A SOCIO-TECHNICAL ASSESSMENT OF MERCURY AND GOLD LOSSES IN ARTISANAL AND SMALL-SCALE MINING (ASM) OPERATIONS IN COLOMBIA

by

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ABSTRACT

In Colombia, the artisanal and small-scale gold mining (ASGM) sector represents about 70% of the mining activities, and approximately 80% of Colombia's gold comes from this sector. In addition, the ASGM sector in Colombia releases about 90 tons of mercury per year. Although the Colombian government banned mercury in 2018 and has implemented a number of programs aimed at eliminating mercury from ASGM mineral processing systems, mercury use continues to be widespread. A number of scholars have emphasized that in order for miners to stop using mercury, any new technology must be at least or more efficient than mercury at recovering gold. However, there has been a lack of quantification of the efficiency, or gold recovery rate, of ASGM mineral processing to provide a baseline for introducing new technologies. Furthermore, miners' perceptions on mineral processing and the risks of mercury have been relatively neglected, even though these beliefs can have significant impacts on their decision-making. Therefore, this thesis provides a socio-technical analysis of mercury use in ASGM mineral processing systems in the department of Antioquia in Colombia. Through gold and mercury mass balances and an ethnographic study of ASGM operators, we found that miners maintained relatively accurate knowledge about their mineral processing systems, especially in terms of the amount of gold and mercury they lost during mineral processing. Even so, miners felt that they were recovering as much gold as they could given their current technologies, and they were not interested in recovering the mercury that was lost in the tailings. Furthermore, miners' awareness of the human health and environmental hazards associated with mercury did not motivate them to change their practices. Instead, they viewed the government's discourse about the risks of mercury with skepticism, and despite some of their concerns about mercury, they were either hesitant to use or did not have access to mercury alternatives for mineral processing. This thesis demonstrates that socio-technical understandings of mercury use can better inform policy makers and development initiatives aimed at eliminating mercury from ASGM mineral processing systems.

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CHAPTER ONE
INTRODUCTION

1.1 Motivation and Problem Description

Mercury emissions are a global concern due to the risks they pose to human health and the environment. Artisanal and small-scale gold mining (ASGM) is responsible for the largest amount of anthropogenic releases of mercury into the environment, releasing approximately 1,400 tons of mercury per year globally (Fritz et al., 2017; UN Environment, 2019; US EPA, 2014). Artisanal and small-scale gold miners use mercury because it is inexpensive, easy to use, and works more quickly than other methods used to recover gold (Gonçalves et al., 2017; Güiza Suárez & Aristizabal, 2013; Telmer & Veiga, 2009;Veiga et al., 2006; Velásquez-López et al., 2010). Mercury binds with the gold in the ore to form an amalgam, which is then heated to burn off the mercury. Often this process releases mercury vapor into the air, which is then deposited in water and soils (Odumo et al., 2014). Mercury also appears in the tailings from ASGM mineral processing and can leach into soils and water bodies causing harm to community members and the environment (Ganesan & Sambathkumar, 2003; Schudel et al., 2019; S. A. Shaw et al., 2006).

Several studies have attempted to understand how mercury is used in ASGM, quantify mercury emissions, and implement remediation plans for mercury-contaminated sites (Black et al., 2017; Cordy et al., 2015; Pirrone & Mason, 2009; Telmer & Veiga, 2009; UN Environment, 2013, 2019a; OITA US EPA, 2014; Wang et al., 2004). In addition, governments, development agencies, and non-governmental organizations (NGOs) have aimed to address mercury use in ASGM. Some governments have banned mercury altogether, which has led to unintended consequences, including the entrenchment of mercury in the black market or miners being forced to burn amalgam at home (Esdaile & Chalker, 2018; Fritz et al., 2016; Gonçalves et al., 2017; Hilson, 2006; Sousa et al., 2011). Others have partnered with development agencies and NGOs to implement educational programs aimed at informing miners about the impacts of mercury on human health and the environment and eliminate the use of mercury in ASGM operations (Centro Nacional de Produccion más limpia y tecnologias ambientales et al., 2017; Selin et al., 2018; Spiegel, 2009; UN Environment, 2020). Technologically focused programs have introduced artisanal and small-scale miners to alternatives to mercury use in mineral processing (UN Environment, 2020; UNDP, 2019a). Although all of these efforts are well-intended, many of them have fallen short in precipitating change; it has been shown that even if miners are aware of the risks associated with mercury, they will continue its use (Novais & Câmara, 2009; Ottenbros et al., 2019; Smith, 2019). Furthermore, there is a growing consensus that in order to motivate artisanal and small-scale miners to discontinue mercury use, they need to be shown that any proposed technologies will be more efficient at capturing gold from the ore than will amalgamation (Cordy et al., 2015; Gonçalves et al., 2017; Lücke, 2005; Veiga et al., 2014; Veiga, 1997; Veiga et al., 2006, 2009, 2018;Veiga & Marshall, 2019).

Efficiency in gold mining is measured by comparing the profits with the cost of the operations. While efficiency metrics often guide large-scale gold mining operations, efficiency in ASGM mineral processing systems has been relatively understudied. Some authors suggest that the solution is beyond technical and policy interventions (Siegel, 2013a), because miners need knowledge, organization, and access to credit to afford better technologies (Veiga et al., 2018). Despite these approaches, miners' perceptions on the efficiency of mineral processing, the mercury ban, and mercury-free technologies have been ignored. However, perceptions of mercury use have been examined to a certain extent in the literature. A study conducted in 2006 showed that miners were unaware of health and environmental hazards (Veiga et al., 2006); however recent studies have shown that over the years, miners are acquiring more knowledge related to the health and environmental impacts of mercury use (Charles et al., 2013; Ottenbros et al., 2019; Sana et al., 2017; Smith, 2019; Smith et al., 2016). Only one study conducted in 2014, revealed miners' perceptions on efficiency, and demonstrated that ASGM operators believed that no mercury was lost in the gold recovery process (Veiga et al., 2014). Studies like this reveal that the perceptions of miners are important to take into consideration because miner's opinions, motivations, and the dynamics of the operation may impact the effectiveness of outside interventions.

Socio-technical approaches aim to identify the ways in which social factors, such as social relations, attitudes, and perceptions, influence the use and uptake of technologies and in turn how technologies influence social factors (Kling & Lamb, 1999; Mitra & Mishra, 2016). In designing solutions to what may appear to be a technical problem, the traditional method was first to design the technical component and then fit people into it (Baxter & Sommerville, 2011). However, Appelbaum, (1997, p. 453) has suggested that is necessary to incorporate social aspects into design work in order to yield positive outcomes. Although this has been done to a certain extent in industries such as coal, and petrochemicals, we believe that this could be done within any sector. This study aims to identify artisanal and small-scale miners' knowledge and perceptions related to their current mineral processing systems and how these perceptions influence their decision making.

To identify barriers to eliminating mercury use in ASGM operations, a socio-technical analysis was conducted at a mine site in the department of Antioquia in Colombia. This examination included a case study analysis of three relatively understudied dimensions of ASGM mineral processing: 1) the efficiency (gold recovery rate) of mineral processing systems; 2) a quantification of the mercury sinks (or losses) in mineral processing systems; and 3) miners' perceptions of the efficiency of their operations and the risks associated with mercury use and tailings exposure. This analysis was carried out by conducting mass balances accompanied by an ethnographic study. Taken together, we demonstrate that miners at this mine site are quite accurate in their estimates of mineral processing efficiency and their estimates of mercury losses. We demonstrate that miners' perceptions are based on their own experiences, and that even if they are aware of the impacts of mercury, it is not enough to change their practices. This study also indicates that miners are skeptical of the government's discourse on mercury, making government led interventions relatively ineffective. Furthermore, in general, miners do not consider tailings as a significant risk, which may pose a barrier to encouraging miners to properly manage and dispose of their tailings.

It is important to note here that this case study is not representative of all of the ASGM operations in the region, around the country, or globally. Mineral processing methods and miner's perspectives on their methods vary across mine sites. However, this study shows that approaching ASGM miners with new or more efficient technologies is not enough and that future projects should be based on the gold recovery rates at each site and understand miners' perspectives.

1.2 Objectives

The study aims to identify artisanal and small-scale miners' knowledge related to the efficiency of their current mineral processing systems, as well as their awareness about the potential risks of mercury and contaminated tailings to human health and the environment.

1.2.1 Sub objectives

- Assess mercury and gold losses by conducting mass balances of mineral processing systems.
- Perform participant observation at a mine site where mercury is used, to observe mineral processing methods and conduct interviews with miners and other ASGM operators to understand their perspectives on mineral processing and gold and mercury losses in general.
- Identify miners' concerns and knowledge about mine tailings management and risks associated with an inadequate mine tailings disposal.
- Propose potential tailings management strategies to avoid future environmental and health issues.

1.3 Hypotheses

A. Artisanal and small-scale miners are aware they are losing gold and mercury in the tailings, but they are not aware exactly how much of each is being lost, nor are they aware of what else occurs in the tailings.

B. Despite government inventions, which have included the introduction of mercury-free technologies, trainings on the effects of mercury on human health and the environment, and efforts to formalize the sector, artisanal and small-scale miners are reluctant to change their current practices using mercury.

C. Artisanal and small-scale miners are aware that tailings pose environmental and human health hazards; however, they are not aware of the exact hazards to the environment and human health, nor are they aware of how to manage the tailings to mitigate these hazards.

1.4 Study design

To prove or disprove the hypotheses and achieve the research objectives, two approaches were employed. The first approach assessed the efficiency (gold recovery rates) of a mineral processing system at an ASGM operation in Antioquia, Colombia, which uses whole ore amalgamation. To do this, mass balances of gold and mercury were conducted at one mine site to quantify gold and mercury losses and identify exactly where gold and mercury were lost. The second approach focused on identifying miners' perceptions of mercury use and the risks associated with mercury and mine tailings. These approaches took place over a two-year period and included three different phases. The initial step consisted of designing the study and establishing the objectives and hypotheses based on a literature review and previous knowledge. This initial phase also included creating a fieldwork methodology and establishing contact with people that had familiarity with the region. The second phase consisted of four months of fieldwork and included conducting the mass balances and performing the interviews. The final stage included analyzing the results of the fieldwork.

1.5 Thesis organization

This thesis in organized into 7 chapters:

Chapter 1—Introduction provides a brief introduction to this research. This chapter identifies the hypotheses, main objectives, and research questions central to this project.

Chapter 2—Literature review provides an overview of ASGM globally, mercury use, and the efficiency of mineral processing systems in ASGM. It also includes an examination of ASGM in Colombia and tailings management in ASGM.

Chapter 3—Site description describes the characteristics of a mine site where this study took place. Since each ASGM site varies in its processing methods, perceptions, and tailings disposals, understanding the ASGM conditions at this mine site provides critical background information for this study.

Chapter 4—Methods provides a description of the activities and the methods conducted to perform this research.

Chapter 5—Results presents the findings of this study, which include an estimation of the mercury and gold losses in tailings and miners' perceptions about the efficiency of their gold recovery process, mercury use, and tailings.

Chapter 6—Discussion provides an analysis of the results, highlights the contributions of this research, and addresses the limitations of this study

Chapter 7--Conclusions presents a summary of the key findings and makes recommendations for future research.

CHAPTER TWO
LITERATURE REVIEW

2.1 Overview of artisanal and small-scale gold mining (ASGM)

Gold (Au) has always had an important role in society and has been coveted by authorities and royalty for centuries due to its value in trade and exchange and its association with wealth and power. Mercury (Hg) has also played an important role in society because of its use in medicine and dentistry, fluorescent bulbs, and in artisanal and small-scale gold mining (ASGM) operations (Rowlatt, 2013). Artisanal and small-scale mining is an important source of minerals and metals and is responsible for about 20-30% of the world's gold production (Fritz et al., 2017). It has been identified as a labor-intensive activity and a "get-rich-quick" scheme (Fritz et al., 2017, p. 38; Hilson, 2010; Ilyas & Lee, 2018; Wilson et al., 2015), as many developing countries have a strong presence of ASGM operations, and rural areas in these countries depend on ASGM as critical livelihood strategy. In 2017, it was estimated that there were approximately 40 million artisanal and small-scale miners in the global south, with 150 million indirectly dependent on the sector (Fritz et al., 2017; World Bank, 2013).

2.2 Mercury use in ASGM

In ASGM, the gold beneficiation process is generally carried out in small processing plants, where different methods are used to mill or crush the ore, so that the gold particles are liberated from the ore. The milling methods employed usually depend on the technology available to miners, as well as the tradition of the operations, which are unique to each mine site. For example, miners in Nicaragua use *rastras,* which are grinding circuits that consist of four rocks dragged in circular movements by an electric motor, and miners in Peru use *quimbaletes*, or large pieces of stone rocked back and forth (Ilyas & Lee, 2018). In some areas, miners use small ball mills; in Ecuador these are called *chanchas* and in Colombia they are called *cocos* (Cordy et al., 2011a, 2015; García et al., 2015; Velásquez et al., 2010). Often, mercury is added to the whole ore along with other materials to capture the gold (Veiga, 1997); however, some ASGM operations add mercury only to the concentrates (Spiegel & Veiga, 2009). Gold-mercury amalgam is heated to separate the gold and vaporize the mercury. Tailings are often disposed of in a concrete pool and dried in the sun to eventually be leached with cyanide (Adiansyah et al., 2015). More mercury is lost in the tailings when miners practice whole ore amalgamation than when they add mercury to just the concentrates (Veiga et al., 2009, 2014). Therefore, some authors and NGOs have designed guidelines for teaching miners to improve their concentration methods and avoid amalgamating the whole ore (Spiegel & Veiga, 2009; UNEP et al., 2012).

Mercury losses in ASGM are usually determined through mass balances based on the mercury introduced to the system and the mercury recovered at the end of the process. Mass balances calculated in some ASGM sites showed that approximately 50-60% of the initial mercury added to the amalgamation process was recovered and 30-50% was lost (Clifford, 2017; Cordy et al., 2011a, 2015; Gonçalves et al., 2017; Veiga, 1997b; Velásquez et al., 2010). In Colombia, mass balances calculated in 2010 and 2013 documented a 44% reduction of mercury and a 21% increase in the gold recovery rate between those years. Mass balances calculated in Ecuador in 2008 and 2013 showed a 30% reduction between those years in the amount of mercury initially added to mineral processing systems, and 33% of the total mercury was lost. This study also showed a 31% increase in the gold recovery rate between 2008 and 2013 (Gonçalves et al., 2017; Velásquez et al., 2010). Generally, gold-mercury amalgam contains about 50% gold and 50% mercury (UNEP, 2012). Amalgam burning releases mercury vapor into the air, which is accumulated in the atmosphere along with other greenhouse gases. Some of these vapors are deposited in water and soils (UN Environment, 2019a).

The adverse effects of mercury in these ecosystems is primarily caused by the formation of methylmercury, which pollutes rivers and soils and contaminates freshwater fish and other aquatic organisms (Hunter & Rusell, 1954; Pierce et al., 1972; Grandjean et al., 2010; OITA US EPA, 2014; Xu et al., 2018; Martinez et al., 2018; R. P. Mason et al., 2019) Mercury also has negative impacts on human health and can compromise nervous, digestive, reproductive, and immune systems (Antunes dos Santos et al., 2016; Henriques et al., 2019; Hong et al., 2012; OA US EPA, 2015; WHO, 2007, 2013). While mercury emissions from amalgamation have been extensively studied (Hinton, 2003a, 2003b; van Straaten, 2000; WHO, 2013), mercury in the tailings produced by ASGM operations has been relatively ignored, even though it can leach into soils and waterbodies and impact human health and the environment.

2.3 Eliminating mercury use from ASGM operations

Initiatives focused on promoting the safer handling of mercury or eliminate mercury entirely from ASGM operations gained momentum in 2017, when the United Nations Minamata Convention went into force. The Minamata Convention is an international treaty aimed at protecting human health and the environment from the adverse effects of mercury (UN Environment, 2017; UNEP, 2013). Artisanal and small scale gold mining is specifically targeted in Article 7 of the convention which states that countries "with more than insignificant" ASGM activities in their territory "shall take steps to reduce, and where feasible eliminate, the use of mercury and mercury compounds in, and the emissions and releases to the environment of mercury from, such mining and processing" (UN Environment, 2019b, p. 25; UNEP, 2013). Countries that ratify the convention are required to draft National Action Plans (NAPs) that outline their strategies for reducing mercury emissions from ASGM (Hilson et al., 2018).

Some signatory countries, like Colombia, Ghana, and Indonesia have banned mercury use in ASGM, while others have conducted projects that introduce mercury-free gold recovery technologies and provided technical assistance. However, eliminating mercury use in ASGM is much more complex, as any intervention must also address other factors that influence mercury use, including miners' reasons for using mercury in the first place, their awareness of the efficiency of their mineral processing systems, and the economic tradeoffs associated with alternative mineral processing technologies (Siegel, 2013a). Furthermore, technical assistance is often offered for a short period of time and lacks follow-up. Finally, none of these projects have been implemented with an understanding of the efficiency of ASGM mineral processing systems or miners' knowledge of or perceptions about their current processing systems.

2.4 Efficiency in ASGM

In conventional, large-scale mining, efficiency is measured by comparing the profits from production with the cost of the operations. Gold recovery efficiency is constantly assessed to improve mineral processing and provide ongoing economic analyses. These analyses are primarily used to drive decision-making in the operations (M. D. Adams, 2005; Ahtiainen & Lundström, 2019; Angove, 2005; Cimon et al., 1987; Fullam et al., 2016; Lawrence & Marchant, 1987; Zheng et al., 2015), and often companies will implement new technologies to improve efficiency (Faraz et al., 2014; Yazici et al., 2020).

In ASGM mineral processing systems, some authors have documented that gold recovery rates using amalgamation range from 20% to 50% (Cordy et al., 2011; Gonçalves et al., 2017; Hylander et al., 2007; Persaud & Telmer, 2015; Veiga et al., 2009, 2014, 2018). In these studies, gold recovery estimates were provided by local operators and miners, but they were not verified through an external quantitative analysis. A few studies have reported on the gold recovery of systems using gravity concentration and river dredging. In these systems, mercury was applied to the concentrates (Balzino et al., 2015; Teschner et al. 2014; Velásquez et al., 2010). One of these studies in particular, showed that miners using graving concentration methods in the Guianas recovered up to 90% of the gold in alluvial deposits (Teschner et al. 2014). Other studies have compared the amalgamation process with other gold recovery technologies. For example, Hylander et al., (2007) compared the amalgamation process with four other methods of gold recovery in the Philippines. The authors showed that amalgamation only recovered 10% of gold. These studies suggest that efficiency can dramatically vary across ASGM processing systems. While it is relatively straightforward to measure the gold recovery rate, it is a challenge to determine the causal factors, as the amount of gold recovered is also based on the geological features, the mineralogy of the deposit, and the gold particle size,. This underscores the importance of characterizing and analyzing each site before introducing technologies aimed at eliminating mercury from mineral processing.

2.5 ASGM in Colombia

Colombia is the eighteenth largest gold producer in the world and the fifth largest gold producer in Latin America (O’Connell et al., 2018; World Gold Council, 2019). In 2018, Colombia produced about 856,300 troy ounces of gold (El Colombiano, 2020), of which about 80% came from the informal mining sector (Fajardo, 2017; Siegel, 2013; Sostenibilidad Semana, 2019; Veiga & Marshall, 2019). The departments of Antioquia and Choco produce the most gold in Colombia and have the largest number of ASGM operations (SIMCO, 2018; UPME, 2018). It has been estimated that approximately 100 tons of mercury are released annually by the ASGM sector in

Antioquia alone, and the region was recognized in 2011 as the world's largest mercury polluter from ASGM activities (Cordy et al., 2011a; Veiga, 2010).

Approximately 72% of the mining activities that take place in Colombia are classified as ASGM (Mining and Energy Ministry, 2012; UPME, 2017a, 2018) and take place in both alluvial and underground mines. The mineral processing systems employed to recover gold vary. The ASGM operations conducted in underground mines, where this study took place, usually process the ore in small facilities called *entables*. Whole ore amalgamation includes directly adding mercury to small ball mills called *cocos* that crush the ore. Then, the amalgam is separated by panning, and the excess mercury is recovered by squeezing the amalgam through a piece of cloth. The remaining amalgam is burned, emitting mercury to the environment as it vaporizes. In addition, mercury also ends up in the tailings (Cordy et al., 2011a, 2015; García et al., 2015; Velásquez et al., 2010), which can leach into soils and water bodies. In many ASGM operations, these tailings are sold to larger processing plants that use cyanide to leach the remaining gold from the tailings. A mercury-cyanide complex forms when tailings are reprocessed in cyanidation plants, which increase the mobility of bioavailable mercury and can create highly toxic compounds that pollute rivers and aquatic ecosystems (Drace et al., 2016; Marshall et al., 2020).

2.6 Colombian initiatives

Colombia ratified the Minamata Convention in August 2019 (Sostenibilidad Semana, 2019a; UN Environment, 2019c); however, mercury was banned a year prior. Before implementing the ban, the Colombian government allocated five years to reducing and subsequently eliminating the use of mercury. Although some ASGM operations have stopped using mercury, there are several across the country that continue to rely on mercury for mineral processing.

The Environmental and Sustainable Development Ministry drafted the Mercury National Action Plan in 2014 to gradually eliminate the use of mercury in the mining and industrial sectors. The Colombian government, in partnership with development agencies and NGOs, has attempted to reduce mercury use in ASGM by implementing projects which introduce clean technologies, provide trainings for miners, and institutionalize programs aimed at formalizing the ASGM sector (Alliance for responsible mining, 2010; Mining and Energy Ministry, 2018; Semana, 2011; UNDP, 2019b, p. 2019; UNIDO, 2017; UPME, 2017b). Despite these efforts, mercury use continues to be a major concern in Colombia (Sostenibilidad Semana, 2019b, 2019a), and the presence of mercury in the black market has increased (Casasbuenas & Silva, 2018; Rubiano, 2017). Furthermore, studies conducted in other countries have reported that even if miners are aware of the risks associated with mercury they will continue use it in their operations (Charles et al., 2013; Novais & Câmara, 2009; Ottenbros et al., 2019; Smith, 2019). This is the case in Colombia, and therefore, there has been little success in eliminating mercury from ASGM processing systems. Moreover, the majority of these initiatives have been implemented by the government or international development agencies with little participation from ASGM communities in terms of their needs and the potential social and economic barriers that stand in the way of changing their practices (PIM, 2020).

2.7 Tailings management in ASGM

Mine tailings are a byproduct of both large and artisanal and small-scale mining operations. The composition of tailings differs according to the nature of the ore body and the mineral processing methods employed. However, tailings generally contain a large amount of heavy metals and toxic chemicals that can leach into soils and pollute water bodies (Ngole-Jeme & Fantke, 2017; Wuana & Okieimen, 2011). Tailings management has captured global attention in recent years due to several devastating tailings dam failures that have occurred at large-scale mining sites (Beacon, 2019; Owen et al., 2020). Tailings from ASGM operations have received less attention; however, ASGM activities generate thousands of tons of tailings every year (Esdaile & Chalker, 2018). In general, ASGM operators do not plan how to manage or dispose of their tailings. For example, at an ASGM site in Ghana, the majority of the operators stockpiled their tailings and did not implement any environmental protections (Amedjoe & Gawu, 2013).

Tailings resulting from ASGM operations are known as “mercury hot spots” and also contain other heavy metals (Falagán et al., 2017; Odumo et al., 2014, p. 12432; van Straaten, 2000), which can be emitted into the air, soil, and water bodies bringing health and environmental issues (OITA US EPA, 2014). In some cases, these tailings are sold to larger processing facilities that then process them with cyanide (NaCN) to recover the remaining gold (Cordy et al., 2011, 2015; Gonçalves et al., 2017; Veiga et al., 2018).

The amount of mercury in ASGM tailings has been estimated through mass balances where the amount of mercury added to either the whole ore or the concentrates is compared to the amount of mercury recovered and the amount of mercury that ends up in the tailings (Cordy et al., 2011a; García et al., 2015; Velásquez et al., 2010). These studies reported that between 46-80% of the mercury was lost to the tailings and 40-50% of mercury was recovered after squeezing. However, these studies did not consider the mercury that naturally occurs in the ore or the mercury losses that occur elsewhere in mineral processing.

Even though Colombia has been mining since colonial times (Singewald, 1949), the country does not have any laws or regulations for tailings disposal (Beltrán-Rodríguez et al., 2018). The National Mining Code of 2001 (Ley 685 del 2001-Codigo de Minas, 2001, p. 83) stated that mine waste should be disposed of in such a way that protects the environment (Mining and Energy Ministry, 2001), and this should be defined during mine planning. Although this code provides some rough guidelines, such as not disposing of mine waste into rivers, these guidelines are designed for large-scale mining (LSM) operations, and in many cases are impossible for ASGM operators to follow because they lack the capital to invest in equipment and supplies, and they lack technologies for proper tailings disposal. The National Development Plan (2014-2018), a roadmap for establishing government programs, investments, and goals, stated the need for a policy directed at managing environmental liabilities (Plan Nacional de Desarrollo 2014 - 2018, 2014, p. 100 Article 251). In 2017, the Mine and Energy Planning Unit (UPME) of the Colombian government created a National Development Plan for Mining that defined the priorities for developing the mining sector, with a goal of increasing mining production in Colombia by 2019 (UPME, 2017a). However, it failed to outline any policies or regulations for tailings management or disposal (UPME, 2017a).

Due to the absence of clear regulations for tailings management, Colombia has a large number of abandoned and contaminated sites. A study conducted in 2018 concluded that there were more than 360 abandoned mines in the Antioquia department alone (Portafolio, 2018). These sites were labeled as "environmental liabilities" by the Environmental and Sustainable Development Ministry and the Mining and Energy Ministry (Ministerio de medio ambiente y desarrollo sostenible, 2014). The government has recently made efforts to identify, diagnose, and assess these liabilities, but the focus has been on abandoned sites, with no attention given to active ASGM sites and their potential environmental liabilities.

CHAPTER THREE

DESCRIPTION OF THE FIELD SITE

3.1 Study area

This study took place at a mine site in the northeast region of the department of Antioquia (Figure 1). The northeast region is in the central mountain range and is one of nine sub regions of the department. It has ten municipalities and an estimated population of 186,500 inhabitants (Cahucopana, 2013). Agricultural and mining activities are the largest economic drivers in this region, and it is now the second largest gold producer in the department of Antioquia (OECD, 2016). Both large- and artisanal and small-scale mining activities take place here, with nearly 1,400 small-scale mining operations (SIMCO, 2018). People pan gold and work on dredges in the rivers, mine underground in hard rock deposits, and there are also *chatarreros* who collect and process waste rock that has been discarded by mines. There are approximately 80 *entables*, or small facilities where miners process their ore and around 70 gold shops that purchase gold from the miners and mineral processors (SIMCO, 2018). In addition, there are many industries that provide goods, services, and supplies to both the mining and agricultural industries.

Gold mines are often associated with social conflicts (Siegel, 2013b), and this region historically has had a strong presence of guerrillas, paramilitaries, and drug traffickers (UNDP, 2017). Segovia and Remedios, municipalities close to the mine where this study took place, are notorious because of the presence of armed groups, unregulated mining, and conflicts between medium and large-scale mining companies over land access and land rights (Alsema, 2019; Fajardo, 2017). These municipalities are also known for the high levels of mercury used in and released by ASGM activities and are said to be some of the world’s most polluted places (Cordy et al., 2011;. Veiga, 2010).

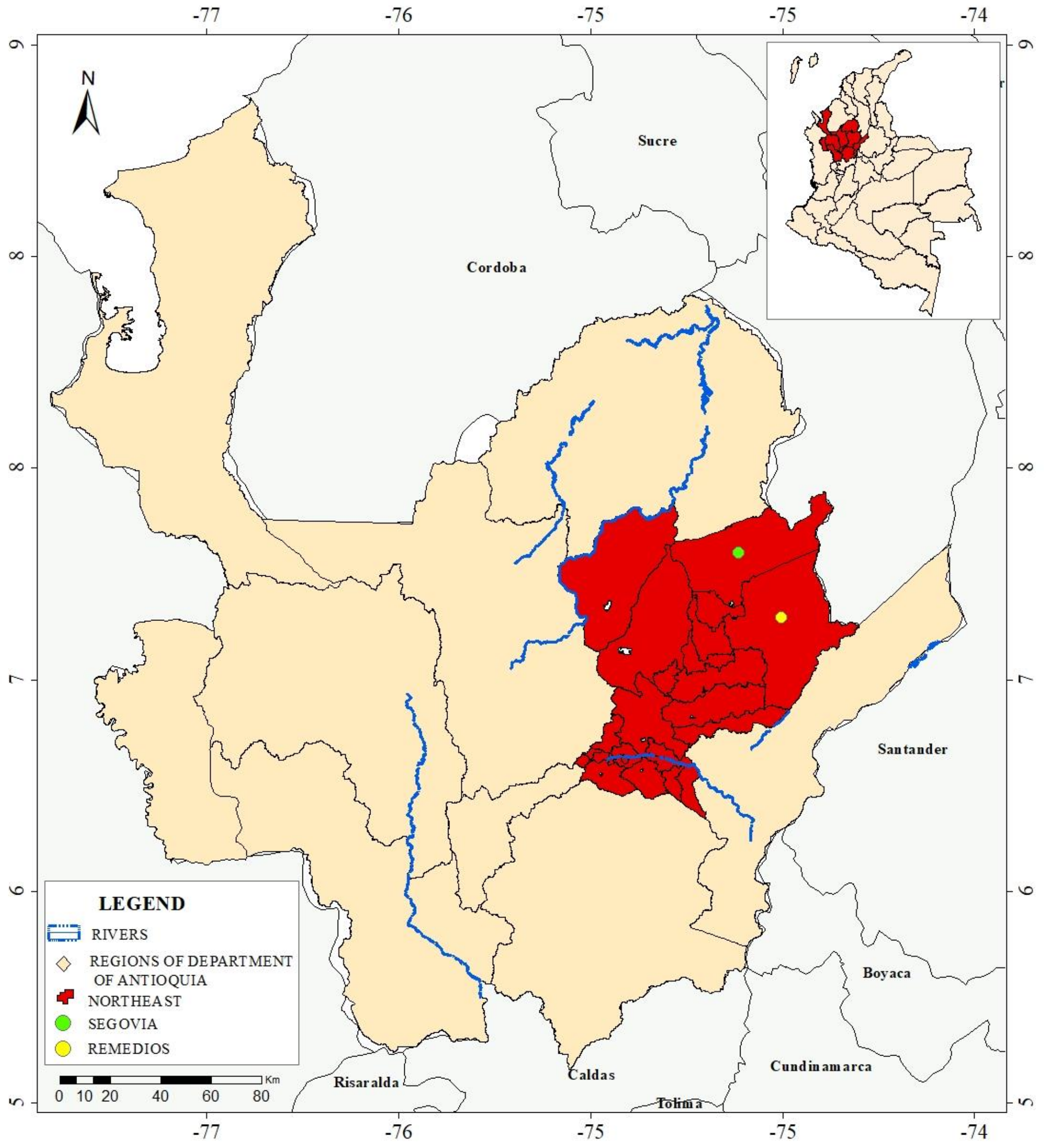

Figure 3-1: Northeast region of the department of Antioquia. Segovia and Remedios are the biggest municipalities in the region and recognized by the strong presence of ASGM operations. [1].

3.2 Regional region

The study sites are located in northeast region of the department of Antioquia, Colombia. This area is situated in the Colombian Andes which comprise three mountain ranges: the eastern, central and western mountains. These mountains are separated by the two biggest rivers in

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[1] The mine site where this study took place is not represented on this map or named in this thesis in order to protect the confidentiality of the research participants.

Colombia. The Magdalena river separates the central and eastern mountains, and the Cauca river separated the central and western mountains. The Cauca-Romeral fault system divided two zones in the northeast region that also include the Segovia batholith and Antioquia batholith. The Segovia batholith is formed by diorites, diorite quartz, and hornblende gabbro (Gonzales, 2001). The Antioquia batholith is predominantly composed of tonalite, diorite and granodiorite phases (Leal-Mejía & Melgarejo, 2008)

The northeast region is characterized by the presence of rich deposits and is known to be one of the important mining districts in Colombia. Gold has been produced in this region since colonial times, and artisanal and small-scale mining operations have occurred in the area for at least the last century. The deposits found in the northeast region are mainly deposits associated with intrusions, most commonly diorites, quartz-diorite, tonalite, granodiorite, and granite from the Jurassic, Cretaceous and Miocene (Manco P. et al., 2012). Most of these are gold (Au) vein deposits and also host copper (Cu) and silver (Ag). In addition, the veins can host electrum, chalcopyrite, pyrite, sphalerite, arsenopyrite, galena, and pyrrhotite, as well as gangue minerals including quartz and biotite with some argillic, and propylitic alterations (Lopez, 2018).

As an example from the region, the Segovia-Remedios mining district hosts mesothermal gold veins which were emplaced in association with magmatism (Galindez et al., 2007; Manco P. et al., 2012). In another example, the Frontino Gold Mines is located in this district and has been exploited since colonial times. This mine is hosted in the Segovia batholith that is predominantly composed of granodiorite and diorite. The gold-vein mineralization of La Aurora mine is hosted in protomylonite with feldspar, plagioclase, quartz and biotite. The mineralogy associated is quartz, pyrite, chalcopyrite, pyrrhotine, galena, and sphalerite (Galindez et al., 2007). Another exploration project in the region is Gramalote, where gold and silver mineralization occurs within a structurally controlled quartz stockwork system within the Cretaceous Antioquia batholith (Leal-Mejía & Melgarejo, 2008). The mineralization at Gramalote is vein hosted, either in sheeted veins or local stockworks (Leal-Mejía & Melgarejo, 2008).

3.3 Demographics and Culture

According to the National Department of Statistics Administration (DANE), about 50% of the population in the northeast region lives in rural areas. In 2017, the government of Antioquia estimated that about 70% of the population living in rural areas had unmet basic needs (Camara de comercio de medellin, 2019). In addition, most of the population has only a high school education (Camara de comercio de medellin, 2019). Men comprise approximately 51% of the population in this region (Cahucopana, 2013; Camara de comercio de medellin, 2019).

3.4 Economic activities

Mining is the main source of income for the people in the northeast region, followed by agriculture (mainly sugarcane), logging, and trade. The region's economic activities are affected by external factors such as climate and weather patterns, market prices, and security. The presence of criminal groups represents an obstacle for the economic development of the region.

3.5 Mite description

The mine site where this study took place is a small-scale operation. Eight associates (*socios)* collectively own the mine, and two managers control all the mining operations. There are twelve miners working underground divided into two teams. Each team has a leader (*frentero*), a leader's assistant *(palero)*, and four laborers (*catangueros)*. Additionally, four chatarreros work close to the mine entrance and along a nearby creek. An entable is located 80 meters from the mine entrance. The entable includes a crusher, twenty small ball mills (cocos), and an elutriator, which is a machine that separates particles based on their size, shape, and density. Miners work Monday through Saturday in nine-hour shifts. According to one of the mine managers, the miners who work at this mine site do not have health insurance, a pension plan, personal leave, or severance funds.

3.6 Mineral processing system

The mineral processing system at this site consists of fourteen steps (Figure 3-2;Figure 3-3). First, miners extract the ore from the mine, manually bring it to the surface, and create a pile in front of the mine entrance (step 1). Once the ore has dried, they use the jaw crusher to reduce the particle size (step 2), load the ore into sacks, and transport it to the entable. At the entable, the miners load each sack of ore into one coco with water, mercury, molasses, and quicklime (CaO); they often add plant material as well (step 3). They mill the ore for three hours, and then put the concentrate into the elutriator (step 4). The coarse particles drop into buckets below the elutriator and the fine particles overflow into a trench (step 5) with three traps. The heavier and larger particles settle in the first trap, and the rest continue to the second and third trap. The material collected in the first trap is put back into the cocos to be re-milled (step 6). The material that is captured in the second trap is put into a pile to be processed in the future by a mine manager (step 7). The material accumulated in the third trap goes into a tailings pool via a pipe (step 8). When the tailings pool is full, the miners stockpile the tailings (step 9) and eventually sell them to a larger processing facility that uses cyanide to extract the remaining gold. The coarse particles that are concentrated in the buckets below the elutriator are panned (step 10) to separate out the amalgam (step 11). The amalgam is poured into a piece of cloth and squeezed to remove the excess mercury (step 12), which is then added with lemon juice to the cocos to process the material that was collected from the first trap (step 13). The amalgam is burned to obtain the doré, an alloy of mainly gold and silver (step 14).

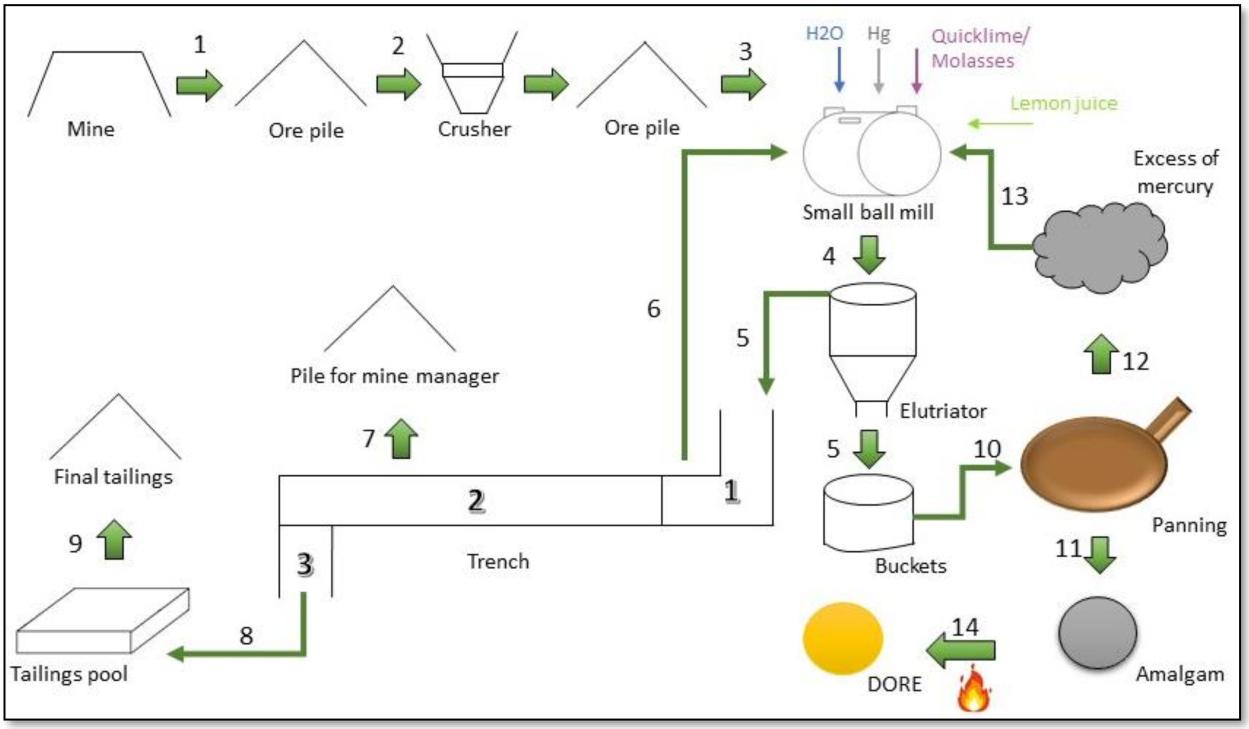

Figure 3-2: Gold recovery process system showing the flow of gold and mercury. The numbers indicate the steps taken by the miners.

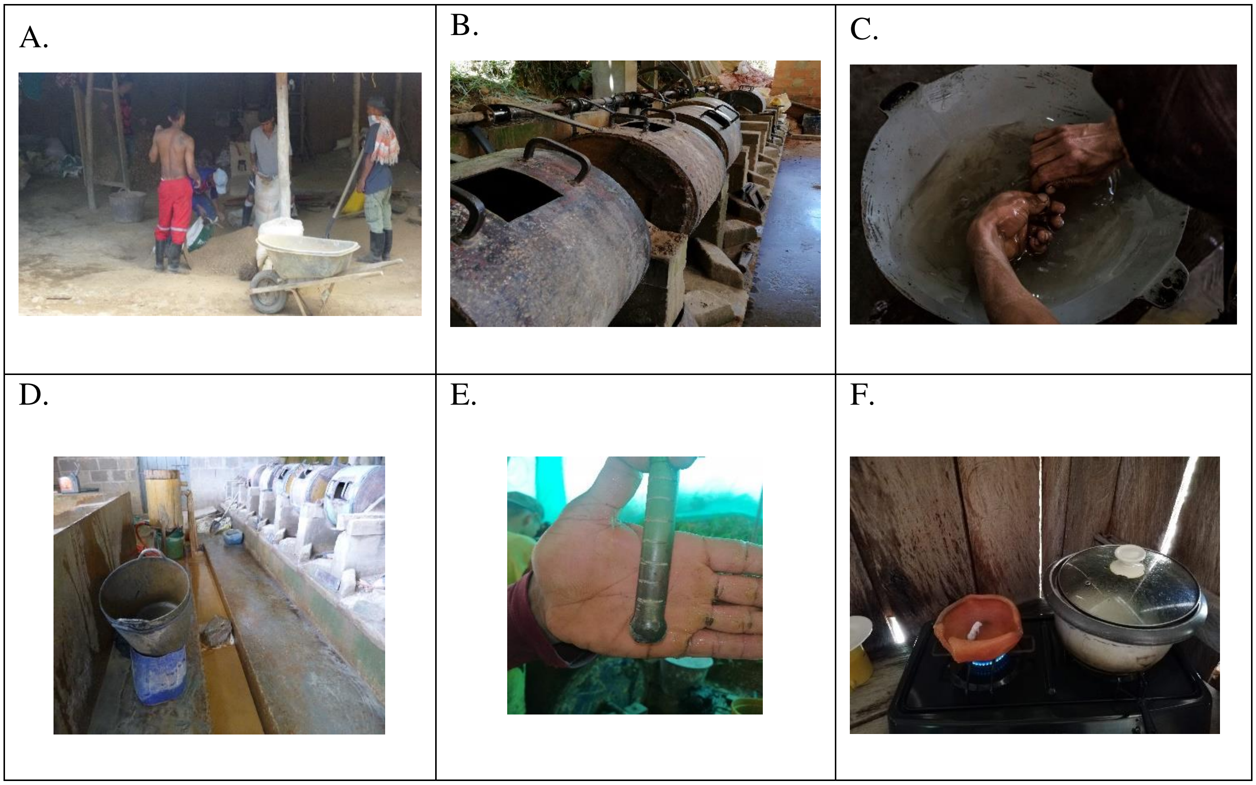

Figure 3-3 Gold recovery process conducted by the miners at this mine site. A: Miners blending the ore. B: Cocos in the entable. C: Squeezing the amalgam to obtain the excess mercury. D: Trench showing the first trap and the elutriator in the background. E: Plastic tube that miners use to measure the amount of mercury added to each coco. F: Amalgam being burned next to a pot of rice.

CHAPTER FOUR

METHODS

4.1 Site Selection

Traditionally, gold production in the Antioquia department takes place in three different sub-regions: Bajo Cauca, which includes the municipalities of El Bagre, Nechi, and Zaragoza; Caceres, Northeast, which includes the municipalities of Segovia and Remedios; and Southwest, which includes the municipalities of Buritica and Andes (Colombian Mining Information System-SIMCO, 2018). Project partners from the Universidad Nacional de Colombia, Uniminuto, and community leaders provided information and assisted me with visits to different mine sites in the Antioquia region to select an adequate fieldwork locale, where miners were using mercury and where there were established relationships with community members. During the first week in the chosen site in the Northeast region, I identified different stakeholders around the site, including community leaders, miners, chatarreros, and governmental agencies to understand the dynamics of ASGM in the region.

4.2 Data collection

Fieldwork for this study took place over a four-month period. During this time, we performed gold and mercury mass balances in a processing plant with assistance from the miners working at the plant. In mineral processing, mass balances use the mass conservation concept to formulate equations based on a process flow diagram (Wills & Finch, 2016). In this study, the mass balances calculated the total amount of gold and mercury outputs relative to the inputs (Lee et al., 2020). We also conducted ethnographic research among both male and female miners, chatarreros, and mineral processors to identify local knowledge related to the efficiency of the gold recovery processes and mercury losses, as well as people's awareness of the health and environmental hazards from using mercury.

4.3 Mass balances

To estimate the amount of gold and mercury recovered and lost throughout the mineral processing system, we conducted three mass balances spaced approximately a month apart (Figure 4-*1*). For the first mass balance, we divided the crushed ore into ten cocos. We collected the material that was captured in the first trap and put it back into five cocos with lemon juice and the mercury that was recovered after squeezing the amalgam from the concentrate collected from the underflow of the elutriator. We repeated this process one more time, using only three cocos. For the second and third mass balances we initially divided the ore into three cocos for each mass balance and reprocessed the material from the first trap only once, also adding lemon juice and the mercury recovered after squeezing the amalgam. The difference in the number of cocos used and the number of times the material from the first trap was reprocessed was a function of the amount of ore initially added to the system and the miners' time and operational constraints.

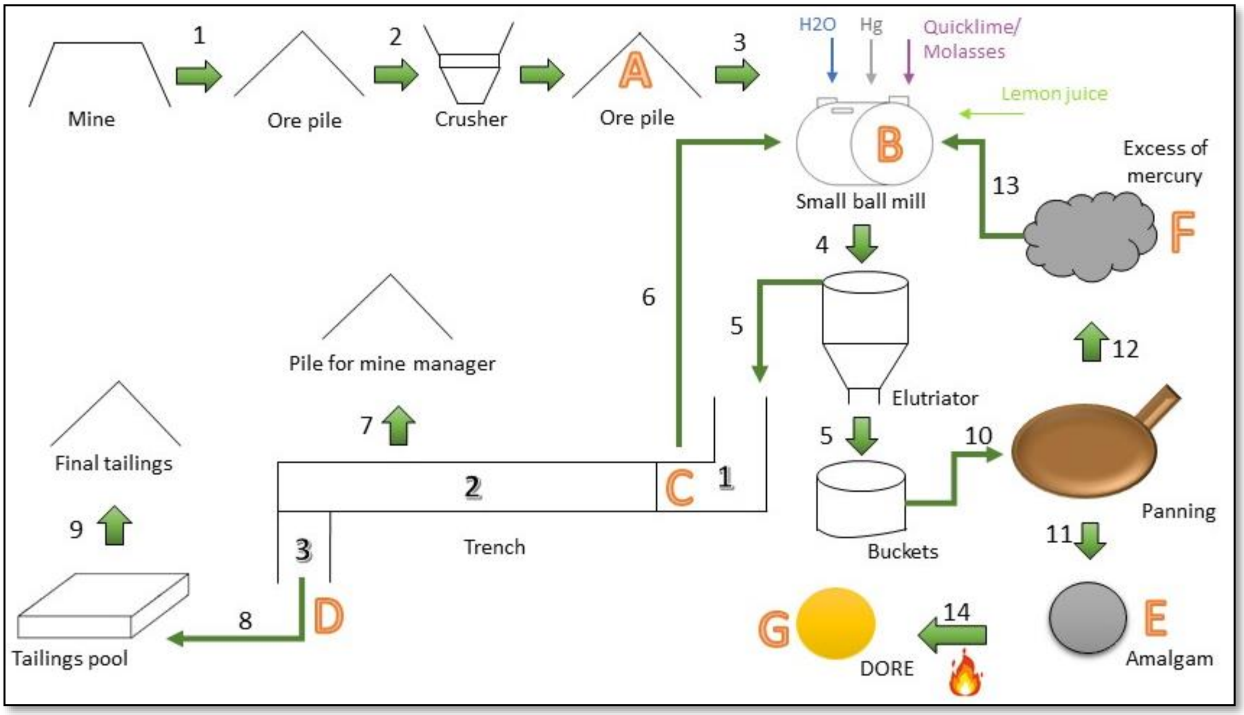

Figure 4-1: Gold recovery process system showing the flow of gold and mercury. The letters indicate the samples that were collected and the measurements that were taken for this study.

To calculate the gold and mercury lost during mineral processing we applied a simple metallurgical balance based on the assumption that the amount of gold and mercury going into the process equals the total gold and mercury exiting the process. For gold, we measured the amount of gold in the plant feed ($Au_{initial}$) and set that to equal the sum of the gold in the products exiting the process: the gold recovered from the amalgam ($Au_{amalgam}$); the gold in the tailings ($Au_{tailings}$); and any lost gold (Au_{lost}). This is shown in equation 4.1: where the amount of lost gold can be calculated by direct arithmetic difference:

$$Au_{initial} = Au_{Amalgam} + Au_{Tailings} + Au_{Lost} \quad (4.1)$$

In this mass balance, the fire assay determines the amount of pure gold in the feed and in the tailings. However, the gold recovered from the amalgam is not pure, but rather it is a gold electrum or an alloy of gold and silver with trace amounts of copper and other metals. Therefore, the value for the amount of gold in the amalgam ($Au_{amalgam}$) was adjusted downward and multiplied by 0.6 to reflect the lack of purity of that gold. This 0.6 factor was chosen according to the miners' reported fineness of their gold, which they learn when they sell the dore in the local gold shops. The mineralogy of the deposit, which would have indicated the amount of free gold, was not considered in this calculation due to economic constraints.

For the mercury mass balance, we weighed the mercury added to the system ($Hg_{initial}$) and set that equal to the sum of the mercury in the products exiting the process: the mercury that vaporarized from the amalgam ($Hg_{amalgam}$); the mercury that was recovered by squeezing ($Hg_{squeezing}$); the mercury that was in the tailings ($Hg_{tailings}$); and the mercury that went elsewhere ($Hg_{elsewhere}$). This is shown in equation 4.2, where the amount of mercury lost elsewhere was calculated through a direct arithmetic difference:

$$Hg_{Initial} = Hg_{Amalgam} + Hg_{Squeezing} + Hg_{Tailings} + Hg_{Elsewhere} \quad (4.2)$$

4.3.1 Sampling methods

For each mass balance, we collect representative samples as best as we could according to the operational conditions. We first collected samples from the pile formed after the miners crushed the ore with the jaw crusher (Figure 4-1: A). These samples were split in half and sent to a laboratory to determine the amount of gold in the ore using the fire assay method (ASTM E1335-08, 2017) and the mercury content through cold vapor atomic adsorption. After the miners divided the crushed ore into ten sacks, we weighed each sack and each sack was added to one coco along with water and mercury. We weighed the mercury and measured the water that were added to each coco (Figure 4-1: B). We then collected two, three kilogram samples of intermediate concentrate from the first trap (Figure 4-1: C) and sent them to the laboratory to determine the gold content using the fire assay method and the mercury content through cold vapor atomic adsorption. We collected two, three kilogram samples from the pipe that ran from the third trap to the tailings pool (Figure 4-1: D) and split them in half to send to the laboratory to determine the amount of gold and mercury in the tailings, as well as the types and amounts of other metals such as copper, lead, aluminum, and zinc using inductively coupled plasma mass spectrometry (ICP-MS). We weighed the amalgam after the miners squeezed out the excess mercury (Figure 4-1: E), and we weighed the excess mercury that was squeezed out (Figure 4-1: F). Finally, we weighed the doré obtained after the miners burned the amalgam (Figure 4-1: G). We repeated this process for each batch of intermediate concentrate that the miners remilled.

4.4 Ethnographic studies

We conducted ethnographic fieldwork from June to September 2019 in the same municipality where the mass balances took place. This included participant observation and 33 semi-structured interviews with both open- and closed-ended questions with men (77%) and woman (23%) who work as miners, mineral processors, and chatarreros in the region. The interviews each lasted for about an hour and allowed the interviewee to elaborate on certain topics. We also administered 30 surveys that were shorter, lasting for approximately ten minutes, and included closed-ended questions to solicit quantitative data. All but three of the men and women who participated in the semi-structured interviews took the survey. These methods were designed to obtain respondents' estimates of the efficiency of mineral processing systems, their perceptions related to mercury use, and their awareness of the hazards associated with mercury use and tailings disposal. All the interviews and surveys were conducted in Spanish, and the interviews were audio recorded when the interviewee permitted. The interviews were later transcribed, translated, and coded according to different themes selected by the researchers.

CHAPTER FIVE

RESULTS

5.1 Efficiency of mineral processing

The three gold mass balances (Table 5-1) showed that 47-69% of the gold was recovered and 28-50% was not captured by the mineral processing system used at this entable. The gold that was not captured appeared in the second trap and the tailings. During the interviews with miners and chatarreros, all of them stated that they were losing gold in the tailings. Despite these losses, more than half of the participants (57%) claimed that they were recovering the maximum amount of gold possible given their mineral processing technologies and methods. When asked to quantify these losses, nearly half (47%) of the interviewees estimated that they were losing less than 10% of the gold in the tailings (Figure 5-1). The rest of the interviewees' estimates of gold losses were distributed between 11% to 60%.

Table 5-1: Gold Mass Balance (MB) Results

	Au Feed (g)	Au Total in tailings (%)	Au Recovered (%)	Au Lost (%)
MB 1	10	8	72	20
MB 2	6	5	47	48
MB 3	3	21	69	10
Range (%)		**5-21**	**47-69**	**10-48**

Compared to the results of the gold mass balance, miner's estimates were slightly lower in terms of the amount of gold that was in the tailings ($Au_{tailings}= 12\%$), but they also mentioned that gold was lost in other stages of mineral processing. Some of these "losses" had economic value, however, as the concentrate captured in the second trap was stockpiled for the manager of the entable to process, or the tailings were sold to larger processing facilities. As one miner remarked, "We know there is gold there because if not, they would not come to buy those tailings. People do not buy to lose money, if they buy those tailings is because there is gold there." Many miners commented that they would like to recover the gold from the tailings themselves, but they were under the impression that cyanide was the only way to do this. They claimed that they did not know how to use cyanide, it was harmful to handle, and it required expensive equipment.

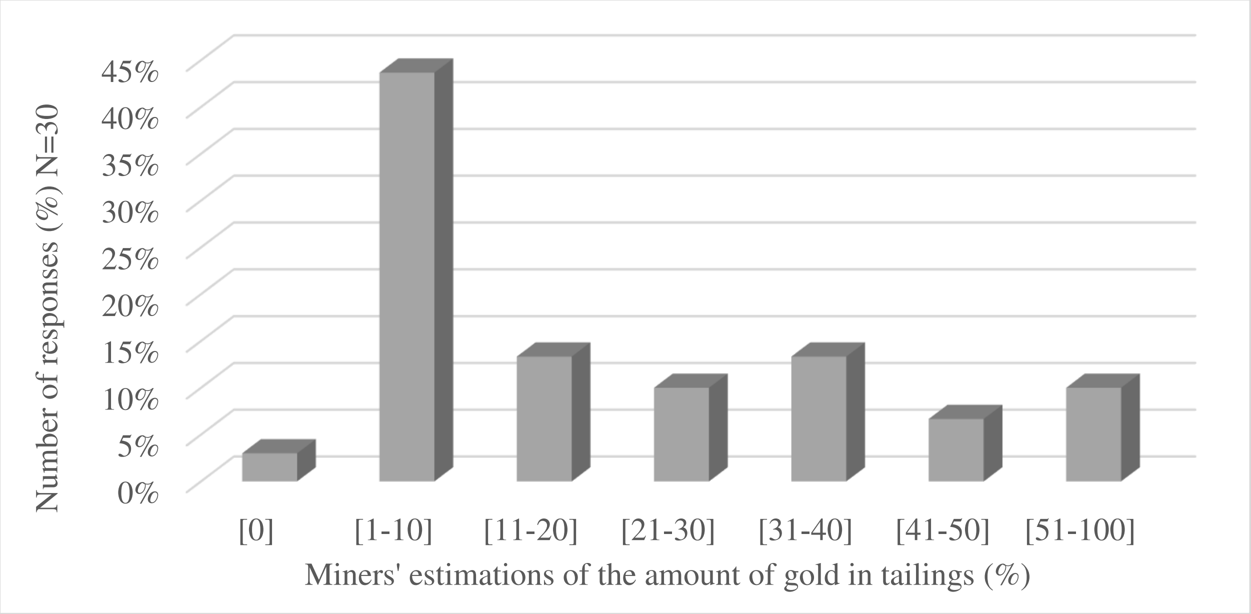

Figure 5-1: Miners’ estimated of the amount of gold in tailings. The average amount of gold in the tailings as calculated by the mass balances was on average 12%.

5.2 Mercury tracking in mineral processing

The mercury mass balances showed that 22-26% of the mercury initially added to the system was lost during mineral processing and released into the environment in different forms (Table 5-2). This mercury appeared in the tailings (5-10%), vaporized when the amalgam was burned (4-6%), and either vaporized when the cocos were opened or remained in the second trap (8-14%). The majority (74-78%) of the mercury was recovered during the squeezing step, which prevented it from being released to the environment; however, an average of 1.5 grams of mercury per coco ended up in the tailings.

Table 5-2: Mercury Mass Balance

	Hg in the ore (g)	Hg added (g)	Hg recovered by squeezing (%)	Hg in amalgam (%)	Hg in tailings (%)	Hg lost elsewhere (%)	Total Hg lost (%)
MB 1	1.7	216.5	78	4	10	8	22
MB 2	0.4	58.7	74	6	5	14	26
MB 3	0.8	51.3	78	4	8	10	22
Range (%)			**74-78**	**4-6**	**5-10**	**8-14**	**22-26**

Most interviewees (87%) believed that mercury was in the tailings, and of these, 30% estimated that less than 10% of the total mercury added ($Hg_{initial}$) was lost in the tailings. These miners' estimates aligned with the results of the mass balance which showed that on average, 8% of the mercury was lost in the tailings. Many stated that they knew they were losing mercury during mineral processing because they could see mercury on the inside of the cocos when they unloaded the ore, as well as along the trench leading to the tailings. Others stated that they were aware that mercury could not recover some of the gold because of the gold's grain size. One miner commented, "the only way mercury does not recover gold is because it must be a microscopic gold that is like water." It is important to note that 13% of the interviewees believed that there was no mercury in the tailings.

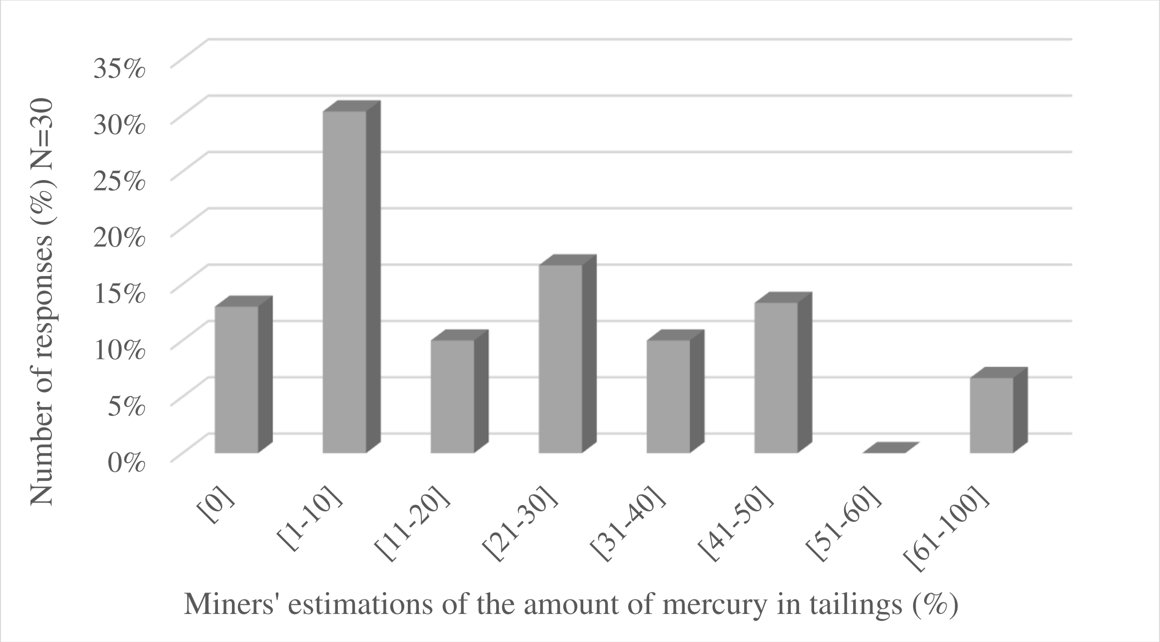

Figure 5-2: Miners' estimated of the mount of mercury in the tailings. The amount of mercury in the tailings, as calculated by the mass balances was on average 8%.

In addition to their qualitative assessments, miners measured the amount of mercury initially added to the cocos and the amount of mercury recovered after squeezing the amalgam. This provided them with the knowledge that mercury was lost; however, they were not trying to prevent these losses, because according to them, they were minimal and did not impact their profits. They were also not recovering the mercury from the tailings. A few miners mentioned that the mine manager recovered the mercury, but the majority stated that the mercury ended up in the cyanidation tanks when the tailings were processed by a larger processing facility. One miner stated, "The only way [to recover mercury from the tailings] is by taking them to a tank and adding cyanide." Some miners stated that it would be too costly to recover the mercury from the tailings. Others shared that even if they did recover the mercury, it would be low quality.

5.3 Perceptions of the impacts of mercury

When discussing mercury in the tailings none of the interviewees mentioned any health or environmental risks of handling mercury; however, we observed several unsafe practices. Miners did not wear any personal protective equipment, some of them burned amalgam in their homes, and most of the time, they did not burn the amalgam in a retort. Even if they did use a retort, they often left the retort open while the amalgam was burning. We also noticed that the water they used for bathing and brushing their teeth came from a reservoir that pumped water from the local river. The pump was located downstream from another mine which discharged process water into the river, and the miners at this site washed the buckets from the entable in the reservoir. In light of these observations, we asked the interviewees if they believed mercury posed a hazard to human health or the environment. The majority (84%) responded that they were aware that mercury was harmful to human health and the environment and had heard this in trainings and from older miners. Some even reported that they had seen the physical signs of mercury exposure, such as neurological tremors. Although most of the miners were aware of the risks of using mercury, there were conflicting views of mercury's impacts on health. One miner stated:

> The government says mercury is bad, but in Segovia, miners have been working with mercury for many years, and I have never heard of anyone dying because of mercury. I also have been working for more than 16 years, and I have never felt anything like trembling.

A miner who attended several trainings expressed that he learned that mercury was harmful; however, he had never had health problems. He stated:

> I think it depends on the type of person, there some who are weaker than others, organisms are different, and mercury could affect more those weaker organisms. I have known miners that have worked for several years, and they have told me they are fine, but I think mercury is harmful. I go to those trainings and they say mercury is bad, and I do believe them because they have studied, and they have much more experience than me.

Miners often mentioned tremors as a health effect, but they associated this with the people who work in the gold shops because of their constant contact with mercury vapor. Some miners believed mercury was only harmful if they were exposed to it for long periods of time. One miner stated, "Many people say mercury is harmful, but I think it is when you don't know how to handle it. I only use mercury for a short time every other week. I don't use it like the people who work in the gold shops that are burning mercury every day."

We asked the interviewees to chart their perceptions of the impacts of mercury on health and the environment on Likert scales, where 1 signaled no impact and 10 signaled significant impacts. The results showed that 69% marked 5 or less for impacts to health, and 60% marked 5 or less for impacts to the environment (Figure 5-3: Miners' perceptions of mercury's impacts on human health and environment charted according to a Likert scale where 1 signaled no impact and

10 signaled significant impacts.Figure 5-3). Overall, more interviewees believed that mercury was more impactful to human health than the environment. The majority (70%) stated that mercury posed an environmental hazard only when the amalgam was burned.

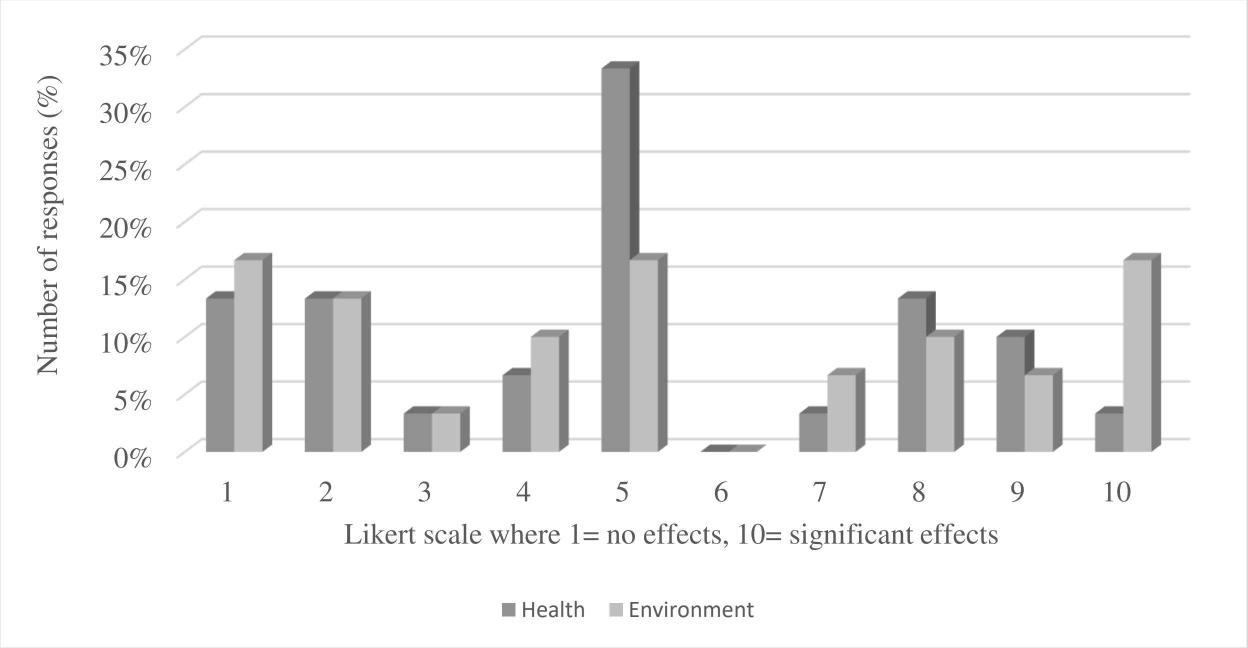

Figure 5-3: Miners' perceptions of mercury's impacts on human health and environment charted according to a Likert scale where 1 signaled no impact and 10 signaled significant impacts.

Some miners (20%) mentioned that they had heard on the news or during the trainings that mercury can pollute water and kill fish, but they expressed doubts, as they claimed that mercury was a heavy metal that settled very quickly to the bottom of the river. All of the miners stated that they will continue using mercury because there is nothing else that works as well, and there is no replacement. One miner remarked, “Mercury is the only thing that is good to work in mining, it is the only thing that I know recovers gold, even if it's harmful, but if we don't use mercury, then what are we going to do to eat?”

5.4 Further skepticism about mercury's impacts

In concert with the perceptions of mercury on human health and the environment and the potentially grim tradeoffs predicted by the miners if they are not able to use mercury, many interviewees stated that it gets more difficult every year to buy mercury because it is less available and the price continues to increase. One miner commented, “Mercury is now even more expensive than gold.” Another miner expressed, “If there is no other way to buy mercury, I will stop using it because if there is nowhere to find it by force, miners must leave it. But if I still find smuggled mercury somewhere, I will keep using it." More than 80% of the respondents had not heard of the Minamata Convention, and many claimed that mercury became illegal and expensive when the government started conducting trainings on how to eliminate its use. They expressed skepticism towards the government's initiatives and believed they were aimed at destroying ASGM and giving more opportunities to large-scale companies. One miner stated, "The government wants to get rid of the mercury, but I do not know the reasons why. Suddenly, they say mercury affects human beings." Another remarked:

> The government began to ban mercury so that small-scale mining ends with the multinational companies. The government does not want the number of multinationals to decrease due to them being a major source of government funding. If the government eliminated mercury, they would also eliminate the artisanal and small-scale miners because we would not have a way to recover the gold. At that point, we would need to send the ore to the multinationals to be processed, but the multinationals would not give us a good price. I also would not trust someone else to process my ore, as gold is not to be trusted. The gold is like a gorgeous woman if you neglect it, someone else arrives and takes it away.

An additional impact of the mercury ban was that many of the gold shops no longer burned the amalgam for miners and only accepted the doré. One miner stated, "I used to sell the amalgam in the gold shops but since mercury turned illegal, gold shops are not receiving amalgam anymore, and I have to burn it here." The miners blamed the Colombian government for this change, adding to their resentment of the government and the mercury ban.

5.5 Tailings

The analysis showed that the chemical composition of the tailings included quartz (SiO_2), Iron oxide (Fe_1O_2), Aluminum oxide (Al_2O_3), and Potassium oxide (K_2O), as well as Arsenic (As), Chromium (Cr), Manganese (Mn), Zinc (Zn), Antimony (Sb), and Lead (Pb) (Table 4). Depending on their concentrations, these metals could pose a hazard for human health and the environment. The Environmental Protection Agency (EPA) has set regulatory limits on the maximum concentration of the following metals in sludge and soils (EPA, 2018): Arsenic (As) = 75 ppm; Copper (Cu) = 4300 ppm; and Lead (Pb) = 420 ppm. The concentration of these metals in the tailings exceeded these limits.

Table 5-3: Mine tailings chemical composition

Analyte Symbol	S	Cd	As	Fe	Cr	Zn	Cu	Mn	Pb	Se	Mo	Ni
Unit Symbol	%	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Tailings	3.1	40.1	89.6	5.81	182	614	4700	167	2100	2.7	10.6	13.7

During the semi-structured interviews, we asked respondents about whether or not they thought that the tailings posed a hazard to human health or the environment. About 40% of the interviewees stated that tailings did not pose any health hazard, and 27% stated that tailings were not a hazard to the environment (Figure 5-4) because they felt that tailings did not have a large concentration of metals. On the other hand, 13% of the miners believed that tailings posed “a lot” or “too much” of a health hazard, while 20% stated that tailings posed "a lot" or "too much" of an environmental hazard. We asked the interviewees to chart their perceptions of the impacts of tailings on health and the environment on Likert scales. Overall, 60% of the miners surveyed believed that tailings had minimal impacts on human health by marking 3 or less on the Likert scale, and 47% believed that tailings had minimal impacts on the environment by marking 3 or less (Figure 5-5). Only 10% believed that tailings had more significant impacts on human heath by marking 8 or higher, and 20% believed tailings had more significant impacts on the environment by marking 8 or higher. Many miners said that tailings were “dead.” One elaborated, “Tailings are waste and thrown away and left as soil; they are sterile materials that are no longer useful.” Several miners felt that tailings could only pose a hazard to human health and the environment after the tailings were treated with cyanide. However, others blamed tailings for killing some of the trees around the mine site, but they attributed this to the lemon juice that was used during mineral processing. Miners also mentioned that they had experienced skin rashes when they transported the sacks of tailings on their backs, but they also associated this with the lemon juice. Some miners argued that mercury in the tailings cold not have any negative impacts because the mercury settled in the bottom of the tailings. Some miners believed that the tailings only contained mercury and gold, but others were aware that tailings contain other metals, such as silver, copper, aluminum, and zinc because they had heard that cyanide recovered these metals from the tailings.

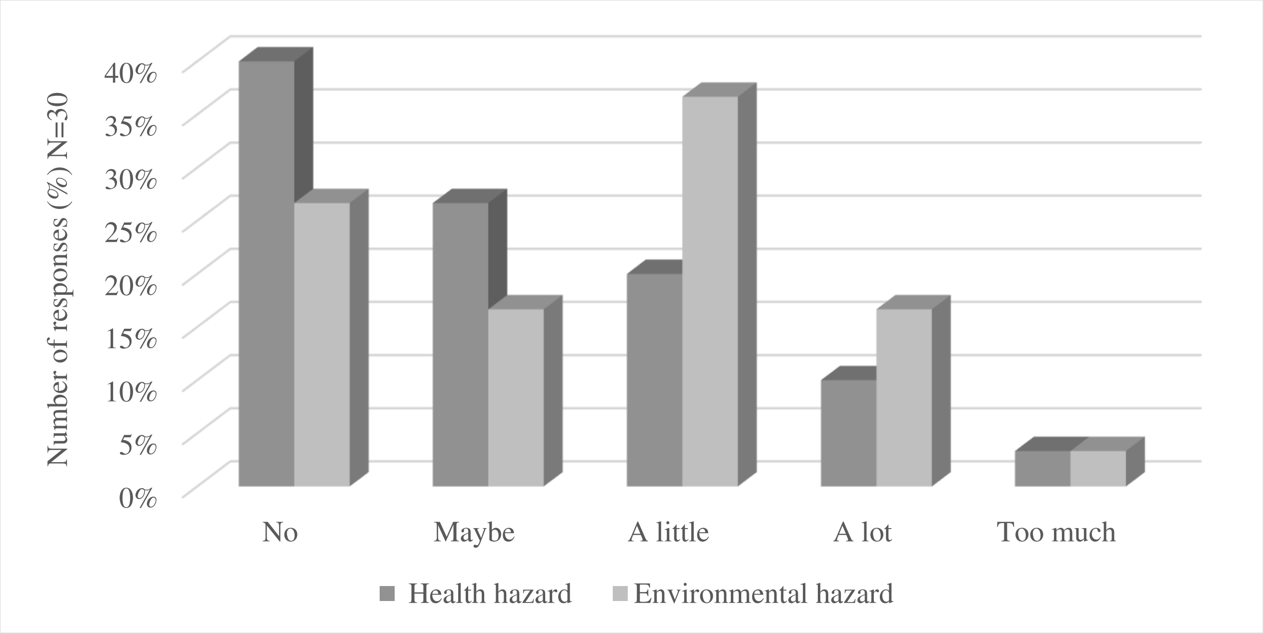

Figure 5-4: Miners' perceptions of the extent to which tailings pose human health and environmental risks.

The interviewees were also queried about their tailings disposal methods. They stated that they collected the tailings in the pools and then put them in a pile to dry until someone was interested in buying them. One miner said, "Those tailings are piled as you can see. There are some mines that cover the tailings to protect them from the rain, but here it is not the case." Although most miners claimed they did not know a different method for disposing of the tailings, some suggested that they could build larger pools in which to dry the tailings to avoid disposing of them next to the trees and on the vegetation.

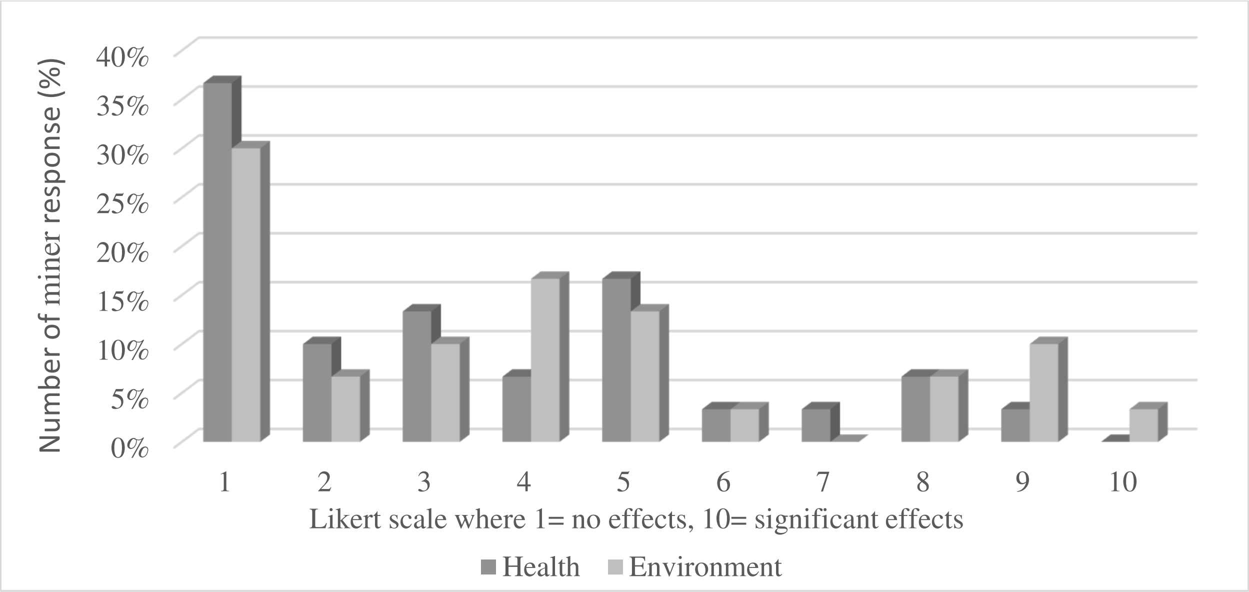

Figure 5-5: Miners' perceptions of tailings impacts on human health and environment charted on a Likert scale where 1 signaled no impact and 10 signaled significant impacts.

CHAPTER SIX
DISCUSSION

This study demonstrates the ways in which a socio-technical approach can provide a better understanding of ASGM mineral processing systems. At this mine site, the mass balances showed that miners recovered more than 50% of the gold and mercury in the mineral processing system, and miners were quite accurate in their estimations of gold and mercury losses. However, it is clear that they were not taking any action to avoid these losses. Furthermore, mercury did not seem to be a major concern for them because they did not see the direct impacts on human health or the environment. Miners appeared to be more concerned about the price of mercury and feared that the mercury ban was another form of marginalizing the ASGM sector. We found tailings were not adequately managed and they were exposed to the sun and rain, which leached heavy metals.

6.1 Mineral Processing Efficiency

Hypothesis *A: Artisanal and small-scale miners are aware they are losing gold and mercury in the tailings, but they are not aware exactly how much of each is being lost, nor are they aware of what else occurs in the tailings.*

The gold mass balances calculated in this study proved part of our initial hypothesis that miners were aware that they were losing gold and mercury in mineral processing. Although miners slightly underestimated the amount of gold losses, it was clear they had a certain level of knowledge about their mineral processing systems. Some experts have suggested that the best way to eliminate mercury from ASGM operations is to show miners that other methods will recover as much or more gold. Our study complicates this recommendation, as the mass balance showed a higher gold recovery rate for whole ore amalgamation than is generally suggested in the literature. Mineral processing efficiency depends on many variables (i.e. geological characteristics, mineralogy, amount of free gold, and grain size), and therefore, the gold recovery rates will vary at each mine site. The introduction of mercury free technologies must be accompanied by an analysis of the efficiency of mineral processing at each site to provide a baseline and ensure that new or different technologies perform as well or better than mercury amalgamation.

There are ways to improve gold recovery such as ensuring an adequate size particle during the crushing stage or amalgamating only the concentrates. Miners could be taught these methods, along with how to use mercury-free technologies. However, it is not enough to only provide them with technology and work with them and these technologies for short periods of time. The implementation of training and mercury-free technologies must be accompanied by constant monitoring and follow-up. Efficiency does not remain constant, and when gold recovery changes appear, miners may return to the processes they believe are more efficient. Miners' perceptions must be taken into account to co-create projects that could lead to long-term changes.

We acknowledge that the efficiency obtained in this case of study would vary in other mine sites because of the geology, mineralogy of the deposit, and the amount of free gold in the ore. It is hard to know the grade of the ore, and we tried to collect representative samples to the best of our abilities. But we know that multiple samples are required to provide a more accurate depiction of efficiency. In addition, we acknowledge that miners' perceptions will also vary depending on their backgrounds and experiences. However, this case study indicates the importance to assess both technical and social compounds to have a better understanding of the ASGM processing systems.

6.2 Mercury use in ASGM

Hypothesis 2: Despite government inventions, which have included the introduction free-mercury technologies, trainings on the effects of mercury on human health and the environment, and efforts to formalize the sector, artisanal and small-scale miners are reluctant to change their current practices using mercury.

At this mine site, most of the miners acknowledged that they were losing mercury and their estimates of the mercury losses were in alignment with the losses calculated by the mass balances. However, they also stated that nothing was as effective as mercury for recovering gold, they were still able to access mercury, and the rising costs of mercury were not enough to dissuade them from using it. In addition, some (13%) believed they were not losing any mercury. Previous studies indicated that artisanal and small-scale miners believed that no mercury was lost in mineral processing (Gonçalves et al., 2017; Veiga, 2010; Veiga et al., 2014; Velásquez et al., 2010). Our study demonstrates that indeed, miners were aware that mercury was lost, but they were unlikely to change their practices simply because they were losing mercury or because they were aware that mercury posed health and environmental hazards.

It is clear that the government's interventions have not been effective in causing a shift away from mercury use. This is compounded by miners' perceptions that the government discourse about mercury hazards was simply code for their real objective of eliminating the sector altogether. Although cyanidation-based technologies have been proposed for the ASGM sector, miners appeared to be hesitant to use cyanide because they believed it was more harmful, impractical, and expensive, and they lacked the knowledge and technologies associated with cyanide use. These perceptions could stand as barriers for miners to switch to other practices. Therefore, our study advocates for a comprehensive understanding of miners' perceptions of mercury and its use, as it reveals the barriers to implementing alternative technologies.

The fact that the majority (74-78%) of the mercury was recovered during the squeezing step of mineral processing indicates that miners at this entable were adding more mercury than necessary, as all of the mercury added was not binding with the gold. At this entable, miners usually process 300 sacks of ore per month using one coco per sack. Therefore, our findings suggest that at this mine site, up to 450g of mercury per month could be released in the tailings. We acknowledge that whole ore amalgamation is generally less efficient than amalgamation of the concentrates; however, if miners at this entable continue to practice whole ore amalgamation, they could add less mercury to each coco and still recover the same amount of gold. In addition, if these miners decrease the amount of mercury initially added they are also will decreasing their exposure to mercury.

Miners were not interested in recovering the mercury from the tailings because they felt that it was not economically advantageous, and they believed that the recovered mercury would be of lesser quality. However, they stated that mercury was less available now, and its price continued to increase. Likely, the mercury ban resulted in this price increase, and if this continues, miners may be forced to use other methods. On the other hand, it may also deepen their engagement with the illicit mercury market, making them more vulnerable to criminal actors. Our study revealed that miners did not totally understand why became illegal, and they believed the government's efforts were not well-intended. This suggests that future projects and trainings should be conducted by a third party to build trust between all stakeholders and that these initiatives must include close monitoring and follow-up to ensure that they are effective over the long term.

6.3 Tailings in ASGM

Hypothesis C: Artisanal and small-scale miners are aware that tailings pose environmental and human health hazards; however, they are not aware of the exact hazards to the environment and human health, nor are they aware of how to manage the tailings to mitigate these hazards.

The interviews with the miners showed that overall they were aware that tailings posed health and environmental hazards. The majority believed that tailings were a hazard to human health (60%) and the environment (73%). However, only 10% of the respondents believed that tailings had *significant* impacts on human health, and 20% believed that tailings had *significant* impacts on the environment. Therefore, these results demonstrate that miners believed that tailings had more significant impacts on the environment than on human health. It appears that miners were more aware of the impacts on the environment because they witnessed the effects on the trees near the tailing piles. Miners believed that tailings did not represent a significant risk, because in their view, tailings were sterile and did not contain hazardous components. Furthermore, miners believed that tailings were harmful not because of the metal concentrations but because of the acid coming from the lemon juice. We also found that miners lacked knowledge of proper tailings disposal; however, tailings management strategies could avoid future contamination.

At a minimum, mercury should be recovered from the tailings, and tailings should be covered and stored away from water bodies. Also, the tailings should be separated from the ground and soils by a barrier to avoid the leaching of heavy metals. Backfilling the tailings into abandoned underground workings could be one disposal method, as long as those sites will not be reworked in the future. We advocate for the government and regulatory agencies to implement tailings management regulations for ASGM; however, because this may lead to additional costs for the miners, support from the government, development agencies, or NGOs is critical.

CHAPTER SEVEN:
CONCLUSIONS

Overall, this study suggests why technical interventions alone are not enough to address mercury use in ASGM. It emphasizes that any initiatives aimed at reducing or eliminating mercury from ASGM mineral processing systems must be informed by an analysis of the gold recovery rates, mercury losses, and miners’ perspectives on mercury in general and their mineral processing systems in particular. Conducting similar studies in different mine sites would provide a better understanding of the efficiency of the gold recovery in ASGM operations. This would help to identify current gold recovery rates so that interventions would have a baseline for “proving” the efficiency of new technologies. In addition, an analysis of the mineralogy and a geological characterization would provide more information on the type of ore the miners are processing. However, understanding miners' perceptions of processing efficiency and mercury can reveal the ways in which these perceptions influence behavior and decision-making and lend new insights into why miners continue to use mercury.

Due to the mistrust and tension between ASGM miners and the government, building trust among the ASGM sector is imperative to develop projects that aim to improve current ASGM practices. We highly recommend to future research to engage with all stakeholders and design very careful the fieldwork outline, setting times and not leave their site for too long to do not leave windows open for misunderstandings. We found that miners are distrustful, and some behaves would make them associate researcher with the government and large companies. Future projects may be implemented by third parties but should include multiple stakeholders, such as universities, technical and research centers, NGOs, community members, and miners’ associations. Building capacity among the sector and offering support to these partners should be the government’s main objectives. Miners should play a central role in determining new technologies and policies aimed at eliminating mercury use from ASGM mineral processing.

In addition, it is necessary to implement a tailings disposal requirement to avoid additional damage to the environment through mercury releases and the generation of acid mine drainage. A tailings facility could include adequate management strategies, especially in recovering all the mercury that is contained in the tailings before they are reprocessed with cyanide.

In sum, we suggest that miners' perspectives are critical to identifying barriers to eliminating mercury use. We argue that miners will not change their current practices unless their perceptions and opinions are taken into account when developing new projects and addressing problems that directly affect them. We noted that the reducing mercury use in ASGM has been approached from a primarily technical perspective. However, understanding miner's knowledge is a first step to creating and designing solutions. Therefore, we reiterate that combining technical and social knowledge and perspectives are key to improving the gold recovery process and eliminating mercury from ASGM mineral processing systems.

7.1 Recommendations for future research

All stakeholders which include government, researchers, international agencies, and ASGM communities are invited to work together as a team, co-create and design projects and ideas where all are included in the brainstorm and design part of the projects. The socio-technical assessment in other mines sites belonging to a same region, it would identify the main drivers for their miners to continue working on mercury and it will stablish a start point to perform projects designed with the community. The provided analysis including the methods and learning outcomes could be used in the future for other researches to assess efficiency in other mine sites that have similar operations like this case of study.

We believe that to continue understanding the dynamics of the ASGM operations, it is imperative to conduct other studies like this to estimate the gold recovery efficiency in ASGM operations. These studies could expand this one by characterizing the mineralogy and geology and collect more samples throughout the mineral processing system. Besides, future research could address other questions to the miners withing the interviews like what percentage of the gold they believe their recovery given their current methods? Are miners willing to follow environmental requirements for tailings disposal? Do miners consider they will be recovering the same amount of gold if they do not add other elements like molasses or plant leaves?

We found in our fieldwork experiences that methods employed by the miners are based on their perception and experiences. We also found that some miners belonging to this northeast region are currently working in other mining areas that do not use mercury in their operations.

Therefore, we consider that conduct a similar study will find some ideas of the motivations of the miners to switch to mercury-free technology. Future studies would also make a comparison between regions to assess the influence that government interventions have on the miners' perceptions. In addition, we believe that an assessment of the impact that the regulations like mercury ban have on the entire supply chain will help to understand other miners' motivations for their current practices.

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APPENDIX A

ORE AND TAILINGS LABORATORY ANALYSIS

This appendix provides the result of the ore and tailings analysis. These results are divided on ore (A), intermediate concentrate (C), and tailings (D). Some results were provided in parts per billion, and we did the conversion to parts per million. Each sample collected had a code assigned to be identified. Each sample also had a double sample that was also sent to the laboratory to corroborate results and minimize the gold nuggets effect.

Table A-1: Results of the ore samples (A) collected from the pile after the grinding process, the results provided the parts per milling of natural gold and mercury contain in the ore.

	Analyte Symbol Unit Symbol	Au ppm	Hg ppb	Hg ppm
1MB	10072019IVOB3R	16.6	2852	2.9
1MB	10072019IVOB3R	>10.0		
2MB	22082019IGO10CJM1 (99)	23.0	7780	7.8
2MB	22082019IGO10CJM1 (100)	51.0	2320	2.3
3MB	16082019IYO10CJM2 (85)	12.2	4960	5.0
3MB	16082019IYO10CJM1 (86)	19.7	4930	4.9

Table A-2: Results of intermediate concentrate (C) collected in the first trap on the trench, the results provide part per million of gold contain in the concentrate.

		Analyte Symbol Unit Symbol	Au ppm
1MB	1st process	12072019IV1TMCL110CJM1 (6)	9.9
		12072019IV1TMCL110CJM2 (6')	9.4
	2nd Process	12072019IV1TMCL25CJM1 (14)	5.0
		12072019IV1TMCL25CJM2 (14')	5.4
	3rd Process	12072019IV1TMCL32CJM1 (13)	3.0
		12072019IV1TMCL32CJM2 (13')	3.3
2MB	1st process	23082019IAM1T1LB4M2 (97)	19.5
		23082019IAM1T1LB4M1 (98)	17.1
	2nd Process	24082019IAM1T2LB4M2 (95)	21.3
		24082019IAM1T2LB4M1 (96)	31.4
3MB	1st process	22082019IAZ1T1LB5M2 (83)	49.6
		22082019IAZ1T1LB5M1 (84)	44.6
	2nd Process	23082019IAZ1T2LB5M2 (77)	93.5
		23082019IAZ1T2LB5M1 (78)	93.4

Table A-3: Results of the tailings (D) collected at the end of the trench from the pipe before that ends up in the tailings pool, the results provide parts per million of gold and mercury contain in the tailings.

		Analyte Symbol Unit Symbol	Au ppm	Hg ppm
1MB	1st process	12072019IVTFPL1B3M1 (15)	1.2	21
		12072019IVTFPL1B3M1 (15')	1.2	
	2nd Process	12072019IVTFPL2B3M1 (10)	0.7	47
		12072019IVTFPL2B3M2 (10')	0.8	
	3rd Process	12072019IVTFPL3B3M1 (11)	3.0	117
		12072019IVTFPL3B3M1 (11')	3.4	
2MB	1st process	TAILINGS 1 LAVADA AMARILLA TUBO M2 (87)	4.7	26
		TAILINGS 1 LAVADA AMARILLA TUBO M1 (88)	2.6	26
	2nd Process	TAILINGS 2 LAVADA AMARILLA TUBO (89)	2.4	33
3MB	1st process	TAILINGS 1 LAVADA TUBO AZUL (74)	5.5	26
	2nd Process	TAILINGS 2 LAVADA TUBO AZUL (75)	5.3	50

APPENDIX B

ORE AND TAILINGS CHARACTERIZATION

This appendix provides a characterization to have a better understanding of the metals contain in the ore and tailings. We conducted the ore and tailings characterization through an ICP-MS analysis. The tailings samples were also analyzed to know the oxides content with X-ray fluorescence (XRF) analysis.

The ICP-MS analysis showed that the ore contains about 38 metals (Table B-*1*;Table B-*2*;Table B-*3*), including silver (Ag), arsenic (As), bismuth (Bi), copper (Cu), manganese (Mn), lead (Pb), vanadium (V), and zinc (Zn) that were found in significant amounts and other metals such as aluminum (Al), iron (Fe), potassium (K), gallium (Ga), antimony (Sb), cadmium (Cd) and others in smaller quantities. The presence of these minerals correspond to the regional geology that is characterized by gold- bearing veins and stockworks with pluton intrusion-related characteristics (R. P. Shaw et al., 2019). The gold-veins were formed by magmatic fluid under mesothermal conditions with a strong presence of pyrite (FeS2), chalcopyrite (CuFeS2), sphalerite ((Zn,Fe)S) and galena (PbS) (Manco P. et al., 2012).

Table B-1: shows parts por millions contain in the ore samples. The ore contain silver, arsenic, bismuth, copper, manganese, lead, vanadium, and zinc in higher amounts.

Analyte Symbol Unit Symbol	Ag PPM	As PPM	Bi PPM	Cu PPM	Mn PPM	Pb PPM	V PPM	Zn PPM
1st Balance	87.5	83	171	5737.7	122	2720	112	466.1
2nd Balance	84.7	112	181	4200	316	1800	282	62.6
3rd Balance	>100	104	250	> 10000	100	> 5000	13	1110

Table B-2: shows the amounts of aluminum, barium, beryllium, calcium, cobalt, chromium, iron, gallium, potassium, lanthanum, lithium, and magnesium in the ore.

Analyte Symbol	Al	Ba	Be	Ca	Cd	Co	Cr	Fe	Ga	K	La	Li	Mg
Unit Symbol	%	PPM	PPM	%	PPM	PPM	PPM	%	PPM	%	PPM	PPM	%
1st Balance	0.31	135	<0.5	0.05	28	14	19	6.33	<10	0.14	2.6	1	0.07
2nd Balance	0.45	30	1	0.05	3.36	7.1	20	5.88	2.69	0.18	6	0.7	0.05
3rd Balance	0.52	3	0.1	0.14	68.9	13.4	18	7.1	2.68	0.19	3.1	2.1	0.13

Table B-3: shows the amounts of molybdenum, sodium, niobium, nickel, phosphorus, antimony, scandium, tin, strontium, titanium, thallium, tungsten, yttrium, zirconium, selenium, and tellurium in the ore.

Analyte Symbol	Mo	Na	Nb	Ni	P	S	Sb	Sc	Sn	Sr	Ti	Tl	W	Y	Zr	Se	Te
Unit Symbol	PPM	%	PPM	PPM	%	%	PPM	PPM	PPM	PPM	%	PPM	PPM	PPM	PPM	PPM	PPM
1st Balance	14	<0.01	<1	8	0.06	1.3	11	1.9	<10	6.6	<0.01	<2	<10	5.9	<0.5	<10	25
2nd Balance	9.9	0.02	< 0.1	4.6	0.07	0.7	9.5	1.2	1.09	5.4	< 0.01	0.09	37.1	8.7	0.6	2.3	25.1
3rd Balance	10.8	0.02	0.2	9.9	0.02	7.3	27.5	1.4	0.42	14.3	< 0.01	0.69	6.7	4.2	1	3.5	30.3

The X-ray fluorescence (XRF) analysis showed the following contain of metal oxides in the tailing samples, We found that the tailings contained a large amount of silica (SiO2), and less amount of iron oxide (Fe2O3) and aluminum oxide (Al2O3).

Table B-4: shows oxides content in the tailings

Analyte Symbol	Co_3O_4	CuO	NiO	SiO_2	Al_2O_3	Fe_2O_3(T)	MgO	CaO	K_2O	TiO_2	P_2O_5	LOI	Total
Unit Symbol	%	%	%	%	%	%	%	%	%	%	%	%	%
	< 0.005	1.0	< 0.003	81.4	3.2	7.9	0.2	0.3	1.4	0.1	0.1	3.1	98.9

APPENDIX C

MASS BALANCES CALCULATIONS

This appendix provides all the calculations conducted to estimate the amount of gold and mercury losses in the mineral processing systems. First, we conducted a mass balance with the ore added to the cocos and the intermediate concentrate collected in the first trap. The result of the ore mass balances are showed in Table C-1, where on average a 54% of the material remains in the first trap and the rest goes to the second trap and the tailings, however, the exact amount of how much material goes to the tailings was not quantified. In the first mass balance, 50% of the material added goes to the tailings in the first process, 60% in the second process and 50% in the third process. In the second and third mass balances, the amount of material that goes to the tailings is higher in the second process rather than in the first process in each balance, being 48% and 50% respectively.

Table C-1: Mass balance calculation with the ore and the intermediate concentrate collected in the first trap.

	Process	Inputs (t)	Tailings (t)	1st trap (t)
Mass balance 1	1st	0.60	0.30	0.30
	2nd	0.30	0.18	0.12
	3rd	0.12	0.06	0.06
Mass balance 2	1st	0.16	0.05	0.11
	2nd	0.11	0.05	0.06
Mass balance 3	1st	0.17	0.06	0.11
	2nd	0.11	0.06	0.06

Gold Mass Balance calculation

The gold mass balances calculation are described in Table C-2. We took the part per millions of gold measured by the fire assay in the feed (ore) and multiply by the tonnes of ore added to the coco to determinate the grams of gold in the ore. Then, we did the same for the tailings results by multiplying by the tonnes of the tailings that were out of the process.

Table C-2: shows gold mass balance calculation

	Analysis Au (ppm)	Dore' Au (g)	Adjusted from Dore (g)	% distributed Au	% distributed Au
1st mass balance					
Feed (measured by Fire assay)	16.6	9.96			100%
Feed (calculated from products)			8.0	100.0%	
Stage 1 Final tailings	1.2		0.4	4.4%	3.5%
Stage 2 final tailings	0.8		0.2	1.9%	1.5%
Amalgam concentrate		11.9	7.1	89.7%	71.7%
Stage 3 final tailings	3.2		0.3	4.0%	3.2%
Lost/unaccountable for Au					20.1%
2nd Mass Balance					
Feed (measured by Fire assay)	37	5.9			100%
Feed (calculated from products)			3.0	100.0%	
Stage 1 Final tailings	3.6		0.2	5.9%	3.0%
Stage 2 Amalgam concentrate (calculated)		4.6	2.8	90.2%	46.6%
Stage 2 final tailings	2.4		0.1	3.9%	2.0%
Lost/unaccountable for Au					48.3%
3rd Mass balance					
Feed (measured by Fire assay)	16.0	2.7			100%
Feed (calculated from products)			2.5	100.0%	
Stage 1 Final tailings	5.5		0.3	13.4%	12.1%
Stage 2 Amalgam concentrate (calculated)		3.1	1.9	75.9%	68.6%
Stage 2 final tailings	5.3		0.3	10.7%	9.7%
Lost/unaccountable for Au					9.6%

Mercury Mass Balance Calculation

The mass balance calculation are described in Table C-3 where to calculate mercury losses we equal the inputs to the waste and the outputs of the process. We took the results from the laboratory, part per millions of mercury measured by the cold vapor atomic adsorption in the feed (ore) and multiply by the tonnes of ore added to the coco to determinate the grams of mercury in the ore. Then, we did the same for the tailings results by multiplying by the tonnes of the tailings that were out of the process.

Table C-3: shows mercury mass balance calculation

		Inputs		Waste		Outputs	
		Hg in ore (g)	Hg added (g)	Hg Tailings (g)	Hg amalgam (g)	Hg squeezing (g)	Hg squeezing 2 (g)
1st Balance	1st process	1.7	105.1	6.3	2.9	79.4	1.3
	2nd process		79.4	8.5	2.9	52.5	1.3
	3rd process		32.2	7.0	2.9	34.3	1.4
2nd Balance	1st process	0.4	36.7	1.3	1.8	22.0	0.6
	2nd process		22.0	1.7	1.9	20.6	0.6
3rd Balance	1st process	0.8	30.4	1.6	1.2	21.0	0.5
	2nd process		20.9	2.8	1.1	18.6	0.4

APPENDIX D

INTERVIEWS

The following questions were used during the interviews with the miners, chatarreros, mineral processors, and community members near to the mine site, where this study took place.

1. General aspects
    - Age
    - Marital status
    - Level of education
    - Ethnic affiliation
    - Children
    - Level of education of their children
    - Date and place of birth
    - Place of residence
    - Are you the owner or your work for someone?
    - Distance from home to mine site
    - Do your work individually, with your family or in a mining association?
    - What transport do you use to go to work?

2. General questions related to Mining activities
    - When did you start working in mining?
    - Why did you start working in mining?
    - What were you doing before you were working in mining?
    - Did you family work in mining before?
    - How did you learn to mine/process ore?
    - Do you like to work in the mining industry?
    - Do your work in a group?
    - How many miners do you work with?
    - Do you think your process is efficient?
    - What do you prefer mercury or cyanide in your benefit process?

- Do you think mercury is the best chemical to recover the ore?
- Do your work for someone?
- Do you think mercury has adverse health and/environmental impacts?
- What are those impacts?
- Have you ever seen some of those impacts? Could you list them?

3. Question about mining process
   - Could you explain to me step by step your mining cycle?
   - What equipment do you use to process your mineral?
   - How do you exploit your mineral?
   - What do you need to improve your mining/ore processing activities?
   - Have you had healthy issues due to the mining activities?
   - Do you prefer to use mercury to recover the ore?
   - Why do you use/prefer mercury to the recover the ore?
   - Do you know other alternative to recover the ore?
   - Why did not you use that alternative?
   - Do you process your ore yourself?
   - What is your final stage in the mining process?
   - What do you do with your tailings?
   - Where do you dispose your tailings?
   - Do you think are you losing mercury in the tailings? / Do you think you have mercury in the tailings?
   - How much mercury do you think you are losing?
   - Do you think is there gold in the tailings? / Do you there are more gold that can be extracted from the tailings?
   - What could be the amount of gold in the tailings?
   - How much mercury cost?
   - Where do you get the mercury?
   - How much mercury do you add to process the ore?
   - How do you sell the gold (concentrates, Dore, bar)?

- Where do you sell the gold?
- How much gold do you sell monthly?

APPENDIX E

SURVEY QUESTIONS

The following survey sheet were used after the interviews with the miners, chatarreros, mineral processors, and community members near to the mine site, where this study took place.

Age:		Gender	F	M	Marital status			
Number of children		Birthplace		Birthday	DD	MM	YY	

Please respond with an X the following questions.

- Do you consider your processing system is efficient? i.e. Do you consider you are recovering as much gold as possible?

Yes		No	

- Do you think there is gold in the tailings?

Not at all	A little	Maybe	A lot	Too much

- Do you think there is Mercury in the tailings?

Not at all	A little	Maybe	A lot	Too much

- Does mercury pose a health hazard?

Not at all	A little	Maybe	A lot	Too much

- Does mercury pose an environmental hazard?

Not at all	A little	Maybe	A lot	Too much

- Do you think mercury has impacts on health? From one to ten how would you rate these impacts, being 1 that does not have any impact and 10 that has many impacts.

1	2	3	4	5	6	7	8	9	10

- Do you think mercury has impacts on the environment? From one to ten how would you rate these impacts, being 1 that does not have any impact and 10 that has many impacts.

1	2	3	4	5	6	7	8	9	10

- Considering the following sack of ore that it has about 100g of gold, please answer the three following questions.

- How much gold do you think you are recovering using mercury?

10g	20g	30g	40g	50g	60g	70g	80g	90g	100g

- How much mercury would you add to the small ball mills to have this amount of gold?
- What percentage of mercury (Hg) of the total you add in the small ball mills to process this sack of ore, is lost in the tailings?

10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

- What percentage of gold is lost in the tailings of the total amount you process in the small ball mills?

10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

- Does tailings pose a health hazard?

Not at all	A little	Maybe	A lot	Too much

- Does tailings pose an environmental hazard?

Not at all	A little	Maybe	A lot	Too much

- Do you think tailings has impacts on health? From one to ten how would you rate these impacts, being 1 that does not have any impact and 10 that have many impacts.

1	2	3	4	5	6	7	8	9	10

- Do you think tailings has impacts on the environment? From one to ten how would you rate these impacts, being 1 that does not have any impact and 10 that have many impacts.

1	2	3	4	5	6	7	8	9	10