santander Public Sewerage Company (SPSC) with the management of control parameters, inspection, regulation through tax tools and the generation of water product or service with pro-jects necessary for its preservation with socially and environmentally sustainable equity that starts of mining governance and respect for bio cultural rights in the region (Escobar, 2020) with the help of the United Nations, Work Program on Protected Areas, Ramsar Convention on Wetlands and Biological Diversity.

In addition, the use of mercury not only causes environmental problems, but also health problems for human beings, where being in contact with elemental, organic and inorganic mercury causes serious damage to the circulatory, digestive, cardiac and muscular system. Mainly, causing not only short-term but also long-term problems, as in the ACSe of pregnant women where breast milk is contaminated by mercury, causing fetal and immunological problems in the development of the newborn. The diseases and health problems caused by exposure to mercury through the respiratory, digestive or skin tract bring about alterations in the nervous system, causing severe heart attacks and brain problems in the worst ACSes, and although its half-life is 40 to 164 days, the damage caused is permanent, it is necessary to replace mercury in the gold mining process to reduce the environmental and human health damages caused and although the damages are already done, through education and new management practices in the community these risks can be minimized for the preservation and protection of the Paramo and with it the sustainable and efficient development of the region.

The Santurban Paramo has been the subject of multiple environmental and social controversies due to artisanal mining, being a practice of economic sustenance for the populations near the Paramo but causing serious problems in the health of people due to the improper use of toxic metals such as mercury, a silent danger that is ending the quality of life of the population by causing diseases, cancer and even death of people who are directly or indirectly related to this activity.

While it is true, mining activity has been known and implemented for a long time, but its consequences and effects until now are being known, many of these conflicts come from the environmental impact that this activity brings. In the first place, the resources necessary for human survival, water, has been deteriorating little by little by the obtaining of liquid gold since when the water mixes with the material and minerals contaminated with sulfur, cyanide and mercury brings with it the formation of acidic water that causes not only the death and deterioration of the animals that inhabit the Paramo when consumed but also to the ground with erosions and emissions that this can cause to the atmosphere.

Likewise, when contaminated minerals are found in the water, aquatic animals are exposed to the toxicity of mercury when introduced into their body and this in turn causes health problems of people who consume it without knowing the risk, they are exposing themselves as a result of the activities that the same community performs.

However, due to the environmental, social and economic problems that Colombia faces in the preservation of the Santurban Paramo, the policies and laws of the country and the region have tried to solve these problems from the root and although the task has not been easy, strategies and improvement plans have been implemented for the benefit of the environment and the environment. seeking solutions not only to protect the ecosystem and the animals that live there but also to protect the economic activity of the region with good manufacturing practices by replacing mercury with another material that does not cause damage to the environment and also maintain a balance between the economic and social factor of Santander and the conservation and protection of the environment and although the consequences of the activity due to mercury are Irreversible when it comes to water resources, what is sought with these strategies is to minimize the risk of contamination of water and soil for future generations and reduce the imminent danger of mercury in the environment.

4. CONCLUSION

Artisanal mining in Colombia is an alternative for communities to get ahead being the livelihood and economic sector of their region, however, over the years there has been a bad practice of this activity causing damage not only in the Santurban Paramo, but also affecting the health of people who are directly or indirectly related to mining.

This affectation is due to mercury, an excessive pollutant for the ecosystem, the environment and people, causing problems in both the nervous, respiratory and muscular systems when in contact with high concentrations of this either by contaminated intake, affectations to a greater degree of children and older adults and the ecosystem by the cur-rent of water that circulates through the ecosystem.

This pollutant brings with it different environmental problems such as the affectation of water resources and soil, affectation in the fauna and flora of the ecosystem due to the exploration and exploitation that are carried out in the Santurban Paramo, affectation in the health of the communities and, therefore, a deterioration in the preservation of the environment. Likewise, contact with mercury in the gold mining process brings with it problems in the immune system of newborns, problems with the fetus and problems for human health such as damage to the circulatory, digestive, nervous and muscular system due to the inhalation of particles dispersed in the air and the ingestion of contaminated species in the soil, water and air for people who are directly related to the metal.

However, today different strategies have been sought to solve this problem through policies and management plans of the Regional Autonomous Corporations of the regions of Santander and Norte de Santander together with the Ministry of Environment to establish a strategic plan where communities and the ecosystem is not affected and likewise meet and meet the needs of the regions without causing damage to the Santurban Paramo, being a natural resource in Colombia.

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Transparency: The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.
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