Impact and future of the gold mining industry in the Coroico River catchment

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Picture front page: Río Yara (part of the Coroico River Catchment) close to Caranavi (march 2024)

Impact and future of the gold mining industry in the Coroico River catchment

The impact of gold mining on water quality, stakeholder perceptions on the social and environmental impact of gold mining, and the future of gold mining in the Coroico River catchment in Bolivia.

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List of abbreviations

- Al: Aluminium
- As: Arsenic
- Ca: Calcium
- Cd: Cadmium
- CRC: Coroico River catchment
- Hg: Mercury
- IRBM: Integrated river basin management
- MCMC: 'Mi Cuenca Mi Casa' (My River catchment My Home, project)
- Mg: Magnesium
- Na: Natrium
- Pb: Lead
- RC: River catchment
- RSQ: Research Question
- SRQ: Specific Research Question
- UAC: Unidad Académica Campesina - Carmen Pampa
- VRHR: Vice-Ministry of Water Resources and Irrigation
- WHO: World Health Organization

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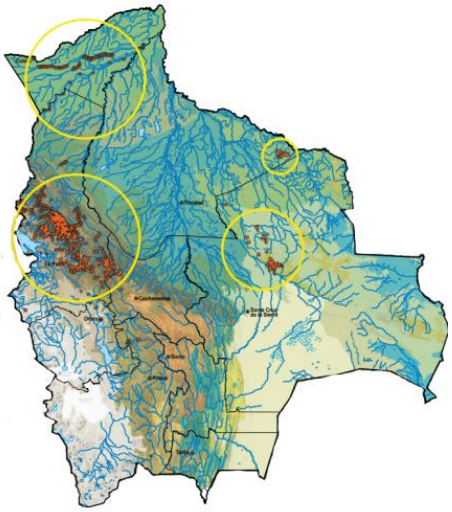
Introduction

In Bolivia, a developing country that has a lot of mineral resources, the mining industry is expanding rapidly. Bolivia has a lot of industrial minerals including zinc, lead, tin, gold, silver, copper, tungsten, sulfur, potassium, borax, and semi-precious stones (Bolivia - Mining | Privacy Shield, n.d.). In the last two decades, gold, zinc, and silver mining together even accounted for 39% of the total export products of Bolivia (TRADING ECONOMICS, n.d.).



Map 1: Locations of mining activities in Bolivia

Although there are areas in which alluvial gold mining dates back decades, such as in the municipality of San Ramón in eastern Bolivia, alluvial gold mining has expanded through mechanization in recent years.
The different areas of gold exploitation are circled on the map: the municipalities of San Ramón, a part of Santa Cruz, and the La Paz and Pando departments (Campanini et al., 2018).
The main part of Bolivia's gold mining takes place in the La Paz region and spreads across the mountains and forests of the Apolobamba, Madidi, and Cotapata National Parks, located north and northeast of the capital city (In Bolivia, Mercury Pollution Spreads Amid a Surge in Gold Mining, n.d.).
The gold mining industry in Bolivia is organized by different mining groups called "cooperatives," which operate both legally and illegally. (In Bolivia, Mercury Pollution Spreads Amid a Surge in Gold Mining, n.d.).
In 2021, the National Statistics Institute (INE) disclosed that minerals accounted for 96.5% of La Paz's exports and 85% of that share was contributed by the gold industry.

Gold mining is an important part of the fragile Bolivian economy. The Boliviano, the current currency in Bolivia has been subject to high inflation rates. The inflation Rate in Bolivia increased to 3.06 percent in March from 2.52 percent in February of 2024. Over a longer period, it is even more evident that there is a significant inflation of the Boliviano, the average inflation Rate in Bolivia from 1968 until 2024 is 251.87 percent. (TRADING ECONOMICS, n.d.)
Since gold has a fixed international value, the gold industry is important to maintain foreign purchasing power. This is one reason why gold mining is important for the fragile economy of Bolivia and why it is very challenging to completely ban gold mining in Bolivia. However, the Coroico River area has to be protected from the destructing impacts of the mining industry, and therefore it is very important to explore options to make gold mining more sustainable, in the social, but also in environmental aspects.

Social impacts of gold mining

(Gold) mining has a major social impact. The mining industry needs access to and control of extensive land and water quantities. This often results in conflicts with the nearby communities, (Perrault et al., 2014) and is the cause of social tensions between mine workers and local inhabitants (Campanini et al., 2018).
While the nearby communities are the ones who often show or try to show resistance to the mining industry, they are not the only stakeholders affected by the environmental impacts of the mining industry on water quality, quantity, and access. The entire area downstream of the mining activities must cope with the impacts (Perrault et al., 2014b).

According to Swyngedouw (2009), these attributes of water rights, access, use, flow, and quality are a result of the (dis)balance of social power relations. Consequently, these features contribute to those power structures.
While on one side the mining actors who profit from the mineral extraction, often state that the mining industry generates jobs and contributes to a better infrastructure, on the other side there are the local inhabitants who experience the destructive impact of mining on their living environment.
Besides the increase of social tensions due to the unequal distribution of environmental resources and the disbalance in power relations, mining often increases illegal practices. A lot of the mining cooperatives in the La Paz department are not registered and therefore illegal. (Gold) mining also results in other illegal activities like gold smuggling, precursor smuggling, mercury smuggling, human trafficking, and illegal prostitution (Campanini et al., 2018).

Environmental impacts of gold mining

Gold mining impacts its environment in different manners, one of the more well-known impacts is mercury pollution.
Gold mining in Bolivia can be divided into two main methods. There is mining in the mountains (mountainous mining) and mining in the riverbanks (alluvial mining) (Inicio, n.d.). In both forms of mining, mercury is often added to form an agglomerate with gold. The gold-mercury agglomerate is separated from the other particles, like rock or sand. Subsequently, the agglomerate is heated, and the mercury evaporates leaving only the gold. (Source: El caso de la minería aluvial del oro en Bolivia la destrucción de nuestros ríos y bosques).
Mercury is extremely toxic, at room temperature mercury evaporates from its liquid state into a vapor (Daniel, 2022). It has been shown that mercury pollution negatively impacts human health and the surrounding ecosystems. Mercury exposure can result in irreversible breathing complications and brain damage (Mercury (Elemental): Lung Damaging Agent | NIOSH | CDC, n.d.).
Besides the effects mercury has on the miners who work with it, it also affects the water quality. Mercury does not break down into other substances but accumulates in the ecosystem and poses a threat to the health of the river catchments where the mining takes place (Mercury (Elemental): Lung Damaging Agent | NIOSH | CDC, n.d.).
There are many downsides to the use of mercury in mining. This is why in the last decades there has been an increase in regulations, limiting the use of mercury in South America (Daniel, 2022).
However, Bolivia is one of the few countries in South America which does not have a ban or specific regulations for the use of mercury (Daniel, 2022). The facilitation of the use of mercury is one of the reasons that Bolivia has become increasingly popular for gold mining (Daniel, 2022).
The water quality is not only compromised by mercury pollution but also by sediment and liquid and solid waste from the gold mining industry. Organic waste includes waste from mine sanitary facilities, dead underwater vegetation, and oils and greases from the operation and maintenance of machinery.
In addition to the effects on the water quality, there are several other negative impacts of mining on the environment. The excavations for the mining industry can result in riverbank erosion or alterations of the river flow due to the occupation and diversion of channels.
Mining can also impact the air quality, due to emissions of particulate matter, gases, and vapors generated in the mining operations (Campanini et al., 2018).
An increase in the risks of floods and avalanches due to damming caused by waste, unused material, and erosive processes is another negative aspect caused by mining (Campanini et al., 2018).
These various impacts affect the quality and diversity of the flora and fauna in the unique Yungas ecosystem (Campanini et al., 2018).

Study area

One place in the La Paz department where gold mining takes place is the Coroico River catchment (CRC) (see Map 2).

Map 2: Coroico River catchment (*Inicio*, n.d.-b)

The CRC originates between the towns Guanay and Teoponte and flows through the La Paz department. It has a surface of 5.356,68 km^2 and flows through four different municipalities; Coroico, Caranavi, Guanay y Teoponte (Ortuño et al., 2021). The CRC is located within the Amazon Hydrographic Region and is characterized by Puna grass and shrublands in the upper part of the CRC, with several freshwater reservoirs such as wetlands and marshes. Transitioning to the middle zone, the landscape changes in the Yunga's rainforest. (Navarro & Ferreira, 2007). The CRC is home to over 59. 996 people. Water is needed for domestic purposes as well as for agricultural activity and for industries such as the mining industry. Environmental pollution results from inadequate management of both solid and liquid waste, the overuse of agrochemicals in monoculture farming, and improper application of mercury in mining operations. These factors contribute to the pollution of water resources and impact livelihood systems in the CRC.

Parts of this thesis research are executed in collaboration with Cáritas Coroico. Caritas Coroico is an institution of the Catholic Church that works in the CRC on various projects for disadvantaged people (QUIÉNES SOMOS – Cáritas Coroico, n.d.).

One of the projects of Cáritas Coroico is called the 'Mi Cuenca Mi Casa' (MCMC) project, which means My Catchment My Home´. This project focusses on the development of Integrated Water Resources Management and Comprehensive Management of the CRC.

When Cáritas Coroico started the MCMC project they identified five main problems in the CRC:

1) poor solid waste management; 2) water contamination from mining activities; 3) contamination from untreated sewage; 4) contamination from pesticides and the advance of the agricultural frontier; and 5) lack of drinking water (Ortuño et al., 2021).

Caritas Coroico constructed a master plan for the CRC. In 2019 they started the project in collaboration with Agua Sustentable and Prometa. One of the aims of the collaboration is to reduce the negative impact of gold mining on the water quality in the CRC.

From 2019 Caritas started to examine the water quality and in the years 2019, 2020, 2021, 2023, and 2024 they took water quality measurements.

Aim of the research

All in all, gold mining has various social and environmental impacts. Social impacts include a disruptive power balance and social tensions. Environmental impacts include water pollution, river flow alterations, and soil degradation.

The goal of this research is to gain more insight in the impact of gold mining in the CRC. The focus of this thesis will be on the impact of gold mining on the river water quality and the perceptions of gold mining of local stakeholders. Furthermore, this research will reflect on the possibilities of reducing the negative impact of gold mining on the CRC in the future.

This will result in more awareness of the change in water quality, a better understanding of the stakeholders' interests, and the possibilities to reduce the negative social and environmental impact of gold mining in the CRC.

Methodology

Research objective

This research will enhance the awareness of the social and environmental impact of gold mining in the CRC in Bolivia, by investigating the changes in water quality and perceptions of different stakeholders on the social and environmental impact of gold mining. Besides this, the research will contribute to integrated river management by reviewing the options to reduce the negative social and environmental impact of gold mining in the CRC.

General research question (GRQ)

How does gold mining impact environmental and social aspects in the Coroico River catchment and what are the possibilities for the future of gold mining in the Coroico River catchment?

Specific research questions (SRQ)

1. How did gold mining affect the water quality of the Coroico River catchment from 2019 to 2024?
2. What are the different perceptions of the environmental and social impact of the gold mining industry in the Coroico River catchment?
3. What are possibilities for the future of the gold mining industry in the Coroico River catchment?

Data sources

For this research, four main data sources were used.

The first data source is secondary quantitative data of the water quality measurements, which Cáritas Coroico has collected. Besides this, primary qualitative data were used from the surveys and interviews that the researcher conducted with different stakeholders. Scientific literature, which is secondary qualitative data, was also used for this research. The final data source used for this research was observations the researcher made in the time she spent in the study area, this is a primary, qualitative, and descriptive data source.

Methods of data collection

The research was divided into four phases.

1. Firstly, literature was gathered to gain a general idea of the situation regarding the gold mines in the CRC, this information was used to construct the research questions and the focus of the research. At the end of the first phase, a research proposal was made.
2. In the second phase of the research, the situation was explored locally. Partaking in activities of the 'Mi Cuenca Mi Casa' project of Cáritas Coroico helped the researcher to understand the specificities of the situation in the CRC. At the end of this phase, the research proposal and its research questions were adjusted to fit the local circumstances.
3. In the third phase the researcher collected data by conducting interviews and surveys with various stakeholders. Besides this, the researcher had a supporting role with the data collection for the annual water quality campaign of Cáritas Coroico. This helped the researcher to gain more insight into their methods for the water quality measurements.
4. In the fourth phase the data was analyzed and the research questions were answered.

Collecting data for SRQ1

The first RSQ examines how gold mining impacts water quality. Since 2019 Caritas Coroico has been working on a campaign to monitor the water quality. From 2019 to 2024 they have been performing water quality measurements almost every year around April, except for 2022. Cáritas Coroico carried out the monitoring together with the UAC (Unidad Académica Campesina - Carmen Pampa), and in 2023 the Vice-Ministry of Water Resources and Irrigation (VRHR) joined their water quality campaign.

The following rivers were researched: River Huarinilla, river Siñari, river Santa Barbara, river Zongo, river Yolosa, river San Juan, river Quita Calzon, river Cajones, river Bronzini, river Yara, river Alcoche, River Zongo Tropica, river Yolosani and the Coroico river.

In the map on the right the locations of the measuring points from the first measurements in 2019, *La linea base*, are indicated in the river catchment.

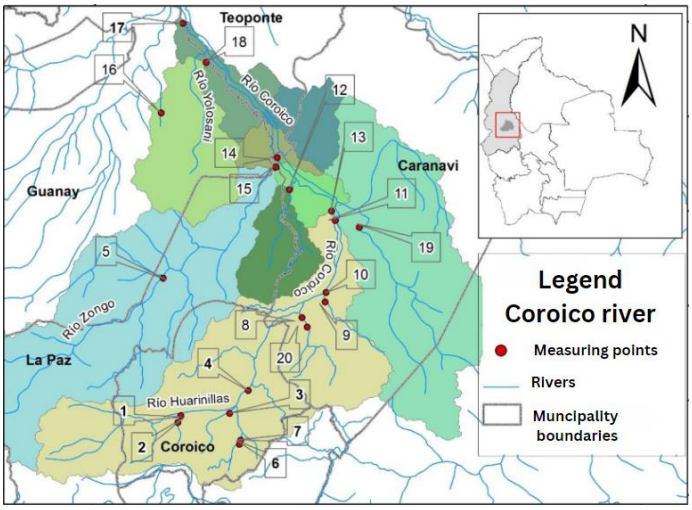
The following parameters were measured and analyzed:

Parameters measured in the field:

- Electrical conductivity
- Temperature
- Oxygen demand
- PH
- Turbidity
- The concentration of solid sediment

Parameters measured in the laboratory:

- Inorganic metals and metalloids: Pb, Cd, Ca, Mg, Na, Hg, As, Al
- Inorganic non- metals: S^{-2}, PO_4^{-3}, SO_4^{-2}
- Added organics: DBO_5, DQO, oils and fats



Map 3: Measure points of the water quality measurements in 2019 (Ortuño et al., 2021)

According to Freddy Flores from the MCMC project, the methods include taking the sample, transferring it to the laboratory, and measuring it using the Hach reagent packs for each parameter, each with a different treatment process, followed by the reading on the spectrophotometer. Three repetitions are made with each sample and the average is noted. Unfortunately, Cáritas Coroico doesn't have the technical data of the measurements like detection limits or measurement errors.

The data from these measurements were analyzed and put into perspective regarding the CRC. To establish to what extent gold mining is responsible for the change in water quality other possible causes for the changes in water quality were also addressed.
Not all points were measured every year. This is because the time and resources available for the measurements varied per year: the available time and the importance of various points determined which points were measured.

Collecting data for SRQ2 and SRQ3

Because of the impact gold mining has on the environment and communities in the CRC, there are various stakeholders with different opinions on and interests in gold mining. Three main stakeholders are local inhabitants, employees of mining cooperatives, and employees of municipalities. Besides these stakeholders, environmental organizations, investors, and national politicians are also important actors in the gold mining industry. However, due to the time available for this research, these stakeholders are not included in this thesis.

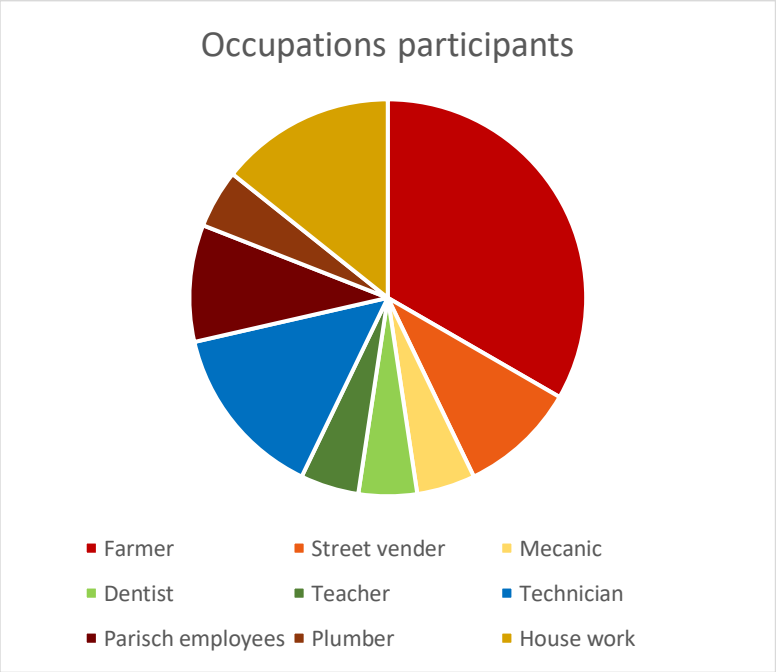
Surveys and interviews were conducted on the employees of mining cooperatives, local inhabitants, and employees of the municipality. The aim was to conduct sixty surveys, twenty with each stakeholder group, and a total of six interviews, two interviews with each stakeholder group. The surveys will allow for a larger sample size. The semi-structured interviews will elaborate on the surveys and will provide more body and depth to the surveys. In Annex 2 the survey used to examine the perceptions of the employees of the mining cooperatives is provided.

The survey for SRQ2 consisted of a total of twelve questions, eight content questions, and four questions about personal data of the participant to provide context for the researcher.
The first questions were about the social impact, these questions were statements that were provided to give more context about the social aspects.
In the question about environmental impact, the participants were asked to fill in how the mining industry in the CRC impacts all the social and environmental factors. With a five-point Likert scale from very positive to very negative.
The survey conducted with the employees of the mining cooperatives and the municipality members contained a second part to help answer SRQ3. The second part contained questions about the measures Cáritas Coroico is trying to promote to decrease the negative impacts of gold mining in the region. This part contained seven questions regarding these measures, their interest in these measures, the limitations of the implementation, and the feasibility of the measures.

Surveys with the local inhabitants

The target audience of the local stakeholder group is people living in the lower parts of the CRC who do not work in the mining industry. The surveys and interviews were conducted with people living in the lower part of the river catchment. The reason for this choice is that in the lower parts of the catchment, there is more mining, and therefore the people who live here will be more familiar with the effects of the gold mining industry.
The CRC is extensive, and it is difficult to establish a group of 20 participants who are representative of the more than 59 996 inhabitants living in the catchment. The first plan of the surveys for the local inhabitants was to perform all the surveys in a small village in the municipality of Guanay, Al Coche so that the surveys would be representative of that village. After the first time conducting surveys in Al Coche, 9 surveys were collected. Later the researcher was advised not to go to Al Coche unaccompanied, due to social tensions and there wasn't anyone available to accompany the researcher this time. This is the reason that the other surveys were executed in Guanay and Teoponte, two larger cities in the lower part of the catchment.

Since the willingness of people on the street to participate in the surveys was relatively low, most participants were contacted through acquaintances of employees of Cáritas Coroico.
The participant selection was influenced by a sampling and volunteer bias. These biases were mainly due to the willingness of the local population to participate. Besides this, due to the time and place the surveys were conducted, some members of the population had a higher chance of being included in the sample than others.
The people living in Al Coche who took part in the survey were acquaintances of an employee of the municipality of Caranavi. This resulted in a sampling bias.
Most of the people interviewed in Guanay were present at the town square in Guanay on the afternoon of June 19th, 2024. At this time there was a demonstration of the indigenous communities which also resulted in a sampling bias. It was more likely that people from indigenous communities would partake in the surveys.
Since all the people were asked in advance if they wanted to participate in the surveys, there was also a volunteer bias. With the interviews the volunteer bias was even higher, this is because the interviews take up more time which results in the fact that people are less willing to participate. One of the interviewees of the stakeholder group of local inhabitants was from Al Coche and the other one was from Caranavi. Caranavi is located in the middle part of the catchment area, however, the person knew a lot about the theme of mining because he was an environmental engineer and he knew a lot about the situation, for this reason, this person was considered to be helpful as an interviewee.
The largest group of participants were farmers, followed by houseworkers. The occupation the participants have could also impact their views, opinions, and interests regarding the mining industry.



Graph 1: Occupations of the local inhabitants who participated in the survey

Surveys with the employees of mining cooperatives

The mineworkers participated in the surveys during activities of the 'Mi Cuenca Mi Casa' project of Caritas Coroico. These activities were workshops about 'Sustainable mining' in which the impact of mining on the CRC was discussed and several measurements the mining cooperatives could implement to make their mining more sustainable. The mining cooperatives that participated were all legal and registered. The fact that these mining cooperatives participated in the workshops could indicate that they already have a certain interest in improving the sustainability of their working methods. For these reasons, they are not representative of all the mining cooperatives in the area.
In total the researcher was able to collect survey data from thirteen employees of different mining cooperatives. Eight people are working on the mining site, four employees are part of the secretary and two are the directors of cooperatives.

The participants were from five different mining cooperatives (coop): one from Coop CAUCE XII, two from Coop Minera Aurifera Esperanza R.L., one from Coop Central Zongo Tropical R.R., one from Coop Esmeralda de San Francisco, and seven from Coop Union Minasa. One of the participants was female and the other participants were male, from the observations of the researcher this male/female ratio is representative of the mineworkers in the area.
All participants have been working in the mining industry for more than seven months and more than half have been working in the mining industry for more than five years. So, it is assumed that the participants have sufficient knowledge of mining practices and the techniques that are currently used.

Surveys with the employees of municipalities
In the lower part of the river catchment, there is more alluvial gold mining, and the effects of gold mining are more visible in the lower part, this is the reason that it has been chosen to conduct surveys and interviews on the municipalities in the mid and low part of the CRC. These municipalities are Caranavi (middle part of the catchment, Teoponte, and Guanay (lower part of the CRC). It has also been chosen to focus only on the employees who have to deal with the issues of gold mining due to their function within the municipality.
Because the municipality of Caranavi is the largest, most of the participants are from this municipality. The initial aim was to collect twenty surveys from municipality members, however in the municipalities of Caranavi, Guanay, and Teoponte together there were only thirteen municipality members who were involved with gold mining within their function. This is the reason that thirteen surveys were conducted instead of twenty. There were two municipality members from Guanay, two from Teoponte, and nine from Caranavi.

Interviews
The interviews lasted about forty minutes, were semi-structured, and delved deeper into the topics of the survey questions. The following people have been interviewed to answer this research question: A local inhabitant of Al Coche (LA), a little community in the lower part of the RC. A local inhabitant of Caranavi (LC), a city in the middle part of the river catchment. Two employees of the Municipality of Caranavi (MC1 and MC2). Two mineworkers (MW1 and MW2) have also been interviewed. However, due to their available time and willingness to participate in this interview, a more informal approach has been chosen.

The measurement validity

The measurement validity of this research is high since there are a variety of data sources used. The multiple data sources allow cross-referencing and the use of triangulation.
It is important to note that the researcher is not fluent in Spanish, which posed some challenges regarding the interviews. To optimize the interviews the questions were well prepared and recorded.
It has been chosen to perform the questionnaires offline. This choice has been made because this way it is easier to make sure the right target audience is reached. However, due to the presence of the researchers, there is also a higher chance for socially desired answers.
Some of the water quality measurements were repeated this year. The researcher could partake in the measurements. Thereby the method of the measurements could be observed and, the validity of the previous measurements performed by Caritas could be assessed.

The researched mining cooperations were all legal cooperations and the cooperations already joined the project of Cáritas. Therefore, it could be that they are more willing to work on the sustainability of mining than the average mining cooperative. The relatively small research group results in a sampling bias and affects the validity of the research. How much the validity is affected depends on the comparability of the different mining cooperations in the area. The researcher established that the main difference between mining operations is whether they are legal or illegal. Besides this another important difference between mining operations is whether the operation is private, from the state, or a cooperative (see Table 1).
Despite these differences, and some other nuanced differences between these mining actors, the researcher assumes that, since all these mining actors share the same goal of making money through the extraction of gold, they will also share generally the same opinion.

Table 1: Mining actors in 2006 and 2022 (CEDLA et al., 2016)

Mining actor	2006	2022
Private	54,30%	36%
Cooperative	44,90%	57%
Owned by the state	0,80%	6%

The internal validity of SRQ1 will be high, assuming the data measurements performed by Cáritas Coroico are performed correctly. The answer to SRQ1 provides a clear answer to the question of how gold mining impacted the water quality in the CRC. The external validity is moderate. It can be expected that in other river catchments where gold mining takes place, generally the same processes of changing water quality occur. However, due to the different composition of substances in the water and soil and differences in working methods of mining companies in other areas, the impact on the water quality could differ.

The external validity of RSQ2 and RSQ3 will be moderate. The research will focus on one river catchment and the constructed framework will be focused on the two mining cooperatives that participate in the 'Mi Cuenca, Mi Casa' project of Coroico.
However, the study will provide a general framework on how to address the motivation of mining cooperations and their investors, to work towards a more sustainable approach. Expectedly, it will be possible to use the constructed approach (with some adaptations to the local circumstances) in other similar cases with mining actors.

Theoretical & Conceptual Framework

In this section, we will examine each research question and establish its corresponding indicators. This process involves an examination of theoretical frameworks and a detailed exploration of key concepts and definitions essential for a comprehensive understanding of each research question.

Water quality:

When analyzing the water quality, it is important to first determine what water quality means.
Water quality refers to the physical, chemical, thermal, and biological characteristics of water, often evaluated based on its suitability for human activities such as consumption, recreation, and aesthetic purposes. It influences all aspects of the aquatic ecosystem, and what constitutes good water quality can vary significantly between different organisms. Therefore, defining water quality and establishing standards that meet all needs is complex. For instance, the water quality parameters necessary for human drinking water differ considerably from those needed for agricultural irrigation (Ritchie & Schiebe, 2000). There are water quality standards for ecosystems and aquatic environments as well as for drinking water. Since the river water is used as a source of drinking water for some Indigenous communities the water quality will be assessed on guidelines for drinking water as well as on guidelines for water quality concerning the aquatic ecosystem.

A waterscape as a socio-spatial configuration:

One of the concepts needed to disentangle the complexity of gold mining in the CRC is a waterscape. According to Budds and Hinojosa, a waterscape, as a “socio-spatial configuration,” is formed through the combination of social and geo-ecological processes, which interrelate (Perrault et al., 2014).
The concept of waterscapes is defined by the interactions between social and geo-ecological processes that often extend beyond river catchments and valleys. Therefore, waterscapes can include distant social or natural processes, social relations, institutions, or artifacts that are not physically close to a specific catchment.

In the context of mining, this means that mining activities are integrated within intricate economic, political, and hydro-ecological networks that go far beyond the local water catchment or immediate area. This encompasses "upstream" connections such as capital investment, diversions across water catchment, and labor influx into mining centers. It also involves "downstream" connections like water pollution, social unrest, and state royalties (Perrault et al., 2014). Consequently, the waterscapes of mining in the Andes include the local communities and landscape affected by a mine and the legal political, and social frameworks governing water, land, and mineral rights (Perrault et al., 2014).

Gold mining and sustainability

What is sustainable mining, and does it even exist? According to the organization Friend of the Earth, which has developed a certification for sustainable mining, Sustainable mining refers to the minimization of negative environmental, economic, and social impacts of mining activities and the limitation of extraction rates that will not compromise the potential needs of future generations. There are four main areas in which sustainable mining can be applied, namely economic, social, cultural, and environmental. (SUSTAINABLE MINING | Friend of the Earth, 2023)
However, it is important to note that total sustainable mining does not exist, since gold mining is the extraction of an ending resource.

SRQ1

In the first research question, it is asked to what extent gold mining impacts water quality. To research this, data from the water quality control campaign of Caritas Coroico will be used (2019-2024).
The data will be put into graphs and figures so that the data is presentable and that Caritas Coroico can use the data to enhance awareness of the change in water quality. Besides this, a format was created in XL for Caritas Coroico to use for the visualisation of their data.
After this, the changes in water quality over the recent years were examined and the measurements have been put into perspective of the CRC.
The points higher in the catchment will be compared with the points lower in the catchment and water quality changes over the years will be established.

SRQ 2

The second research question asks what the perception is of the mineworkers from various mining cooperatives, employees of the municipality of Coroico, Caranavi, Teoponte, and Guanay, and local inhabitants of the lower part of the CRC on the environmental and social impact of the mining industry.

To answer this question, it is important to first establish the meaning of perception. Perception is a psychological process through the experience gained by the five senses, individuals can process responses into positive or negative perceptions. Obtaining responses is obtained through the stages of selection, interpretation, and reaction (Erin, & Maharani, 2018).

To research the perceptions of the social impact several factors will be addressed. To establish these factors the research: Social impact assessment in the mining sector: Review and comparison of indicators frameworks of Lucia Mancini was used (Mancini & Sala, 2018b).
Because this research contains a lot of social indicators, and the focus of this research will be mainly on the environment a selection is made, based on the indicators which are most likely to influence the transition to sustainable gold mining. The following indicators have been selected:

- Income
- Business
- Criminality
- Social tensions
- Employment
- Skills and education
- Poor working conditions
- Infrastructure

Because the terms criminality and social tension can provoke intense reactions or even come across as disrespectful these terms were replaced by social connections and illegal activities. To provide more context, the social aspects are asked in the form of a statement, this makes it easier to understand for the participants of the survey.

To research the perceptions of the environmental impact the following factors will be addressed.
These factors are established based on the Plan Director de la Cuenca del Río Coroico.

- Water quality
- Water availability
- Soil cover
- Soil fertility
- Preservation of flora and fauna
- Biodiversity
- Health of people
- Environmental hazards: Erosion, landslides, Inundations

SRQ 3

For the third research question: What are the possibilities of the future of gold mining in the CRC? Several possibilities to reduce the negative impact of gold mining will be addressed. Cáritas Coroico currently is trying to implement several measures. The feasibility and limitations of these measures will be addressed.

Results 1: Effects of gold mining on water quality of the Coroico River catchment

To answer the following research question: How did the water quality of the CRC change from 2019 to 2024 and to what extent is this due to gold mining? Data of water quality measurements from the years 2019, 2020, 2021, 2023, and 2024 of rivers in the Coroico catchment, were analyzed. These measurements were executed by Cáritas Coroico. In 2020 and 2021 Cáritas Coroico carried out the monitoring together with the UAC (Unidad Académica Campesina - Carmen Pampa), and in 2023 the Vice-Ministry of Water Resources and Irrigation (VRHR) joined their water quality campaign.

To put the data into the perspective of the river catchment it is important to first discuss the main activities of the CRC and address the water uses in the CRC.
Then per parameter, its relationship with and impact on the water quality will be established. The development of the changes per parameter over time and from high to low in the catchment will be discussed.
The causes of the changes in water quality will be addressed and the (possible) relation of the water quality changes with the mining industry will be examined.

Characteristics of the river catchment

Agriculture is the largest economic activity in the river catchment, the main crops used for cultivation are coca, coffee, rice, citrus fruits, avocado, banana, and cacao (Pastoral Social Caritas Coroico, 2020). Other economic activities are related to mining, tourism, transportation, and construction.

There are large differences between the levels of water supply services in the river catchment. Most towns and villages are supplied with a domestic water service via water pipes. The water sources are rivers or other water bodies upstream. The water is not treated, only filtered on sediment. Therefore, the domestic water supply is not used as drinking water but only for other purposes like washing clothes, cooking, and personal hygiene.
The uses of the river water of the CRC are visualized in Annex 1.

Not the entire water catchment has a sewage system, presumably more than 80% of the inhabitants of the river catchment use latrines or rustic bathrooms connected to a septic chamber or cesspit which are sometimes emptied in water bodies. During the water measurements, one location close to Yolosa was encountered where it appeared that latrine waste was being dumped in the river. The people who don't have a domestic water supply also bathe, do their laundry, and wash their cars in the rivers, these activities affect the water quality.

Figure 1: People washing their clothes in Río Yara close to Caranavi

Another activity in the river catchment which impacts water quality is the mining industry. Especially in the lower parts of the river catchment, parts of Caranavi, Guanay, and Teoponte where the gold mining industry has immensely intensified over the past decades, there is expected to be a change in water quality (Pastoral Social Caritas Coroico, 2020). Research by Abdul-Wahab and Marikar (2012b) the connection between gold and mining heavy metal pollution was established. This heavy metal pollution amongst other changes in water quality like an increased concentration of solid sediments are expected impacts of the mining industry on water quality in the CRC.

Other economic activities in the CRC which has impact on the water quality are agriculture and the construction industry (Pastoral Social Caritas Coroico, 2020).
Agriculture affects the water quality mainly due to nutrient runoff from fertilizers, pesticides, and herbicides.
Fertilizer contains nitrogen and phosphorus, and heightened nitrogen and phosphorus concentrations can cause eutrophication in water bodies, this can lead to the domination of certain water plants and result in oxygen depletion of the water (Environmental Protection Agency, n.d.).
The chemicals used in pest and weed control can run of into nearby rivers, where it contaminates the water and harms aquatic life (Environmental Protection Agency, n.d.).
There are also sand excavations, for the construction industry in different parts of the CRC.
According to research from Bhattacharya et al. (2019), sand mining can result in an increase in TSS and turbidity.

All these different activities in and around the rivers in combination with insufficient water management and climate change have resulted in a deterioration of the water quality and quantity of the river catchment in recent years (Ortuño et al., 2021).
To map the water quality and changes in water quality Caritas Coroico started with water quality measurements in 2019. The results of these measurements will be discussed and analyzed in the next section.

Electrical conductivity
Electrical conductivity expresses how easily an electrical current can pass through the water (Electrical Conductivity and Resistivity | US EPA, 2024). Electrical conductivity (EC) is affected by different factors. The concentration of dissolved charged chemicals in water and the temperature. The concentration of the dissolved solids is impacted by the soil and groundwater flow. The rainwater, or groundwater flows dissolve and pick up chemicals along the way. The longer the residence time in the soil the more chemicals of the soil are dissolved in the water. The electrical conductivity can also be influenced by human activity. For example, by dumping sewage water, agricultural chemicals, or due to water contamination from mining (*5.9 Conductivity | Monitoring & Assessment | US EPA*, n.d.). An increase in EC can indicate pollutants. A sewage leak, agricultural runoff, or mining can increase the EC. Due to these activities, additional ions such as chloride, phosphate, mercury, and nitrate are released. However other polluting events, such as an oil spill, decrease the EC. Therefore, a higher EC does not necessarily indicate a lower water quality (Pomelo, 2022).
In Annex 3 the results of the conductivity measurements are visualized and the points are sorted from high to low in the catchment. The EC values vary for the different points, however, there is a general trend of an increase in the EC over the years. What immediately stands out are the high EC values measured in point seven in 2020 and 2021, to establish this cause, further research is needed. The dip in EC value in points ten and nine is also remarkable, however, this can easily be explained by looking at the points of the location. Upstream of points nine and ten, the river converts with another river. It is likely that his river has a lower EC concentration and therefore dilutes the EC concentration.
There are no health or aesthetic values for electrical conductivity in water (Electrical Conductivity, n.d.). For this reason, it is not possible to draw a general conclusion about the water quality based on the EC.

Nevertheless, with the fact that the EC of water bodies such as streams have a conductivity range between 0-200 µS/cm (Pomelo, 2022b) it can be concluded that there are no abnormal values.

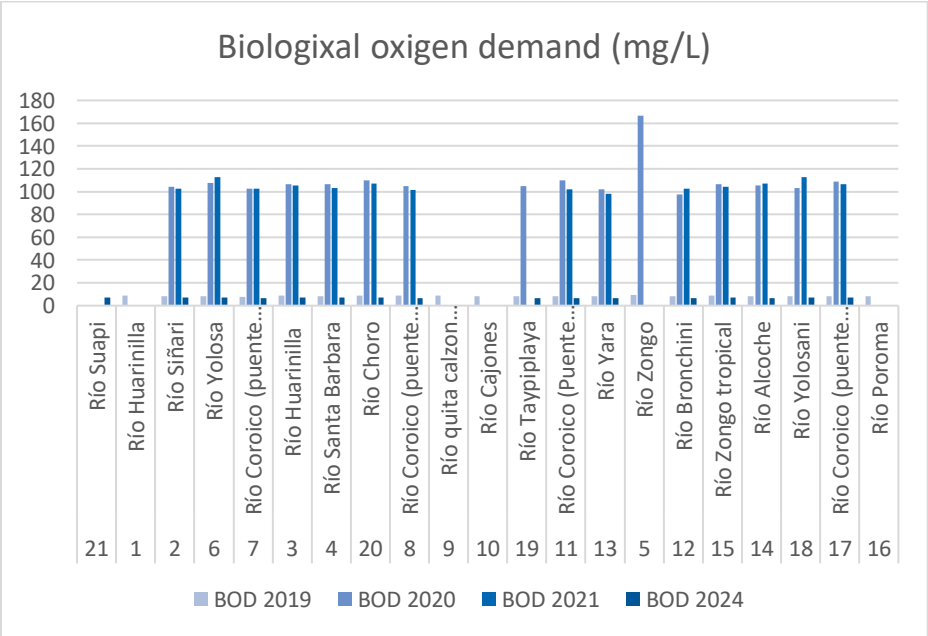
Temperature

Temperature is a critical water quality and environmental parameter because it affects the kinds and types of aquatic life, regulates the maximum dissolved oxygen concentration of the water, and influences the rate of chemical and biological reactions. In addition to its effects on aquatic organisms, high water temperatures can increase the solubility and thus toxicity of certain compounds (Fondriest Environmental, 2014). The temperature is impacted by the date, the time, and the place (higher or lower in the catchment) of the measurements. Since these differ per year and measurement point it is difficult to draw conclusions from the temperature changes in water quality within the different years and different locations in the river catchment. The changes in water temperature from 2019 to 2023 are visualized in Annex 4.

Oxygen demand

Biological oxygen demand (BOD) is the amount of dissolved oxygen needed by aerobic biological organisms to break down organic material present in a given water sample at a certain temperature over a specific period (Kaiser, 1998) A higher BOD illustrates that more oxygen is required to break down the amount of organic material in the river, therefore there is less oxygen available for the aquatic life. This is why a high BOD indicates poor water quality. Inversely, low BOD means less oxygen is being removed from the water, so water is generally purer (Biochemical Oxygen Demand - Water Education Foundation, 2020). The BOD was measured in situ in 2019, 2020, 2021 and 2024As can be observed in Graph 2 the BOD has significantly increased in 2020, in 2021 the BOD values stayed approximately the same, and in 2024 the BOD decreased again and reached more or less the same value as in 2021. The increase between the measurements in 2019 and 2020 could be due to increased mining and agricultural activity. The decrease in BOD would indicate a healthier river catchment and more aquatic life, however, according to local inhabitants the number of fish in the rivers has only decreased in recent years. There are two possible explanations. Either aquatic life needs more time to recover, or the measured results are incorrect.

Based on the water quality classification in the table below, the water quality is poor in 2019 and 2024 and very poor in 2020 and 2021.



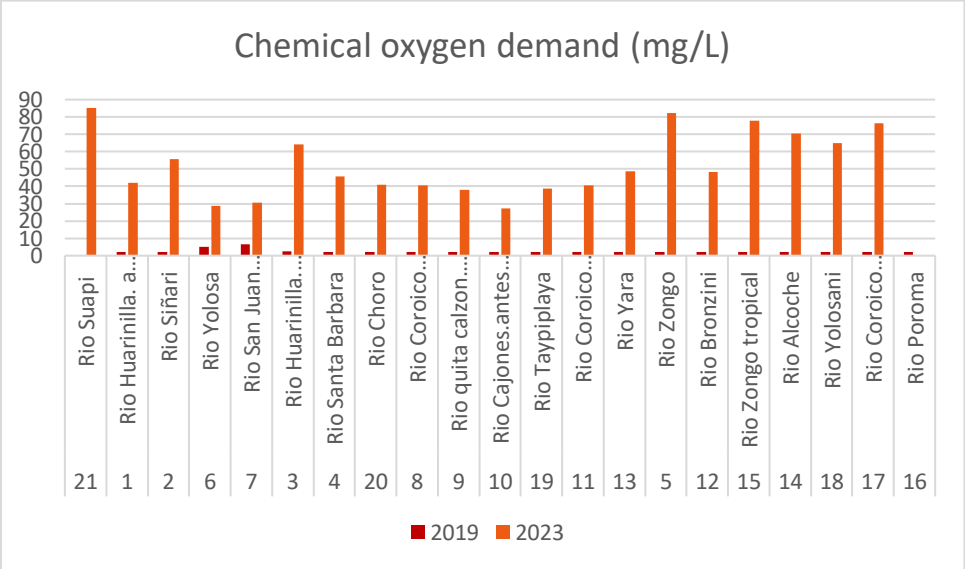
Graph 2: Biological oxygen demand (mg/L) at different points along the Coroico River catchment

BOD level in mg/ litre	Water Quality
1 – 2	Very Good: There will be much organic matter present in the water supply.
3 – 5	Fair: Moderately Clean.
6 – 9	Poor: Somewhat Polluted – Usually indicates that organic matter is present and microorganisms are decomposing that waste.
≥ 100	Very Poor: Very polluted – Contains organic matter.

Table 2 Water quality classification based on BOD level in mg/L (Choudhary, 2023)

Chemical oxygen demand

Chemical oxygen demand measures the amount of oxygen needed for the oxidation of all the organic and inorganic pollutants present in the water. Therefore, it is an important parameter when establishing water quality. (*Biochemical Oxygen Demand Vs Chemical Oxygen Demand*, 2024).
The permissible limit for COD is 250 to 500 mg/L (*Biochemical Oxygen Demand Vs Chemical Oxygen Demand*, 2024).
The COD has increased significantly between 2019 and 2023, this can be seen in the graph below. The cause of this increase is the increase in organic and inorganic pollutants, these pollutants are partly from the mining industry. Even though the COD has increased significantly, the COD per Liter is still below the permissible limits. However, it is important to keep monitoring the COD and to mitigate this trend of increasing COD.



Graph 3: Chemical oxygen demand (mg/L) at different points along the Coroico River catchment

pH

pH is a measure of the relative amount of free hydrogen and hydroxyl ions in the water. Water that has more free hydrogen ions is acidic, whereas water that has more free hydroxyl ions is basic. Since pH is affected by chemicals, a changing pH indicates a change in the chemical compounds of the water. The pH is measured on a logarithmic scale from 0 to 14, with each unit representing a tenfold difference in acidity or alkalinity (The Editors of Encyclopaedia Britannica, 1998). The recommended pH range for most fish is between 6.0 and 9.0 according to Fondriest Environmental, a research institute (Fondriest Environmental, 2013). The pH values measured are between 4,64 and 7,88, this means that the water is a bit more acidic than optimal for the aquatic life. According to the World Health Organization (WHO), the ideal pH level for different water supplies depends on the water's composition and the materials used in the distribution

system. Generally, this pH range is between 6.5 and 9.5. The cause of extreme pH levels can occur due to accidental spills, treatment failures, or inadequately cured cement mortar pipe linings (World Health Organization & Fawell, 2007). For the WHO standard of pH level for drinking water the water in the CRC is also too acidic, however, the WHO also noted that it is not necessary to propose a health-based guideline for pH (World Health Organization & Fawell, 2007). As can be seen in Annex 5, the pH fluctuates around the same value and no clear trends in changes per year or per location in the catchment can be observed. All in all, the pH values seem to be quite normal, and the fact that the pH is a bit more acidic than in most water bodies doesn't have a drastic effect on the health of the water catchment.

Turbidity

Turbidity measures how clear a liquid is by evaluating how much light is scattered by particles in the water. The more scattered light, the higher the turbidity. Turbidity-causing materials include clay, silt, organic and inorganic matter, algae, and microscopic organisms. Rainstorms wash particles into rivers, making the water muddy and increasing turbidity. High water flow can also stir up particles from the stream bed, raising turbidity levels. High turbidity affects light penetration and therefore ecological productivity, and habitat quality. When the turbidity of a water body is high the algae and other aquatic plants have less light and will be less productive, which in turn influences other aquatic such as fishes. Particles also attract pollutants like metals and bacteria, making turbidity a useful indicator of potential water pollution. Excessive turbidity in drinking water is visually unappealing and may pose health risks by providing shelter for pathogens, which can lead to waterborne diseases. (Source: U.S. Environmental Protection Agency). Even though local inhabitants and my colleagues said that they noticed a clear trend in increasing turbidity in the last years, consequently with the increase in mining, there is no clear trend visible in the measurements (Annex 6). During the turbidity measurements in 2024, the water samples used for the measurements were collected from the shore/ shallow part of the river. Due to the low water flow on the sides of the river, there will be fewer particles in the water than in the middle of the river where there is a higher water flow. More measurements should be performed with the same method to increase the database and form a sound conclusion on the trend of turbidity in the CRC.

The concentration of solid sediments

Sediment plays a major role in the transport and fate of pollutants and is a concern in water quality management. Toxic chemicals can become attached, or adsorbed, to sediment particles and then transported to and deposited in other areas. These pollutants may later be released into the environment.

Like can be seen in Annex 7, the amount of solid sediment in the water strongly varies and there is no clear trend. This can be explained by the method of measuring, the water collected for the measurements was collected from the shore or the place in the middle of the river which could be reached by stepping on stones. Besides this, the water monster collected was in or close to a river bend which also influences the flowing speed of the water and therefore the amount of sediments picked up by the water flow. If these measurements were all taken in the middle of a straight part of the river, then they could be compared properly.

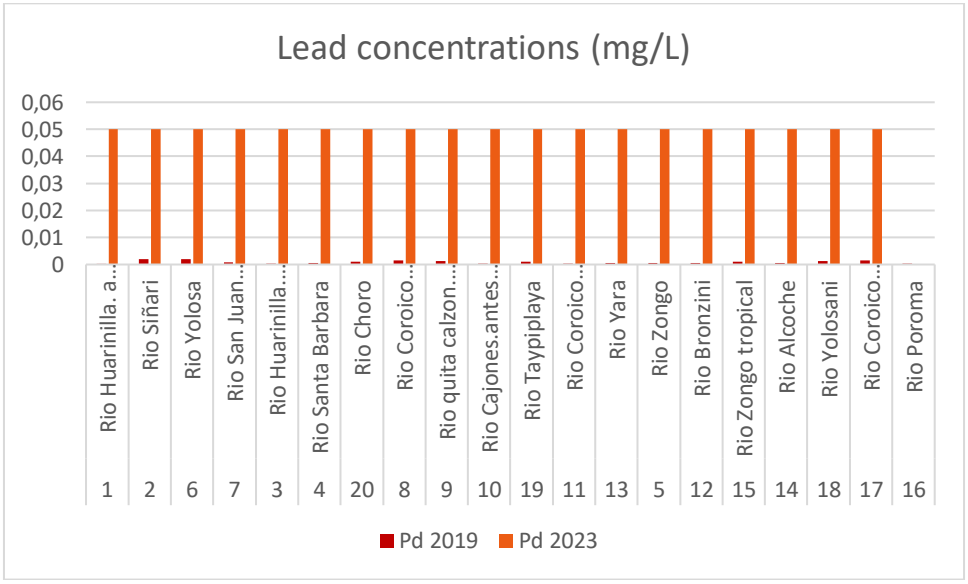
Lead

Lead (Pb) is a harmful metal found in the earth's crust. It can come from corroding pipes, brass faucets, artificial turf, and explosives. These can cause lead to enter our waterways. This pollution is a big problem, especially when water treatment doesn't work properly. High Pb levels in water are dangerous for both people and marine life. Even small amounts of lead can cause serious health problems. In children, it can lower IQ and slow down development. In adults, it can cause high blood pressure and infertility (Ricks & Twitty, n.d.). Major sources of environmental contamination include

mining, smelting, manufacturing, recycling activities, and the use of various products (World Health Organization: WHO, 2023).

The US Environmental Protection Agency has set the maximum contaminant level goal for Pb in drinking water at zero because Pb is a toxic metal that can be harmful to human health even at very low exposure levels. Pb is persistent, and it can bioaccumulate in the body over time (Basic Information About Lead in Drinking Water | US EPA, 2024). Pb is not only harmful to humans but also to aquatic life. Research showed that lead levels of 0.015mg/L harmed the development of aquatic life and levels of 0.0252mg/L increased the mortality rate of aquatic life (Ricks & Twitty, n.d.).

As can be seen in the graph below, the Pb concentration increased significantly between 2019 and 2023. Research from Pelletier et al. (2020) showed that gold mining significantly impacts Pb pollution. From this fact and the extreme growth of gold mining activities in the area, we can conclude that it is very likely that the cause of the increased lead levels is gold mining. The concentration of Pb measured in 2023 was 0,05 mg/L, double the amount that already resulted in an increased mortality rate, this is extremely worrisome.



Graph 4 Lead concentration (mg/L) in different points along the Coroico River catchment

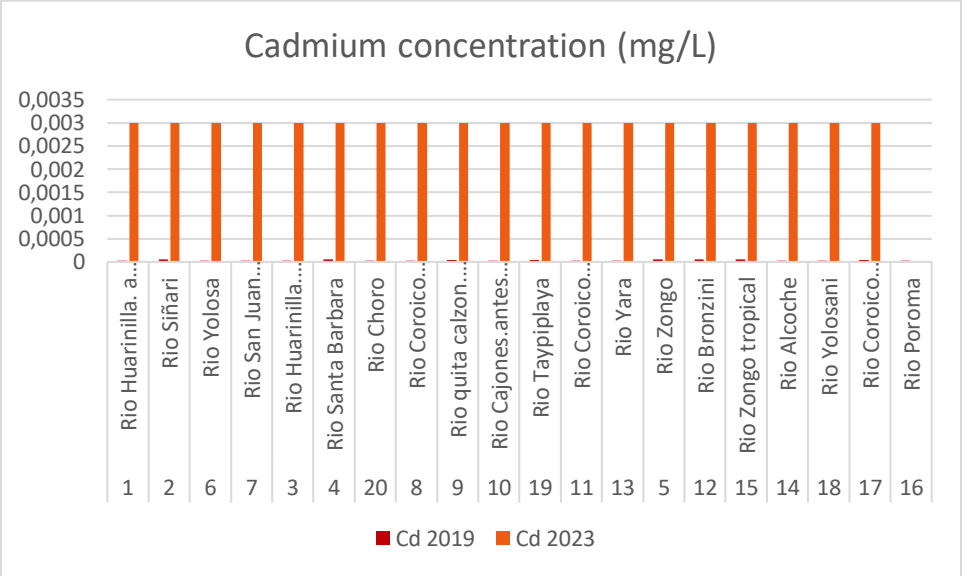
Cadmium

Cadmium (Cd) can significantly impact water quality and pose various health risks. It is a toxic heavy metal that can contaminate water sources through natural and human activities.

Cd is harmful to both freshwater and marine ecosystems. It is toxic to aquatic life, affecting species like fish, crustaceans, and algae even at low concentrations. The contamination levels considered safe are extremely low because of cadmium's high toxicity. Bolivia does not have specific regulations regarding the Cd concentration in drinking water. In Australia and New Zealand, the 95% protection level for freshwater ecosystems is set at just 0.2 µg/L (Australian & New Zealand Guidelines For Fresh and Marine Water Quality, 2000).

For humans, Cd in drinking water can cause serious health problems. Long-term exposure can lead to kidney damage, bone fragility, and increased risks of cancer, particularly lung cancer. It also impacts the nervous and circulatory systems (Water Quality Association, 2022)

One cause of Cd pollution is industrial activity, such as metal plating, battery manufacturing, and plastic production (WHO, 2009). Other main causes of Cd pollution are Agricultural runoff, corroded plumbing, and mining operations (WHO, 2009). The latter mentioned, mining activities, especially those involving lead, zinc, and copper, can release cadmium into the environment. Improper handling of mining waste can lead to Cd water contamination (WHO, 2009). In 2019 the Cd concentrations were between 0,02 and 0,06 µg/L, these concentrations were below the protection levels. As can be seen in the graph below the Cd concentration drastically increased between 2019 and 2023. In 2023 the Cadmium concentration is 3 µg/L, which is fifteen times higher than the protection level for freshwater ecosystems of 0.2 µg/L (which can be converted to 0.0002 mg/L). The probable causes of this increase in Cd concentration in the river water are the increase in agricultural and mining activities in the CRC.

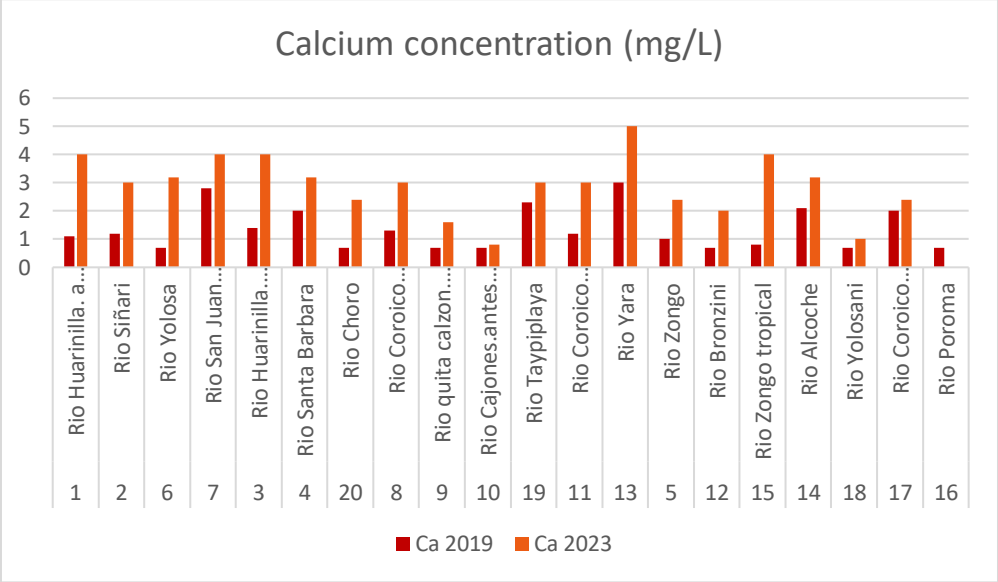


Graph 5 Cadmium concentration in (mg/L) at different points along the Coroico River catchment

Calcium

Calcium (Ca) naturally occurs in water, the main reason for this is the occurrence in the earth's crust (Bogardi et al., 2020). Besides occurring naturally, Ca can also get into water through human activities however, mining is not one of them. The main human causes of an increased Ca concentration are the construction and manufacturing industries (Bogardi et al., 2020). Ca is used in construction materials such as cement, brick lime, and concrete, and can be found in batteries and plaster (Bogardi et al., 2020).

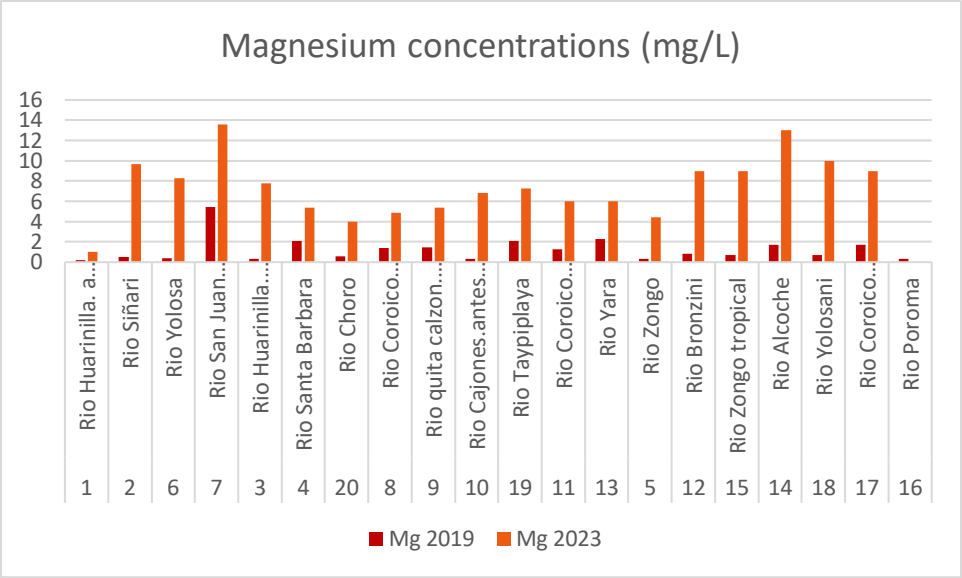
Ca contributes to the hardness of water (Bogardi et al., 2020). In drinking water Ca does not pose a threat for human health, however in extremely high concentrations calcium can disrupt ecosystems (Bogardi et al., 2020).
Rivers generally contain 1-2 mg Ca per Liter of water (Calcium (Ca) and Water, n.d.).
As can be seen in the graph below the Ca concentration increased between 2019 and 2023 in all the measure points. The probable cause of this increase is the construction industry in the area.
With an average of 2,9 mg Ca per Liter of water the Ca concentration is higher than the average Ca concentration for rivers. However, since there are no specific guidelines set regarding Ca pollution, and Ca has a low ecotoxicology this increase isn't a cause for concern.



Graph 6 Calcium concentration in (mg/L) at different points along the Coroico River catchment

Magnesium

Together with other alkali earth metals magnesium (Mg) is responsible for the hardness of water. If water contains a lot of alkali earth ions it is hard water and if it contains a little of these ions it is called soft water. Mg ends up in water naturally, because it occurs in rocks. Besides this, human activities can result in an increase in the Mg concentration in water. Human causes of Mg pollution are the use of magnesium in chemical industries, magnesium from fertilizer and from cattle feed. There are often no guidelines for magnesium content in drinking water because there is no evidence of Mg toxicity (Magnesium (Mg) and Water, n.d.). In the graph below can be seen that the Mg content of the water has increased since 2019, the increase in this concentration is probably due to the increase in agricultural activity in the CRC.



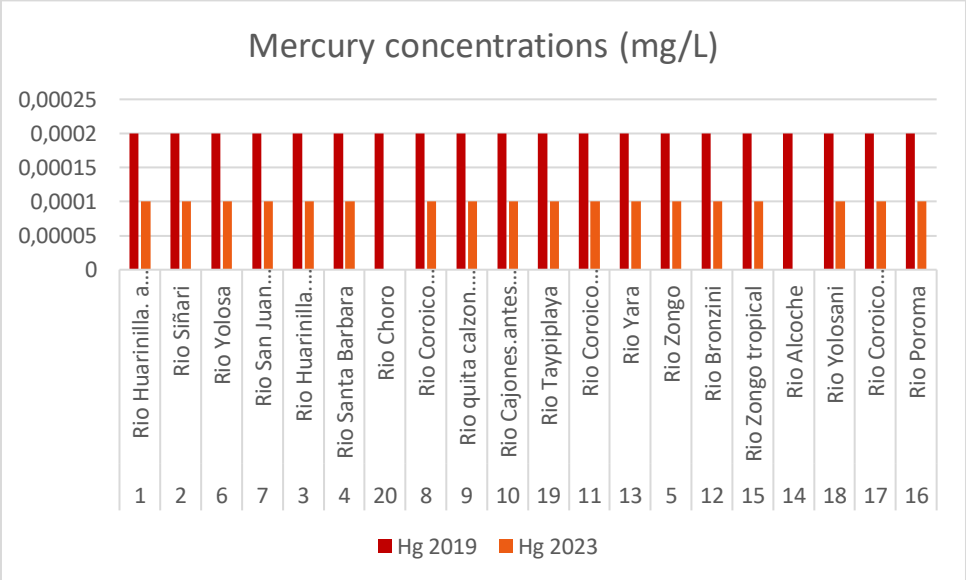
Graph 7 Magnesium concentration (mg/L) on different points in the Coroico River catchment

Mercury

Mercury (Hg) is an element that occurs in the water due to natural processes like volcanic activity. However, the use of Hg in industrial processes like mining has significantly increased the amount of mercury present in nature and in water. Naturally, the level of Hg in groundwater and surface water is less than 0.5 µg/liter (WHO, 2002).

The solubility of Hg varies: Elemental Hg vapor is insoluble, while mercury (II) Chloride is very soluble. Mercury (I) chloride is less soluble and mercury sulfide has a very low solubility (WHO, 2002). From these facts, we can conclude that only a small part of the Hg pollution ends up dissolved in the water.

In the Figure below we can see the results from the measurements. It is very striking that the Hg concentrations in 2023 are 50% less than in 2019, this is a very surprising result since the mining industry which is the main source of Hg pollution in the river catchment has only intensified. During the research, all employees of gold mining cooperations I spoke with said that they use mercury for the gold extraction. An explanation could be that they are more aware of the harmful impact of mercury pollution and use mercury more adequately.



Graph 8 Mercury concentration (mg/L) on different points in the Coroico River catchment

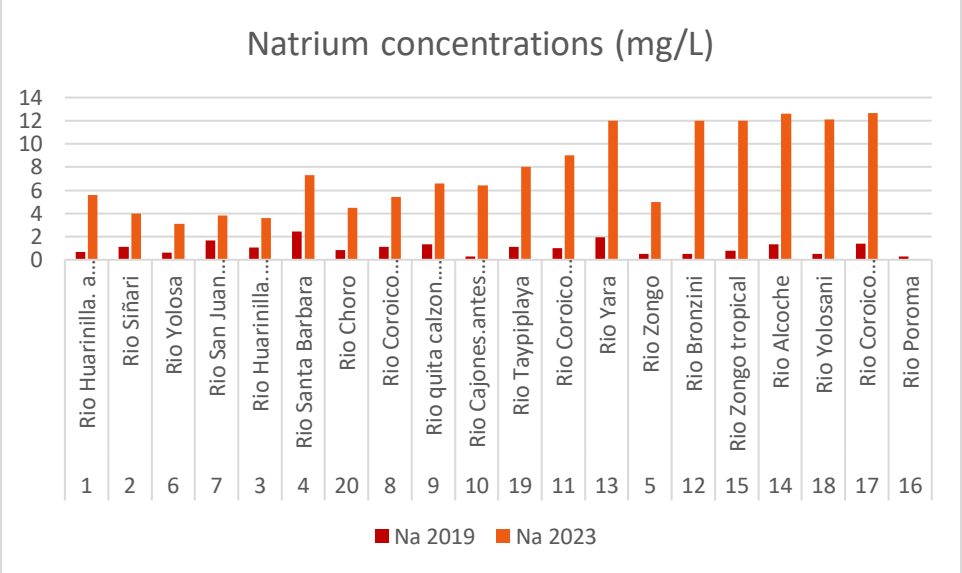
Natrium

Most freshwater bodies contain less than 20 mg of natrium (Na) per Liter. However, in some countries, levels can exceed 250 mg/Liter. Sources of Na in water include saline intrusion, mineral deposits, seawater spray, sewage effluents, road de-icing salt, and water-treatment chemicals. There are no health guidelines for the Na concentration in drinking water according to the World Health Organisation (WHO, 2003).

One of the main consequences of Na pollution is the change in water chemistry, resulting in increased salinity. This rise in salinity can create an inhospitable environment for freshwater species, leading to stress, reduced reproductive rates, and potentially mortality. Elevated salinity interferes with the osmoregulation processes of aquatic organisms, which is vital for maintaining their fluid balance and overall survival (Bhide et al., 2021). However, there are no specific guidelines for Na concentrations regarding the protection of aquatic life.

As seen in the graph below the Na concentrations increased immensely in all the locations where measurements took place. To establish the specific cause of the Na concentrations further research is needed.

What also can be seen in the graph is that the Na concentrations increase towards the lower part of the catchment. The Na concentrations still don't have abnormal values according to the WHO norm. It is not expected that this increase will have a big impact on aquatic life. However, if the trend continues the Na concentrations may harm the river ecosystem.



Graph 9 Natrium concentration (mg/L) at different points along the Coroico River catchment

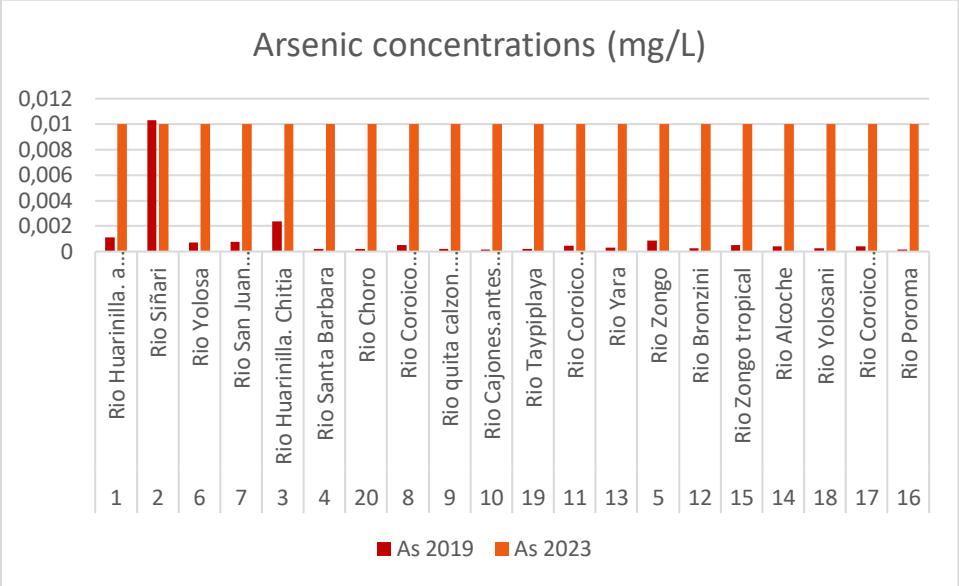
Arsenic

Arsenic (As) is a metalloid, a non-metallic with metallic properties. As is highly toxic in its inorganic form (World Health Organization: WHO, 2022), and is recognized as one of the most dangerous inorganic pollutants worldwide (Wang et al., 2022). As can wind up in river water through natural processes such as weathering and erosion. The concentration of As can be heightened due to human activities, such as mining, the use of pesticides in agriculture, or the use of fossil fuels (Jin et al., 2024). The WHO set a guideline for the maximum concentration of As in drinking water at 0,01 mg/L (World Health Organization: WHO, 2022).

As can also have an extreme impact on aquatic life and river ecosystems, it can result in reduced reproduction and growth, immune disorders, cell and tissue damage, and cell death in aquatic organisms (Byeon et al., 2021). The national recommended water quality criteria set by the EPA is 150 µg.

As can be seen in the graph below there is a severe increase in the concentration of As in the river water between 2019 and 2023 in all the measuring points, except for the point in Río Siñari, the As concentration has increased. According to the results of the measurements the concentrations of If

the concentration of As is still far below the guidelines for aquatic organisms however, the As values measured in 2023 are exactly the maximum concentration of As for drinking water. If the As concentration would continue to increase at this rate, extreme arsenic pollution will result in the disruption of the river ecosystem and the water will not be safe to utilize as drinking water. A study by Jin et al. (2024b) has linked gold mining to an increased As concentration. In the CRC, it is also likely that the increased amount of arsenic in the water is the result of gold mining.



Graph 10 Arsenic concentration (mg/L) at different points along the Coroico River catchment

Aluminium

Aluminium (Al) is the most abundant metallic element on earth and thus occurs naturally in water. Human activities like intensive industry and agriculture have been associated with a disrupted Al balance (Senze et al., 2021). The mobility of Al in water is influenced by water pH, sulfate, carbon dioxide, and organic matter levels (Senze et al., 2021).

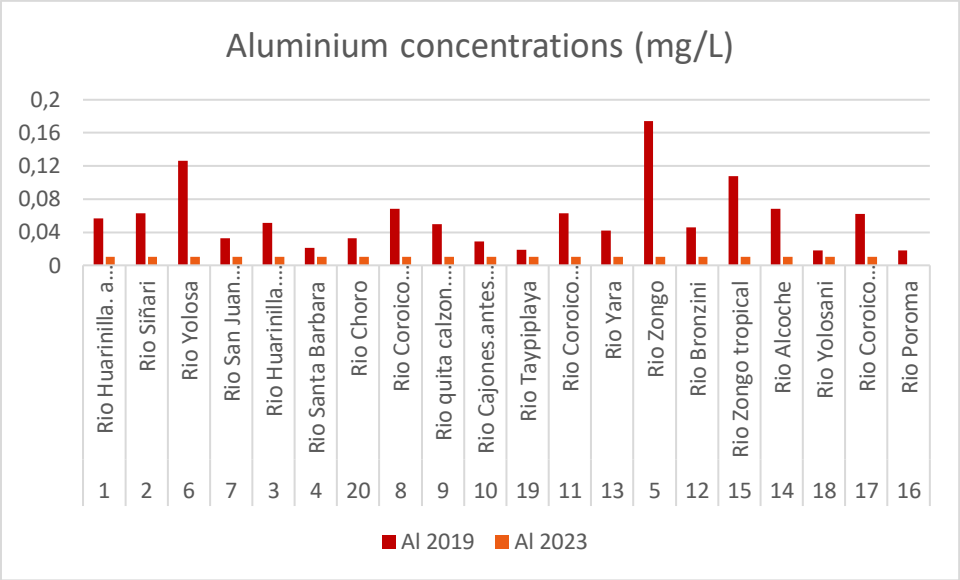
A health-based value mentioned in a report on drinking water quality by the WHO is 0.9 mg/L. However, they note that there are many uncertainties regarding the Al absorption due to its depending mobility (Chemical Fact Sheets: Aluminium, n.d.).

Al is present in various forms which are potentially toxic for aquatic organisms. Research from Botté et al. (2022) researched the effects of Al concentrations on aquatic organisms. The research showed that at a pH between 6 and 8, the ecotoxicity is lowest, this would be the case in most rivers in the CRC, which has an average pH value of 6,6. For fish, an increase in Al can have negative health effects like oxygen depletion, or liver and kidney damage. Freshwater invertebrates also suffer from Al exposure, affecting reproduction and survival (Botté et al., 2022).

According to the EPA's Water Quality Criteria, the chronic (harmful after four days of exposure) freshwater aquatic life criterion for Al is 0.087 mg/L at pH 6.5 to 9.0 (2018 Final Aquatic Life Criteria for Al in Freshwater | US EPA, 2024).

As can be seen, the Al concentration decreased between 2019 and 2023, in 2019 the Al concentrations roughly follow the same pattern as the Mg concentrations in the year of 2023.

In 2023 all the measured Al concentrations were 0,01 mg/L which is well below the criteria set by EPA. In the year 2019 Río Zongo, Río Zongo Tropical, and Río Yolosa were all above the critical value, which indicates that the Al concentrations could have harmed the aquatic life and with that the aquatic ecosystem of the river. Research from Abdul-Wahab and Marikar (2012) showed that there was a connection between gold mining and elevated Al levels in rivers, it is very likely that the gold mining industry also contributes to the Al concentration in the river water.



Graph 11 Aluminium concentration (mg/L) at different points along the Coroico River catchment

Sulfide

The sulfide (S^{-2}) concentration was only measured in 2023. In 2023 all the measuring points have exactly the same value for the S^{-2} concentration. This could be due to the detection limits and the measurements are invalid. For these reasons, I excluded this parameter from the analysis and did not use the data from this parameter to answer SRQ1. The data of the S^{-2} measurements can be found in Annex 8.

Sulfate

Sulfate (SO_4^{-2}) occurs in river water from natural sources, like erosion of minerals such as pyrite, volcanic activity, and atmospheric deposition. Human activities like Industrial discharge, mine drainage, agricultural runoff, and municipal wastewater can increase the amount of Sulfate present in river water (Zak et al., 2021).

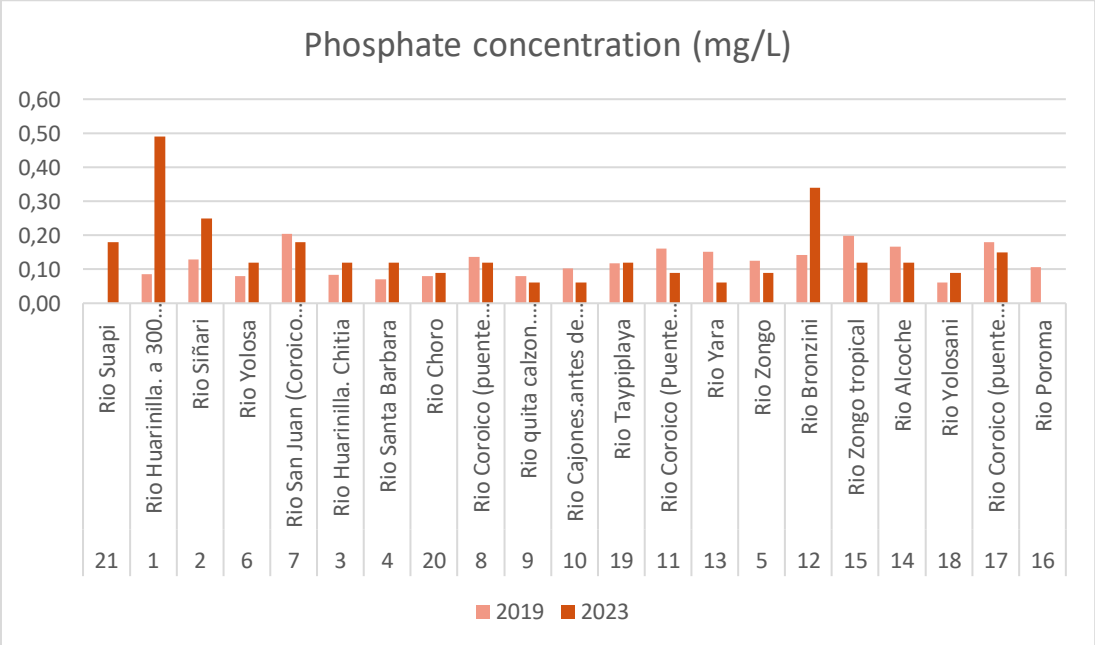
EPA guidelines for Sulfate in drinking water are 250 mg/L, however, this guideline is mainly based on aesthetic effects. In high concentrations, Sulfate can harm human health (*Sulfate in Drinking Water | Unregulated | US EPA*, n.d.). Increasing sulfate (SO_4^{2-}) concentrations in freshwater systems can significantly influence the biogeochemical cycles of carbon, nitrogen, and phosphorus. Research indicates that sulfate pollution has toxic effects on aquatic plants and animals, including fish, invertebrates, and amphibians (Zak et al., 2021). While specific guidelines for Sulfate in river water are not very common, Canada has established a sulfate guideline of 100 mg/L to protect aquatic life (*Canadian Council of Ministers of the Environment | Le Conseil Canadien Des Ministres De L'environment*, n.d.).

As can be seen in the graph in Annex 9 the Sulfate concentration increased for half of the measured concentrations between 2019 and 2023. For the other half, the Sulfate concentration decreased. To determine the specific cause of the changes in Sulfate level further research would be needed. However, all the sulfate levels in the CRC are fare below the guidelines, and therefore they do not form a threat to the water quality.

Phosphate

Orthophosphate (PO_4^{3-}) is the soluble form of phosphate and naturally occurs within water (*Phosphorus in Water, Measurement, Monitoring and Removal*, n.d.), this is also the form of phosphorus that aquatic plants require for nutrition and the only source directly used by aquatic

flora and fauna (Canadian Council of Ministers of the Environment, 2002). Orthophosphate is the phosphate form measured during the water quality campaign of Cáritas Coroico.
Sources of phosphorus pollution in freshwater bodies are agricultural runoff, runoff from urban areas, leaking septic systems, or discharges from wastewater treatment plants (*Indicators: Phosphorus | US EPA*, 2024). In excessive quantities, phosphate can result in eutrophication and algae bloom. This excessive algae growth can block the sunlight, and this causes problems for other aquatic organisms (*Indicators: Phosphorus | US EPA*, 2024). The WHO does not have a specific guideline value for phosphates in drinking water, as phosphates have a low toxicity. Phosphates are often added to drinking water to prevent corrosion in pipes and reduce lead and copper levels in water systems (*Guidelines for Drinking-water Quality, 4th Ed., Incorporating the 1st Addendum (Chapters)*, 2021).
There are no specific guidelines set for the phosphate concentration in river water. However, different countries have policies for the total phosphorus levels. The EPA recommends that total phosphorus concentrations in flowing rivers and streams should not exceed 0.1 mg/L to prevent eutrophication (Litke, 1999).
As can be seen in the graph below the orthophosphate concentrations often exceed the EPA recommendations for phosphorus levels, which means that the phosphate concentrations could harm aquatic life. Since the data collected only contained orthophosphate, the actual phosphorous levels are likely even higher. There is no clear trend in the development of the orthophosphate levels between 2019 and 2023.



Graph 12: Phosphate concentration (mg/L) at different points along the Coroico River catchment

Oils and grease
A single Liter of oil can contaminate up to one million Liters of water, posing significant risks to human health, flora, and fauna.
The behavior of the oil in water depends on its density: it may float, partially submerge, or sink in rivers, lakes, or streams (Water Contamination - Oil Spill in Lakes & Rivers - Ideal Response, 2023). Oil pollution can spread over the surface of the water if it floats, or over the surface of plants, soils, or organisms if it sinks, it spreads in a thin layer that obstructs the oxygen supply (Oil & Grease and DO) – UNICERT – a Partner of Managing Risk, n.d.).
Causes of oil and fat pollution are domestic wastewater, urban runoff, agricultural runoff, and industrial oil spills. Household activities, such as cooking contribute to oil and fat pollution. In urban

areas, runoff can contain oils and fat from spilled motor oil or petrol leaks. Runoff from agricultural lands can contain oils from farming equipment into rivers and improper handling of industrial discharges can also result in oil pollution (Shaffer et al., 2005).
Oil or fat concentrations as low as 1 to 10 mg/L can affect fish and other aquatic life (Masifwa et al., 2022).
As can be seen in the graph in Annex 10 the measurements in most of the rivers indicate a decreasing concentration of oils and fats between 2019 and 2023. In 2019 all, except for two points are below 1 mg/L and in 2023 all the measurements are below 1 mg/L.

Conclusion SRQ1

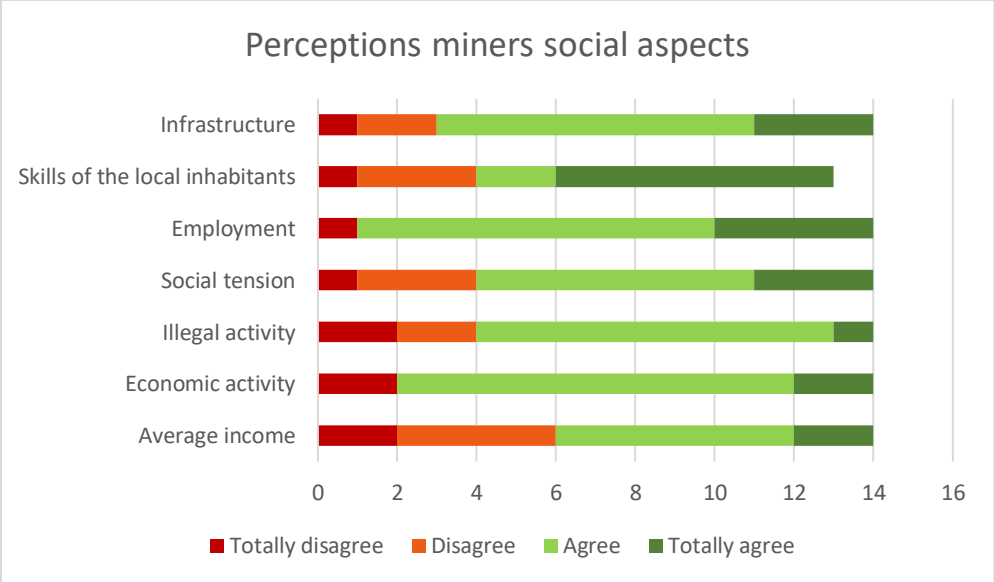
To conclude, there have been various changes in the water quality of the CRC.
The most important changes are the changes in toxic metal concentrations. There seems to be a significant increase in the concentrations of lead, cadmium, and arsenic in the river water. The gold mining industry is likely the cause of this increased heavy metal(liod) pollution. This increase in heavy metals is a threat to aquatic life and human health.
According to the results, there is a decrease in Mercury concentration in the water. This could be the result of more adequate mercury use in gold mining.
The COD has increased significantly, this indicates that the total sum of organic and inorganic pollutants present in the CRC has increased between 2019 and 2023.
There also have been other changes in the water content, which are less likely to negatively impact the water quality.

Results 2: Perceptions of stakeholders on the environmental and social impact of the gold mining industry in the Coroico River catchment

This chapter discusses SRQ2: What are the different perceptions on the environmental and social impact of the gold mining industry in the Coroico River catchment of employees of mining cooperations, employees of municipalities, and local inhabitants? To answer this question interviews and surveys have been performed. There is also a lot of information gathered through informal conversations with the participants of the surveys and through conversations with other local inhabitants. Besides these sources, observations of the researcher also helped to answer this question. First, the results of the surveys are discussed. The results of the collected data are discussed per stakeholder starting with the employees of the mining cooperatives subsequently, the perceptions of members of the municipality will be discussed and lastly, the perception of the local inhabitants will be discussed. After this, the perceptions will be compared, and a stakeholder analysis will be performed.

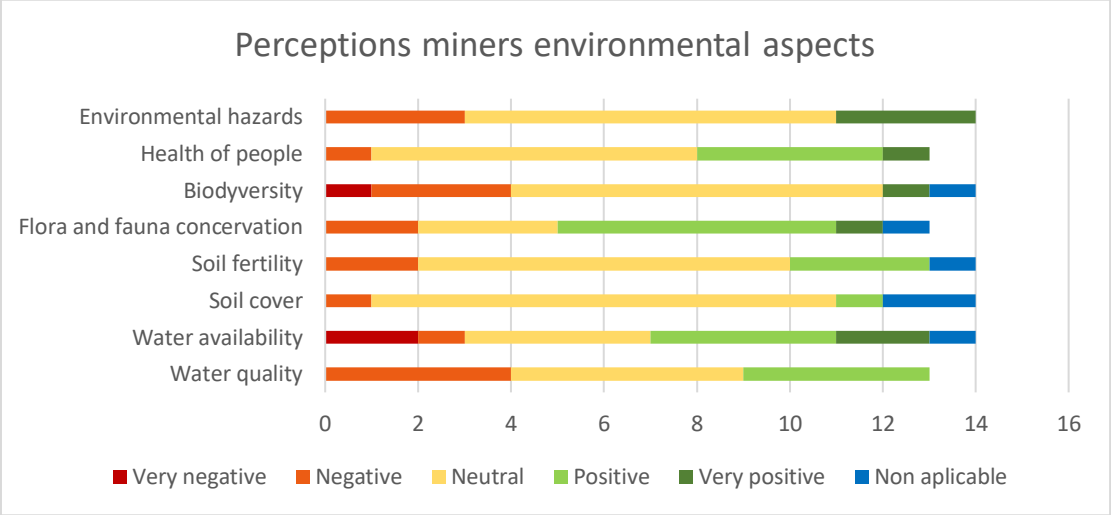
The perceptions of the employees of the mining cooperatives are visualized below (Graph 21). In the surveys, the indicators are formulated in a statement to give the participants more context.
The following statements have been used:

- Gold mining has improved the infrastructure in the CRC area.
- Gold extraction has a positive impact on the skills of the inhabitants of the CRC.
- The gold mining industry has provided more jobs in the CRC.
- Gold mining has improved social relations in the CRC.
- Due to gold mining, there are fewer illegal activities in the CRC.
- Gold mining has increased economic activity in the CRC.
- Gold mining has increased the average income in the CRC



Graph 13: Perceptions of the employees of mining cooperatives on the social aspects of gold mining

As can be seen in Graph 21 for each social indicator selected most of the miners agreed with the statements that mining had a positive effect on the social indicators. It could be that the employees of the mining cooperatives think that mining has a positive impact on these social-economic factors. However, another explanation of the answers could be that the employees of the mining cooperatives want to place mining in a more positive light.



Graph 14: Perceptions of the employees of mining cooperatives on the environmental impact of gold mining.

Looking at the perceptions of the miners on the environmental aspects (Graph 22) we see that only a few miners acknowledge the negative impact of gold mining on the environment. This is very interesting given the fact that all the employees of the mining cooperatives who participated in the surveys did take part in workshops about sustainable mining, which could indicate that they are aware of the negative environmental impact of gold mining.

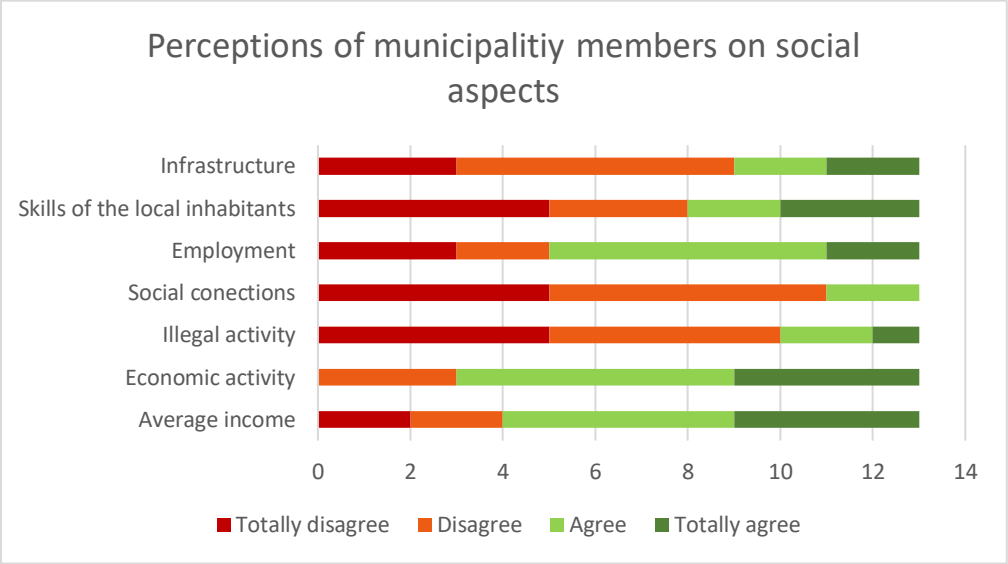
The employees of the mining cooperatives indicated that the mining industry mainly had a positive impact on the health of people. Nevertheless, when they were asked if they experienced adverse health changes since they started working in the mining industry the majority confirmed. These contradictory answers may indicate that they did not complete the surveys completely truthfully and confirm the suspicion described in the previous paragraph.

Another aspect that stood out is that with this stakeholder group, there was one participant who left several questions open. This could be because it is confronting, and the participant does not want to acknowledge the negative impact. However, it also could be a result of a disinterest in the survey that caused the participant to put less effort into the survey.

Overall, we can conclude that most of the first stakeholder group, the employees of different gold mining cooperatives in the CRC, indicated in the survey that mining has a positive impact on the social aspects, mainly on the economic activity and employment in the CRC.

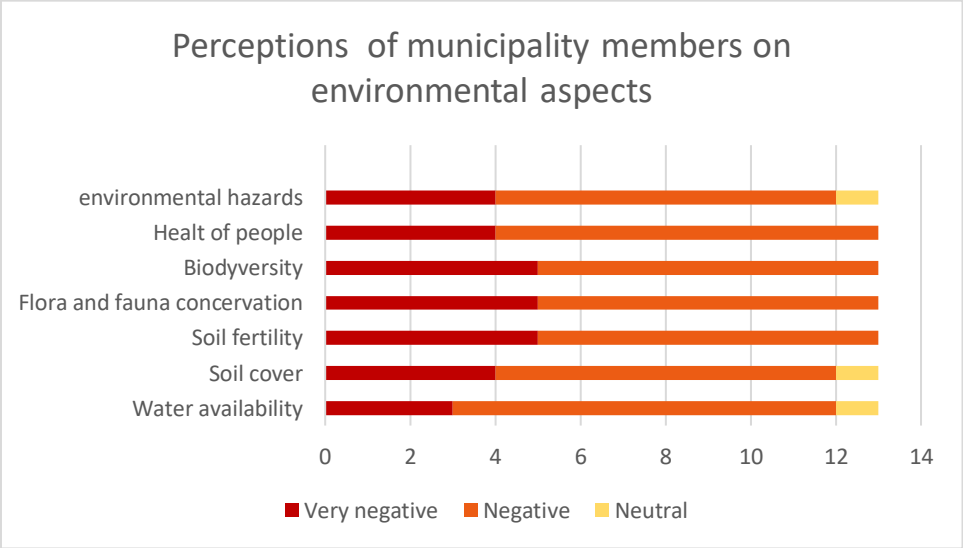
Besides this, the answers to the survey suggest that most of the miners think that gold mining doesn't have a negative impact on the environmental aspect, but rather a neutral or positive impact. However, we can question the integrity of the answers of the miners because of their social-formative power regarding the mining industry.

The next stakeholder group is the group with employees of the municipalities. This is a very interesting stakeholder group because they can take up a role in the regulation of gold mining and therefore, they are an important link in the transition toward more sustainable mining.



Graph 15: Perceptions of members from different municipalities on the social impact of gold mining

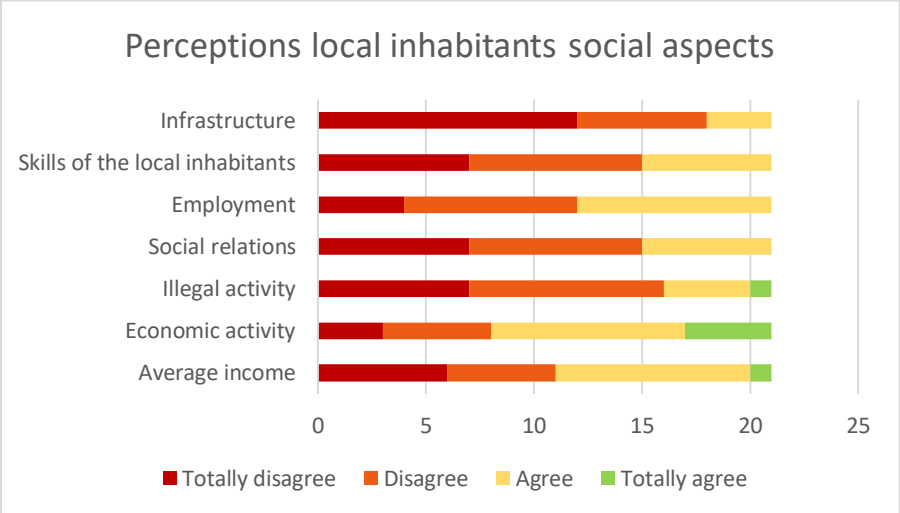
Looking at the results from the survey visualized in Graph 23 we can conclude that most of the employees of the municipality don't acknowledge that mining has had a positive impact on most the social aspects. However, most of the participants agreed with the statements that gold mining had a positive impact on employment, economic activity, and the average income in the CRC.



Graph 16: Perception of members from different municipalities on the environmental impact of gold mining.

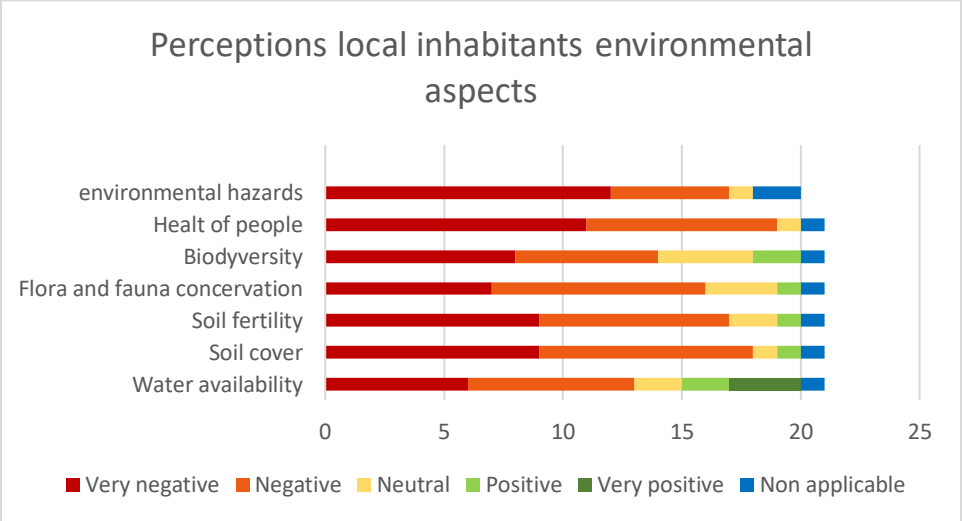
With regards to the environmental aspects, we see that the perceptions of employees of the municipalities are way more negative than the perceptions of the mine workers. This is because this stakeholder group is more independent from the subject of gold mining. They have different interests concerning gold mining than the employees of the mining cooperatives whose incomes are dependent on the gold mining industry and who benefit from a positive outlook on the gold mining industry. All in all, the perspective of members of the municipalities is mostly negative on the social as well as on the environmental impact of the gold mining industry.

The next stakeholder group is the local inhabitants of the CRC.
When the surveys were administered it was noticed that the participants were hesitant to participate. However, when it was made clear that the surveys were anonymous the participants were reassured and did want to partake in the survey. This shows that local people are reluctant to speak out openly about mining, this may be because they are afraid of possible consequences.
According to the answers to the survey, the local inhabitants saw the negative impact of gold mining on society. They saw even more negative consequences than the members of the municipalities. This is logical, the local inhabitants have a negative opinion of the mining industry since they experience the negative consequences. One of the local inhabitants said during the conduction of the survey that he worked in tourism, but that due to the mining there is less and less tourism because mining is ruining the landscape. He also said that they tried to make pictures of mining sites with a drone, but that someone shot their drone out of the air and that he thought miners did that. The same participant said that miners tried to set his house on fire. From these statements, it becomes clear that there is social tension between the local population and the miners.



Graph 17: Perceptions of the local inhabitants on the social impact of gold mining.

The perceptions of the local inhabitants concerning the environmental impact are a bit more divided than the perceptions of employees of the municipality. Most of the local inhabitants thought that gold mining negatively impacts the environmental aspects, there are even more local inhabitants than municipality members who thought that the impact of gold mining was very negative on the environmental aspects. However, there are a few participants who filled in the survey that the gold mining had a positive impact on biodiversity, flora and fauna conservation, soil fertility, and soil cover. There were also a few participants who stated that gold mining has a very positive effect on water availability.
While conducting the surveys, I also spoke to someone who had worked in the mining industry. She said it was dangerous, but that she did it because she could not find other work. One day while working, she became buried with debris up to her hip. After that day, she was so scared that she had never gone back to her job as a miner. This shows that, at least in some cases, working at gold mines is dangerous, working conditions are not good and workers' health is at risk.



Graph 18: Perceptions of the local inhabitants on the environmental impact of gold mining

More in-depth information was gained from interviews. In Table below the interviewees are listed with their abbreviations.

Table 3: Interviewee abbreviations

Interviewee	Abbreviation
Local inhabitant Caranavi	LC
Local inhabitant Al Coche	LA
Employee municipality Caranavi 1	MC1
Employee municipality Caranavi 2	MC2
Mineworker 1	MW1
Mineworker 2	MW2

Overview results interview social aspects

The general opinions of the interviewees regarding the social aspects are visualized in Table 3. During the interviews, a thing that stood out concerning the social impact of gold mining is that there is often a difference in the perception of the impact of illegal and legal mining. Legal and registered cooperatives pay taxes, and the jobs they offer must meet certain standards. Besides this, there is a higher chance that they meet or try to meet the Bolivian environmental regulations.

MC1 stated that the legal mining cooperatives had contributed to the infrastructure in his village, whereas the illegal mining cooperatives did not contribute to the infrastructure at all. MC1 also stated that the legal mining operations paid taxes and therefore contributed more to the economy.

When LA was asked about the influences of the mining industry on the social connections in the area, he said he could not answer this question and seemed uncomfortable. I was under the impression that LA was afraid to share too much specific information so that the interview could be linked to him and that he was scared that if this were the case he would be at risk of being harmed in any way by miners.

Table 4: Perceptions of the interviewees on the impact of gold mining on social aspects.

Aspects	*LA*	*LC*	*MC1*	*MC2*	*MW1*	*MW2*
Average income	Balanced	Balanced	Neutral	Balanced	Positive	Positive
Economic activity	Positive	Balanced	Positive/ Neutral	Balanced	Positive	Positive
Illegal activities	N/A	Negative	Negative	Negative	Negative	Negative
Social Connections	Negative	Negative	Negative	Negative	Positive	Positive
Available jobs	Balanced	Balanced	Balanced	Positive	Positive	Positive
Competencies local inhabitants	No impact	No impact	No impact	No impact	Positive	Positive
Infrastructure	Positive	Positive/ Neutral	Negative	Negative	Positive	Positive

Overview results of the interviews Environmental aspects

The general perception of the interviewees regarding the impact of gold mining on different environmental aspects has been put in Table 4. Remarkable is the big difference in the perception of the responses from the miners compared to the questionnaire. The reason for this could be that with the surveys miners found it easier to give answers that were not true, to put the mining industry in a better light.

When talking about water quality during the interview, LA said that since the mining industry had increased, water quality had deteriorated.

'Three years ago, we could still catch a fish within an hour, last year we went fishing again a few times but caught nothing at all. Because of mining, the water quality has deteriorated strongly, and there are almost no fish left in the water.'

Table 5: Perceptions of interviewees on the impact of gold mining on environmental aspects.

Aspects	*LA*	*LC*	*MC1*	*MC2*	*MW1*	*MW2*
Water quality	Negative	Negative	No impact/ Negative	Negative	Negative	Negative
Water availability	No impact	Negative	No impact	Negative	No impact	No impact
Soil cover	Negative	Negative	Negative	Negative	Negative	Negative
Soil fertility	Negative	Negative	Negative	Negative	Negative	Negative
Flora and Fauna Conservation	Negative	Negative	Negative	Negative	Negative	Negative
Biodiversity	Negative	Negative	Negative	Negative	Negative	Negative
Health of people	Negative	Negative	Negative	Negative	No impact	No impact
Environmental risks	Negative	Negative	Negative	Negative	Negative	Negative

Conclusion SRQ2

All in all, the general perceptions of the local inhabitants and the members of municipalities towards the environmental and social impact of the gold mining industry are negative. The perceptions of the employees of the mining cooperatives toward the social impact of the mining industry are positive. While the perceptions of the employees of mining cooperatives on the environmental impact appear to be neutral from the results of the survey their perspective seems to be negative from the results of the interviews.

Results 3: The future of gold mining in the Coroico River catchment

In the previous research questions, various impacts of the gold mining industry in the CRC are addressed. In this chapter, the future of goldmining in the CRC will be discussed.
The measures now being taken by Cáritas Coroico to reduce the negative impact of gold mining will be examined in detail. Perceptions of miners and municipality members of these measures and their feasibility are investigated. The benefits of the implementation of these measures on the CRC and the limitations of the measures will be addressed.

Despite its negative social and environmental impact, gold mining activity in the CRC keeps growing. Since approximately 2020, protected parks in the surrounding areas are also subjected to mining (Graham, 2022).
In December of 2021 mining rights already had been granted for 8% of Madidi National Park.
The legal framework around mining benefits the mining actors. In 2014 Law 535 was implemented, which made mining cooperatives almost unaccountable. Because of this new law, cooperatives only need a registration request to receive a legal mining title or contract (Graham, 2022).
These remarkable benefits the gold mining industry receives from the government, suggest that the gold mining cooperatives' power is embedded in Bolivia's local and national government structures.

Even the actors who oppose gold mining, acknowledge that halting it entirely is unrealistic given its significant social and economic importance. However, they urge the state to take action to mitigate the environmental damage it causes (Graham, 2022).

Cáritas Coroico is trying to mitigate the impact of gold mining in the CRC. During the time that I participated in this project, I observed the actions Cáritas Coroico undertakes to try to reach its objectives, among which reducing pollution from gold mining. Gold mining methods that do not require mercury are being developed and workshops are being given about sustainable mining to employees of mining cooperatives and municipal members.
Two measures were often promoted during the workshops, those were the elimination of mercury in mining processes, and soil restoration during and after gold mining.
Interviews and surveys were executed to gain more information about the perceptions on these two Measures: the elimination of mercury and soil restoration.
These measures were selected for this research because a consultant who works for Caritas said that these are the two most relevant measurements to work toward sustainable gold mining. He said that currently for both alluvial and mountainous mining mercury pollution is a major problem. Besides this, for alluvial mining, the removal of soil covers, and the alteration of river flows are also causing problems, like erosion and a deterioration of soil quality. That is why according to him the two main changes in the mining industry should be reducing mercury pollution and restoring soil quality.

Short introduction measures

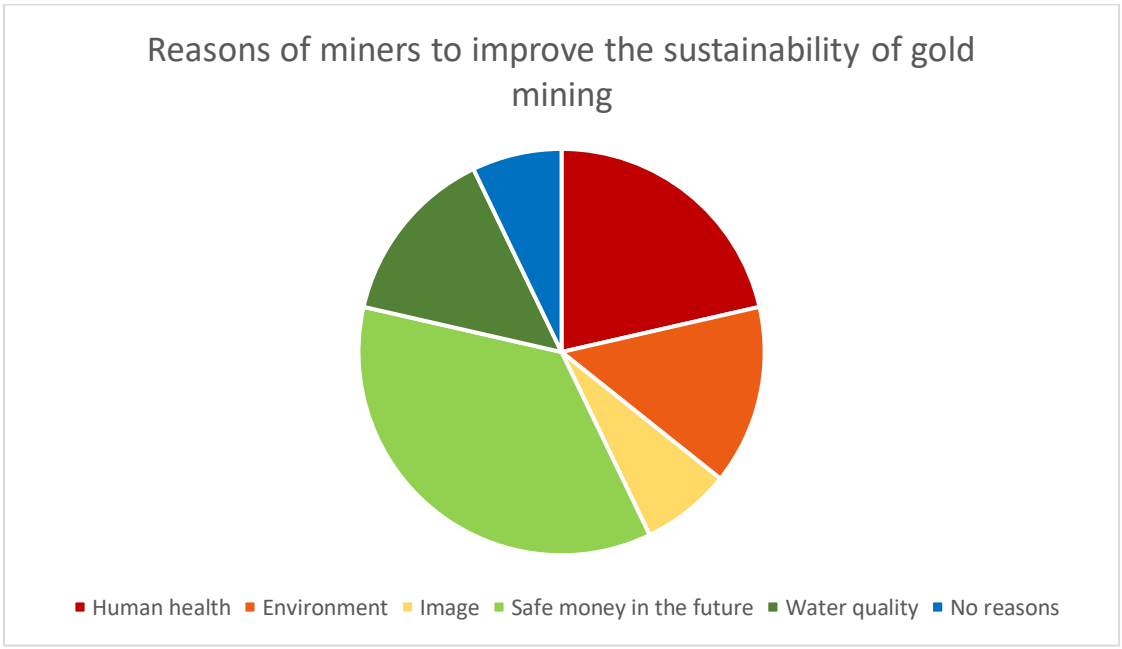
Reduction and elimination of mercury

As explained in the introduction mercury is used because it is a relatively simple and easy method to separate the gold. Because the small gold particles are difficult to extract usually mercury is added. Mercury has the property that it does bind to gold particles, but not to sand particles. The gold and mercury form an agglomerate and can be extracted. After this, the agglomerate is heated, the mercury evaporates, and the gold is left behind. Caritas Coroico is currently investigating techniques to extract the smaller gold particles with a gravitation-based method. The implementation of this measure would lead to a major reduction of mercury pollution in the Coroico River shed.

Restauration and rehabilitation of the soil

Measures to restore the soil quality and keep the natural flow of the river in general require less technique. Restoration refers to the process of repairing and returning damaged or degraded soils to a condition like the pre-degradation level of capability for supporting plant growth and maintaining environmental quality. (Blanco & Lal, 2023). Restoration and rehabilitation of the soil are needed, this will safeguard the natural river flow. Restore the riverbanks, reduce erosion, and minimize the harmful impact of mining on the flora and fauna in the area.

To be able to implement any measures it is important to make sure the stakeholders are on board. This is the part where the surveys come in. The surveys aim to understand the views of the miners and the municipalities on the transition to more sustainable mining. The miners and the municipalities will have certain views on what is feasible to implement and how long it will take. Besides this, it is important to establish what could be the limitations and what are their main motivators to reduce the negative impact of the gold mining industry on the environment and society.
They could put this information to good use in the project 'Mi Cuenca Mi Casa' of Caritas Coroico where they work with gold mine cooperatives to reduce the negative effects of gold mining on the environment in the CRC. The surveys will map the drivers of the stakeholders to work towards more sustainable mining (visualized in Graph 25), these drivers can be emphasized during workshops to motivate the stakeholders. Besides this, the surveys will help to gain more insight into the view of the stakeholders on the limitations in the transition to sustainable mining.



Graph 19: Reasons of miners to improve the sustainability of gold mining.

The question was a closed multiple-choice question where the miners could select one option or multiple options or they could add another option if their reason wasn't listed. Noticeable is that the reason which was mentioned the most was to save money in the future. This again suggests that one of their motivators is money.

Only three out of the 14 participants noted that human health was a motivator to improve the sustainability of gold mining. This is remarkable because 9 of the 14 mineworkers who took part in the survey stated that they experienced changes in their health since they were working in the gold mining industry. Perhaps the miners are not very aware of the fact that their job in the mining industry has an impact on their health, they care less because it is normalized or the benefits of the job are so important to them that they overshadow the health risks.

For the employees of the municipality, there were more reasons to improve the sustainability of gold mining, this could indicate that they are more motivated to improve the sustainability of the CRC than the miners. For the municipality, the main reason is the environmental health.

During an interview with a member of the municipality of Caranavi (MC2), the interviewee stated the following when asked about his reasons for improving the sustainability of gold mining*:*

'Saving the planet is my number one reason. Not only to take care of the environment but also to mitigate the environmental impact of mining activities for the sake of the population health.'

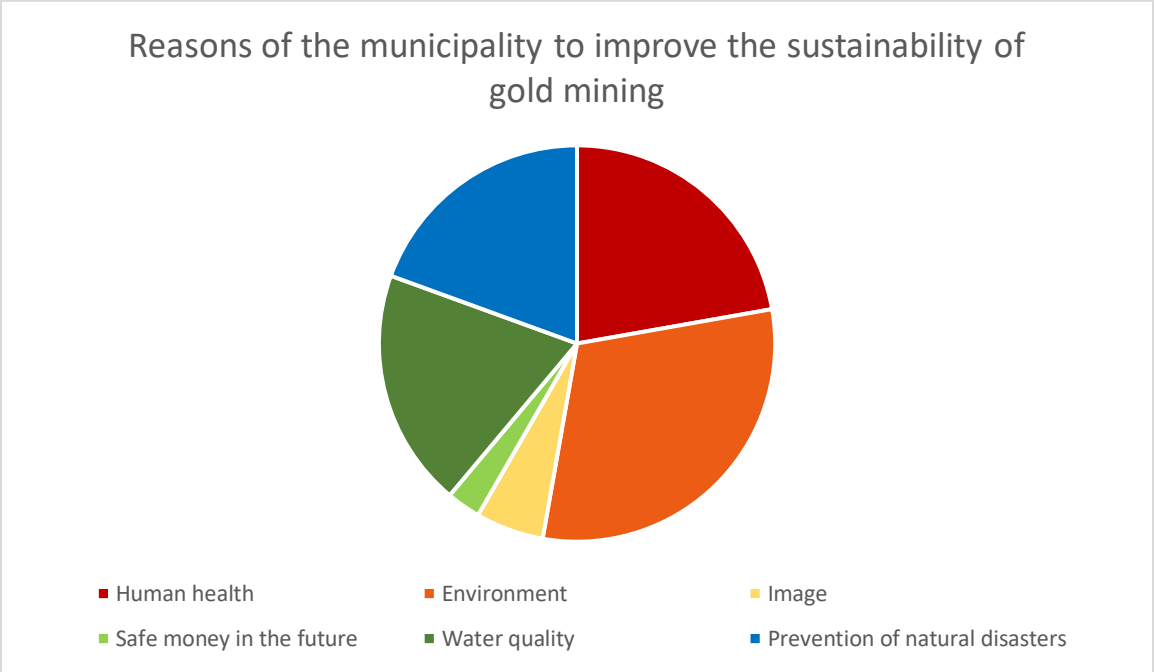


Figure 2. Reasons of the municipality to improve the sustainability of gold mining.

The (perceptions on) feasibility and the limitations of the measurements

First, the measure for the elimination of mercury usage will be discussed.
Most of the miners already knew a bit about this measure. All the miners were interested in learning more about technology to reduce or eliminate mercury usage in gold mining. They noted that the main limitations to applying these technologies are the lack of knowledge and financing.

The members of the municipality were familiar with this measure, more than the mineworkers. Four-fifth of the municipality members stated that they were familiar with this measure. From the employees of the mining cooperatives four-fifth stated that they only knew a bit about the measure. There were some employees of the municipality neutral regarding learning more about eliminating mercury usage, this could be because they are already familiar with the technologies.
According to the municipalities, there were additional limitations. The main limitations were the same as for the miners: lack of knowledge and lack of financing. A part of the municipality members declared that mining without mercury would be less efficient, that there was no technology for eliminating mercury usage in mining, or that the existing technology needed to be updated.

The miners were asked after how many years they thought it would be possible to eliminate the use of mercury in their cooperative. Most of them thought that it would be possible. The time they thought that was required to achieve this goal strongly varied from two years to over twenty years.

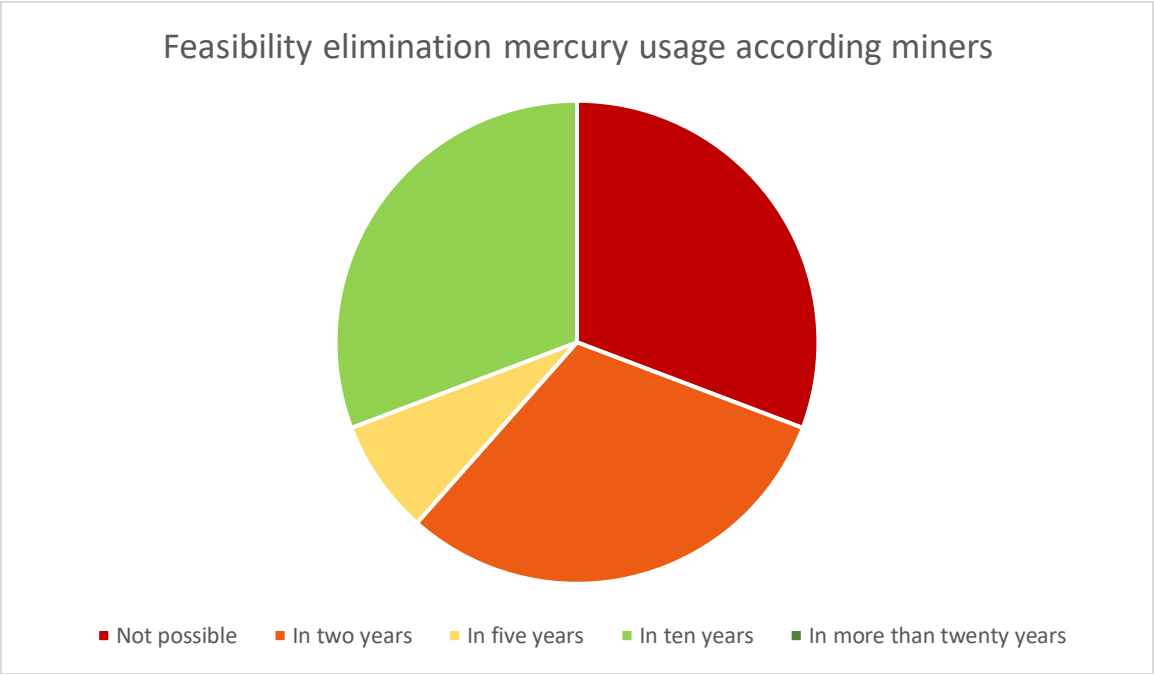


Figure 3. Feasibility of the elimination of mercury usage according to the miners.

The municipality members were asked how many years it would be possible to eliminate mercury use in gold mining in the entire CRC. It is difficult to compare these questions because it is more challenging to eliminate mercury use in the entire river catchment than in one cooperative. It is no surprise that the answers to this question from the municipality members indicated that it would not be possible to entirely eliminate mercury use.

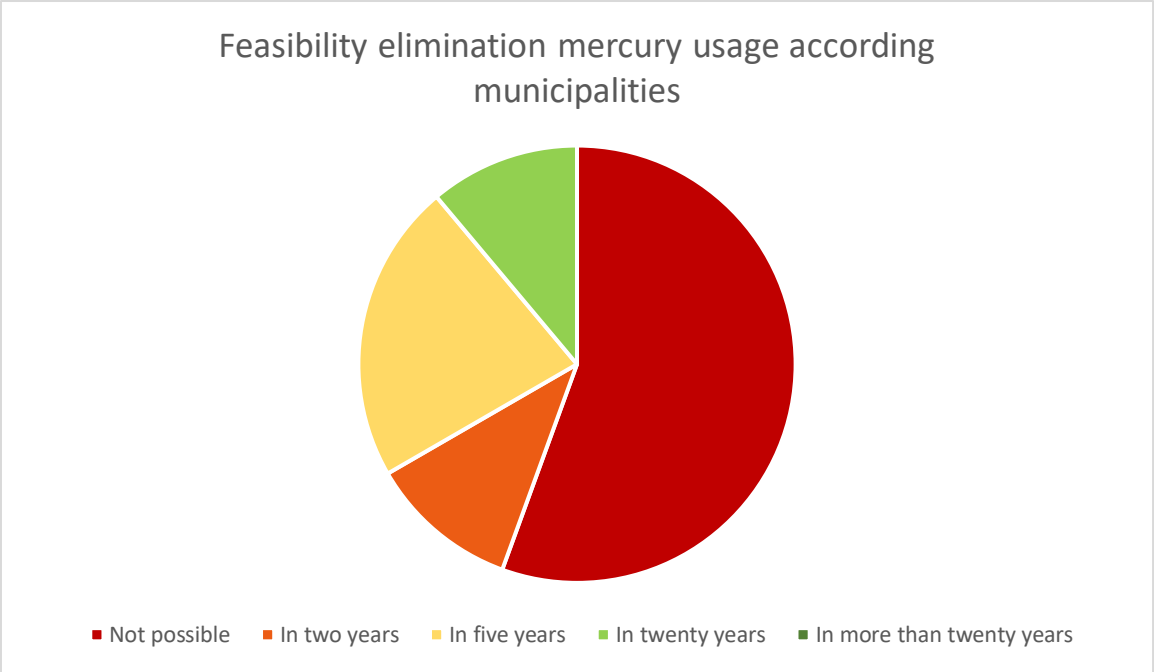


Figure 4. Feasibility of the elimination of mercury usage according to the municipalities.

According to the consultant of Caritas, a mining expert who gives workshops on sustainable alternatives for the current mining methods, it is definitely possible to establish mercury-free gold mining in the CRC within the upcoming twenty years. The knowledge is available and even though the miners and municipality members see money as a limitation the new techniques are overall not more expensive. This means that the main challenge is to provide the mining cooperations with the knowledge and guide them in the transition to mercury-free mining.

In the next part, the measure for soil restoration and rehabilitation will be discussed.
Roughly half of the miners knew a little bit about this measure and one-third of the miners who took part in the survey were familiar with this measure. Almost nineteen percent of the miners were interested in learning more about soil restoration and rehabilitation. According to the employees of the mining cooperative, the main limitation of this measure is the lack of financing followed by a lack of knowledge. One miner stated that the efficiency would also be a limitation. It is interesting that compared to the measure of mercury elimination the main limitation is financing instead of knowledge. This could be because the miners know relatively more about this measure, or because they think it would cost more money to execute the measure.

Most of the employees of the municipality were familiar with this measure. Less than ten percent of the municipality members didn't know anything about it. Most of the municipality members were very interested in learning more about Soil rehabilitation and restoration. According to the employees of the municipality, the lack of knowledge was the most limiting factor, followed by financing. Two participants noted that mining would be less efficient when including this measure.

The miners were asked in how many years they thought it would be possible to apply soil restoration and rehabilitation methods in their cooperatives. Most of the mine workers roughly eighty percent thought that it would be possible. The time in which they thought it would be possible strongly varied from two years to more than twenty years.

The municipality members were asked in how many years it would be possible to apply soil restoration and rehabilitation methods in gold mining in the entire CRC. More than nineteen percent thought that it would be possible. The municipality is regarding soil restoration more optimistic than the miners. The time they thought was required to achieve this goal strongly varied from two years to over twenty years.

According to the consultant of Cáritas, a mining expert who gives workshops on sustainable alternatives for the current mining methods, the mining cooperatives can do a lot concerning soil restoration and rehabilitation. Some of the measures they could undertake are simple and don't require money. An example is changing the place where they deposit the filtered sand. Currently, mining cooperations often deposit the filtered sand in the middle of the river course, see Figure 7, where it obstructs the natural flow and can result in riverbank erosion and contribute to the flooding risk. If the sand is placed on the riverbank, it won't disrupt the river flow, and it will be easier to rehabilitate the soil

Figure 5: Visible obstruction of the natural river course ate a mining site of cooperation Quillacas close to Teoponte

Limitations technical solutions

Due to the imbedded power of the gold mining actors, it is not surprising that Cáritas Coroico has this relatively pragmatic approach with the focus on implementing technical measures. The implication of these technical measures will reduce the environmental pollution and soil degradation due to mining. However, gold mining will always need extensive land and water resources. For example, about 700 Liters of water are consumed on average for each ram of gold produced (Mudd, 2007). This claim on land and water resources will inevitably affect the local inhabitants, also the ones who do not profit from the gold mining industry.
The implementation of technical solutions won't resolve this disbalance of power over resources and unequal profit distribution.

In their 'Plan Director de la Cuenca del Río Coroico' Cáritas Coroico often mentions integrated river basin management (IRBM). One of their aims is to defend the rights of disadvantaged people (QUIÉNES SOMOS – Cáritas Coroico, n.d.)
According to the Global Water Partnership Technical Advisory Committee IRBM also includes maximizing the economic and social benefits derived from water resources equitably (*Integrated Water Resources Management*, 2000).

Currently the focus of Cáritas Coroico seemes to be mainly on reducing the negative impact on the environment. It is an opportunity for Cáritas Coroico to also include the social aspects in their planification and actions, and address the unequal distribution of profit from the mining industry.

Conclusion SRQ3

All in all, according to the surveys and interviews it seems possible to implicate the measures of mercury elimination and soil restoration in the mining industry in the future in the CRC. If these measures are implemented it would result in a reduction of the negative impact of mining on the environment. However, it would not reduce the social inequality of water rights.

Research by Perrault et al. (2014a) addressed the shortcomings of technological ´fixes ´ with regards to mining and water rights. According to this research, the importance of water in the mining industry made mining companies secure legal rights to water and design hydraulic infrastructures in a manner that is beneficial for their industry.

Even if the environmental effects of gold mining concerning pollution and soil degradation will be reduced. The mining industry will still need resources and have an impact on water availability. Mining operations inevitably require a lot of resources and therefore place a claim on available resources such as water and land and impact the waterscape. This will always affect other stakeholders and result in unequal distribution unless the gains of the mining industry are equally distributed and benefit not only the mining operations but all the actors in the area. The findings of Perrault et al. (2014a) suggest that solely technical solutions are not sufficient to eliminate mining-related conflicts, and that underlying issues of unequal power distribution regarding the hydrosocial cofigurations should be addressed. Also for the future of gold mining in the CRC it is important that these aspects are taken into account with policy making.

Conclusions

Gold mining in the CRC impacts the water quality because of heavy metal and metalloid pollution. Besides the change in water quality local inhabitants and municipality members recognized other social and environmental impacts of the gold mining industry.
The negative social aspects are the increase of social tension and the increase of illegal activities. Positive social effects of the mining industry include an increase in employment, economic activity, and average income. The negative environmental aspects are the decrease in water quality, water availability, soil cover, and soil fertility. Other environmental aspects that are negatively impacted by gold mining are flora and fauna conservation, biodiversity, and health of people. Besides this, there is an increase in environmental hazards according to the local inhabitants and the members of the municipality. According to the employees of the mining cooperatives, the social impact of the gold mining industry in the CRC was positive. While in the surveys the mining employees stated that the environmental impact was positive, they acknowledged its negative impact during the interviews.

According to the surveys and interviews, it seems possible to implicate the measures of mercury elimination and soil restoration in the mining industry in the future in the CRC. If these measures are implemented that would mean a reduction of the negative impact of mining on the environment. However, it wouldn´t solve other issues in the CRC caused by gold mining, such as social tensions and an unequal distribution of resources. To safeguard the CRC, its biodiversity, and the well-being of its inhabitants. It is very important that not only measures are implemented to reduce the negative environmental impact of gold mining, but that the social aspects are also included in policy-making with regards to gold mining in the CRC.

Discussion

Discussion RSQ1

This research provides a better understanding of water quality and the evolution of various parameters in the CRC.
There were some methodological limitations, nonetheless, the analyses will contribute to insights into the water quality (measurements) in the river catchment and will help Cáritas Coroico to improve the IRBM of the CRC.

The methods of water measurements in 2023 differed from the methods used in 2019.
During the measurements in recent years, the sampling method varied from the method described in 'la linea base', the investigation report made in 2019 as a start of the MCMC project In 2019, several water samples were taken at the monitoring points, at different spots in the river cross-section. In subsequent measurement years, only one sample per monitor point was taken near the riverbank. Due to this difference in measurement methods, the results of parameters such as turbidity and solid sediment cannot be compared properly. For further research, It is of great importance that the methods are evaluated and that the methods used during the different measurements are kept the same.
Besides this, establishing trends or causal links from the data is difficult, because the parameters have been measured for only four years and the amount of time between the measurements has not always been the same.

There were a few surprising findings in the water analysis. Remarkable is that in 2023 the data points of the toxic metals lead, cadmium, mercury and arsenic showed exactly the same concentration for all the measurement points in the CRC. According to Freddy Flores from the team of the MCMC project, a probable cause is the detection limits of the measuring devices used in 2023. Assuming that the measuring device was not sensible for values below 0,05 (Pb-measurements), he stated that the results from 2023 therefore might be invalid. These uncertainties regarding the technical details of the measurements make it difficult to draw conclusions from the measurements of the lead, cadmium, mercury, and arsenic concentrations.
The fact that the data of the measurement methods of the water quality measurements were not shared, indicates a lack of transparency.
One other surprising finding was the decrease in mercury concentration between 2019 and 2023. Because mining activities have increased in these years, an increase in mercury content in the water was to be expected. The measured decrease in mercury concentration could be a result of measurement errors, (accidental) data alteration, or non-representative samples.
Due to time and (cooling)space limitations for sample taking and transportation, only one sample was taken per river. To increase the reliability of the data, several samples should be taken at the cross-section of each river.
For future research, Caritas Coroico is advised to carry out measurements independently and to keep the methods of the measurements the same, to ensure data reliability.

For further research on the impact of gold mining on the water quality in the CRC, it is important that not only the pollutants in the water are measured, but also the pollutants in the sediment, since a lot of the pollutants bind to sediment present in the river water.

Discussion RSQ2 & RSQ3

In this section, the perceptions of Local inhabitants, municipalities, and mineworkers on the impact and future of gold mining in the CRC are compared with the expectations and are put in context.

The results are fairly in line with expectations. There are many different perceptions about mining. It is clear to all stakeholders that gold mining harms the environment. Regarding the impact of mining on social aspects, opinions strongly differ. On one hand, the municipalities and residents see many negative effects. On the other hand, the miners mainly see positive social effects.
As expected, the main motivator among the miners was money. This also emerged in questions on implementation. An important motivation for miners to become more sustainable was the possibility of saving money in the future. However, some miners were worried that becoming more sustainable would cost extra money and saw this as the biggest limitation to the implementation of the measures.
The social aspects of the survey were presented in statements to provide context and make it more understandable for the participants. The statements are also phrased positively because it is assumed that this way it would elicit less violent reactions. A downside of the positive formulation of the statements is that it results in acquiescence (agreement) bias.
For a follow-up study, it is therefore important that the survey questions are better defined and that a pilot is conducted to evaluate the survey questions thoroughly. It was not possible to perform a pilot for this thesis research, due to the limited possibility of going into the field and the long travel distances from Cáritas Coroico to the lower part of the catchment area where the surveys were conducted.

In this research, the investigated stakeholders are local inhabitants, mineworkers, and municipalities. Besides these, environmental organizations, investors, and national politicians are also important stakeholders in the gold mining industry. Because of time restrictions, these stakeholders are not included. However, this could be an interesting follow-up study.
Another aspect that would be interesting for follow-up research, but which does not fall within the Land and Water Management domain, is the regulation of cooperatives. This research would help to find a way to ensure that all cooperatives are registered so that illegal (side) activities are limited and the transition to sustainable mining can be regulated.

This thesis research offers more information about the perception of stakeholders, which allows Cáritas Coroico to respond better to the stakeholders in the CRC. The opinions of the stakeholders can be included in the plan for IRBM. Besides this, the opinions of the miners and municipality members provide a better picture of what the challenges and possible limitations are in the transition to more sustainable mining. This information will help with the strategies and planification of further stages of the MCMC project.

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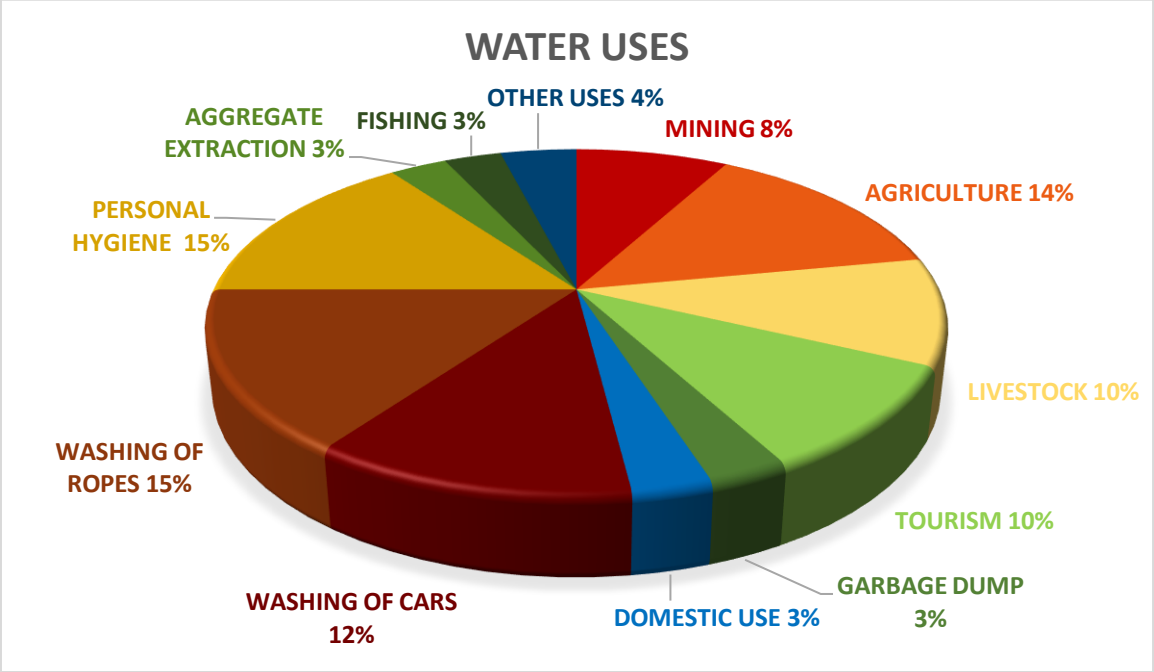
Annex

Annex 1: Water uses of the river water of the Coroico River catchment (Ortuño et al., 2021)



Annex 2: Survey for the employees of mineworkers in Spanish

Estimado Sr./Sra,

Me llamo Myrthe Brouwer y soy estudiante, estudio Gestión Internacional de Tierras y Aguas. Actualmente estoy realizando una investigation con el objetivo, aumentar la sostenibilidad de las prácticas de minería de oro en la cuenca del río Coroico, departamento de La Paz, Bolivia, mediante el análisis de datos recientes (2019-2024) de la calidad del agua del río Coroico y la investigación de las percepciones de los trabajadores mineros, los municipios y los habitantes locales sobre el impacto ambiental y social de la industria minera del oro y la percepción de los trabajadores mineros y los municipios sobre las diferentes medidas que posiblemente podrían aumentar la sostenibilidad de la minería de oro en la cuenca del río Coroico.

Por lo tanto me gustaría realizar una encuesta entre los empleados de las cooperativas mineras. Esta encuesta durará unos 15 minutos y se enfoca en obtener más informacion sobre la perspectiva de usted de los diversos impactos sociales y ambientales que la industria minera del oro podría tener en la cuenca del río Coroico

La primera parte de esta encuesta sobre los posibles impactos sociales que la industria minera tiene, la segunda parte será sobre los posibles impactos ambientales, la tercera parte será sobre posibles medidas y la final parte será su cooperativa y sobre datos personales.

La encuesta será anónima, es decir, no se anotarán nombres ni se relacionarán las respuestas con la persona. La información sólo se utilizará con fines de investigación.

No hay respuestas correctas o incorrectas, así que no dude en dar su opinión sincera.

Le estoy muy agradecido por su tiempo y esfuerzo.

Si tienes alguna pregunta no dudes en hacérmela y si tienes alguna duda después puedes contactar conmigo a través del correo electrónico:
myrthe1.brouwer@gmail.com

Impactos sociales

1) La minería de oro ha aumentado la renta media en la cuenca del río Coroico.
- o nada de acuerdo
- o en desacuerdo
- o de acuerdo
- o muy de acuerdo

2) La minería de oro ha incrementado la actividad económica en la cuenca del río Coroico.
- o nada de acuerdo
- o en desacuerdo
- o de acuerdo
- o muy de acuerdo

3) Debido a la minería de oro, hay menos actividades ilegales en la zona del río Coroico.
- o nada de acuerdo
- o en desacuerdo
- o de acuerdo
- o muy de acuerdo

4) La minería de oro ha mejorado las relaciones sociales en la cuenca del río Coroico.
- o nada de acuerdo
- o en desacuerdo
- o de acuerdo
- o muy de acuerdo

5) La minería del oro ha proporcionado más puestos de trabajo en la región del río Coroico.
- o nada de acuerdo
- o en desacuerdo
- o de acuerdo
- o muy de acuerdo

6) La extracción de oro repercute positivamente en las competencias de los habitantes de la cuenca del río Coroico.
- o nada de acuerdo
- o en desacuerdo
- o de acuerdo
- o muy de acuerdo

7) La construcción de minería de oro mejoró la infraestructura.
- o nada de acuerdo
- o en desacuerdo
- o de acuerdo
- o muy de acuerdo

Impactos ambientales

8) ¿Cómo cree que ha influido la minería del oro en la cuenca del río Coroico a estos factores?
Por favor, dé su opinión a través de la siguiente escala

	Muy negativo	Negativo	Neutro	Positivo	Muy positivo	N/A (No se aplica)
Calidad del agua						
Disponibilidad de agua						
Cobertura del suelo						
Fertilidad del suelo						
Concervación de la flora y la fauna						
Bioderversidad						
La salud de la gente						
Peligros medioambientales (erosión, corrimientos de tierras, inundaciones)						

medidas para la sostenibilidad

Evitar o eliminar mercurio

9) ¿Conoce las técnicas para reducir o eliminar el mercurio en la minería del oro?
- o Sí, conozco muy bien.
- o Sí, conoczo.
- o Un poco.
- o Nada.

10) ¿Le interesaría conocer mas sobre las técnicas para reducir o eliminar el mercurio en la minería del oro?
- o Muy interesado
- o Interesado
- o Neutral
- o No le interesa
- o Totalmente desinteresado

11) ¿Cuáles serían las posibles limitaciones de la aplicación de reducir o eliminar el mercurio en la minería del oro? (se puede marcar varías opciones)
- ☐ Falta de conocimiento/educación sobre la medida
- ☐ Falta de financiación/recursos financieros para la medida
- ☐ Esta medida hará que el proceso de extracción de oro sea menos eficaz
- ☐ Esta medida hará que el proceso de extracción de oro sea menos eficiente (cuesta más tiempo)
- ☐ Otros, a saber_____

12) ¿En cuantos años cree que se puede llegar a cero mercurio en su cooperativa?
- o No es possible
- o En dos años
- o En cinco años
- o En diez años
- o En veinte años
- o En mas que veinte años

Rehabilitación y restauración del suelo

13) ¿Conoce las méthodos para rehabilitación y restauración del suelo en la minería del oro?
- o Sí, conozco muy bien
- o Sí, conoczo
- o Un poco
- o Nada

14) ¿Le interesaría conocer mas sobre las méthodos para rehabilitación y restauración del suelo en la minería del oro?
- o Muy interesado
- o Interesado
- o Neutral
- o No le interesa
- o Totalmente desinteresado

15) ¿Cuáles serían las posibles limitaciones de la aplicación de méthodos para rehabilitación y restauración del suelo en la minería del oro? (se puede marcar varías opciones)
- ☐ Falta de conocimiento/educación sobre la medida
- ☐ Falta de financiación/recursos financieros para la medida
- ☐ Esta medida hará que el proceso de extracción de oro sea menos eficaz
- ☐ Esta medida hará que el proceso de extracción de oro sea menos eficiente (cuesta más tiempo)
- ☐ Otros, a saber_____

16) ¿En cuantos años cree que se puede llegar a méthodos para rehabilitación y restauración del suelo en su cooperativa?
- o No es possible
- o En dos años
- o En cinco años
- o En diez años
- o En veinte años
- o En mas que veinte años

Su cooperativa

17) ¿En qué coperativa trabaja?

_____

18) ¿Cuál es su cargo?

_____

19) ¿Cuánto tiempo lleva trabajando en la industria minera?
- o 0-6 meses
- o 7-12 meses
- o 1-2 años
- o 3-5 años
- o 5 años o más

Datos personales

20) ¿Cuáles son sus razones para hacer más sostenible la minería del oro? (se puede marcar varías opciones)
- ☐ Salud humana
- ☐ Salud del medio ambiente
- ☐ Imagen de cooperativa
- ☐ Shorro de dinero a largo plazo
- ☐ Mejora de la calidad del agua
- ☐ Otros, a saber_____

21) ¿Ha experimentado cambios en su salud desde que trabaja en la cooperativa minera?
- o Sí
- o No

22) En caso afirmativo, ¿cuáles son los cambios que ha experimentado en su salud?
- o Sensaciones anormales de hormigueo o escozor, calor o frío en los pies, las manos, la cara, etc.
- o Movimientos oscilatorios involuntarios y rítmicos de grupos musculares de las extremidades
- o Irritabilidad o angustia
- o Encías acaloradas
- o Dificultad o incapacidad para retener la saliva en la boca
- o Insomnio vigilia, falta de sueño a la hora de dormir
- o Inflamación de la mucosa oral
- o Pérdida prematura de dientes y sensación de alargamiento de los dientes
- o Problemas visuales en la visión periférica y daños en la visión de los colores
- o Pérdida de control del comportamiento. Excesiva timidez y excitabilidad)
- o Sabor metálico constante
- o Vómitos y diarrea
- o Dificultad para respirar o tos
- o Otros a saber:

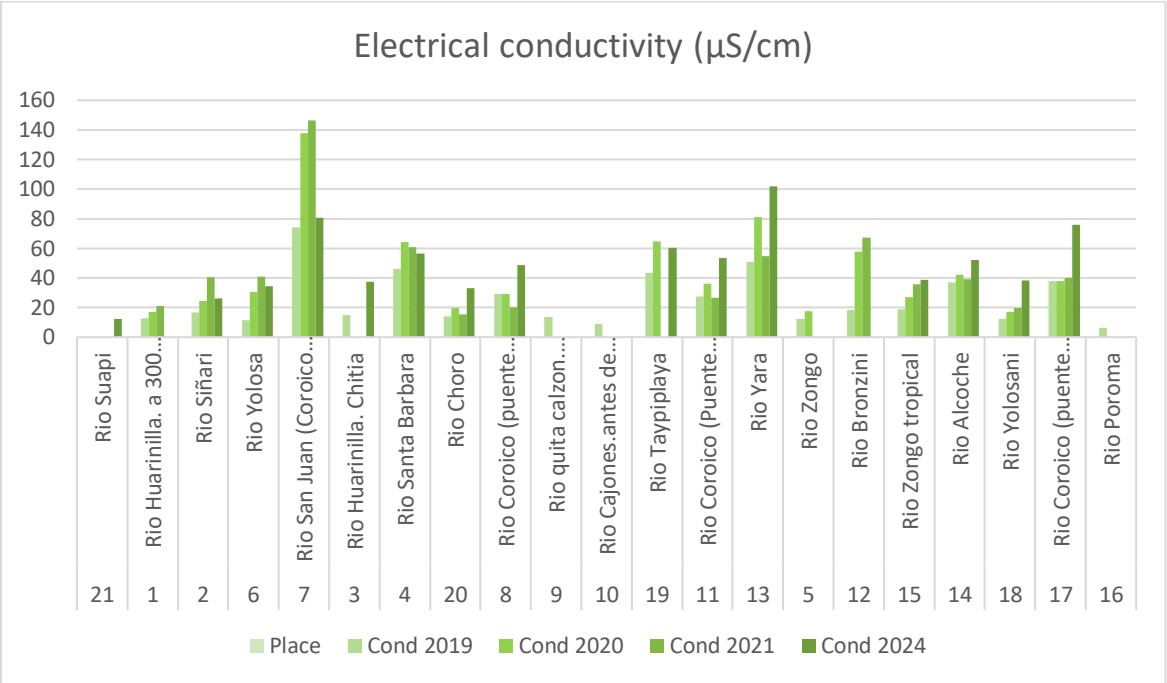
_____

23) ¿Que edad tiene?

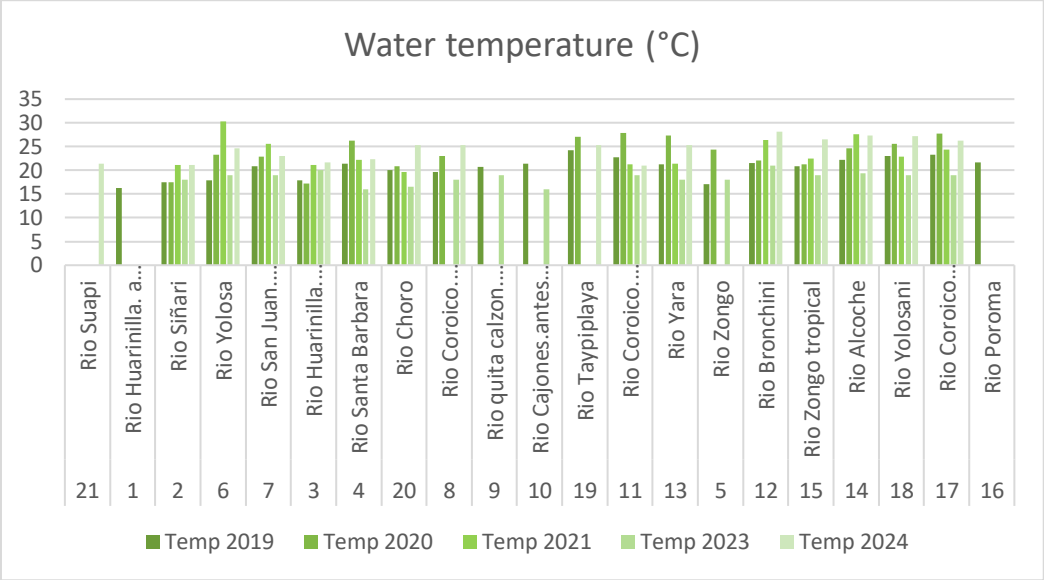
_____

24) ¿Cuál es su sexo?
- o Feminino
- o Masculino

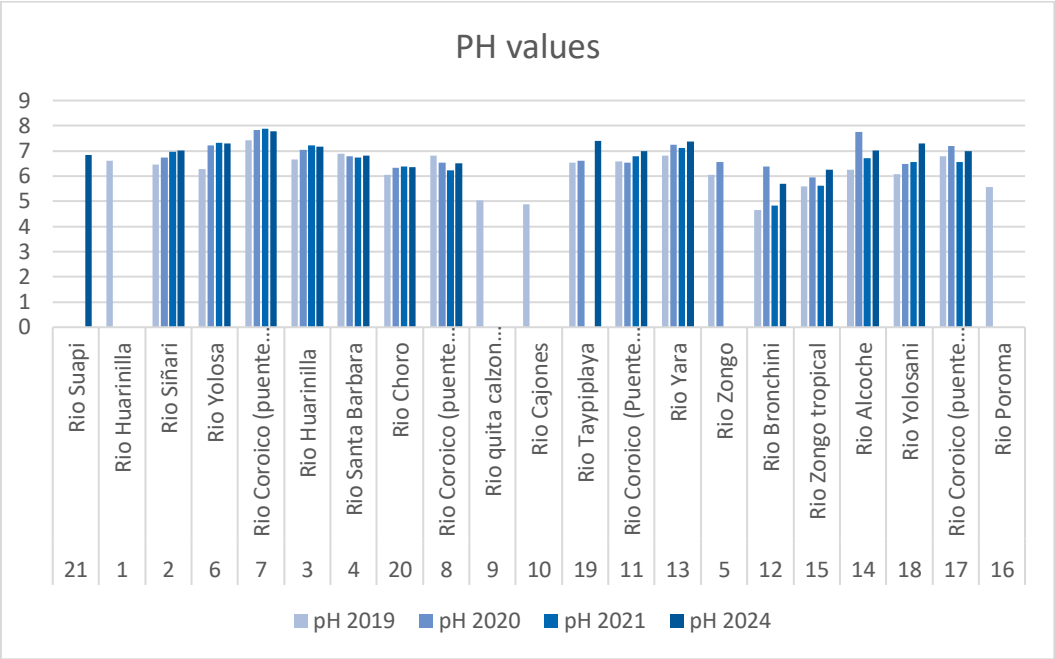
Annex 3: Electrical conductivity at different points along the Coroico River catchment



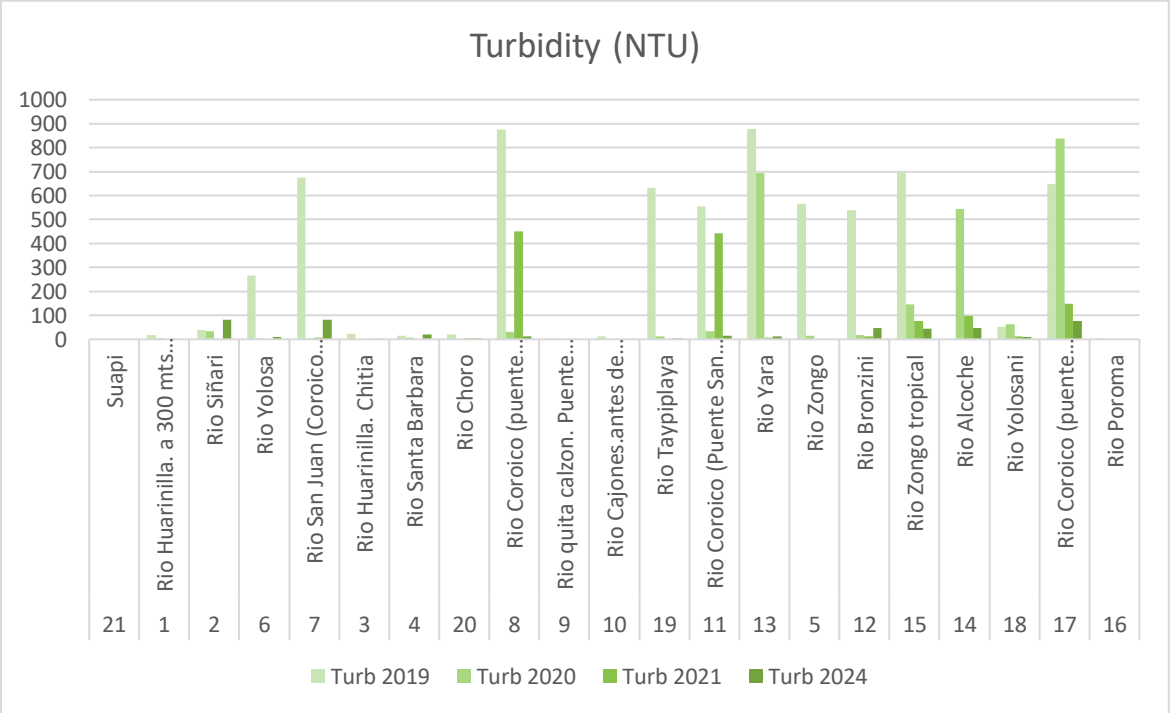
Annex 4: Water temperature at different points along the Coroico River catchment



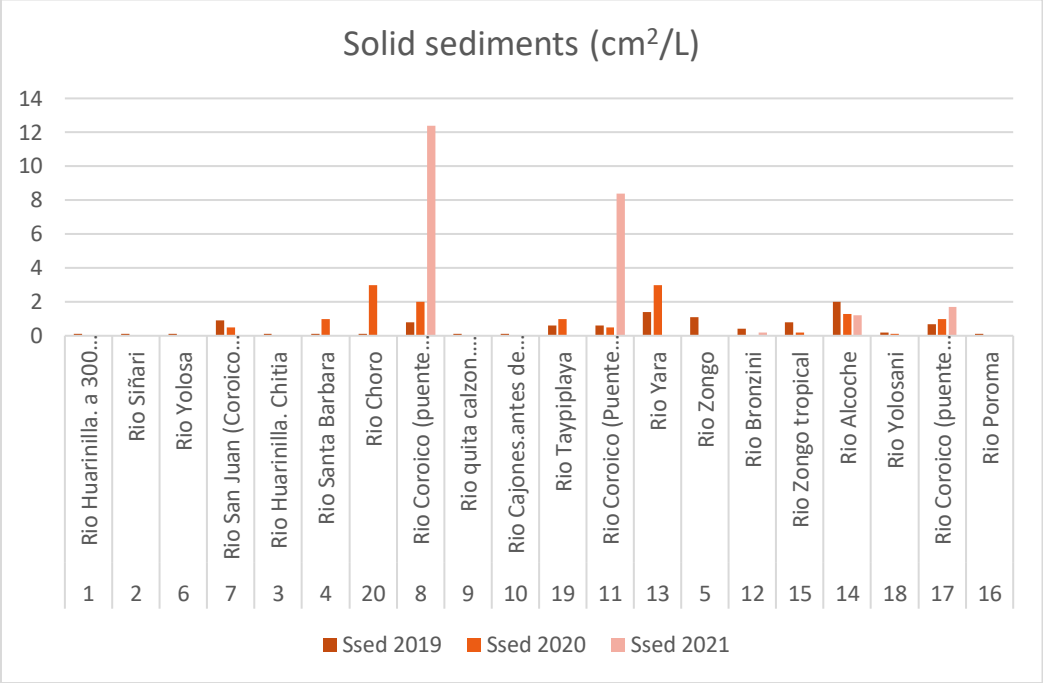
Annex 5: PH values at different points along the Coroico River catchment



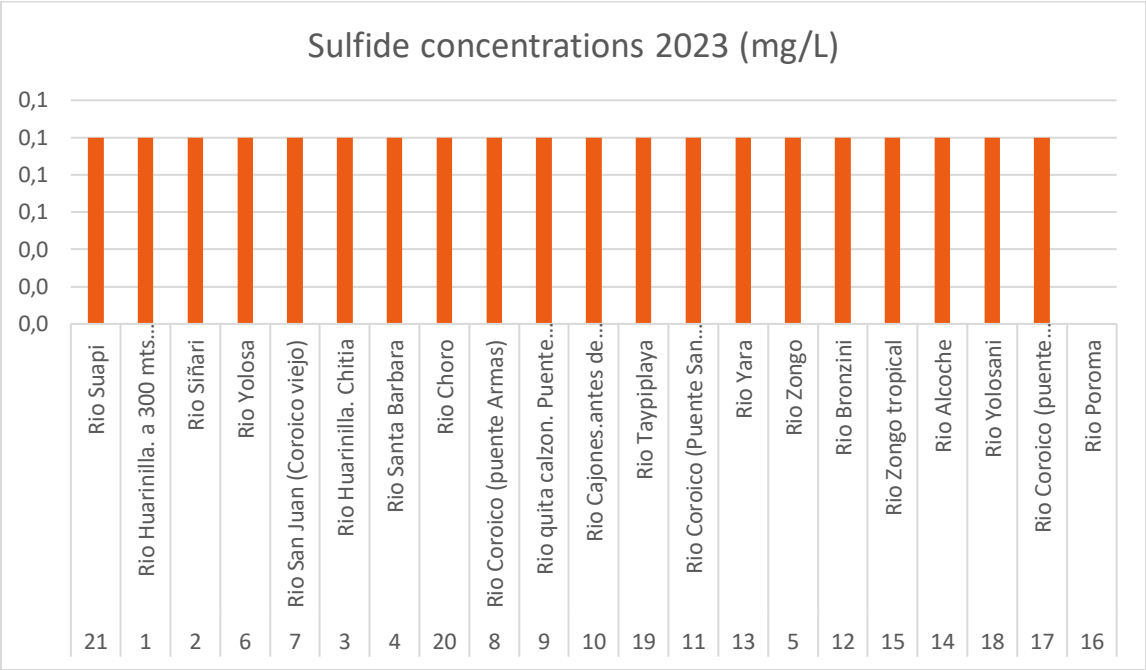
Annex 6: Turbidity (NTU) in different points along the Coroico River catchment



Annex 7: Amount of solid sediments (cm^2/L) at different points along the Coroico River catchment



Annex 8: Sulfide concentration (mg/L) at different points along the Coroico River Catchment



Annex 9: Sulfate concentration (mg/L) at different points along the Coroico River catchment