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How lessons from an evolving comprehensive approach for water and sanitation can improve artisanal and small-scale mining environmental initiatives

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ABSTRACT

Environmental risk mitigation strategies employed in developing communities to address mercury pollution from artisanal and small-scale gold mining (ASGM) have largely failed to meet community needs, resulting in their abandonment. In contrast, the water and wastewater treatment sector has gained more traction, introducing sustainable and community supported water treatment strategies. This paper discusses why initiatives in water and wastewater treatment in developing communities are succeeding while initiatives in ASGM environmental risk mitigation are falling short. Selected case studies illustrate that water and wastewater treatment project success is contingent on the inclusion of a fully comprehensive approach that considers the socio-economic and ecological context of communities and individuals along with behavior change interventions. These elements of successful WASH projects were then applied to past ASGM environmental projects to determine their applicability to the sector. By adopting the core traits of successful water and wastewater treatment projects in developing communities, a framework can be developed for ASGM projects that, when applied correctly, could lead to measurable impact and long-term sustainability.

1. Introduction

Mercury (Hg) amalgamation is a common mineral processing method used in artisanal and small-scale gold mining (ASGM) that has serious environmental and health consequences for miners, local populations, and the global community (Esdaile and Chalker, 2018; Smith et al., 2016). With approximately 10- to 19-million miners working in the ASGM sector across 70 countries (Cordy et al., 2011), Hg amalgamation is the world's largest source of anthropogenic Hg pollution, releasing an estimated 740–1350 metric tons of elemental Hg into the environment each year (Telmer and Veiga, 2009; UNEP, 2013). Despite the health and environmental concerns associated with Hg use in ASGM and the increased awareness at the international level, there is little agreement among international agencies, national governments, and local miners about how to address this urgent environmental crisis. Past initiatives address portions of the issue, for example, by deeming the use or sale of Hg illegal (Congreso de Colombia, 2013) or partially addressing Hg release, exposure, or cleanup. However, these initiatives have fallen short of leading to measurable impact, thereby requiring a modified framework for addressing ASGM Hg pollution.

Attempts to address the release, exposure, and cleanup of Hg from ASGM operations encompass a wide range of technical interventions with varying levels of acceptance. For example, to address release, some miners have transitioned to Hg-free technologies, such as gravimetric methods (Ernawati et al., 2018; Teschner et al., 2017; Vieira, 2006) or the use of alternative chemicals such as cyanide (Sousa et al., 2010; Veiga et al., 2009). Hg management technologies, such as retorts (Babut et al., 2003; Jønsson et al., 2009; Kiefer et al., 2015; Shandro et al., 2009; UNEP, 2012) and Hg-condensing fume hoods (UNEP, 2012; Veiga, 1997) have also been implemented in several locations. Despite such technological interventions, miners oftentimes return to previous practices due to various practical concerns (Smith, 2019). Hg

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Abbreviations

ASGM	Artisanal and small-scale gold mining
RANAS	Risk, attitude, norms, ability, and self-regulation
WASH	Water, sanitation and hygiene

cleanup efforts mostly focus on environmental and health assessments rather than site remediation (e.g., Clifford, 2017; Goix et al., 2019; Taylor et al., 2005; Tomiyasu et al., 2017). Such assessments generally focus on one media (soil, sediment, water, or air) or a select population (e.g., women or children) and demonstrate the extent of pollution or exposure specific to the assessed media or population. However, assessments rarely lead to implementation and often fail to provide feedback or guidance to community members. Cleanup efforts that go beyond assessment to implementation often fail to address the continued release from ore processing, leading to short-term environmental improvements but ultimately a reoccurring environmental problem (Gottesfeld et al., 2019; O'Brien et al., 2020).

To date, most cleanup techniques that address Hg pollution have been predominantly applied in developed countries due to their high cost and technical complexity. Proposed methods for Hg remediation in developing countries, by comparison, is limited mostly to on-site containment using physical barriers to prevent mobilization of Hg through soil or air, phytoremediation, or excavation to remove the soil or sediment from the site for treatment off site (e.g., Blacksmith Institute, 2005; Chamba et al., 2017; Marrugo-Negrete et al., 2016; Veiga and Meech, 1995). Except for a limited number of extraction and stabilization projects (e.g., Espinosa et al., 2019; Pure Earth Blacksmith Institute, 2017), little has been accomplished in terms of Hg remediation from ASGM.

While ASGM development and regulatory initiatives have fallen short in addressing Hg release, exposure, and cleanup, water and sanitation projects worldwide have seen high levels of acceptance in developing communities (Cairncross et al., 2005; Keirns, 2007). The 2017 UNICEF/WHO joint monitoring program, reports considerable increases in access to water, sanitation, and hygiene on the order of 10–17% from the inception of the program in 2000; 71% of the world population now use safely managed drinking water, 45% now use safely managed sanitation systems, and approximately 60% use handwashing stations (UNICEF and WHO, 2019). Two key traits are common to successful water, sanitation, and hygiene (WASH) projects: (1) a comprehensive approach addressing water, sanitation, and hygiene (WASH) that integrally includes systemic community involvement (Christen et al., 2011; Eisenberg et al., 2007; Fuller et al., 2015; Graf et al., 2008; Keirns, 2007; Liang et al., 2010; Wolf et al., 2018) and (2) the inclusion of behavioral change interventions the comprehensive project approach (Allen et al., 2002; Hulland et al., 2015; Mosler, 2012; Murphy et al., 2009; Peal et al., 2010; Thevos, 2002). Such success raises the question as to whether key approaches used by water and sanitation initiatives can be applied to other pressing environmental and health concerns such as Hg pollution and remediation from ASGM.

This work addresses how successful approaches used in WASH initiatives in developing communities can be applied to ASGM environmental projects. By focusing on case studies from WASH, we identify key aspects of intervention, in particular, a comprehensive approach that integrates community involvement and behavior change initiatives. We also study the ways in which select approaches have led sustainability and community support. These select approaches provide the basis for a proposed framework that can be applied to Hg pollution and remediation in ASGM. It is anticipated that projects using this framework will have greater community acceptance and long-term success and may also be applied to other ASGM efforts beyond Hg pollution.

2. The importance of comprehensive approaches

In WASH, comprehensive approaches aim to prevent human exposure to pathogens through hygiene (e.g., handwashing) and water treatment while reducing contaminant release through wastewater treatment (Parsons, 1996; UNICEF, 2016). Failure to address contaminant release (e.g., through a lack of appropriate sanitation facilities) leads to the degradation of environmental systems as well as increased human exposure; failure to address human exposure (i.e., through a lack of clean water and hygiene) results in limited health benefits and community acceptance (Eisenberg et al., 2007; Fuller et al., 2015). For example, the goal of India's Total Sanitation Campaign was to eliminate open defecation through education and sanitation infrastructure (Barnard et al., 2013; Hueso and Bell, 2013). However, by not also addressing water and hygiene practices, the latrines were eventually abandoned due to the added challenges of cleaning and maintenance (Keirns, 2007). When addressed holistically, WASH interventions show measureable success in disease prevention and public acceptance (Cairncross et al., 2005; Eisenberg et al., 2007; Fuller et al., 2015; Graf et al., 2008; Tilley et al., 2014; Wolf et al., 2018). In a comparative study incorporating 217 studies across 74 countries, Fuller et al. (2015) observed that isolated water *or* sanitation interventions had no effect on the prevalence of diarrheal disease (e.g., 0.4–0.7% reduction). In contrast, the combination of both water and sanitation initiatives resulted in a reduction of 7.1%. A study conducted by Wolf et al. (2018) observed similar trends. Similarly, a study conducted in the Philippines illustrated how water access limitations for hygiene and facility sanitation played a major role in community acceptance (Pfadenhauer and Rehfuess, 2015).

Although successful WASH initiatives are comprehensive, they are often executed in multiple phases due in part to project resources and requirements of site-specific project design and implementation (Fewtrell et al., 2005; McConville and Mihelcic, 2007). An example of such an intervention can be seen in Keirns (2007), in which Gram Vikas, a non-governmental organization based in Orissa, India, approached WASH interventions through community prioritization linked to project resources. The project first addressed sanitation, as open defecation was a primary concern among stakeholders, and later addressed water supply. Hygiene efforts, however, were ongoing throughout the entire project. Gram Vikas viewed the provision of WASH services as components to an overarching project and planned accordingly in terms of community priorities, timing, and budget.

Comprehensive approaches can be applied to ASGM environmental initiatives by holistically addressing release, exposure, and cleanup within the full socio-economic and ecological context of a community. This approach addresses all sources and pathways of human and environmental exposure rather than a limited intervention addressing only release or cleanup. The approach would integrate the knowledge miners and community members already possess about safety and mitigation strategies and their own desires for sustainable livelihoods. For example, a comprehensive ASGM environmental initiative would include modified ore processing techniques (e.g., retorts, gravimetric methods, or alternative chemicals) to prevent release by using available resources and community knowledge of the mineral properties of the ore. Hg exposure ASGM could be addressed through public health interventions, such as relocating ore processing sites away from communities or encouraging the use of appropriate personal

protective equipment, by working with local community leaders and local health clinics to train miners. ASGM cleanup efforts would go beyond assessment to studying the fate and transport of Hg and the remediation of contaminated sites from past operations by utilizing community knowledge of the location of contaminated sites, the history of operation at the sites, and available resources for remediation. As demonstrated by past WASH efforts, the execution of a comprehensive ASGM project may include multiple phases to avoid resource limitations while also addressing community priorities. However, throughout each phase of implementation is a focus on the overall, comprehensive project.

3. Addressing behavior change

In addition to a community centric-comprehensive approach, successful WASH projects address the modification of human behavior at both the individual and community levels. Previous behavioral change research includes general efforts of applying behavior change strategies to international development (Allen et al., 2002; Mosler, 2012; Murphy et al., 2009; Thevos, 2002) and psychological studies to identify what facilitates behavior change (Fishbein and Ajzen, 2010). One successful approach used in WASH is based on the theory that behavior change is only possible if a community's or individual's risk perceptions, attitudes, norms, abilities, and self-regulation are taken into account. This approach is commonly referred to as the RANAS (risk, attitude, norms, ability, and self-regulation) approach (Mosler, 2012). When applied to WASH, a baseline is first established for each factor to identify which one(s) are inhibiting behavior change. Once identified, these factors can be addressed using different interventions (Mosler, 2012). The following sections provide examples of the RANAS approach as applied to WASH and extend to ASGM environmental initiatives. For a complete description of the RANAS approach and other behavior-changing methods, the reader is referred to Mosler (2012) and Peal et al. (2010).

3.1. Risk perception

In WASH projects, community members' perception and understanding of risks from exposure to untreated water, inappropriate sanitation facilities, and lack of hygiene are evaluated. Previous WASH studies have shown that community members' belief that untreated water, poor sanitation, and poor hygiene were health threats was a precursor to sustained use of WASH initiatives (Cairncross et al., 2005; Daniel et al., 2018; Nagata et al., 2011). In communities where risk perception, or "the belief of potential harm or the possibility of loss" (Darker, 2013), is the inhibiting factor for behavior change, this factor is typically addressed in WASH projects through educational initiatives using various forms of media (e.g., pamphlets, promotional merchandise, posters, and skits) tailored to specific demographics (Boisson et al., 2010; Keirns, 2007; Kgabi et al., 2014; Liang et al., 2010; Quick et al., 2002; Roma et al., 2014; Thevos, 2002). Often, educational outreach activities are led by local health centers and community leaders who seek to engage community members in both the classroom setting (Roma et al., 2014) and in the planning stage for additional outreach activities (Cairncross et al., 2005).

Risk perception is also the most commonly addressed aspect of behavior change interventions in ASGM projects. Hg management practices are usually presented to communities in conjunction with health and educational outreach to miners and their families. This can take the form of formal training (Hilson, 2006; Hilson et al., 2007; Veiga, 1997), educational pamphlets (Hinton et al., 2003), or through non-traditional, artistic presentations (Metcalf and Veiga, 2012; Veiga and Marshall, 2017). A lack of clear understanding of the health and environmental risks of Hg can lead to misinterpretation and continuance of the behavior, as shown in Hilson (2006) and Hinton et al. (2003), so care needs to be taken to ensure that the community understands the health risks of Hg exposure. Diversifying how the information is delivered, whether by pamphlets, local health clinics, or videos, can help to increase the reach of educational outreach and clarify concepts that may be confusing (Ottenbros et al., 2019).

3.2. Attitude

WASH interventions typically use a variety of techniques to address a community's attitude towards behavior change. The attitude towards a particular behavior tends to be shaped by the belief in the outcome of the behavior: if a behavior is expected to have negative consequences the attitude towards that behavior tends to be negative, while if a behavior is expected to have a positive outcome, the attitude towards that behavior is positive (Fishbein and Ajzen, 2010). Techniques such as persuasive arguments, demonstrations, or peripheral cues are typically used to address negative attitudes towards desired behaviors (Mosler, 2012), though such interventions only work once credibility is established by building rapport. Many successful WASH initiatives spend considerable time building relationships with community members and gaining trust (e.g., Elson, 2019; Liang et al., 2010; Peletz et al., 2013; Thevos, 2002). By building a relationship with community members, the intervening agency can gain a better understanding of social norms and the history of the community, increasing their credibility to community members and ultimately improving community members' attitudes toward the project (Mosler, 2012).

Determining community members' general attitudes towards health and safety and ASGM, as well as their attitudes towards development initiatives, is critical for project development, as it was with water and sanitation. Although there may be awareness about the hazards of Hg, Hg exposure may be less of a priority than other community health and safety concerns (Smith, 2019). Additionally, negative experiences with intervening agencies on the national or international level may lead to distrust of remediation projects: in particular, projects that take place where governments have used drastic measures, such as military force, to curb ASGM (Hilson et al., 2007; Metcalf and Veiga, 2012; Smith et al., 2017). ASGM environmental initiatives may be perceived by community members to negatively impact income levels, whether due to a perceived reduction in gold extraction or a perceived increase in the cost of operations (Hinton et al., 2003). In order for an ASGM environmental initiative to be sustainable, it is necessary to understand how miners feel about health, safety, and development initiatives in order to work *with* them and support them in developing practical approaches to improving their livelihoods.

3.3. Norms

The most successful water and sanitation projects have been the result of a community who actively sought out water and sanitation projects (Giné and Pérez-foguet, 2008; Liang et al., 2010), indicating that the community already embraced a cultural norm that values the behaviors associated with proper WASH. These norms, or behaviors that are deemed acceptable within a social network (Fishbein and Ajzen, 2010), dictate the adoption of a behavior, as an individual will be hesitant to change behavior if it is viewed negatively by friends, family, community members, and leaders (Mosler, 2012). Norms are often addressed in behavior change initiatives by highlighting the desired behavior, even if it occurs infrequently, in an attempt to normalize it (Mosler, 2012).

Successful WASH projects have worked with established community norms and included all members as active participants of the project (Giné and Pérez-foguet, 2008; Keirns, 2007; Liang et al., 2010).

As with past WASH projects, comprehensive ASGM initiatives need to determine a community's norms specifically with regard to mining practices (Cordy et al., 2011; Persaud et al., 2017; Sousa et al., 2010; Telmer et al., 2006; Vieira, 2006) and environmental protection. The norms associated with the gold supply chain may significantly affect the outcome of comprehensive ASGM projects, as miners may be constrained by other more powerful actors in the gold supply chain. This is seen especially in areas in which the gold buyers are also the distributers of Hg (Smith, 2019). Community norms surrounding the role of the environment, either as a resource of materials for human use or as a critical part of a community's tradition and identity, also dictate how environmental projects are interpreted and implemented (Sælemyr, 2004). Mining communities may have a more anthropocentric view of the environment, which is reflected by studies in which environmental risks are less of a concern to miners than health and security risks (Sana et al., 2017).

3.4. Ability

Water and sanitation projects often address ability, or the skills, resources, or knowledge needed to successfully perform a behavior (Mosler, 2012), by focusing on capacity building. Capacity building is defined as "the process through which individuals, organizations and societies obtain, strengthen and maintain the capabilities to set and achieve their own development objectives over time" (UNDP, 2015). Because ability depends on a wide variety of factors, such as economics, available resources, and knowledge bases, attempts to address this aspect are multi-faceted and complex. Financial limitations (as described in Giné and Pérez-foguet, 2008; Keirns, 2007; Whittington et al., 2009) and the lack of necessary skillsets (as described in Giné and Pérez-foguet, 2008; Keirns, 2007; Murphy et al., 2009; Ongley and Booty, 1999; UNICEF, 2015) are some of the largest reasons that water and sanitation projects fail after an extended period of time. The introduced skills are usually technical in nature (e.g., basic engineering, plumbing, masonry), but sometimes include organizational and financial training to ensure the longevity of a project. Developing skillsets locally ensures that a project will continue after the intervening agency leaves, as local experts can address challenges as they arise (Ongley and Booty, 1999).

As with WASH projects, comprehensive ASGM projects need to approach ability in a holistic manner. Educational initiatives to develop skillsets have been a primary technique used to build capacity among miners. Past educational initiatives have been focused on mining techniques that do not involve Hg (Hilson, 2006; Hilson et al., 2007; Jønsson et al., 2009; Metcalf and Veiga, 2012), but additional training could increase the community's ability to monitor and remediate Hg pollution (e.g., citizen science). Furthermore, training community members on how to reduce their exposure to Hg or other hazards could enhance a community's ability to prevent major health issues in the future.

3.5. Self-regulation

Self-regulation, or the ability to continue and maintain a behavior change long after the intervening agency is gone, can occur at the individual level (Mosler, 2012), the community level

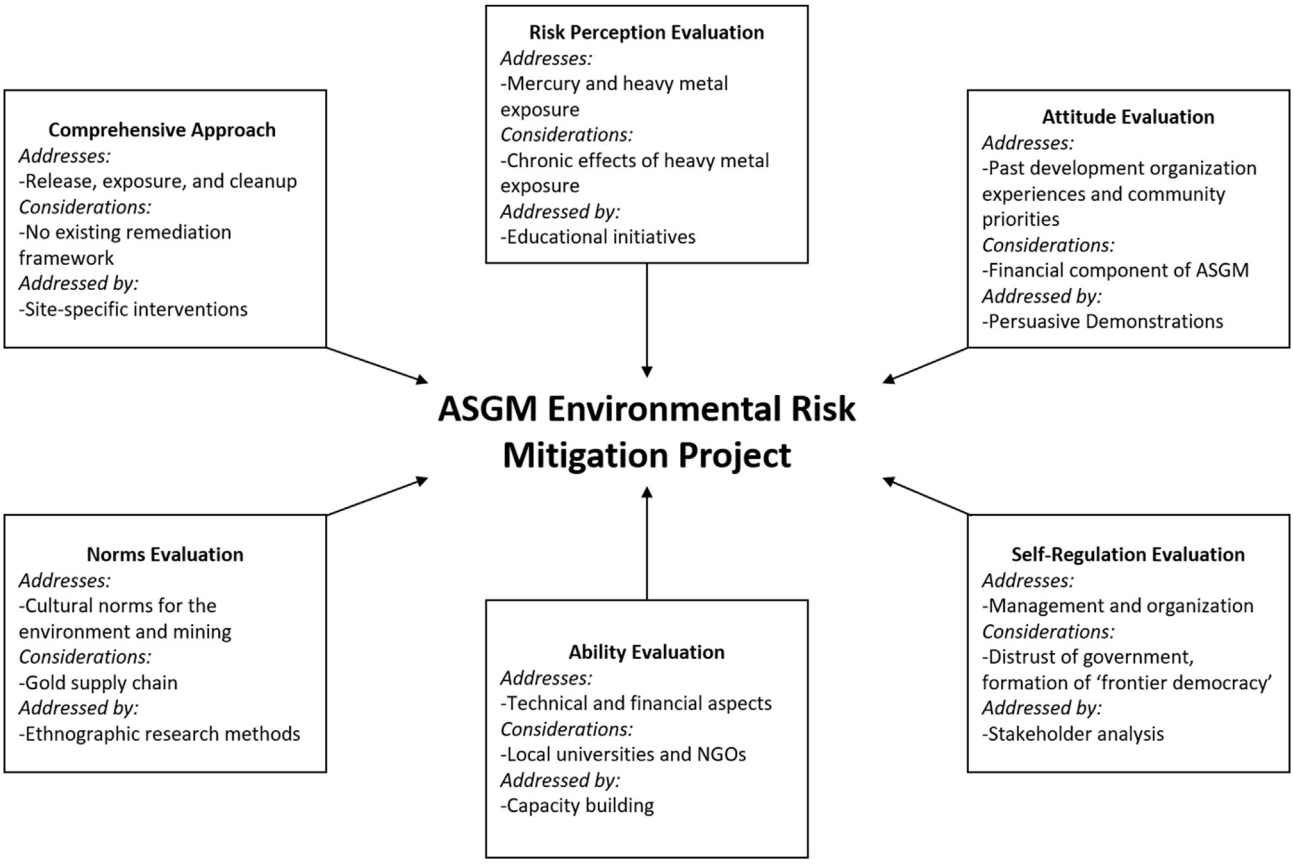

Fig. 1. Summary of how lessons from WASH (e.g., comprehensive project design and behavior change initiatives) can be applied to environmental projects within the ASGM sector.

(Keirns, 2007; UNICEF, 2015; Whittington et al., 2009), or at the local government level (Singhirunnusorn and Stenstrom, 2009; UNICEF, 2015) in successful WASH interventions. Rather than being dependent upon finances or skillsets, self-regulation addresses the ability to self-monitor and course-correct if there is a return to existing behavior. Typically, smaller communities use strategies such as village water committees, in which elected or appointed members are responsible for collecting and managing funds, overseeing the operation and maintenance, monitoring environmental conditions, and enforcing community-established rules associated with the water and sanitation project (Keirns, 2007; Whittington et al., 2009). For larger communities, utilizing local government officials to oversee the WASH project may be beneficial, provided that local government members are trained to be able to identify aspects of a water and sanitation system that need to be monitored (Singhirunnusorn and Stenstrom, 2009).

When addressing self-regulation in comprehensive ASGM environmental projects, it is important to consider the implications of ASGM being part of an "extralegal" economy, meaning that the operations of the mine are outside the legal economy and the authority of the law (Siegel and Veiga, 2009). The nature of operating in an extralegal economy may lead to some distrust among miners towards government officials (as described in Hilson et al., 2007), indicating that federal and local governments may not be effective in regulating the behavior change. Additionally, because ASGM often occurs in remote, rural parts of the world, regulatory agencies and government officials are constrained in what they can do to monitor and regulate (Siegel and Veiga, 2009). Such areas may also have a large presence of criminal organizations which further restricts the influence of local and federal government (Cordy et al., 2011). Instead, a type of "frontier democracy," in which rules and regulations are established and enforced, albeit informally, has been established in ASGM communities as a method of self-regulation for mine operation and property rights (Bryceson, 2018). Use of these pre-existing frontier democracies may improve overall success when developing self-regulating organizations for comprehensive ASGM projects, given their success at informally organizing and regulating day-to-day operations.

4. Conclusions

Approaches used by past WASH projects may be applied to ASGM environmental initiatives to achieve long-lasting, successful outcomes, as shown in Fig. 1. A comprehensive community-centered approach to ASGM environmental projects would address the release, exposure, and cleanup while considering the full socio-economic and ecological context of the community and integrating the knowledge miners and communities already possess about safety and mitigation strategies. Within each component of a comprehensive approach, modifications to community and personal behavior to include perceptions of risk, attitudes, norms, abilities, and self-regulation through the RANAS framework can help identify factors that may influence community actions and to address those that may prevent the adoption of environmental initiatives. The use of a community-centric comprehensive approach linked with RANAS-based behavioral interventions will likely increase community buy-in and produce more sustainable ASGM environmental projects. Future efforts plan on applying this model with ASGM communities to test the efficacy of the approach.

CRediT authorship contribution statement

Michelle Schwartz: Investigation, Formal analysis, Writing - original draft. **Kathleen Smits:** Conceptualization, Supervision, Writing - review & editing, Funding acquisition. **Nicole Smith:** Validation, Writing - review & editing, Funding acquisition. **Thomas Phelan:** Validation, Writing - review & editing, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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