Article

Mercury Pollution and Artisanal Gold Mining in Alto Cauca, Colombia: Woman's Perception of Health and Environmental Impacts

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Abstract

This article discusses the results of a pilot research strategy for monitoring environmental hazards derived from the use of mercury in artisanal gold mining in the Alto Cauca region, Colombia. During 2016 and 2017, a transdisciplinary approach was established to inquire on the health, environment, and territorial problems originated from artisanal mining. In this article, we specifically focus on how this particular issue affects women in the area. We establish a closed-loop approach for integrating social action research with analytical sciences/engineering to understand risks associated with Hg^{2+} levels in artisanal and small-scale gold mining in the Cauca department. We develop a platform known as closed-loop integration of social action and analytical chemistry research.

Keywords

contamination, artisanal gold mining (AGM), Afro-descendants, sensors, cartography, CLISAR

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Artisanal gold mining (AGM) is a globally relevant social and economic activity. AGM supports the economy of more than 100 million people in developing countries, particularly in rural areas where miners, service providers, and their families articulate their livelihoods to gold mining. In fact, approximately 20% of global gold is extracted in this form (Armah, Boamah, Quansah, Obiri, & Luginaah, 2016). While artisanal gold mines can be diverse in their social and environmental nature, they are generally characterized by unmechanized operations, rudimentary tools, labor-intensive techniques, and small-scale extraction of ore (Lahiri-Dutt, 2015; Malpeli & Chirico, 2013).

The dynamic and heterogeneous technical conditions found in AGM contribute to the vaguely understood legal status of the mines. Most artisanal mining is considered informal, and some is also named as illegal in the sense that (a) the ownership of the sites is not formally licensed by the government (Lahiri-Dutt, 2008; Vélez-Torres, 2016) and (b) the extracted ore is not always traded through legal channels, violating tax laws. In Colombia, this is exacerbated by the link between the production of cocaine and the extraction of gold (Rettberg & Ortiz-Riomalo, 2016). Illegal commercialization of gold is thus another layer adding complexity to the narrative surrounding AGM.

The Colombian mining sector is characterized by a great number of stakeholders, including policy makers, governmental institutions, mining corporations, local communities, armed groups (legal and illegal), and different types of small-scale miners (Arango-Aramburo et al., 2017; Rettberg & Ortiz-Riomalo, 2016; Vélez-Torres, 2014). In the Alto Cauca region, discussions on formalization have resulted in differentiation of three types of mining practices: (a) corporative mining (licensed), (b) AGM made by people who are foreign to the local community (not licensed), and (c) traditional gold mining as a form of AGM that is culturally rooted and does not use chemicals such as mercury and cyanide (not licensed; Vélez-Torres, 2016).

Mining sites are gendered geographies. On one hand, it has been argued that poverty is the most important driver to the growing number of women participating in AGM (Lahiri-Dutt, 2015). On the other hand, the unregulated nature of AGM implies less barriers to miners and service providers, and therefore, it results in job uptake by women due to the immediacy and continuous availability of AGM (Gamu, Le Billon, & Spiegel, 2015; Hilson, 2016). While AGM can result in a source of income for women and their families, the poor working conditions often result in regressive inequality for the women involved in mining activities. Furthermore, due to the scarce life conditions encountered by most women who participate in AGM, the economic dependency on the activity makes them more vulnerable to different forms of exploitation and abuse.

It is important to acknowledge the tension between economic benefits and socioenvironmental risks of AGM (Kelly, King-Close, & Perks, 2014) to avoid victimization of women who are miners or service providers. Improving our understanding of this juxtaposition is important for developing policy steps needed to improve the gendered working conditions of miners. The growing feminization of AGM compels to visualize female participation in legal, informal, and illegal artisanal mining (Lahiri-Dutt, 2015) and to analyze the differentiated roles and exposure to health and environmental risk (Kelly et al., 2014; Yakovleva, 2007). Among the environmental and public health risks associated with AGM, the use of mercury is by far the most dangerous.

The use of mercury in AGM is a global concern that attracted dozens of countries to Switzerland in 2013, where the Minamata Convention was signed during the fifth session of the Intergovernmental Negotiating Committee in Geneva (United Nations Environment Programme [UNEP], 2013b). The Minamata Convention provided a blueprint for intersectoral actions needed to promote and protect the health of populations that depend on small-scale gold mining. The purpose of this agreement was to align efforts to prohibit the emergence of new mines that use mercury, eliminate existing mines, develop control measures on atmospheric emissions of mercury, and generate regulatory frameworks for the informal mining sector to prevent health and environment risks arising from exposure to mercury.

For countries where AGM is an important activity, Article 7, Annex C of the treaty calls for elimination or reduction of the use of mercury and to formulate a National Action Plan by 2016 that guarantees to step back mercury contamination (Sippl, 2015). While the treaty has directed much of the public sector's attention toward the impacts of mercury on the human health, particularly of miners and local inhabitant of mining sites (Black, Richard, Rossin, & Telmer, 2017), it has also resulted in renewed research efforts on mercury pollution in ASM (Clifford, 2017). In addition to technical, toxicological, and medical approaches, important recent research has called for addressing updated baseline data, governance, citizen empowerment, capacity building, and education as primary conditions for reducing mercury emissions (Clifford, 2014; Evers, Keane, Basu, & Buck, 2016; Sippl, 2015; Spiegel, Yassi, Spiegel, & Veiga, 2005; Veiga, Angeloci-Santos, & Meech, 2014).

In Colombia, which is a signatory to the Minamata Agreement, implementation of the national plan to reduce mercury contamination has failed up to date, a situation that is reflected in the growing numbers of artisanal and illegal mining. Artisanal mining, or small-scale mining, accounts for more than 60% of mining at the national level (Ministerio de Minas y Energía, 2012). This situation is even more worrisome in the Department of Cauca because nearly 90% of mines lack mining titles (Güiza, 2013). In fact, the growth of illegal gold mining over the past decade in Alto Cauca has been expressed with alarm in the regional and national press (Bolaños, 2012; Montero, 2012; VerdadAbierta, 2014); this situation also concerns local communities due to the negative effects on the ability of community members to control their territory as well as detrimental effects of mercury on human health and the environment.

This article presents the problem of mercury usage in AGM from a territorial perspective and from the perception of the women of Alto Cauca. We establish a model system for participatory monitoring that is based on previous environmental citizen science programs (Crall, Switzer, Myers, Combes, & de Bivort, 2017; Hand, 2010; Kosmala, Wiggins, Swanson, & Simmons, 2016; Schnoor, 2007) and develop a platform for closed-loop iterative actions related to social action and analytical sciences/engineering. The initial call to action was based on a series of community alerts reporting large fish kills in the upper Cauca River basin, and a group of researchers from different disciplines and institutions undertook a pilot study of participatory environmental monitoring near active small-scale gold mines in the Alto Cauca region in mid-2016. Through the use of social mapping and SenSafe® Mercury Check detectors to approximate ionic mercury (Hg^{2+}) levels in water, numerous water bodies were found to have Hg^{2+} levels that are approaching critical contamination conditions. In collaboration with Afro-descendant rural communities, this rapid analysis tool was combined with social mapping to understand how this particular issue affects women in Alto Cauca. The research addresses the health impacts of mercury from artisanal mining, and the closed-loop participatory monitoring platform can contribute to multiple areas within the planetary health spectrum (Horton & Lo, 2015).

This research is presented in four parts. First, the problem of AGM using mercury is described and is contextualized for the case of the Alto Cauca region. Next, the methodology used for social mapping and mercury detection is presented, which is characterized by an interdisciplinary and participative nature. Third, the results are described with an emphasis on the perspective of the women who live in the Alto Cauca territory. The final section presents general conclusions and recommendations for future research and government actions on the illegal gold mining and mercury pollution problem from a territorial and gender perspective.

Background and Motivation

Mercury in AGM

AGM is a growing economic activity in many developing countries. This phenomenon is attributed mainly to the global trend of increasing gold prices in recent decades (Gold Panel International, 2018), which has led to “gold rushes” in several countries in Latin America, Asia, and Africa (de Lacerda & Salomons, 1998). In addition, the phenomenon of mining extractivism is magnified by the reduction and devaluation of other complementary rural subsistence means, such as artisanal fishing and family agriculture. This situation is strongly related not only to the sociopolitical dynamics of each country but also to global climatic factors (Morton, 2007) and to phenomena such as agrarian commoditization (Edelman & Borras, 2016).

Different investigations in Central and Western Africa (Gamu et al., 2015; Hilson, 2016; Hilson, Hilson, Maconachie, McQuilken, & Goumandakoye, 2017) have demonstrated how small-scale mining and artisanal mining are intertwined with other means of rural subsistence, mainly with small-scale agriculture insofar as the income obtained in mining allows the farmers to obtain agricultural supplies. The economic benefits received from the mining activity, as a primary and supplementary source of income for many impoverished populations in the third world, may explain why people accept risks to health and the environment (Gamu et al., 2015).

According to the UNEP (2006), between 20% and 30% of the world's gold production comes from informal mines. The artisanal extraction of gold is particularly problematic when it involves the sustained and uncontrolled use of chemical pollutants such as cyanide and mercury. Mercury has been widely used throughout the history of gold mining because it is a simple and inexpensive mining technique, which facilitates the separation of gold through the amalgam created between gold and mercury. Between 10% and 15% of the mercury used is estimated to be lost or released into the environment during the process (Huidobro & Marcello, 2008), and these numbers can be significantly higher when crude methods such as open pit burning are used.

It is estimated that approximately 37% of global mercury emissions into the atmosphere come from the small-scale mining sector. In addition, an estimated 800 tons of mercury is released annually into soil and water sources around the world (UNEP, 2013a), often released in large quantities when gold is retorted using crude methods such as open pit burning, releasing vapor phase ionic mercury into the atmosphere where it can travel long distances before being deposited through precipitation or dust aggregation (Lin & Pehkonen, 1999). Although the use of mercury is economically advantageous for artisanal miners because it increases extraction productivity, this practice carries a high risk of dispersion of dangerous pollutant loads in the environment. In ecosystems, mercury causes serious problems to the health of all biota and the human communities that depend on them (Basu et al., 2015). The costs derived from environmental damage due to mercury contamination and the deterioration of human health (both mining workers and the inhabitants of mining areas) have not been calculated, although the problem is cumulative and states must address the serious public health problems caused by mercury pollution.

Mercury is a nondegradable, global pollutant that can travel thousands of miles in the atmosphere before precipitating and depositing (Lin & Pehkonen, 1999). Mercury is a complex environmental pollutant that can occur in different chemical forms with varying levels of toxicity (i.e., ionic mercury or as methylmercury if conjugated with organic compounds). Moreover, mercury has a high potential for bioaccumulation and biomagnification at all levels of the trophic chain (Morel & Kraepiel, 1998). Depending on the form, mercury is highly toxic upon ingestion, inhalation, and even skin contact, leading to severe neurological, renal, or immune problems (Gibb & O'Leary, 2014). In humans, acute and chronic mercury poisoning is manifested mainly in alterations of the nervous system, including visual and auditory impairments, olfactory and gustatory alterations, cerebellar ataxia, somatosensory alterations, and psychiatric symptoms (Ekino, Susa, Ninomiya, Imamura, & Kitamura, 2007).

Mercury and Illegal Mining in Colombia

As a member of the Minamata Agreement, the Colombian government has begun to develop public policies aimed at reducing exposure to mercury from anthropogenic activities. As part of these regulations, in 2013, the Congress of the Republic approved Bill 1658, which prohibits the use of mercury in industrial and mining projects and provides a transition period of 10 years for industrial projects and 5 years for small-scale mining. Since then, the government has implemented several regulations on mercury, such as the Single National Mercury Plan, sectoral plans, and Decree 2133 of 2016, which establish controls on the importation and commercialization of mercury and the products that contain mercury (Minambiente, 2018). Unfortunately, despite the governmental initiatives, the use of mercury prevails in many informal mines that operate in different regions of the country; in 2016, Colombia was reported as one of the most mercury polluting countries of the world with an estimated output of more than 175 tons Hg/year (Evers et al., 2016).

Between 2010 and 2011, the national government developed a mining census in 23 departments of the country, which was aimed at understanding the technical, environmental, socioeconomic, and administrative conditions of the mining production units (MPUs; Ministerio de Minas y Energía, 2012). The census showed that 63% of registered mines, which corresponds to 9,041 MPUs, have no mining title and that 92.6% of the mines without a title lack an environmental authorization, permit, or license.

Illegal mining is even more dramatic in the Department of Cauca, where 87.5% of the 544 MPU censuses have no mining title. In this department, 170 MPUs are engaged in the extraction of gold, which corresponds to 31.1% of the total number of registered mines. According to the Ministry of Environment and Sustainable Development and the UNEP (Minambiente, 2018; UNEP, 2013a), in the Department of Cauca in 2011, gold production exclusively from small-scale mining was estimated at 1,127.6 kg, which indicates the use of approximately 15,806 kg of mercury during that year alone.

Illegality of artisanal mining, as well as its limited environmental control through permits and licenses, has been the focus of the discussion in other regions of the world such as Central and Western Africa (Fisher, Mwaipopo, Mutagwaba, Nyange, & Yaron, 2009) and South Asia (Lahiri-Dutt, 2008). Rettberg and Ortiz-Riomalo (2016) acknowledge that is not only the lack of technical capacity by the artisanal miners but also the obstacles imposed by the governments for the exercise of small-scale mining that has led artisanal miners to operate outside the law. Such illegalization more easily connects AGM with criminal networks and other territorial actors that obtain benefits for the informal control of the ore extraction.

The illegality and limited environmental control through environmental permits and licenses not only reveals the inability of state institutions to regulate the extraction of mining resources but also generates a profound uncertainty about the environmental and human health effects of the current extraction technologies. In addition, environmental institutions and public health officials have limited willingness, capacity, and opportunity to perform follow-up studies to determine the state of deterioration and contamination of the ecosystems as well as the impacts on the populations that work in the mines or inhabit the mining areas.

The scale of the social and environmental impact increases as a direct consequence of the inefficient processing methods and informality of the AGM sector, creating a pressing need for generation of strategies that facilitate and promote the formalization of AGM. Hence, an intervention in the public sector is necessary to create simple, clear, understandable, and sensible legal frameworks that have the capacity to strengthen AGM with legality, promoting a route to formalization that considers technical investment along with the betterment of labor and environmental conditions related to artisanal mining operations (Kamlongera, 2011; Sinding, 2005).

Sociogeographical Context and Mining Trajectory in Alto Cauca

The region known as Alto de Cauca is located north of the Department of Cauca between the central and western mountain ranges in the upper Cauca River basin. It is characterized by its high percentage of Afro-descendant communities, who make up 21.5% of the regional population (Urrea, 2010). These groups are organized into Community Councils of Black Communities, and the main regional organization is the Association of Community Councils of North of Cauca.

The communities that inhabit this region are traditionally mining communities. In fact, their ancestors began arriving in the area in 1636 from West Africa as an enslaved population that was used to extract gold (Buenaventura & Trujillo, 2011). Once slavery was abolished in 1851, the Afro-descendant population remained in the area and made the agro-mining practice their main livelihood along with artisanal fishing in the upper Cauca River basin. Both men and women participate actively in mining activities. Although the 2012 mining census counted only 26 women in the MPU within the Department of Cauca (Ministerio de Minas y Energía, 2012), many women in the region perform different types of mining, particularly for the extraction of gold from sand.

Historically, several types of mining have been performed in the area, which are referred to as extraction technologies. The Afro-descendant communities in the region use a series of traditional extractive practices characterized by the use of manual energy and mechanical tools for the manipulation of rocks, sands, and mud, including shovels, picks, mallets, pans, and, more recently, revolving cylinders for the pulverization of ore.

In addition, mining technologies with greater environmental impacts have been used during three distinct periods over the past century: (a) In the 1930s, two multinational companies, the Asnazu Golden Company and Gold Dredging Limited, established mechanized dredging activities along the Cauca River for the extraction of gold (Buenaventura & Trujillo, 2011); (b) in the 1950s, the Mosquera brothers, who were from Popayán, installed the first artisanal gold mill using Californian technology, which provided greater efficiency in the separation of gold and consequently led to an increase in the amount of extraction; and (c) since 2000, and particularly since 2008, the region has experienced a significant increase in the number of foreign actors in the territory, who perform AGM with machinery such as dredgers and backhoes and use chemicals such as cyanide and mercury intensively, which facilitate the purification of gold and increase the yield of the process (Lacerda, 1997).

Methodology

Approach

This project began after a series of telephone calls that Professor Vélez-Torres received in May 2016 from several residents of the village of Yolombó. During these conversations, the inhabitants of the region reported massive fish death in the Ovejas River, which is a tributary of the Cauca River and the main source of artisanal subsistence fishing by the community. Two months after the first call, a community leader called for urgent help; according to him, due to the persistent omissions by the state institutions, the only hope that the community had to understand what was occurring in the river was the assistance of Universidad del Valle.

Research Team

Faced with this call, two professors from Universidad del Valle, Dr. Vélez-Torres, who is a philosopher with a doctorate in human geography, and Dr. Vanegas, who is a food engineer with a doctorate in agricultural and biological engineering, decided to join forces to understand the problem and develop a solution. Subsequently, this initiative was joined by MSc. Hurtado, who contributed to the fieldwork and provided technical support to the study of the water quality, and by Dr. McLamore of the University of Florida (USA), who has extensive experience in the development of devices for environmental monitoring and who supported the technical needs to complete the investigation. In addition, Dr. Carlos Passos from University of Brasília (Brazil), who is an expert in environmental contamination by mercury, accompanied the team from Universidad del Valle during one of the visits to Yolombó, performed a reconnaissance of the area, and provided advice during a presentation of the findings to the community.

The project was interdisciplinary from the beginning because the problem could only be addressed by incorporating both technical and social knowledge. In this sense, the methodology integrated the participative frameworks from the social sciences in addition to the technical understanding of the problem, which was a component that the biological and environmental sciences/engineering contributed to.

Work Strategy

The interdisciplinary strategy had the following objectives: (a) to locate areas of recent incursions by foreign actors into the region and characterize polluting technologies used for gold extraction; (b) to locate water sources of community importance in Yolombó, which is a subregion of Alto Cauca, and measure the presence of mercury in these sources using commercial ionic mercury strips (SenSafe®, U.S. patent # 6541269); and (c) to characterize some of the socioenvironmental impacts of mining by foreigners, particularly from the perspective of women.

Based on other successful environmental programs for participatory monitoring (Cohn, 2008; Kim, Zimmerman, Pierce, & Haber, 2011; Marshall, Kleine, & Dean, 2012), we developed an approach for closed-loop integration of social action and analytical chemistry research (CLISAR) shown in Figure 1. CLISAR involves social action research, integrated with analytical sciences and engineering, using continuous feedback among interdisciplinary team members and community leaders. The model has some similarity to the persistent organic pollutants risk management strategy developed by the World Bank as well as the participatory assessment, monitoring, and evaluation developed by Food and Agriculture Organization of the United Nations but is unique in that CLISAR focuses on community-led participatory monitoring that leads to social action.

The first phase of social action research included establishment of objectives based on face-to-face meetings, surveys, and community-led social cartography (green background). This was followed by two analytical science/engineering phases. The information gathering phase involved analysis of cartography maps, sample site selection, and screening Hg^{2+} concentration (yellow). Data classification and evaluation involved expert analysis of integrated water quality data and cartography/survey results (blue). The final phase was social action research that involved socialization of the data and community action (gray).

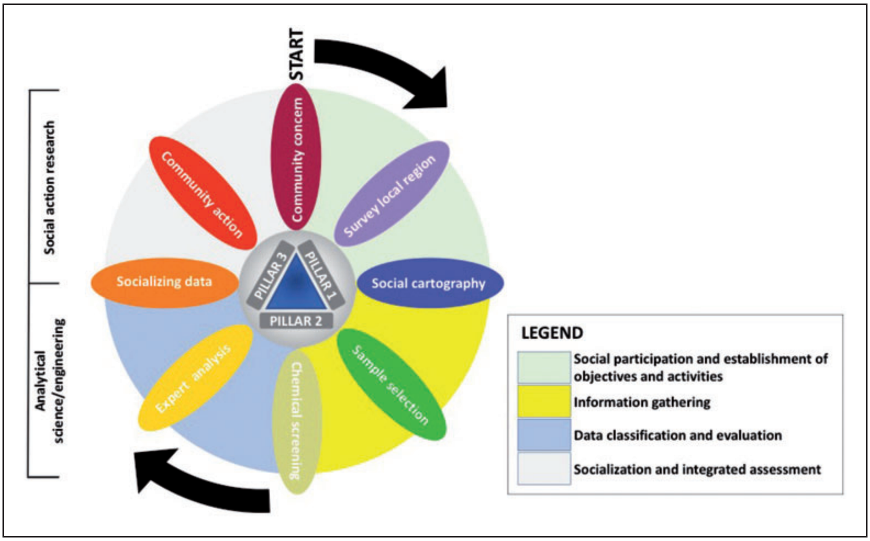

Figure 1. Closed-loop integration of social action and analytical chemistry research (CLISAR). The three CLISAR pillars serve as a foundation for integrating the four phases of research, including social participation and establishment of objectives (12 to 3 clockwise orientation), information gathering (3 to 6 clockwise orientation), data classification/evaluation (6 to 9 clockwise orientation), and socialization/integration of data (9 to 12 clockwise orientation).

Importantly, the CLISAR process is community-driven and stands on the integration of three pillars:

Pillar 1: Community-driven research: The environmental concern initially arose from the local inhabitants. Community members were primarily interested in understanding what was occurring in their region and the probable cause of the observed fish kill. Therefore, any environmental information or data would be socialized with the community.

Pillar 2: Participatory monitoring for producing data: The intention to resolve community concerns about fish mortality and its relationship to discharges of polluting substances was the impetus for developing strategies that address local knowledge about the locations and discharges of MPUs. Tours were conducted through the territory, which included direct observations of extraction technologies and dumping sites, social cartography workshops to collectively assess the most important locations of perceived contamination, and collection of water samples for laboratory analysis by experts. Analysis of social sciences data from Pillar 1 (surveys, cartography) was used to decide on locations of water samples. It is important to note that security during the tours could be achieved only through joint participation with the inhabitants.

Pillar 3: Community action and integrated assessment: After integrating comprehensive expert analyses (surveys, social cartography, water quality data), specific sites were selected that represented various risk levels for contamination. This action research was based on Pillar 1 and Pillar 2, closing the loop of integrated social action research and analytical science/engineering.

Results and Discussion

The results of this research are organized into three sections. First, the geography and communities of Norte del Cauca are described. In the second section, we present results of screening ionic mercury levels in various water sources in the community. In the last section, the impacts of mercury on traditional mining practices and health of the community as perceived by local women are discussed.

Social Cartography as a Participatory Tool

Social cartography was used in two different territorial contexts, namely, (a) for identifying whether the local mines were operated by native or nonnative actors and (b) for geoidentification of the different mining practices that had been identified previously.

First, at the Women's School of Norte del Cauca, social cartography was used during two workshops with the objective of identifying and characterizing the differences between traditional mining practices and mining practices of nonnative actors. This exercise was carried out with the aim of constructing elements of analysis with the inputs of more than 80 women representing all of the municipalities from Alto Cauca and focused on rapid transformation of the regional mining environment.

Second, a group of 30 representatives of the community of Yolombó and Gelima identified major mines operated by foreigners in the region as well as primary water resources for the community (drinking, cooking, bathing, etc.). The objective of this third workshop was to understand the vulnerability of the local water sources to potential mercury contamination from AGM.

During the first day of the workshop at the Women's School of Norte del Cauca, nine different mining practices were identified using a dialogical approach (Shor & Freire, 1987). These practices were described by participants as having been developed by foreign actors or local communities as follows: (a) Although men primarily work in foreign mining, both men and women participate in traditional local mining; (b) extraction techniques exclusively used by women; and (c) extraction techniques exclusively used in mines operated by foreigners. Figure 2 shows a summary of the mining practices identified by the group; it highlights foreign practices in red and traditional practices of local

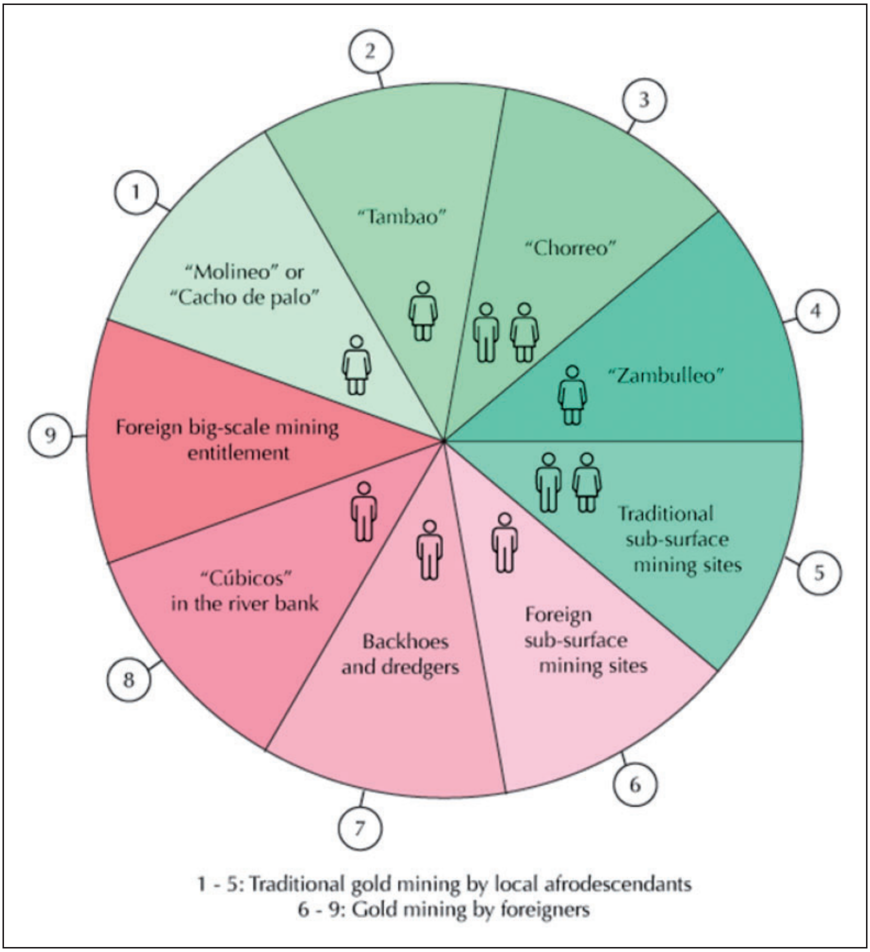

Figure 2. Identification of mining practices in Alto Cauca.
Note. Although foreign mining may include the participation of some women, the number is irrelevant when compared with the predominance of masculine participation.

communities in green and shows the gender participation in traditional and foreign mining.

The second workshop with the women consisted of geographically locating the different mining practices that had been identified previously. For this exercise, six A4-sized maps of the administrative divisions between the municipalities of Alto Cauca were printed. The 80 women were divided into six groups with the intent of having representatives of each municipality and livelihood (i.e., every group contained female miners). To locate the different mining practices on the map, different colors were used to differentiate traditional mining practices from

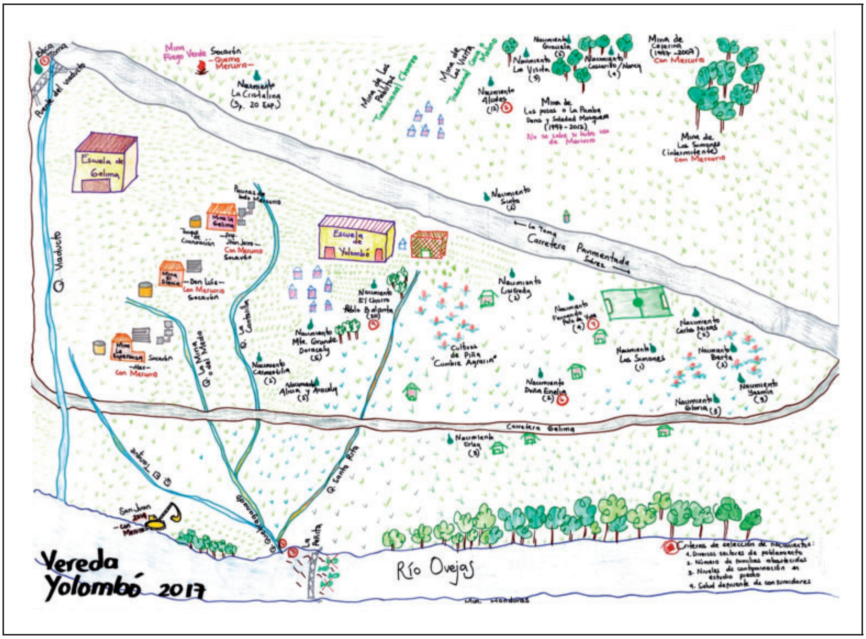

Figure 3. Social cartography for the identification of mines and water sources in Yolombó, 2017.

those used by foreign actors. At the end of the exercise, each group shared their findings in a plenary session; the results of the groups were complementary and synthesized into a unified map (see Figure 4).

During the cartography workshop in Yolombó, which also included participants from the village of Gelima and was composed of 70% women, three active foreign production units were identified, which are administered by "paisas." The foreign operations perform reef mining and use mercury and cyanide to extract gold; these foreign mines are located in the left region of the map shown in Figure 3. In addition, the mapping allowed us to identify an area that was exploited by foreign actors during the 1970s and whose gold extraction technique is unknown by the community (Figure 3, upper right region of the map).

Expert analyses of (a) the locations and distances between the mines and water sources, (b) the number of users of different water sources, and (c) the uses of the natural water source (creeks and streams) allowed us to better understand the local conditions in the area and collectively prioritize water sources for chemical screening.

Rapid Screening of Ionic Mercury in Water

A patented, commercially available technology (SenSafe® Mercury Check, Industrial Test Systems, Inc., Rock Hill, SC, USA) was used to screen water samples taken based on the results of social cartography. The colorimetric strips produce a visible color change in the presence of ionic mercury in concentrations higher than 50 μg/L (parts per billion [ppb]). This technology was selected as the initial screening tool due to its low cost and portability compared with standard laboratory techniques for measuring ionic mercury (i.e., cold vapor atomic absorption spectroscopy). In addition, it is an easy-to-use device that allows on-site detection as needed (no laboratory facilities are required). Due to these characteristics, it was possible to quickly analyze a large number of samples at different locations in the area influenced by mining with subsequent secondary validation to take place at a later date. Screening with these rapid indicator strips facilitates "heat mapping" for optimization of future water sampling schemes to focus on areas of probable mercury contamination (or a lack of contamination) using quantitative standardized laboratory methods.

The first sampling visit was made on September 11, 2016. As this was a Sunday, most of the mines were not operating at maximum capacity, and some of them were not operating at all. On this date, the La Mina, El Tanque, and Santa Rita streams, which flow into the Ovejas River, were visited, and water samples were collected at locations adjacent to three informal mines: "La Gelima," "El Silencio," and "La Esperanza." In addition, samples were collected from the Ovejas River, and a sample of water for human consumption was collected from one of the houses in the village of Yolombó, which obtained its water from the community aqueduct system.

The second visit was made on October 12, 2016. On this date, samples were obtained during two trips made by the technical team of Universidad del Valle and local leaders. Based on a community decision, the sampling strategy was concentrated in two areas: The first area included the basins of the La Mina, El Tanque, and Santa Rita (also included the first sampling), and the second area included wells that are the main water sources that supply the Yolombó community. Samples from the second area were collected by community members on October 17, 2016. All samples, including those collected by the community members, were analyzed by the technical team of Universidad del Valle for water quality parameters (Hg^{2+}, pH, temperature).

The criterion used for the locations along the streams was to collect samples before and after discharges from the three active mines. For the wells, the criterion for selecting sampling sites was based on the largest number of families actively using the well. The results of the sampling have been released to the community during assemblies in which the miners who are allegedly involved in the water pollution have also participated. During the 2 days in which this second set of samples was collected, normal mining activity (extraction or washing) occurred in the mines that discharged liquid waste to the La Mina, El Tanque, and Santa Rita streams. Table 1 shows the results obtained from the

Table 1. Characterization of the Water Quality of Different Sources of Surface Water in Yolombó and Gelima.

Sampling site	Samples collected by technical team	
	First sampling campaign: September 2016	Second sampling campaign: October 2016
	Ionic mercury (μg/L)	
"La Gelima 1": Sample taken from a creek, about 50 m upstream from the wastewater discharges of the artisanal mine called La Gelima.	≤100	100–200
"La Gelima 2": Sample taken from a creek, about 5 m upstream from the wastewater discharges of the artisanal mine called La Gelima.	≤500	200–500
"La Gelima 3": Sample taken from a creek, about 50 m downstream from the wastewater discharges of the artisanal mine called La Gelima.	≤500	500–1,000
"El Silencio 1": Sample taken from a creek, about 50 m upstream from the wastewater discharges of the artisanal mine called El Silencio.	≤200	≤1,000
"El Silencio 2": Sample taken from a creek, about 50 m downstream the wastewater discharges of the artisanal mine called El Silencio.	≤500	500–1,000
"La Esperanza 1": Sample taken from a creek, about 50 m upstream from the wastewater discharges of the artisanal mine called La Esperanza.	≤100	–
"La Esperanza 2": Sample taken from a creek, about 50 m downstream the wastewater discharges of the artisanal mine called La Esperanza.	≤100	≤200
Yolombó Elementary School: Sample taken from the tap. The school water is supplied by from the Community Aqueduct of La Toma district.	–	≤50
Downtown: Sample taken from the tap. The downtown area is supplied by the aqueduct of the municipality of Suarez.	≤50	–
Ovejas River 1: Sample taken from the Ovejas River, about 100 m upstream from the confluence of the creeks that surround the artisanal mines.	≤50	≤50
Ovejas River 2: Sample taken from the Ovejas River, about 100 m downstream from the confluence of the creeks that surround the artisanal mines.	≤100	≤200
Distilled water: Sample taken from the biosensors lab at Universidad del Valle. Negative control	≤50	≤50

(continued)

Table 1. Continued

	Samples collected by community members	
	Number of families supplied from water source	Sampling campaign: October 2016 Ionicmercury (μg/L)
"La Pamba Lucrecia": Sample taken from the wellspring that supplies some of the community families.	3	≤50
"Doña Graciela": Sample taken from the wellspring that supplies some of the community families.	2	≤100
"Orlency": Sample taken from the wellspring that supplies some of the community families.	5	≤50
"Dancy" or "Monte Grande": Sample taken from the wellspring that supplies some of the community families.	5	≤500
"Alcides": Sample taken from the wellspring that supplies some of the community families.	5	100–200
"Chorro Pablitos" or "La Cristalina": Sample taken from the wellspring that supplies some of the community families.	3	≤100
"Sixta": Sample taken from the wellspring that supplies some of the community families.	2	≤50
"Eduar": Sample taken from the wellspring that supplies some of the community families.	2	≤50
"Erley": Sample taken from the wellspring that supplies some of the community families.	3	≤50
"Enelia": Sample taken from the wellspring that supplies some of the community families.	6	200–500
"Lisifrey": Sample taken from the wellspring that supplies some of the community families.	2	≤100
"Abraham": Sample taken from the wellspring that supplies some of the community families.	3	100–200
Runoff: Sample taken from the rainwater runoff coming from the roof of a house.	–	≤500

Note. The samples were collected in September and October 2016.

SenSafe® Mercury Check mercury indicator strips, which were operated according to the manufacturer's instructions regarding the correct pH range and temperature of the samples during analysis.

The Hg^{2+} measured with the test strips in Yolombó and Gelima was higher than levels reported in similar studies of regions impacted by illegal mining in Colombia. For example, Olivero-Verbel, Caballero-Gallardo, and Turizo-Tapia (2015) analyzed several environmental matrices, including water samples from the mining district of San Martin de Loba in southern Bolívar. The levels of mercury in the water ranged from 0.17 to 39.18 µg/L, and the highest concentration was found in the discharge from the Catanga mine. Marrugo-Negrete, Benitez, and Olivero-Verbel (2008) analyzed environmental samples in the municipality of Montecristo in southern Bolívar and reported concentrations between 0.16 and 0.46 µg/L in water samples collected from different locations along the Ciénaga Grande. Olivero-Verbel et al. (2015) and Marrugo-Negrete, Verbel, Ceballos, and Benitez (2008) used atomic adsorption spectroscopy for sample analysis, which is a highly accurate standard analytical tool but is often cost prohibitive for screening studies such as the work herein.

It is important to note that climatic factors such as fluvial precipitation (which affects the dilution of the pollutant load) and wind speed (which transports atmospheric mercury originating in amalgam burns) can induce variability in the concentrations of mercury found in the surface water of the region, which further complicates direct comparison. The day of the week in which the sampling is performed also has an influence because many of the mines do not operate at their normal capacity during the weekends.

The results obtained by commercial indicator strips should be considered to be preliminary information for early warning of a potential problem and not taken as quantitative. The importance of laboratory confirmation of these screening results using standard techniques cannot be overstated, and secondary testing is currently underway. Currently, the most important information that can be obtained with this methodology is the real-time and in situ determination of sites most impacted by potential mercury contamination, and this nuance has been openly expressed with the community members during socialization of the data. While the quantitative amount of mercury and additional studies on mercury speciation remain under investigation, this early screening study allowed us to investigate the specific role of women in mining practices and how this may link to potential mercury exposure.

Afro-descendant Women in the Mining Environment of Alto Cauca

There is growing agreement among development agencies, governments, and mining industries on the differential impacts of large-scale mining on women (Lahiri-Dutt & Ahmad, 2012). It is also recognized that in the case of AGM, the ways in which women participate differ according to the different geographic characteristics, histories, and cultures of the mining environments (Fisher, 2007); this diversity includes levels of responsibility and access (Li, 2009).

Based on the workshops carried out with the Women's School of Norte del Cauca, the traditional mining practices of women are characterized by seasonality and spatial mobility. These practices are different from those traditionally worked by men, as masculine mines are located at permanent extraction sites and require significantly higher degree of manual labor. This situation resembles the one described by Malpeli and Chirico (2013) for Western and Central Africa, in which the geomorphology of the mining sites was found to be a crucial characteristic with great influence in the gender roles of male and female in alluvial diamond and gold mining.

Permanent forms of mining, such as trickling and traditional male production units, require an economic investment that women cannot afford in this region. However, other traditional extraction techniques, such as diving, *molineo* (grinder), or *tambao* (grazing technique), are more affordable because they require cheaper materials, such as wooden boards, canoes, and traditional rafts. This characteristic of women's mining in Alto Cauca is consistent with the participation of women in mining in other countries, such as Tanzania and Indonesia, where men are considered to be the "owners" of the production units and women conduct manual labor with their immediate family, usually husbands or brothers (Fisher, 2007; Lahiri-Dutt & Mahy, 2005).

On the other hand, women perform mining activities during the summer on the banks of rivers and streams, which implies the direct use of the mining resources available in the region as opposed to requiring invasive extraction technologies. Machinery or chemical substances are typically not used by the women, which results in low risk of harm to the environment or local community human health.

The spatial and temporal mobility of traditional mining practices allows women to have diverse livelihoods, primarily based in agriculture. In addition, the seasonality, mobility, and collectivity of traditional female mining practices allow women to perform other activities, such as home care and cultural and traditional culinary activities, which are central to their Afro-descendant identity.

Figure 4 shows a map (by municipality) of the mining practices in Alto Cauca that was developed by the women of the school. This work clearly shows an overlap between the locations of traditional mining and mining by foreigners.

The transformations in the regional mining environment are a result of dynamic factors including spatial overlap of traditional mining and mining by foreigners and economic and power-related factors that have gradually displaced traditional practices based on either the promise of better yields or economic dependencies of miners employed by new foreign production units (a dependency that includes services in addition to direct employment). As foreign miners remain in the region for longer periods, more social relationships are woven into the culture, which leads to greater dependence and the inability to regain control. This was expressed by a woman from Buenos Aires during the socialization in the plenary session of the cartographic findings:

> I'm going to be honest: I'm not sorry to say that almost 10 years ago, I let one of those miners enter my farm. I couldn't have imagined... They told me that this

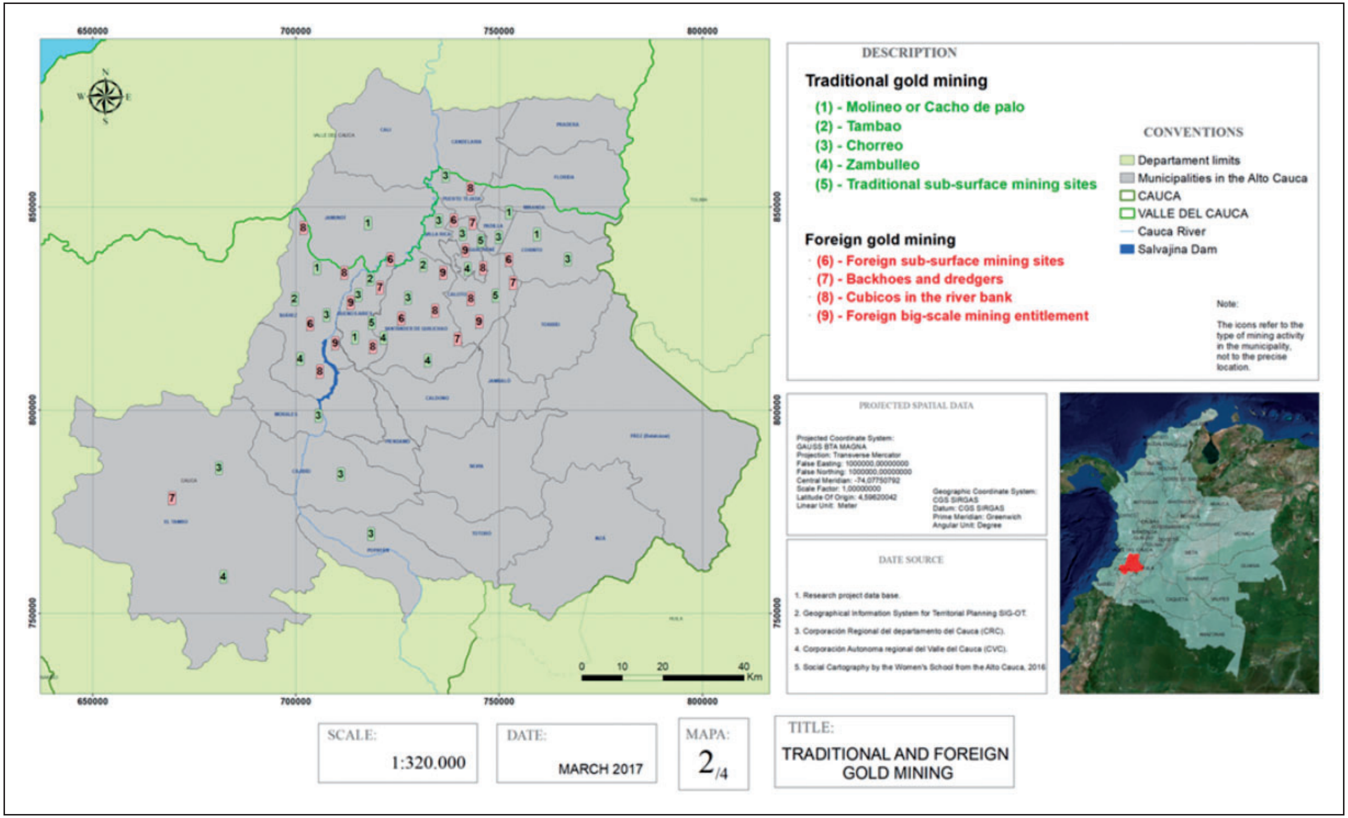

Figure 4. Locations of traditional mining and mining by foreigners in Alto Cauca.

would be good for me and my children because they were going to pay me to rent the piece of land. But the problem is that it was growing and growing, and I was never told about mercury or anything like that. Today, I cannot even go there! And those gentlemen, there is no one to take them out. (Woman from Cerro Teta, 55 years old, workshop at the Women's School of Norte del Cauca, October, 2016)

The loss of territorial control occurs through subtle mechanisms. The miners arrive one by one and make direct agreements with the families that have land that is rich in gold. Almost without realizing it, the traditional Black communities' territories in Alto Cauca have been inhabited, exploited, and controlled by miners from Antioquia, Nariño, and Chocó over the past 10 years. Some of these miners even make strategic use of their African ethnicity to create empathy and consolidate exploitive relationships with the local inhabitants.

The greater participation of women in the social mapping exercises in Yolombó was due to their concern about the effects of contamination on pregnant women and on the children of the community. In the first meeting for the presentation of the results, one of the inhabitants said,

I do want to know what is happening to us because there have been miscarriages, there have been children born without their legs, and we are getting sick without knowing why. That's why I want to know what we have to do . . . (Woman from Yolombó, 30 years old, community assembly, November, 2016)

Faced with this concern about the health of the population, a leader reinforced this comment, saying,

Here, we all know that whatever happens to our children and our girls is going to have to be taken on by us women because it is not a secret that we are mothers, heads of the families. Let's say it flat out: here, having children is our responsibility. And God forbid that a malformation or a very ill child should occur, who will answer for that? Who is going to be responsible for paying for medicines and the health of those children? It is not fair that everything we have fought for in this region . . . and in the end, they will end up killing us with these chemicals! (Woman from Yolombó, approximately 35 years old, community assembly, November, 2016)

The particular way in which Afro-descendant women take on the care of children (matrilineal child care) results in a different impact of the pollution in the children and women. As a result, women express greater concerns about the environmental conditions in the area. The women's resistance in the Alto Cauca region against the AGM performed by foreign miners mirrors the women's experience and resilience to large-scale mining in the Andes (Jenkins & Rondóon, 2015).

Figure 5 is a visual summary showing the most important factors that have transformed traditional mining practices due to the mining by foreigners.

The health and livelihoods of women are affected in a singular way by the pollution generated by the use of mercury and cyanide in mines by foreigners. First, this effect occurs whenever the discharges of polluting substances impact the places that women have traditionally used for the extraction of gold, particularly surface water sources.

On the other hand, this effect also occurs when the soils are contaminated, either by runoff or directly through the deposition of sludge that contains mercury and cyanide; in this case, the effect is on agriculture, which is a central activity in the diversification of women's livelihoods. In this sense, the effect of the death of fish on artisanal fishing is an example of the effect on the local economic diversification.

In this sense, the pollution generated by the mining units creates a public health problem and causes an environmental displacement of the traditional mining practices of women and others of their livelihoods. The differentiated effect influences the economy and traditional agro-mining practices.

There is an intimate connection between human health, agricultural, environmental, and social issues, currently referred to as Planetary Health (Demaio &

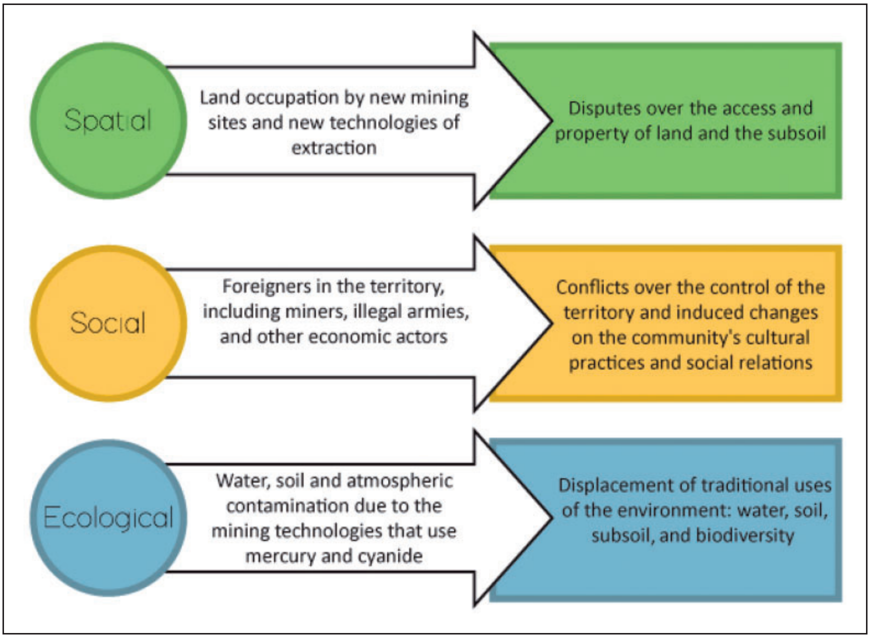

Figure 5. Impact factors of foreign mining on traditional mining.

Rockström, 2015; Raudsepp-Hearne et al., 2010; Whitmee et al., 2015). To understand these complex issues, methodologies are needed which use technology, state of the art knowledge in topical areas, and methods that are community-driven. The CLISAR approach presented here (Figure 1) allows identification of problems related to human and environmental health potentially linked to mining activity in the area, which is socialized with the community after careful evaluation of all data by an expert team. With each CLISAR cycle, it is anticipated that socialization of the results leads to at least one social action. This social action induces one or more additional CLISAR cycles, leading to a continuous "spiral" of divergent CLISAR cycles that increase community knowledge with each iteration (see the Conclusions and Recommendations section for the divergent CLISAR cycles that may result from this preliminary study). Participation of the communities in the case studies and the series of workshops integrated with the Women's School of Norte del Cauca, which were co-organized by Association of Community Councils of North of Cauca and the Universidad del Valle, were aimed at the development of a broader view of the mining situation in other communities in the region and increasing knowledge for both community members and researchers.

Conclusions and Recommendations

Although it is critical to perform subsequent analyses using standardized laboratory techniques, the implementation of commercial test strips allowed us to rapidly characterize the presence of mercury in the water of the villages of Yolombó and Gelima, warning of the presence of mercury in water sources in the following concentrations:

- Water for human consumption: 50–500 μg/L (ppb)
- Surface water: 50–1,000 μg/L (ppb)

Considering the maximum levels of mercury in water allowed by the Colombian legislation, which are 1 μg/L for drinking water (Resolution 2115 of 2007) and 20 μg/L for surface water (Resolution 0631 of 2015), the environmental and health risks to the population are presumably high, even more if additional factors are taken into account, such as (a) the frequency of exposure of the community and the local ecosystems to mercury, (b) the impossibility of diversifying the sources of water due to a lack of aqueducts, and (c) the bioaccumulation of mercury that could be affecting the community via the consumption of fish from the Ovejas River, which is a traditional cultural practice.

The results from this study were used by the community as leverage to garner attention from the environmental authorities regarding the presumed presence of mercury in some of their water sources. The Regional Autonomous Corporation of Cauca (CRC in Spanish) collected water samples in the area between March and April 2017. Results from such assessment were published in the CRC technical report No. 180.176.01 on April 11, 2017. This report confirms mercury contamination in surface water sources and soils, which can be directly linked to artisanal mining activity in the area (it is noteworthy that atomic adsorption spectroscopy was used as the analytical technique in this technical report). Conclusion remarks from the report are that (a) mercury concentrations were found to exceed the normative limits and (b) none of the surveyed mining entanglements have environmental permits as required by the Shedding or Water Concession (Decree 1076 of 2015). Although the response of the environmental institution is the result of the community organization, the preliminary data gathered during our research served as key tool for lobbying public institutions, demonstrating the effectiveness and importance of a participatory environmental monitoring strategy in areas of environmental/social conflict.

In spite of the CRC's findings, the government institutions have not taken concrete actions to limit mercury exposure in rural mining communities of Alto Cauca. In fact, regardless of the collected evidence, the CRC's report rates the environmental risk in Yolombó as "moderate." While current legislature prohibits mercury usage in mining activities, this harmful practice persists in most artisanal mines in the region.

Considering the different roles, access, and impacts of women in the gold-mining context, it is paramount to adopt a gender perspective to comprehend the different layers and complexities associated with the mining activity, as well as its influence on rural and agrarian transformations. In the case of Alto Cauca, this study has exposed impacts on women in relation to the contamination from artisanal/illegal mining entanglements in the region. On one hand, women showed the most concern for the potential effects on public health, particularly for children and pregnant women in the community. This is in part explained by the family configuration of the regional Afro-descendant society, where women take most of the responsibilities of the home life, particularly in raising children. On the other hand, traditional women's livelihoods have been shifted because of the intrusion of foreign miners in the territory in four specific ways:

- Environmental displacement: due to (a) reduction in soil and water quality, which limits subsistence activities such as fishing and farming, and (b) territorial hoarding by foreigners in the gold extraction spaces;
- Geophysical displacement: due to superposition of new artisanal mines run by men on the locations of traditional mines run by women;
- Loss of sociopolitical authority: due to social reconfigurations caused by the intrusion of foreign miners who have (a) created relations of economic dependence with locals and (b) incorporated armed security schemes to protect their particular interests; and
- Finally, loss of diversification of local economies—particularly of women's livelihoods—will most likely affect the resilience of the entire community to

adverse events, as the whole economic system becomes heavily dependent on the success of one single activity.

Given this situation, a promising alternative for protecting human and ecosystem health in the Alto Cauca is to establish participatory programs for continued environmental surveillance; awareness campaigns, appropriation of cleaner extraction technologies, education, and community actions for social change are key components of environmental and community protection in the artisanal mining contexts (García et al., 2015; Veiga, Bern, Shandro, Velasquez, & Sousa, 2009; Veiga & Marshall, 2017). With this approach, the community should be able to autonomously assess the levels of mercury in their territory, enabling them to take informed decisions on the use of their natural resources without completely depending on governmental interventions. However, viability of this approach is conditioned to (a) availability of low-cost and user-friendly technologies for rapid and in situ detection of environmental contaminants, (b) articulation with educational programs to facilitate technology appropriation while also sensitizing the community on the risks derived from inadequate management of natural resources, and (c) governability and communitarian control over the territory to confront uneven actions by armed groups (legal and illegal) and people with private interests who are foreign to the territory.

As other studies have suggested, making visible the role of women in AGM is urgent to academic research and public policies (Lahiri-Dutt, 2015; Yakovleva, 2007). By understanding the reproduction of gender inequality involved in AGM, formalization and environmental regulation are important conditions not only to help reducing mercury pollution (Clifford, 2017; Evers et al., 2016; Sippl, 2015) but also to improve the general conditions of women miners: first, in terms of improving the economic recognition for their work; second, in terms of identifying and protecting traditional practices by women; and third, in terms of reducing their exposure to chemical contamination.

In the case of Alto Cauca, a plan for formalizing and regulating AGM that could potentially improve the livelihoods and environment of local women necessarily implies the recognition and defense of traditional gold mining as a specific form of AGM that does not involve the use of chemicals and differs from AGM practiced by people who is foreign to the territory. As was described in the article, traditional mining essentially compels diversification, clean technology, and extraction on a small scale that generate limited environmental impact and allows resources to be available for future generations.

These characteristics, of what can be called traditional sustainable mining, do not compete with the formalization objective. As has been demonstrated by Franco and Ali (2017), formalized mining in Risaralda, Colombia, has pursued the diversification of livelihoods, next to gold mining, as a strategy for resilience to conflict and sustained economic development. Joined collaborative efforts by the local government, the private sector, and the civil society have generated relevant approaches that tackle key community issues hand in hand with the corporate mining development.

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References

Arango-Aramburo, S., Jaramillo, P., Olaya, Y., Smith, R., Restrepo, O. J., Saldarriaga-Isaza, A., . . . Castellanos-Niño, L. Y. (2017). Simulating mining policies in developing countries: The case of Colombia. *Socio-Economic Planning Sciences*, *60*, 99–113.

Armah, F. A., Boamah, S. A., Quansah, R., Obiri, S., & Luginaah, I. (2016). Working conditions of male and female artisanal and small-scale goldminers in Ghana: Examining existing disparities. *The Extractive Industries and Society*, *3*(2), 464–474.

Basu, N., Clarke, E., Green, A., Calys-Tagoe, B., Chan, L., Dzodzomenyo, M., . . . Wilson, M. L. (2015). Integrated assessment of artisanal and small-scale gold mining in Ghana—Part 1: Human health review. *International Journal of Environmental Research and Public Health*, *12*, 5143–5176.

Black, P., Richard, M., Rossin, R., & Telmer, K. (2017). Assessing occupational mercury exposures and behaviours of artisanal and small-scale gold miners in Burkina Faso using passive mercury vapour badges. *Environmental Research*, *152*, 462–469.

Bolaños, E. A. (2012, March 6). La ruta del oro en el Cauca [The Cauca's gold route]. *El Espectador*. Retrieved from https://www.elespectador.com/noticias/nacional/rut

Buenaventura, A. C., & Trujillo, D. (2011). *Historia doble del Cauca: Reconstrucción de las historias locales de Suárez y Buenos Aires, Cauca* [Double history of Cauca. Reconstructions of the local histories in Suarez and Buenos Aires, Cauca] (Tesis de grado para optar al título de Antropología). Universidad ICESI, Colombia.

Clifford, M. J. (2017). Assessing releases of mercury from small-scale gold mining sites in Ghana. *The Extractive Industries and Society*, *4*(3), 497–505.

Cohn, J. P. (2008). Citizen science: Can volunteers do real research? *BioScience*, *58*(3), 192–197. Retrieved from http://academic.oup.com/bioscience/article/58/3/192/230689/Citizen-Science-Can-Volunteers-Do-Real-Research

de Lacerda, L. D., & Salomons, W. (1998). The use of mercury amalgamation in gold and silver mining. In: *Mercury from Gold and Silver Mining: A Chemical Time Bomb?*. (Environmental Science). Berlin/Heidelberg: Springer. doi: https://doi.org/10.1145/1978942.1979251

Crall, J. D., Switzer, C. M., Myers, S. S., Combes, S. A., & de Bivort, B. L. (2017). Pesticides and pollinators, an automated platform to assess the effects of neonicotinoid exposure and other environmental stressors on bee colonies: A computational, ethological study. *The Lancet*, *389*, S4. Retrieved from http://linkinghub.elsevier.com/retrieve/pii/S0140673617311169

Demaio, A. R., & Rockström, J. (2015). Human and planetary health: Towards a common language. *The Lancet*, *386*(10007), e36–e37.

Edelman, M., & Borras, S. M. (2016). *Political dynamics of transnational agrarian movements*. *Agrarian change and peasant studies*. Rugby, England: Practical Action. Retrieved from http://www.developmentbookshelf.com/doi/pdf/10.3362/9781780449142

Ekino, S., Susa, M., Ninomiya, T., Imamura, K., & Kitamura, T. (2007). Minamata disease revisited: An update on the acute and chronic manifestations of methyl mercury poisoning. *Journal of the Neurological Sciences*, *262*(1–2), 131–144.

Evers, D. C., Keane, S. E., Basu, N., & Buck, D. (2016). Evaluating the effectiveness of the Minamata Convention on Mercury: Principles and recommendations for next steps. *Science of the Total Environment*, 569–570. 888–903.

Fisher, E. (2007). Occupying the margins: Labour integration and social exclusion in artisanal mining in Tanzania. *Development and Change*, *38*(4), 735–760.

Fisher, E., Mwaipopo, R., Mutagwaba, W., Nyange, D., & Yaron, G. (2009). "The ladder that sends us to wealth": Artisanal mining and poverty reduction in Tanzania. *Resources Policy*, *34*(1–2), 32–38.

Franco, I., & Ali, S. (2017). Decentralization, corporate community development and resource governance: A comparative analysis of two mining regions in Colombia. *The Extractive Industries and Society*, *4*(1), 111–119.

Gamu, J., Le Billon, P., & Spiegel, S. (2015). Extractive industries and poverty: A review of recent findings and linkage mechanisms. *The Extractive Industries and Society*, *2*(1), 162–176.

García, O., Veiga, M., Cordy, P., Suescún, O., Molina, J., & Roeser, M. (2015). Artisanal gold mining in Antioquia, Colombia: A successful case of mercury reduction. *Journal of Cleaner Production*, *90*, 244–252.

Gibb, H., & O'Leary, K. G. (2014). Mercury exposure and health impacts among individuals in the artisanal and small-scale gold mining community: A comprehensive review. *Environmental Health Perspectives*, *122*(7), 667–672.

Gold Panel International. (2018). *SmartName*. Retrieved from https://www.goldprices.org

Güiza, L. (2013). La pequeña minería en Colombia: Una actividad no tan pequeña [Small-scale mining in Colombia. A not so small activity]. *Dyna*, *80*(181), 109–117.

Hand, E. (2010). Citizen science: People power. *Nature*, *466*(7307), 685–687.

Hilson, G. (2016). Farming, small-scale mining and rural livelihoods in sub-Saharan Africa: A critical overview. *The Extractive Industries and Society*, *3*(2), 547–563.

Hilson, G., Hilson, A., Maconachie, R., McQuilken, J., & Goumandakoye, H. (2017). Artisanal and small-scale mining (ASM) in sub-Saharan Africa: Re-conceptualizing formalization and 'illegal' activity. *Geoforum*, *83*, 80–90.

Horton, R., & Lo, S. (2015). Planetary health: A new science for exceptional action. *The Lancet*, *386*(10007), 1921–1922.

Huidobro, P., & Marcello, V. (2008). *El uso del mercurio en la minería del oro artesanal y en pequeña escala* [Mercury use in artisanal and small-scale gold mining]. PNUMA. Retrieved from: https://ige.org/archivos/IGE/mercurio_en_la_Mineria_de_Au.pdf

Kim, S., Robson, C., Zimmerman, T., Pierce, J., & Haber, E. M. (2011). Creek watch: pairing usefulness and usability for successful citizen science. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '11)*. New York, NY: ACM, 2125–2134. doi: https://doi.org/10.1145/1978942.1979251

Jenkins, K., & Rondón, G. (2015). 'Eventually the mine will come': Women anti-mining activists' everyday resilience in opposing resource extraction in the Andes. *Gender and Development*, *23*(3), 415–431.

Kamlongera, P. (2011). Making the poor 'poorer' or alleviating poverty? Artisanal mining livelihoods in rural Malawi. *Journal of International Development*, *23*(8), 1128–1139.

Kelly, J. T. D., King-Close, A., & Perks, R. (2014). Resources and resourcefulness: Roles, opportunities and risks for women working at artisanal mines in South Kivu, Democratic Republic of the Congo. *Futures*, *62*, 95–105.

Kosmala, M., Wiggins, A., Swanson, A., & Simmons, B. (2016). Assessing data quality in citizen science. *Frontiers in Ecology and the Environment*, *14*(10), 551–560.

Lacerda, L. D. (1997). Global mercury emissions from gold and silver mining. *Water, Air, and Soil Pollution*, *97*(3–4), 209–221.

Lahiri-Dutt, K. (2008). Digging to survive: Women's livelihoods in South Asia's small mines and quarries. *South Asian Survey*, *15*(2), 217–244.

Lahiri-Dutt, K. (2015). The feminisation of mining. *Geography Compass*, *9*(9), 523–541.

Lahiri-Dutt, K., & Ahmad, N. (2012). Considering gender in social impact assessments. In F. Vanclay & A. M. Esteves (Eds.), *New directions in social impact assessments. Conceptual and Methodological Advances* (pp. 117–137). Cheltenham, England: Edward Elgar.

Lahiri-Dutt, K., & Mahy, P. (2005). *Report to World Bank: Impacts of mining on women and youth in Indonesia: Two mining locations* (Report from Creating Empowered Communities: Gender and Sustainable Livelihoods in a Coal Mining Region in Indonesia Project). Retrieved from https://www.banktrack.org/download/cr3_kld_mahy_impacts_mining_indonesia_pdf/cr3_kld_mahy_impacts_mining_indonesia.pdf

Li, F. (2009). Documenting accountability: Environmental impact assessment in a Peruvian mining project. *PoLAR Political and Legal Anthropology Review*, *32*(2), 218–236. Retrieved from http://www3.interscience.wiley.com/journal/123201860/abstract

Lin, C. J., & Pehkonen, S. O. (1999). The chemistry of atmospheric mercury: A review. *Atmospheric Environment*, *33*(13), 2067–2079.

Malpeli, K. C., & Chirico, P. G. (2013). The influence of geomorphology on the role of women at artisanal and small-scale mine sites. *Natural Resources Forum*, *37*(1), 43–54.

Marrugo-Negrete, J., Benitez, L. N., & Olivero-Verbel, J. (2008). Distribution of mercury in several environmental compartments in an aquatic ecosystem impacted by gold mining in northern Colombia. *Archives of Environmental Contamination and Toxicology*, *55*(2), 305–316.

Marrugo-Negrete, J., Verbel, J. O., Ceballos, E. L., & Benitez, L. N. (2008). Total mercury and methylmercury concentrations in fish from the Mojana region of Colombia. *Environmental Geochemistry and Health*, *30*(1), 21–30.

Marshall, N. J., Kleine, D. A., & Dean, A. J. (2012). CoralWatch: Education, monitoring, and sustainability through citizen science. *Frontiers in Ecology and the Environment*, *10*(6), 332–334.

Minambiente. (2018). *Ministerio de Ambiente y Desarrollo Sostenible. Ministry of Environment, Housing and Territorial Development*. Retrieved from http://www.minambiente.gov.co/

Ministerio de Minas y Energía (2012). *Censo minero departamental 2010–2011* [Departmental mining census 2010–2011]. Bogotá, Colombia: Author.

Montero, D. (2012, February 14). La fiebre por el oro le llevó una nueva guerra al norte del Cauca [The fever for gold led to a new war in northern Cauca]. *Silla Nacional*. Retrieved from http://lasillavacia.com/historia/la-fiebre-por-el-oro-le-llevo-una-nueva-guerra-al-norte-del-cauca-31273

Morel, F. M. M., & Kraepiel, A. M. L. (1998). The chemical cycle and bioaccumulation of mercury. *Annual Reviews Ecological Systems*, *29*, 543–566.

Morton, J. F. (2007). The impact of climate change on smallholder and subsistence agriculture. *Proceedings of the National Academy of Sciences*, *104*(50), 19680–19685. Retrieved from http://www.pnas.org/cgi/doi/10.1073/pnas.0701855104

Olivero-Verbel, J., Caballero-Gallardo, K., & Turizo-Tapia, A. (2015). Mercury in the gold mining district of San Martin de Loba, South of Bolivar (Colombia). *Environmental Science and Pollution Research International*, *22*(8), 5895–5907.

Raudsepp-Hearne, C., Peterson, G. D., Tengö, M., Bennett, E. M., Holland, T., Benessaiah, K., ... Pfeifer, L. (2010). Untangling the environmentalist's paradox: Why is human well-being increasing as ecosystem services degrade? *BioScience*, *60*(8), 576–589. Retrieved from https://academic.oup.com/bioscience/article-lookup/doi/10.1525/bio.2010.60.8.4

Rettberg, A., & Ortiz-Riomalo, J. F. (2016). Golden opportunity, or a new twist on the resource-conflict relationship: Links between the drug trade and illegal gold mining in Colombia. *World Development*, *84*, 82–96.

Schnoor, J. L. (2007). Citizen science. *Environmental Science & Technology*, *41*(17), 5923.

Shor, I., & Freire, P. (1987). What is the "dialogical method" of teaching? *Journal of Education*, *169*, 11–31.

Sinding, K. (2005). The dynamics of artisanal and small-scale mining reform. *Natural Resources Forum*, *29*(3), 243–252.

Sippl, K. (2015). Private and civil society governors of mercury pollution from artisanal and small-scale gold mining: A network analytic approach. *The Extractive Industries and Society*, *2*(2), 198–208.

Spiegel, S. J., Yassi, A., Spiegel, J. M., & Veiga, M. M. (2005). Reducing mercury and responding to the global gold rush. *The Lancet*, *366*(9503), 2070–2072.

United Nations Environment Programme. (2006, November). *Summary of supply, trade and demand information on mercury*. Paper presented at the United Nations Environment Programme Meeting, UNEP Governing Council Decision 23/9 IV, Geneva, Switzerland.

United Nations Environment Programme. (2013a). *Global mercury assessment 2013: Sources, emissions, releases and environmental transport*. Paper presented at the United Nations Environment Programme Meeting, UNEP Chemicals Branch, Geneva, Switzerland.

United Nations Environment Programme. (2013b). *Minamata Convention on Mercury*. Paper presented at the United Nations Environment Programme Meeting, UNEP Chemicals Branch, Geneva, Switzerland.

Urrea, G. F. (2010). Patrones sociodemográficos de la región del sur del Valle y norte del Cauca a través de la dimensión étnica-racial [Sociodemographic patterns from an ethnic-racial dimension in the region formed by the South of the Valle and North of Cauca]. In Castillo et al. (Eds.), *Etnicidad, acción colectiva y resistencia: El norte del Cauca y el sur del Valle a comienzos del siglo XXI* [Ethnicity, collective action and resistance: The North Cauca and South Valle at the beginning of the 21st century] (pp. 25–124). Cali, Colombia: Universidad del Valle.

Veiga, M., Angeloci-Santos, G., & Meech, J. (2014). Review of barriers to reduce mercury use in artisanal gold mining. *The Extractive Industries and Society*, *1*(2), 351–361.

Veiga, M., Bern, D., Shandro, J., Velasquez, C., & Sousa, R. (2009). Mill leaching: A viable substitute for mercury amalgamation in the artisanal gold mining sector? *Journal of Cleaner Production*, *17*(15), 1373–1381.

Veiga, M. M., & Marshall, B. G. (2017). Teaching artisanal miners about mercury pollution using songs. *The Extractive Industries and Society*, *4*(4), 842–845.

Vélez-Torres, I. (2014). Governmental extractivism in Colombia: Legislation, securitization and the local settings of mining control. *Political Geography*, *38*, 68–78.

Vélez-Torres, I. (2016). Disputes over gold mining and dispossession of local afrodescendant communities from the Alto Cauca, Colombia. *Third World Thematics*, *1*(2), 235–248. doi:10.1080/23802014.2016.1229131

VerdadAbierta. (2014). *Minería en el Cauca: ¿riqueza para quién?* [Mining in the Cauca: Wealth for who?] Retrieved from VerdadAbierta.com

Whitmee, S., Haines, A., Beyrer, C., Boltz, F., Capon, A. G., de Souza Dias, B. F., . . . Yach, D. (2015). Safeguarding human health in the Anthropocene epoch: Report of the Rockefeller Foundation-Lancet Commission on planetary health. *The Lancet*, *386*(10007), 1973–2028.

Yakovleva, N. (2007). Perspectives on female participation in artisanal and small-scale mining: A case study of Birim North District of Ghana. *Resources Policy*, *32*(1–2), 29–41.

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