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Impact of Artisanal Gold Mining in Community Conserved Areas with High Biodiversity Using a Multi-Criteria Approach: A Case Study in Colombia

Franco Hernan Gomez [1,2,*], Natalia Pelegri [3], Juan Guillermo Lopez [4], Kelly Cristina Torres [5] and Mentore Vaccari [1]

[1] Research Centre on Appropriate Technologies for Environmental Management in Resource Limited Countries (CeTAmb), Department of Civil, Environmental, Architectural Engineering and Mathematics, University of Brescia, Via Branze 43, 25123 Brescia, Italy; mentore.vaccari@unibs.it
[2] Group on Governance of Climate Change (GGCC), Universitat Politècnica de Catalunya—BarcelonaTech, Av. Maristany, 16, 08019 Barcelona, Spain
[3] International Action for Peace (IAP), Via Laietana, 16. Planta 1 Office: 123, 08003 Barcelona, Spain; derechoshumanos@actionpeace.org
[4] Lateinamerika Institut (LAI), Freie Universität Berlin, Kaiserswerther Street, 18, 14195 Berlin, Germany; juanlopezve@zedat.fu-berlin.de
[5] Research Group on Conservation and Use of Biodiversity (BioCon), Instituto Universitario de la Paz—UNIPAZ, km 14, vía B/manga, Barrancabermeja 687033, Colombia; vicerectoria@unipaz.edu.co
* Correspondence: franco.gomez@unibs.it

Abstract: Artisanal small-scale gold mining (ASGM) using mercury affects community agreements for the conservation of forests (CoS) and lakes (CoH), which have a high level of biodiversity in the Peasant Reserve Zone of the Cimitarra River Valley (ZRC-VRC) in Colombia. In this research, a multi-criteria approach (MCA) was applied to analyze the impact of ASGM. This analysis is based on the community environmental agreements to preserve CoS and CoH areas, the ecological importance of these areas, as well as the results of mercury dispersion in the Cimitarra river basin, with concentrations found 40 km downstream of the mining area of 0.09 μgTHg L^{-1} in the Cimitarra river, 0.07 μgTHg L^{-1} in the CoH, and 0.01 mgTHg kg^{-1} in the tissues of macrophytes, as well as the increase in deforestation since 2020 in the CoS, due to a 1.8% (990 ha) loss of forest cover, with 693 ha of the forest cover loss coinciding with areas related to the opening of new mines. The MCA showed that the main impact is found within the criterion *Social and armed conflict*, followed by *Deforestation*. This research offers recommendations to reduce impact scores, such as the implementation of a sustainable development plan (PDS) of the ZRC-VRC, and it highlights the urgent need to safeguard the community conservation areas.

Keywords: deforestation; biodiversity; polluted waters; mercury; multi-criteria analysis; ASGM

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1. Introduction

Artisanal small-scale gold mines (ASGMs) are associated with poor communities, illegality, and armed conflict over territorial control of the mining area [1–3]; likewise, mining activities are linked to pre-conflict, conflict, and post-conflict scenarios between government, social, and armed actors, identifying a connection in variables such as population growth, mining activities, and consumption of natural resources [4,5]. Mining activity is linked to deforestation due to its natural resource requirements, in particular the wood that supports the structures of the mineral extraction tunnels. Also, a new inhabited nucleus is created around the new mines. It is a refuge for the employees working in the mine and their families [5–7], expanding the agricultural and livestock production frontier around the new population center in order to supply the food needs of the community [2,8]. Deforestation problems are an important factor linked to climate change issues. Globally,

it is estimated that between 12% and 20% of global greenhouse gas emissions are generated by changes in land use, mainly deforestation [9–11]. Around 178 million hectares of forest were lost between 1990 and 2020, with the highest level of deforestation occurring across the humid tropics, mostly in Africa and South America [12]. The tropical forests of Colombia are among those with the highest levels of deforestation worldwide. In 2014 alone, Colombia lost 140,358 hectares of forest, with an increase of 16% increase compared to 2013 data. These losses are related not only to pressures from the productive sector, but also to armed conflict: it is estimated that 58% of deforestation in Colombia has taken place in municipalities with the highest levels of armed conflict [13,14].

Another important problem of ASGM mining is the emissions of wastewater contaminated with mercury (MWW) from ASGMs, either in the active or abandoned phase, which is a persistent problem that affects ecosystems and communities that are close to these mines [15–18]. The presence of total mercury (THg) occurs because the process has a low degree of mechanization and it is the most economical form of gold production [1,19–21]. MWW from the amalgamation phase (Au-Hg) is normally discharged into the environment without any treatment at an average concentration of 54 μgTHg L^{-1} [22,23]. Mercury pollution produces negative effects on human health and the environment, and it has several adverse effects, especially on the endocrine, as well as the central and peripheral nervous system [17,24–26].

This research will use a Multi-Criteria Analysis (MCA) to help in decision-making as it is a tool that allows researchers represent any difference between the criteria studied, and make the subjective elements of analysis evident and transparent in order to carry out a quantitative assessment, especially where the intervention aims to consider heterogeneous criteria in evaluation [27,28]. The MCA was applied to determine the main impacts of ASGM in the community conservation agreement areas of the Peasant Reserve Zone of the Cimitarra River Valley (ZRC-VRC), in the south of the Serranía de San Lucas (SSL). This paper highlights the significant role of local communities in bottom-up environmental conservation initiatives under community conservation agreements within territories marked by armed conflict and extractive interests of multinational mining companies [12].

2. Materials and Methods

2.1. Location of the Study

The case study unfolded within the ZRC-VRC, a region distinguished by its abundant biodiversity, water resources, and natural forests [29–32]. Simultaneously, the area is characterized by the presence of numerous gold deposits in the subsoil and widespread poverty among the local population, where the local community is exposed to a higher rate of inequality and poverty. Currently, the ZRC-VRC spans an area of 570,196 ha and it is home to 29,000 inhabitants, including peasants, artisanal miners, and fishermen, residing in 120 villages. Each village in the mining zone is inhabited by an average of 200 people, residing in rural settings marked by vulnerability, low income (below the poverty level), and constant exposure to the ongoing armed conflict [8,33–35].

The region hosts approximately 50 active ASGM types, lacking proper wastewater treatment systems. Mining activities have persisted in the territory for over three decades. The community agreement for the conservation of forest (CoS) covers about 55,000 ha, and the lake conservation area (CoH) covers about 20,000 ha. The conservation areas are located downstream of the mining area: the CoS 10 km and the CoH, 40 km from the mining area [6–8] (Figure 1).

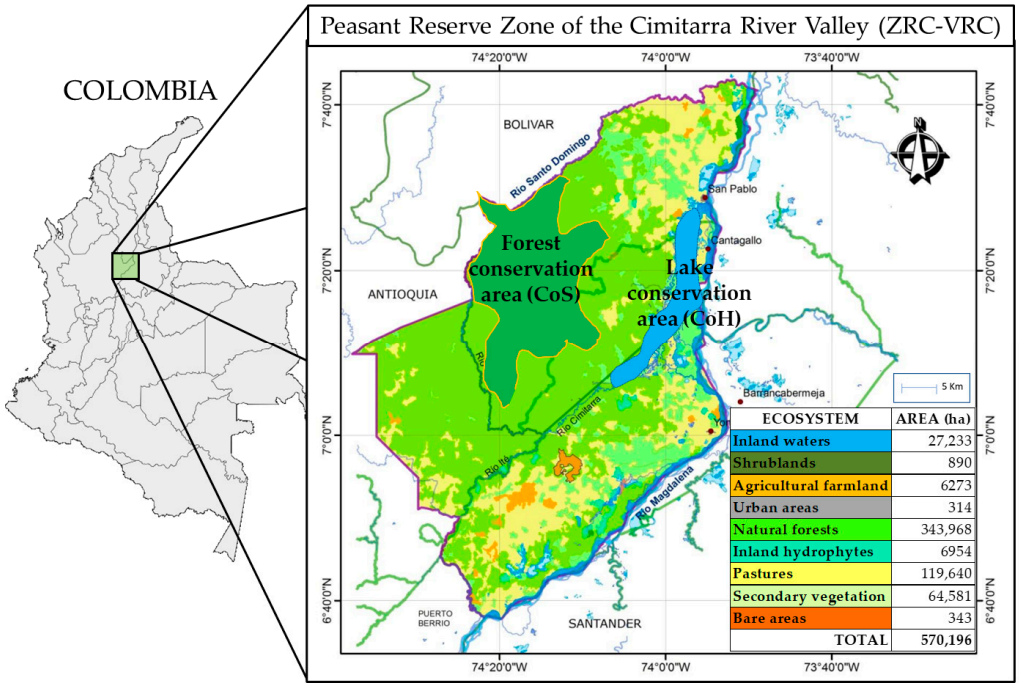

Figure 1. Physical map of the ZRC-VRC in Colombia. The forest conservation area (CoS) in dark green is 55,000 ha and the lake conservation area (CoH) in blue is 20,000 ha [7].

2.2. Systematization of Information and Management Mode

Three phases were carried out with different aims.

Phase A (Ph-A) was carried out using a review of technical information, with a historical memory perspective and a social mapping. It was combined with interviews to male and female leaders of the Peasant Association of the Cimitarra River Valley (ACVC), in order to acquire a specific assessment of the social, environmental, ecological, and economic context of the ZRV-VRC.

Phase B (Ph-B) was the characterization of mercury contamination. It was carried out through quantification of the THg present in different points of the Cimitarra river basin. The solids and liquids samples were taken for laboratory analysis.

Phase C (Ph-C) was carried out to develop the MCA using the information and results of Ph-A and Ph-B to determine which criterion has the greatest impact due to ASGM in the community agreements for the conservation areas of the ZRV-VRC and to propose alternative solutions to reduce the impact.

2.3. Social, Ecological, and Environmental Review and Analytical Methods

This research was carried out through qualitative and quantitative analysis with a historical memory perspective, which consists of conducting interviews with male and female leaders of the Peasant Association of the Cimitarra River Valley (ACVC) who live in the territory. The research is aimed at finding out how the occupation of land has developed over time, and been understood as a dynamic and conflictive process of construction and appropriation of space, which takes place between the actors who live in the territory and who generally have different and contradictory visions of it [35]. This process is developed for the use and control of the territory for political, social, and economic purposes, which evolves in a differential way in specific historical-geographical contexts [36]. A total of 9 interviews were conducted with ACVC members. A review of information was also carried out with technical reports and scientific articles in order to gain a specific assessment of the ZRV-VRC, considering the social, environmental, ecological and economic context, and to possess valid inputs of the general criteria defined for environmental, health, social and economic aspects and thus be able to develop the MCA phase to quantify the impacts,

as recommended by [27]. For the analysis of deforestation in the CoS—related to the loss of forest cover—a social mapping was carried out. It was combined with interviews carried out with male and female leaders of the ACVC regarding the new human settlements, and new mining and production activities in the CoS [37], alongside the results of using the open access QGIS project as a source for geographical information system.

2.4. Monitoring of Mercury Contamination and Analytical Methods

Seven sampling points were identified according to the starting point considering the origin of the contamination: 100 m, 1000 m, and 5000 m (Manila river); 20,000 m (Tamar river); 30,000 m (Cimitarra river); 40,000 m (Cimitarra river); and 40,000 m (San Lorenzo lake). At each monitoring point, 300 mL of water and 250 g of sediment were taken in duplicate. Each liquid sample was placed in a glass bottle; each solid sample was placed in a plastic bag, sealed, labeled, packed in ice, transported to the laboratory, and stored at −5 °C [22,38]. Three samples of macrophytes (*Eichhornia crassipes*) were manually collected from Lake San Lorenzo (CoH). The points of the mercury monitoring can be seen graphically along the water course of the Cimitarra river basin (Figure 2).

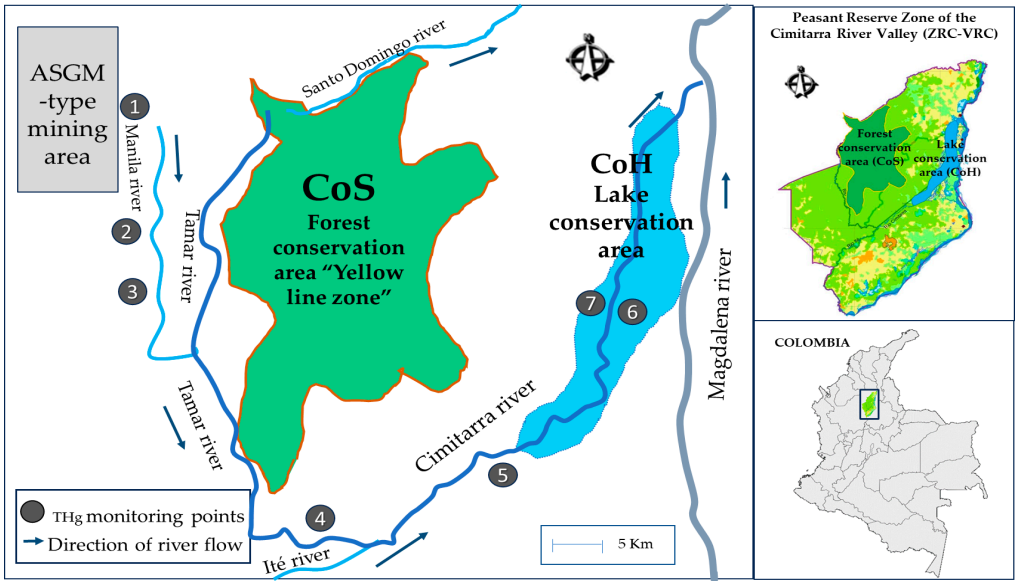

Figure 2. Geographic location of the study area in the Cimitarra river basin with mercury monitoring points and protection zones: CoH (light green Surface) and CoS (light blue Surface). GPS coordinates of points 1: N 07°22.059′ W 074°28.014′; 2: N 07°21.020′ W 074°27.627′; 3: N 07°18.709′ W 074°28.433′; 4: N 07°00.638′ W 074°16.848′; 5: N 07°06.357′ W 074°08.652′; 6: N 07°12.729′ W 074°00.873′; 7: N 07°14.757′ W 074°01.522′.

All analyses for the determination of total mercury (THg) concentrations in solid and liquid samples were analyzed in the laboratory at the Chromatography and Mass Spectrometry Laboratory (Crom-Mass) of the Universidad Industrial de Santander, in Bucaramanga (Colombia). These analyses were carried out using the RA-915M spectrometer (manufacturer by Lumex Instruments, Mission, BC, Canada) with RP-92 attachment for determination of mercury concentration in liquid samples and PYRO-915+ pyrolysis attachment for solid samples. The analyzer's operation is based on the measurement method of differential atomic absorption spectrophotometry and, together with its couplings, allows the concentration of mercury in numerous gaseous, solid or liquid matrices to be determined, converting mercury bound to complex molecules into its atomic form. Before analysis, solid samples undergo a drying pretreatment, while liquid samples are treated with stannous chloride ($SnCl_2$) and sodium hydroxide (NaOH). Two measurements are taken for each sample and the result given is the arithmetic mean of the two resulting values [39].

2.5. Multi-Criteria Analysis (MCA)

The MCA approach was applied to the impact of human activities in the ZRC-VRC. The methodology is divided into six main phases: i. definition of the matrix, which represents decision criteria; ii. assignment of weights to the criteria by comparison in pairs; iii. normalization of the comparison criteria; iv. calculation of the final scores for the comparison criteria; v. sensitivity analysis or consistency analysis of the judgments; vi. identification of recommendations or actions to lessen the impact. The MCA should be consistent with a CI index greater than 11% for matrices with a number of criteria ≥ 9. In the last phase of the analysis, each criterion was assigned a value on a scale from 1 to 3. The final impact score for each criterion was obtained by multiplying the relative weights of each criterion by the score given [27,28,40]. The assessments of the MCA exercise were carried out by a total of 12 people, made up of delegates from the ACVC (the social organization that promotes the community conservation agreements), delegates from the ACVC technical team, and the research team. These delegates established the respective score through face-to-face and virtual participatory workshops. To identify general criteria (GC), those suggested by [41–45] were used, adapted to contexts and territories. Table 1 lists the GC used for this case study.

Table 1. General criteria (GC).

Impact Category	Code	General Impact Criteria
Environmental/Health impact	C1	Pollutant emissions in water, air, and soil.
	C2	Effects on human health and local biodiversity.
	C3	Physical/geological characteristics of the territory.
	C4	Consumption of natural resources and raw materials (wood, groundwater, energy).
	C5	Living conditions of the local community over time.
	C6	Deforestation in conserved areas with high biodiversity.
Social impact	C7	Community agreements for forest and lake conservation.
	C8	Organizational culture of the local community.
	C9	Social and armed conflict over land use and occupation.
Economic impact	C10	Technological development and investment in infrastructure.
	C11	Generation of employment and development of the local economy.
	C12	Creation of new inhabited nuclei with livestock and agricultural production areas.

3. Results

3.1. Ph-A—Review of Information on the Social, Environmental, and Economic Situation in the ZRV-VRC

3.1.1. Settlement or Colonization Process of the ZRC-VRC

The process of populating and settling in rural territories in the contemporary history of Colombia has been spontaneous, improvised, without any support of the state, and mainly motivated by the reigning violence that marked the 20th century [46]. This goes through the opening of new lands and returns again to the point of conflict and migration (in a dynamic that has conflict and migration as its starting point), establishing a vicious circle in which violence is a fundamental component [47]. In the specific case of the ZRC-VRC, one of the particularities of the last wave of colonization, which began in the 1950s and took hold in the 1970s, is that even though it was an improvised process without support of the state, it was carried out by the peasants with a certain degree of organization and a clear vision of territorial planning. This was supported by the administration and management structures created by the peasants themselves, such as the so-called "land committees". These committees contributed to regulating the pressure exerted in the region by the armed conflict in Colombia, which led to forced displacement [48] and, therefore, the massive arrival of peasants to the Cimitarra River Valley [33]. Since 2000 and every 10 years, the peasant and mining communities have been shaping their region projection in the so-called Sustainable Development Plan (PDS) of the ZRC-VRC. This document covers 12 thematic axes, some of which are environment, peasant economy, education, health, infrastructure, human rights, and rural women. This document is a grassroots tool for territorial peace building and integral defense of human rights [6,49].

3.1.2. Community Conservation Agreements in the ZRC-VRC

An important measure put into practice at the end of the 1980s was the delimitation of the territorial appropriation progress. In the case of the preserved rainforest areas, the peasants approved the "Yellow Line Zone" (CoS): an imaginary line that cordons off an area of virgin rainforest originally about 70,000 ha for conservation. In the case of the CoS and CoH, the delimitation of this boundary is carried out through a community consultation process known locally as "community agreements". This strategy is based on dialogue, negotiation and consultation with all actors within the territory [6,7,34]. The CoS and the CoH are grassroots figures of territorial administration and environmental protection, which are part of the peasant process of territorialization [35]. This process results in the use and control of the territory for political, social, and economic purposes, which is developed in a differential manner in specific historical-geographical contexts [38]. Local peasant movements acquire roles in the administration of their territories and are given power and resources to limit the expansion of the agricultural frontier and ensure human well-being as well as ecosystem and biodiversity conservation [32,50,51].

3.1.3. Ecological Relevance of CoS and CoH

Since the 1990s, the high water and biodiversity richness of the CoS and CoH areas have been observed, due to the proper vegetation and forest cover that guarantees the great diversity of ecosystems ranging from wetlands in the lower parts of the Cimitarra river basin (75 masl) to the forest areas in the south of the SSL range, with average altitudes of 650 masl. It guarantees strategic biological corridors for endemic animals [6,52]. Its rich biodiversity is also due to the presence of endemic species distributed in a reduced territory because the SSL was a Pleistocene refuge for biological interactions, which is why unique species evolved in this area [53]. Other documents reporting biodiversity richness were based on sightings made by the community. These sightings and the need expressed by the communities to find alternatives for the protection of these nature conservation areas were reflected in the 2000–2010 and 2012–2022 versions of the ZRC-VRC Sustainable Development Plan (PDS) [6,49].

Since 2015, biological characterizations and technical studies have been carried out in the territory to show the level of biodiversity in the areas of the community conservation agreements. These organizational processes have demonstrated the sustainable use of their territories for decades [30–32]; territories that have become a refuge for many species, some of them at high or critical risk of extinction, as well as strategic biological corridors for "umbrella species" such as the jaguar, the tapir, or the spectacled bear. From the results found in the biological characterizations carried out in the forest areas of community conservation agreements, particularly in the CoS, the following data stand out, certifying the high biodiversity present in the territories subdivided into species and most outstanding subgroups: Butterflies: 240 species; Small mammals: 28 species; Herptiles: 59 species collected; Primates: 5 species; Plants: 130 species; Aquatic Macroinvertebrates: 12 to 15 families identified; Birds: 250 species identified; Coprophagous beetles: 16 species; Medium and large mammals: 12 species identified (tapirs, jaguar, American cougar, ocelot, and jaguarundi, as well as the spectacled bear) [29,32].

The information reported in the technical report of biological characterization of the CoH supports the high richness of habitats and species present, where the aquatic ecosystems and their surrounding forests in the Cimitarra River Valley represent one of the last areas in an appropriate conservation status for the maintenance of populations of species heavily impacted by human activities such as: Herpetofauna: 66 species in total, (24 amphibians and 42 reptiles); Avifauna: 200 species, 47 families, and 20 orders; Small mammals: 38 species (Chiroptera: 33 species belonging to five families; Marsupials: 3 species belonging to one family; Rodents: 2 species belonging to two families); Primates: 5 species, many of them with a high degree of threat, including one critically threatened with extinction (the brown spider monkey); Mammals: 8 orders, 16 families and 23 species; the presence of large mammal species such as the lowland tapir (*Tapirus terrestris*) and

the jaguar (*Panthera onca*). Among the fish, 54 species, of which 22 were endemic species, 12 migratory species, and 13 species with some category of threat according to the IUCN, were recorded: one Critically Endangered—(*Pseudoplatystoma magdalenae*), seven Vulnerable, and four Near Threatened species [8]. From the biological characterizations in the CoS zone and the CoH zone, it can be concluded that they have three basic components for the declaration of biodiversity hotspots: a. high species richness; b. high threat to diversity; c. high degree of endemism (species only distributed in Colombia) [53].

3.1.4. Socio-Environmental Conflicts in CoS and CoH

Socio-environmental conflicts refer to debates and disputes that confront various institutional and inter-sectoral actors at local, national, and supranational levels in the face of threats to people's quality of life in the society–nature relationship [41,54,55]. Two scenarios were considered:

- *Microsocial scenarios:* The increase in deforestation in the CoS community conservation agreement has been registered in different reports [7,8,34] where the loss of forest was 3.82% during the period 2017–2019 [32]. The results of the analysis of deforestation in the CoS polygon using the social cartography methodology alongside the QGIS tool from 2020 to 2023, indicates a loss of forest cover of 1.8% (990 ha), with 70% (693 ha) of the hotpots of cover loss coinciding with the new opening areas directly or indirectly related to ASGM activity. Directly, it refers to the point of gold extraction and, indirectly, it refers to the supply of wood requirements and services in general for mining activity (Figure 3).

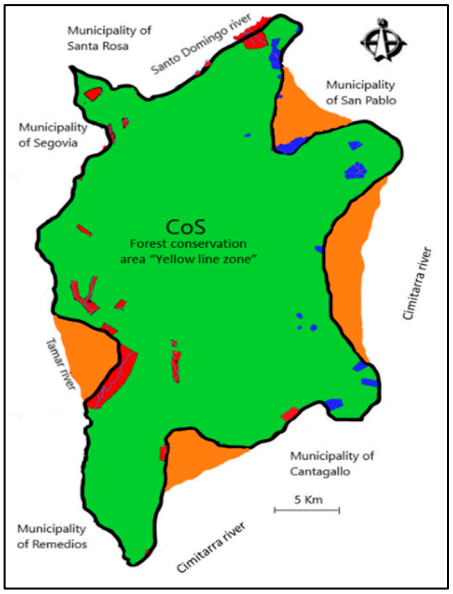

Figure 3. CoS forest polygon (green peach) with new deforestation hotspots (red boxes) coinciding with new mining activity. The areas in blue correspond to deforestation points due to other activities such as timber extraction or new coca cultivation zones. The area in orange corresponds to the losses of rainforest with respect to the original limit of the CoS in the 1980s when the CoS had about 70,000 ha (according to interviews).

Another productive activity in the territory with a strong impact is cattle ranching as an agent of forest transformation. Communities stated that many of the marshes present in the territory have been drying up due to drainage practices through water channeling works used to dry up the beaches for extensive livestock farming and monocultures such as African oil palm [7].

- *Macro-social scenarios:* The development model established by the Colombian state for several decades has been based mainly on an extractive model of mining and energy

resources. Taking this into account, the two main scenarios of socio-environmental conflicts at the macro level are generated by the expansion of gold mining activity and by the expansion of oil activity. In ZRC-VRC, there are currently two areas of 62,342 ha with production contracts, two areas of 93,349 ha with exploration contracts, and five areas of 142,995 ha declared as available, without contract, of which two are intended for unconventional extraction [7,8]. In the Colombian Mining Information System, it is observed that on the territory of the ZRC-VRC there are currently 16 applications for mining titles (2010–2016) for the exploitation of gold, precious minerals, and construction materials with a total area of approximately 39,493 ha, and two mining titles granted (2010–2012) within CoS with a total area of 13,301 ha [8].

The armed conflict that has persisted for decades in the ZRC-VRC is a response to a macro and micro scenario and to the fact that it is located in a strategic corridor in the middle of Colombia, historically disputed by different armed groups. Although in the years following the signing of the 2016 Peace Agreement, a decrease in homicides due to the conflict and in the total number of victims was reported [56], the territorial dispute and the control of illegal rents by armed groups still continue to violently affect the civilian population. There is massive displacement, landmines, and restrictions on mobility and access to basic goods and services, as well as a 32.6% increase in homicides in 2023 compared to 2022 [57]. These violations deepen systemic humanitarian crises, perpetuating poverty and inequality in rural communities.

3.2. Ph-B—Results of the Characterization of Mercury Contamination

The presence of mercury downstream is evident in the Cimitarra river basin. The THg in water and sludge decreases the further away they are from the mining area. As such, 40 km downstream the concentrations in the Cimitarra river resulted 0.09 μgTHg L^{-1}, in the San Lorenzo Lake 0.07 μgTHg L^{-1}. The concentration of mercury in the tissues of the samples of Eicornia crassipes was 0.01 mgTHg kg^{-1}. The results of the mercury monitoring can be seen in Table 2.

Table 2. Mercury contamination in the Cimitarra river basin.

Monitoring Point	Distance from the Mine (m)	Water Flow Rate (m^3s^{-1})	Water (μg THg L^{-1})	Sludge (mgTHg kg^{-1})
1	100 (Out of mine)	0.005	21.73	13.64
2	1000	1	1.24	4.17
3	5000 (Manila river)	83	0.87	0.94
4	20,000 (Tamar river)	170	0.53	<0.005
5	30,000 (Cimitarra river)	500	0.16	<0.005
6	40,000 (Cimitarra river)	537	0.09	<0.005
7	40,000 (San Lorenzo lake)	0	0.07	Macrophytes: 0.01

3.3. Ph-C—Results of the Multi-Criteria Analysis MCA

The pairwise comparison values were entered and then normalized. The matrix of weights related to each criterion and the final scores are presented in Appendix A—Tables A1 and A2. The criteria that resulted higher (weighted scores) were C9 (Social and armed conflict over land use and occupation: 0.46 points), followed by C6 (Deforestation in conserved areas with high biodiversity: 0.335 points), C7 (Community agreements for the conservation of forests and lakes: 0.324 points) and C2 (Effects on human health and local biodiversity: 0.295 points). The consistency criterion was met: the GC matrix showed a CI equal to 11.3%. And finally, the results of the highest final scores were C9 (Social and armed conflict over land use and occupation: 1.40 points), followed by C6 (Deforestation in conserved areas with high biodiversity: 1.01 points) and C2 (Effects on human health and local biodiversity: 0.88 points). Figure 4 shows the results of the impact assessment conducted through the MCA.

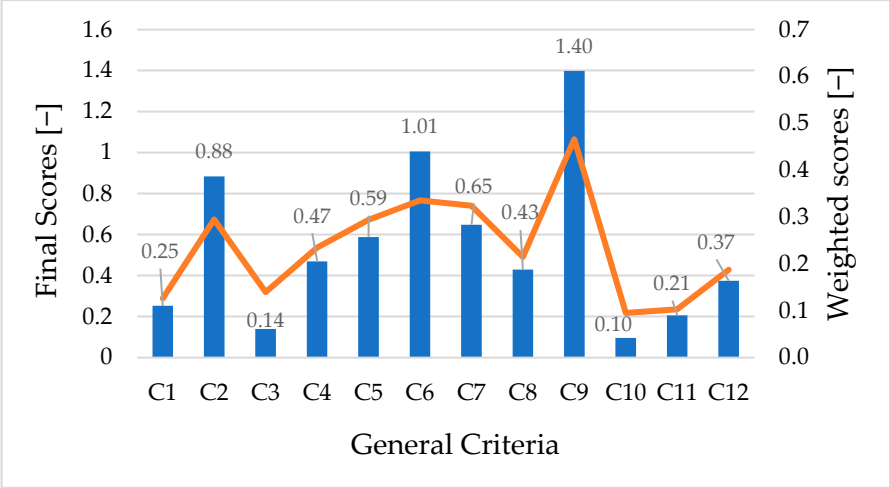

Figure 4. Contribution of GC in weighted scores for SMGA and final scores for impact (blue bars). C1: Pollutant emissions in water, air, and soil; C2: Effects on human health and local biodiversity; C3: Physical/geological characteristics of the territory; C4: Consumption of natural resources and raw materials; C5: Living conditions of the local community over time; C6: Deforestation in conserved areas with high biodiversity; C7: Community agreements for forest and lake conservation; C8: Local community organizational culture; C9: Social and armed conflict over land use and occupation; C10: Technological development and investment in infrastructure; C11: Generation of employment and development of the local economy; C12: Creation of new inhabited nuclei with livestock and agricultural production areas. The orange line represents the normalized weighted scores for each criterion (weighted scores).

The last part of the MCA exercise was developed according to the criteria with the greatest impact (C9, C6, and C2), proceeding to identify recommendations to reduce the impact in the short, medium, and long term (Table 3). The recommendations/actions are to be developed mainly by the social organization ACVC, promoter of the ZRC-VRC, and the community conservation agreements [11,42,58,59].

Table 3. Criteria with higher scores and recommendations for reducing impacts.

Criterion with the Greatest Impact	Actions/Recommendations to Be Developed
C9 (Social and armed conflict over land use and occupation) 1.40 points	Social organizations present in the ZRC-VRC continue to implement the commitment to comprehensive territorial peace and the defense of human rights, embodied in the Sustainable Development Plan of the ZRC-VRC. The grassroots social organizations present in the ZRV-VRC join the dialogue processes with different armed actors and position in the dialogue tables opened by the government. There is an emphasis on the importance of community conservation agreements and on their respect as well as on the search for legal formulas for safeguarding and institutional support.
C6 (Deforestation in conserved areas with high biodiversity) 1.01 points	To consolidate the endogenous peasant community model in the ZRC-VRC, which seeks to economically stabilize the peasant and mining families present in the ZRC-VRC through agroecological models, sustainable agricultural and livestock production, investment in infrastructure, education, productive innovation and, in general, implementation the PDS of ZRC-VRC. To guarantee forestry economics incentives for social organizations and peasant families to protect forests and wetlands, aimed at stabilizing the peasant economy and preventing the expansion of the agricultural frontier or the opening of new agricultural production or mining zones in the areas of the community conservation agreements. To find a figure of protection within the legal regulations of Colombia that is aligned with the principles established in the community conservation agreements for the CoS and the CoH.
C2 (Effects on human health and local biodiversity) 0.88 points	To implement good artisanal gold production practices that are in line with a technological transition process in order to achieve, in the short and medium term, that mercury is no longer used for gold production. To recover the areas already polluted by mercury mainly located around the mining villages.

4. Discussion

In the ZRC-VRC, there is a prevalence of conflicts that respond to macro and micro social interests as defined in [47,54,55], since the economic interests of gold extraction prevail. This fact has a correlation with the presence of illegal armed groups that, within their methods of territorial control, charge extortive payments to allow the development of mining activity. This dynamic of encouraging the opening of new mines, coupled with the situation of poverty and lack of labor opportunities for young people, creates social pressure for local peasants to work for the opening of new ASGM-type operations within protected community areas with high biodiversity. This dynamic also coincides with that found in other areas of Colombia, such as the departments of Cauca and Choco, as shown in the research of [2,5]. It is also interesting to identify how the post-conflict scenario after the signing of the peace agreement in Colombia in 2016 led to an opportunity to stabilize the peasant and mining economy that would lead to stopping deforestation. Unfortunately, since the peace agreement was not consolidated and, together with the appearance of new armed actors in the territory, the conditions were created for the continued opening of new gold mines, including new areas of colonization and deforestation in the areas of community conservation agreements. This panorama coincides with the conflict and post-conflict scenarios defined in [1–4].

The biodiversity studies in the CoS and CoH protection zones, as well as the general situation of land use conflicts in the territory of the ZRC-VRC, show two aspects: firstly, the importance and relevance of the protection work carried out by the peasant communities in these ecosystems; and secondly, the urgent need to continue and to strengthen the work of safeguarding these zones, which are of crucial importance both for the maintenance of flora and fauna species and for the connectivity between them, in accordance with [32–34,52].

The situation of mercury contamination in the Cimitarra river basin is evident, due to the presence of active or abandoned mines present in the territory which play a role in contamination as suggested by [15]. The processes of methylation in the biodiversity present in the protected ecosystems are being verified in accordance with [60], as a consequence of aquatic plants analyzed (macrophytes); the concentration in their tissues was 0.01 mgTHg kg^{-1}. The concentration of mercury in the water decreases with distance from the source of contamination. The mercury, as it is to be expected, gradually bioaccumulates in the macrophytes and the same will probably occur in the fish present in the river (which the population uses as a source of animal protein); in the maize, cassava, banana, and rice crops that use water from the river for irrigation; and in the population that collects water for consumption, as was found in the research [2,38]. This panorama requires further and more detailed research to study other contamination matrices in the population and fish of the Cimitarra river to allow us to verify the effects on the animal and human endocrine system, with a particular effect on the productive efficiency as stated by [24]. Due to new international measures and agreements banning the use of mercury in gold mining, a technological transition and environmental waste management is necessary to gradually ensure compliance with national and international agreements, as suggested by literature and Colombian regulations [5,19,21,58].

The results of the MCA show that the community conservation agreements in the ZRC-VRC are bottom-up environmental conservation initiatives that constitute a key effort to preserve flora and fauna, to curb the expansion of ASGMs and its effects, to fight deforestation, to mitigate the effects of climate change, and to meet the global challenge specifications agreed at the Paris Agreement. It is therefore imperative to safeguard and promote these community agreements on biodiversity conservation. The implementation of the PDS is a grassroots instrument that contributes to the stabilization of the peasant economy. The PDS helps to ensure a balance between the need to safeguard conservation areas and promote existing agricultural areas, as well as to ensure the stabilization of public order, as well as the respect for human rights in these territories. The bottom-up environmental conservation initiatives constitute a key effort to preserve flora and

fauna, protect water resources, stop mining expansion and mercury pollution, and combat deforestation in accordance with [12,14,42].

5. Conclusions

The research shows the dispersion of mercury in the Cimitarra river basin where 40 km downstream from the mining area, concentrations of 0.09 μgTHg L^{-1} and 0.07 μgHg L^{-1} were found in the Cimitarra river and the CoH, respectively, and the methylation is present in macrophytes with 0.01 mgTHg kg^{-1} in their tissues. In regards to deforestation since 2020 in the CoS, a forest cover loss of 1.8% (990 ha) was found, which corresponds to 70% (693 ha) forest cover loss due to areas directly or indirectly related to ASGM activity. The results of the MCA approach showed the main impacts that ASGMs have in relation to environmental/health, social, and economic aspects. The main impact identified is *Social and armed conflict* (criterion C9 = 1.40 points), followed by *Deforestation* (C6 = 1.01 points) and *Effects on human health and local biodiversity* (C2 = 0.88 points). These results confirm the imperative need to seek the stabilization of public order and the construction of peace scenarios in the ZRC-VRC. One grassroots tool identified that contributes to this effort is the implementation of the PDS of the ZRC-VRC. Beyond that, there are two different requirements: on the one hand, to consolidate a technological transition model in the region that allows a reduction in the use of mercury. On the other hand, it is also essential to find a legal figure for the protection of forest areas that supports the community conservation agreements and safeguards all the biodiversity that these areas harbor.

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Appendix A

Table A1. The matrix of the weights related. The scale that provides a relationship between qualitative and numerical values is the relative importance scale according to which the given value (between 1 and 9) represents the relative importance between the two criteria: Equal 1; Weak 3; Significant 5; Strong 7; Absolute 9; Intermediate values 2, 4, 6, 8.

Impact Category	Code	General Impact Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
Environmental/ Health impact	C1	Pollutant emissions in water, air, and soil.	1.00	0.39	2.78	0.44	0.31	0.25	0.24	0.24	0.17	2.00	1.67	0.56
	C2	Effects on human health and local biodiversity.	2.67	1.00	1.75	1.67	1.00	0.83	1.00	3.00	0.44	3.33	3.00	2.67
	C3	Physical/geological characteristics of the territory.	1.18	1.61	1.00	0.58	0.33	0.36	0.31	0.53	0.31	1.33	1.33	0.83
	C4	Consumption of natural resources and raw materials (wood, groundwater, energy).	2.33	0.78	2.33	1.00	1.00	1.00	0.67	1.33	0.51	2.17	2.33	2.00
	C5	Living conditions of the local community over time.	3.33	1.00	3.00	1.00	1.00	0.83	1.33	1.33	0.40	3.67	3.67	2.67
	C6	Deforestation in conserved areas with high biodiversity.	4.00	1.33	3.00	1.00	1.33	1.00	1.00	1.67	1.33	3.33	3.00	2.33
Social impact	C7	Community agreements for forest and lake conservation.	4.33	1.00	3.33	1.67	0.83	1.00	1.00	1.67	1.00	4.00	2.33	2.00
	C8	Organizational culture of the local community.	4.33	0.33	2.67	0.83	0.83	0.67	0.67	1.00	0.31	2.67	2.00	1.50
	C9	Social and armed conflict over land use and occupation.	6.67	2.33	4.00	3.00	3.00	0.83	1.00	3.33	1.00	3.33	3.00	1.00
Economic impact	C10	Technological development and investment in infrastructure.	0.61	0.31	0.83	0.89	0.28	0.31	0.26	0.39	0.31	1.00	0.83	0.75
	C11	Generation of employment and development of the local economy.	0.67	0.36	0.83	0.44	0.28	0.33	0.44	0.50	0.33	1.33	1.00	1.11
	C12	Creation of new inhabited nuclei with livestock and agricultural production areas.	2.33	0.53	1.33	0.61	0.53	0.56	0.61	1.00	1.00	2.00	1.50	1.00

Table A2. Final scores. Each criterion was assigned a value between 1 and 3. The final impact score for each criterion was obtained by multiplying the relative weights of each criterion by the score given.

Impact Category	Code	General Impact Criteria	Weight of the Standardized Criterion	ASGMs in High Biodiversity Community Conservation Areas	Weighted Score (Final Score)
Environmental/Health impact	C1	Pollutant emissions in water, air and soil.	0.13	2	0.25
	C2	Effects on human health and local biodiversity.	0.29	3	0.88
	C3	Physical/geological characteristics of the territory.	0.14	1	0.14
	C4	Consumption of natural resources and raw materials (wood, groundwater, energy).	0.23	2	0.47
	C5	Living conditions of the local community over time.	0.29	2	0.59
	C6	Deforestation in conserved areas with high biodiversity.	0.34	3	1.01
Social impact	C7	Community agreements for forest and lake conservation.	0.32	2	0.65
	C8	Organizational culture of the local community.	0.21	2	0.43
	C9	Social and armed conflict over land use and occupation.	0.47	3	1.40
Economic impact	C10	Technological development and investment in infrastructure.	0.10	1	0.10
	C11	Generation of employment and development of the local economy.	0.10	2	0.21
	C12	Creation of new inhabited nuclei with livestock and agricultural production areas.	0.19	2	0.37

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