International Journal of
Georesources and Environment
http://ijge.camdemia.ca, ijge@camdemia.ca
IJGE 2018 4(3): 99-104
Available at http://ojs.library.dal.ca/ijge
Research and Development and Industry

A Framework for Research and Education on Artisanal and Small-Scale Mining in Latin America

Nicole Smith[1], Juan Lucena[1], Jessica Smith[1], Oscar Jaime Restrepo Baena[2*], Gustavo Aristizabal[2], Alejandro Delgado[2]
[1] Colorado School of Mines, USA
[2] Minerals Institute – CIMEX, School of Mines Universidad Nacional de Colombia

Abstract: In Colombia, Peru, and other Latin American countries, different scales of mining activity usually develop in areas with high social, economic, and environmental complexity. Artisanal and small-scale gold mining (ASGM) is one mining sector that continues to grow and pose challenges for governments, industry, communities, and academics. Although numerous attempts have been made to intervene in this sector and implement cleaner, safer, and more environmentally friendly technologies, the majority of these initiatives have been relatively unsuccessful for they have been founded on myopic understandings of ASGM and the perspective that technology is a silver bullet for addressing the problems associated with ASGM. The complexity of ASGM warrants a different research approach. This paper provides an example of a framework that is being applied to research and engineering education on ASGM. The framework is highly interdisciplinary, international, inter-institutional, and intergenerational in nature. We contend that this type of approach is necessary to support ASGM in becoming a more sustainable livelihood for rural communities in the developing world.

Keywords: artisanal and small-scale gold mining (ASGM), mining-sustainable development, mining communities, social innovation, humanitarian engineering

1 Introduction

Artisanal and small-scale gold mining (ASGM) is widespread in mineral rich developing countries and is credited with producing about 20-30% of all the extracted gold in the world used in jewelry, finances, electronics, aerospace, and medicine (UNEP 2008). The ASGM sector is extremely diverse in scale, legality, demographics, and seasonality, and definitions vary according to who is defining the sector and for what purpose (Buxton 2013). Most generally, ASGM includes activities that contrast corporate led large-scale mining activities by requiring relatively low capital inputs and labor-intensive processes to exploit marginal or small deposits. The low cost of entry into ASGM and the increasing need to diversify rural livelihoods impacted by climate change, processes of deagrarianization, and increasing population pressures means that ASGM is a critical livelihood strategy for millions of people worldwide (Hilson and Banchirigah 2009). However, it poses significant health and environmental hazards at local and global levels (Smith et al 2016).

ASGM is one of the largest contributors to deforestation and atmospheric mercury pollution in the world, resulting in widespread land, water, and air quality harms for rural and indigenous communities (UNEP 2013). In the Amazon Basin, one of the world's most bio-diverse ecosystems, ASGM results in large-scale deforestation, air and water contamination, and human health risks, especially from the mercury used by miners to process the ore (Cremers et al 2013). Governments, industries, and development agencies currently struggle with regulating and minimizing the negative impacts of ASGM while also supporting rural livelihoods (Smith et al 2017).

Most current interventions treat technology as a panacea for solving ASGM's many problems. However, few efforts to develop more sustainable ASGM technologies and practices have achieved longevity, mainly because they were developed *for* miners rather than *with* miners and affected communities (Davies 2014, Hinton et al 2003, Veiga and Baker 2004). In addition, these interventions are often implemented without taking into account the full socio-economic and ecological context of why and how people choose to mine, the knowledge miners and communities already possess about hazards and mitigation strategies, and their own desires for sustainable livelihoods.

This paper proposes a framework that aims to reverse this trend. Funded by the National Science Foundation Partnerships in International Research and Education program (NSF - PIRE), the Colorado School of Mines, in partnership with US and international universities and non-governmental organizations (NGOs), has embarked on a five year project in Colombia and Peru that brings together faculty, students, community members, and NGOs to work together to understand the context in which ASGM takes place in these countries and co-design and develop socio-technical innovations, combining improved technologies

* Corresponding Author: Oscar Jaime Restrepo Baena, Email: ojrestre@unal.edu.co, phone: +57 3007829270

DOI: 10.15273/ijge.2018.03.017

and techniques with new social organizations and networks, to make ASGM cleaner, safer, and more sustainable.

2 Background

The practical and academic challenges posed by ASGM are inherently international in nature, linking producers in the developing world with suppliers and consumers around the globe, hence requiring an international collaboration to be addressed (Ali 2006). Colombia and Peru are two of the top four biggest exporters of gold to the US. In Colombia, approximately 70% of the national gold production comes from ASGM, while in Peru 15% of the gold comes from ASGM; however, because of the vast amounts of gold produced by large-scale industrial mining in Peru, the proportion of gold coming from ASGM in this country is significant.

The characteristics of ASGM communities and the unique challenges they encounter (e.g., geography, political, economic, etc.) present different ASGM scenarios worth comparing in order to provide lessons for a variety of contexts in the Andean and Amazonian regions. Understanding the ASGM challenges in Colombia and Peru is vitally important not only for scholarly communities, but also for the people who practice and are impacted by ASGM, local and national governments, the mining industry, and development networks. Over 400,000 people work in the ASGM sector in Colombia and Peru, providing rural communities with employment, a source of identity and cultural belonging, and increased participation in schooling and business activities. ASGM activities will continue to increase.

Both Peru and Colombia are signatories to the Minamata Convention, demonstrating their commitment to eliminating mercury use in ASGM. Both governments recognize the ASGM sector and have made numerous attempts to formalize and regulate the sector. In both countries, however, only a small proportion of miners have completed the formalization process because of a lack of capacity among government agencies to oversee and regulate the sector, the absence of miners and ASGM communities in designing processes and techniques, and complex bureaucratic formalization procedures.

ASGM thus presents crucial international challenges that are simultaneously technological, social, economic, political, geological, and environmental, requiring research that transcends disciplinary silos and reaches across national borders. Furthermore, ASGM systems encompass technologies, practices, and social institutions. Grounded in the unique contexts in which they take place, these systems present risks and opportunities that are differently perceived and acted upon by diverse actors, from miners to environmental activists. To design, implement, evaluate, and ensure the long-term sustainability of ASGM, therefore, it is necessary to have a comprehensive understanding of these systems, their interrelationships, and these actors.

3 Research Sites

The project will take place in comparable, yet distinct contexts to investigate how ASGM relates to the larger social and environmental dimensions of each country. This presents illuminating comparative studies for research and unique opportunities for faculty and students to learn how to define and provide solutions in differing contexts. Not only will the project provide a comparison of ASGM in Colombia and Peru more generally, but it will also compare two distinct ASGM sites in each country.

In Colombia, research will be conducted in two primary ASGM regions of the department (state) of Antioquia. Antioquia is the leading producer of gold in Colombia and has a long-standing tradition of gold mining. It has the strongest institutional framework for governing ASGM, whereby the Governor's office can decide on mining title applications. Nevertheless, it holds the reputation for being the world's largest mercury polluter per capita from ASGM (Cordy et al 2013). In addition to ASGM activities, there are two active gold mines and several others under development that are owned and operated by international mining companies. Because Antioquia holds some of the most promising gold mining deposits, it has experienced waves of in-migration by miners from other departments of Colombia, as well as from other countries such as Brazil.

In Peru, the project will focus on one ASGM site where underground, hard rock mining takes place, and one site with alluvial mining. In the department of Arequipa, many small-scale mining operations are located in former large-scale mining sites and the area is home to extensive ASGM processing centers that purchase ore from mining operations located up to 1100 km away. Because of the arid climate characteristic to this region, tailings dust and mercury vapor pose serious threats to human health and the environment. In Madre de Dios, infrastructural developments such as the Interoceanic Highway connecting the coasts of Brazil and Peru have prompted an influx of migrant miners, expanding the mining frontier. Massive deforestation has occurred in the area and the riparian landscape has been severely degraded.

4 Educational Activities and Research

Closely integrated with the research dimensions of this project are educational activities that will contribute to the development of a global engineering workforce through interdisciplinary collaboration in a very relevant yet invisible problem that implicates consumers around the globe. US academic faculty and students will work with their science and engineering counterparts and with artisanal and small-scale gold miners and communities in Colombia and Peru to research, define, design, implement, and monitor socio-technical innovations that improve mining and processing systems, decrease and mitigate environmental and human health risks, and contribute to more sustainable livelihoods in Latin America. The main expected educational outcomes are socio-technical global competency, situated learning, and broadened participation in engineering.

4.1 Socio-technical global competency

This project will create international research and teaching experiences for US graduate students and faculty and problem definition, solution, and design experiences for undergraduate students in socio-technical settings. Beyond basic language and cultural competency, faculty and students will learn how to understand engineering problems as socio-technical in different engineering and community settings through highly integrated classroom, project-based, research, and field experiences both in the US and abroad. The expected outcome is socio-technical global competency defined as having the knowledge, skills, and attitudes to research, define and solve problems in different international settings (Lucena and Schneider 2008). Knowledge understands how engineering problems and research questions as socio-technical are shaped by the historical, cultural, economic, and physical dimensions of a place. Skills are learning to define and solve problems and research questions with perspectives different than their own. Attitudes are the desires to continue engaging both expert and non-expert perspectives, working abroad, and serving communities after graduation.

4.2 Situated learning

This project will create new knowledge of how different forms of a) social relations (graduate or undergraduate; expert or non-expert; US or non-US, etc.); b) pedagogical strategies for engineering problem definition, solution, design, and research; and c) different contexts affect faculty and student learning. We will explore situativity – the central role that physical and social context of an educational environment plays in learning – in different institutional, national, and classroom contexts. Specifically, we will assess the differences between a) modules (e.g., to be given to some students who cannot complete full courses related to ASGM) and courses (to be given to other students); b) in-classroom research-question and problem definition (graduate seminars and undergrad courses) and in-field experiences with multiple stakeholders (summer field sessions); and c) faculty-led and student-led contexts.

4.3 Broadened participation in engineering

Engineering students are underrepresented among STEM students studying abroad, and students who are ethnic and racial minorities or come from low-income backgrounds are especially underrepresented in engineering study abroad programs as well as engineering as a whole. Because of the challenges that these students face in engineering, this project will make an explicit, concerted effort to recruit students from underrepresented groups in engineering. Because explicit ties to community engagement and social justice in engineering, have lead to higher interest and retention of underrepresented groups in engineering, we hypothesize that participation in this project will help broaden participation in engineering.

5 Research Advances through Interdisciplinary International Collaboration

The synergy of partners from US, Colombian, and Peruvian universities provides a robust platform for achieving both research and educational outcomes. The participating institutions complement each other with their different disciplinary strengths and their expertise along the distinct stages of gold mining, processing, and remediation, as well as engineering education (see Table 1). The project team brings together disciplinary expertise in anthropology, engineering education, geology, environmental engineering, mining and metallurgical engineering, and geography.

The lead institution, Colorado School of Mines (CSM), is one of the world's premier engineering universities with a specialty in natural resource production and protection, on the one hand, and the country's greatest concentration of research and education on engineering, social justice, and social responsibility, on the other. Faculty from CSM created the country's first Humanitarian Engineering (HE) program in 2003, whose students now learn about the intersection of mineral extraction and community development. CSM is internationally recognized for its research and teaching in ASGM, community-based research, engineering education, corporate social responsibility, environmental remediation, mining, and geochemistry. CSM has a history of positive collaborations with the other project partners, including those in Colombia and Peru.

The University of Colorado at Boulder (CU) houses a world-class environmental studies program with a strong commitment to applied research with communities, the Governors' Climate and Forests Task Force (GCF), and the Mortenson Center in Engineering for Developing Communities. The GCF focuses on reducing emissions from deforestation and establishing lasting frameworks for low emissions development, including those related to ASGM. The GCF has members in thirty-five states and provinces from nine countries (Brazil, Indonesia, Peru, Mexico, Colombia, Nigeria, the Ivory Coast, Catalonia, and the US). As a key actor in facilitating the exchange of experiences and lessons across states, provinces, and municipalities and supporting processes for multi-stakeholder participation and engagement, the GCF is instrumental in the dissemination of lessons learned across the countries of Peru and Colombia and later to other countries dealing with the environmental impacts of ASGM

As one of four armed forces academies, the US Air Force Academy (USAFA) in Colorado Springs, educates engineering student-cadets through a combination of engineering, humanities and social sciences, and leadership courses with the goal of producing leaders who will serve the country in many areas, including humanitarian missions and the construction of sustainable civil and environmental systems. Their department of Civil and Environmental Engineering brings faculty expertise in hydrology, sustainability, and engineering education plus student cohorts, who, during semester- to year-long independent studies, will develop their understanding of the complex

nexus of technical, ecological, and cultural factors affecting ASGM in Latin America. Specific to the project, USAFA has expertise in water treatment and site remediation, environmental fate and transport, and construction in developing environments. They also host a Field Engineering and Readiness Laboratory where cadets have the opportunity to learn the skills necessary to implement engineering solutions in the field and have access to the U.S. Department of Defense High Performance Computing Network and water/wastewater, hydraulics, and geotechnical engineering laboratories.

The Universidad Nacional de Colombia's Facultad de Minas (FdM) was the first school of engineering in Colombia and has been working with gold miners for more than 130 years. Their faculty members have an extensive knowledge base in mining and metallurgy complemented by a Center for Social Responsibility in Mining. FdM will contribute their teaching and research expertise in mining and metallurgy including: a) techniques for gold mining and extractive metallurgy; b) community engagement and technical support to artisanal miners; and c) sustainability in mining. FdM's work with miners in Colombia's gold regions will provide links between project partners and communities. In addition, FdM works with national and state governments in securing, managing, and analyzing data related to ASGM and has long-standing contacts with the Ministry of Mines of Antioquia and ASGM associations.

The Corporación Universitaria Minuto de Dios (UNIMINUTO) in Colombia has a Social Innovation Science Park dedicated to delivering social justice and community development to the most vulnerable communities. UNIMINUTO has a vast and effective network of education/training and social innovation programs aimed at Colombia's poorest communities. Their Social Innovation Science Park supports community-based social innovation projects and ventures by connecting miners, as social entrepreneurs, with public and private enterprises to enhance communities' capacities to generate new forms of revenue that will incentivize them to use mercury-free techniques. UNIMINUTO has six campuses in Antioquia with programs to educate communities about the advantages of mercury-free mineral processing and entrepreneurship.

With deep connections in Peru and Colombia, the NGO, Alliance for Responsible Mining (ARM), sets standards for responsible ASGM and supports and enables producers to deliver "Fairmined" certified metals and minerals through economically just supply chains. ARM has strong connections with miners and communities in Peru and Colombia. They will facilitate relationship building among the project team and miners and communities. Specifically in Antioquia, ARM has supported more than thirty ASGM organizations in the processes of formalization, capacity building, safety education, health, and mining. ARM also facilitates transfer between experts and communities of geological, geotechnical, metallurgical, and environmental knowledge.

In Peru, the Pontificia Universidad Catolica de Peru (PUCP) is the oldest and most prestigious private university in the country, dedicated to teaching and research that contribute to social justice and national development and their relationship to mining. Faculty from the Department of Mining Engineering and the Department of Geography will contribute their expertise in geology and mining, metallurgy, chemistry of environmental recovery of metal substances in mining water, geospatial analysis of socio-environment dynamics in rural communities, and social networks of ASGM practices. As the only ABET (American Board of Engineering and Technology) accredited Mining Engineering Department of Peru, PUCP's Mining Engineering Department has extensive experience working with ASGM communities in the Arequipa and Ayacucho Regions. Inside such projects, faculty and students advised ASGM communities in the topographic location of claim boundaries, safety in mining practices, spatial distribution of mining operations versus domestic uses of the locality, and technical measurements for extraction. PUCP's faculty have close relationships with the Sociedad Nacional de Minería Petróleo y Energía (SNMPE—The National Society for Mining Oil and Energy), local mining companies, and the Sociedad Nacional de Mineria en Pequena Escala (SONAMIPE—The National Society of Small Scale Mining).

Also in Peru, the University of Technology and Engineering (UTEC) maintains state-of-the-art laboratories for engineering analyses, and its faculty members contribute expertise in mining engineering and the mining-water nexus. Faculty from Environmental Engineering and the Center for Water Research and Technology (CITA) at UTEC will contribute their existing research on ASGM in Colombia and Peru, including knowledge of the mining process and expertise in the mining-water nexus. UTEC's CITA is developing expertise on hydrogeology, hydro climatology, tele-detection and remote sensing, and hydrochemistry; each of these research areas has a state-of-the-art laboratory. CITA has an ongoing project with SNMPE to monitor two watersheds, one related to the mining-water nexus. UTEC's scientist are measuring water quantity and quality at these watersheds and implementing community-based monitoring activities. Contributions from UTEC include logistics in all Peruvian regions, access to laboratories, and research-oriented collaboration.

This project brings existing ASGM research into direct collaboration with the Facultad de Minas' innovative research and technology development on mercury-free gold processing, Uniminuto's unique tools for developing economic opportunities in marginal communities, CU's expertise in social-ecological landscape changes and jurisdictional programs for reducing emissions from deforestation, PUCP's and UTEC's involvement in ASGM in Peru, USAFA's and CSM's expertise in site remediation engineering, and CSM's unique program in humanitarian engineering.

More than an entry point to and contacts in their countries, the four non-US universities involved in this project provide: a) bilingual teaching and expertise related to ASGM; b) relevant knowledge of the history and current state of ASGM in their countries, including what has been

tried, worked, and failed to make ASGM more sustainable; c) key and relevant lab, classroom, and library facilities that US students and faculty can use; and d) in-depth connections to local governments and associations related to ASGM.

Table 1 Project partners showing areas of disciplinary expertise

Country	Institution	Areas of Expertise
USA	Colorado School of Mines (CSM)	- Anthropology - Engineering Education Studies - Environmental Engineering - Mining & Geological Engineering
	University of Colorado (CU)	- Anthropology - Geography - Public Policy
	US Air Force Academy (USAFA)	- Civil and Environmental Engineering
Colombia	Universidad Nacional de Colombia Facultad de Minas (FdM)	- Mining and Metallurgical Engineering
	Corporación Universitaria Minuto de Dios (UNIMINUTO)	- Social Innovation and Entrepreneurship for Community Development
	Alliance for Responsible Mining (ARM)	- ASGM Community Engagement - ASGM Formalization
Peru	Pontificia Universidad Catolica de Peru (PUCP)	- Anthropology - Geography - Geological and Mining Engineering
	University of Technology and Engineering (UTEC)	- Environmental Engineering

6 Conclusions

In sum, this project is highly interdisciplinary, international, inter-institutional, and intergenerational in nature. The complexity of ASGM systems in Colombia and Peru warrants this approach. Moreover, this project is founded on principles of engagement *with* communities, such that ASGM community members are considered integral to the project design and execution. We anticipate that the framework presented here will enable stronger collaborations among all of the ASGM stakeholders and support efforts to move ASGM into a more sustainable livelihood activity.

References

Ali, S., 2006. Gold mining and the golden rule: A challenge for producers and consumers in developing countries. Journal of Cleaner Production, **14:** 455 - 462.

Buxton, A., 2013. Responding to the challenge of artisanal and small-scale mining: How can knowledge networks help? IIED.

Cordy P., M. Veiga, B. Crawford, O. Garcia, V. Gonzalez, D. Moraga, M. Roeser and D. Wip, 2013. Characterization, mapping, and mitigation of mercury vapour emissions from artisanal mining gold shops. Environmental Research, **125**: 82 - 91.

Cremers, L., J. Kolen, and M. de Theije, Eds., 2013. Small-scale gold mining in the Amazon: the cases of Bolivia, Brazil, Colombia, Peru, and Suriname. Amsterdam, The Netherlands: Centre for Latin American Studies and Documentation.

Davies, G.R., 2014. A toxic free future: Is there a role for alternatives to mercury in small-scale gold mining? Futures, **62**: 113 - 119.

Hilson, G. and S.M. Banchirigah, 2009. Are Alternative Livelihood Projects Alleviating Poverty in Mining Communities? Experiences from Ghana. Journal of Development Studies, **45**(**2**): 172 - 196.

Hinton, J.J., M.M. Veiga, and A.T.C. Veiga, 2003. Clean artisanal gold mining: a utopian approach? Journal of Cleaner Production, **11**(**2**): 99 - 115.

Lucena, J., and J. Schneider, 2008. Engineers, development, and engineering education: From national to sustainable community development. European Journal of Engineering Education, **33**(**3**): 247 - 257.

Smith, N.M., S. Ali, C. Bofinger and N. Collins, 2016. Human health and safety in artisanal and small-scale mining: An integrated approach to risk mitigation, Journal of Cleaner Production, **129**: 43 - 52.

Smith, N.M., J.M. Smith, Z.Q. John and B.A. Teschner, 2017. Promises and perceptions in the Guianas: The making of an artisanal and small-scale mining reserve, Resource Policy, **51**: 49 - 56.

UNEP, 2008. Mercury Use in artisanal and small scale gold mining. United Nations Environment Programme, Geneva.

UNEP, 2013. Global mercury assessment: sources, emissions, releases, and rnvironmental transport. United Nations Environment Programme, Geneva.

Veiga, M. and R. Baker, 2004. Protocols for environmental and health assessment of mercury released by artisanal and small-scale miners. The Global Mercury Project: Removal of barriers to introduction of cleaner artisanal gold mining and extraction technologies. GEF/UNDP/UNIDO.