RAPID ASSESSMENT OF ENVIRONMENTAL HEALTH RISKS POSED BY MINING OPERATIONS IN LOW AND MIDDLE INCOME COUNTRIES: SELECT CASE STUDIES

Rapid assessment of environmental health risks posed by mining operations in low and middle income countries: select case studies

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ABSTRACT: Previous studies have evaluated associated health risks and human exposure pathways at mining sites. Others have provided estimates of the scale of the issue based in part on surveys. However, a global census of mining-related hazardous waste sites has been lacking. The Toxic Sites Identification Program (TSIP) implemented by Blacksmith Institute (New York, NY, USA) since 2009 is an ongoing effort to catalogue a wide range of chemically contaminated sites with a potential human health risk (Ericson et al., Environ Monit Assess doi:10.1007/s 10661-012-2665-2, 2012). The TSIP utilizes a rapid assessment instrument, the Initial Site Screening (ISS), to quickly and affordably identify key site criteria including human exposure pathways, estimated populations at risk, and sampling information. The resulting ISS allows for comparison between sites exhibiting different contaminants and pollution sources. This paper explores the results of a subset of ISSs completed at 131 artisanal and small-scale gold mining areas and 275 industrial mining and ore processing sites in 45 countries. The authors show that the ISS captures key data points, allowing for prioritization of sites for further investigation or remedial activity.

Keywords: Health risks, Mining, Pollution, Rapid risk assessment, Waste site.

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ABSTRACT: Previous studies have evaluated associated health risks and human exposure pathways at mining sites. Others have provided estimates of the scale of the issue based in part on surveys. However, a global census of mining-related hazardous waste sites has been lacking. The Toxic Sites Identification Program (TSIP) implemented by Blacksmith Institute (New York, NY, USA) since 2009 is an ongoing effort to catalogue a wide range of chemically contaminated sites with a potential human health risk (Ericson et al., Environ Monit Assess doi:10.1007/s 10661-012-2665-2, 2012). The TSIP utilizes a rapid assessment instrument, the Initial Site Screening (ISS), to quickly and affordably identify key site criteria including human exposure pathways, estimated populations at risk, and sampling information. The resulting ISS allows for comparison between sites exhibiting different contaminants and pollution sources. This paper explores the results of a subset of ISSs completed at 131 artisanal and small-scale gold mining areas and 275 industrial mining and ore processing sites in 45 countries. The authors show that the ISS captures key data points, allowing for prioritization of sites for further investigation or remedial activity.

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Introduction

Mining and ore processing generate significant amounts of waste material (Dudka and Adriano 1997). These wastes can contain toxic chemicals that may migrate into human exposure pathways, presenting a health risk (Telmer and Veiga 2009; Razo et al. 2004). Epidemiological studies at particular locations have explored attributable health outcomes (Berry et al. 2012; Kreiss and Zhen 1996; Stassen et al. 2012), and others have provided estimates of the global scale of the issue based in part on surveys and trade data (Jordan 2009; World Bank 2012). However, a global inventory of potentially contaminated areas has not yet been conducted. Such an inventory might result in improved ability to identify and mitigate exposures at high-risk sites. High-income countries have made significant efforts. The US Comprehensive Environmental Response, Compensation, and Liability Act of 1980, commonly referred to as the Superfund Act, has resulted in the identification of tens of thousands of contaminated sites (US EPA 2012). By contrast, few low- and medium-income countries have begun to develop similar inventories (Yáñez et al. 2002). In the context of rapid industrial growth and urbanization in many of these countries, there is an increasing need to address this gap.

The Toxic Sites Identification Program (TSIP) implemented by Blacksmith Institute (New York, NY, USA) since 2009 is an ongoing effort to catalogue contaminated sites with a potential human health risk, including mining sites (Ericson et al. 2012). The TSIP utilizes a rapid assessment instrument, the Initial Site Screening (ISS), to quickly and affordably identify key site criteria including human exposure pathways, estimated populations at risk, and sampling information. The resulting ISS allows for comparison between sites exhibiting different contaminants and pollution sources. This paper presents the development and implementation of a rapid environmental health assessment program that targets mining and other waste sites for potential public health impact. To highlight these efforts, the authors will present three brief case studies that exemplify the program.

Methodology

The TSIP is focused entirely on low- and middle-income countries, as defined by the World Bank (2012). Within this group, further focus is placed on countries with large populations and industrial bases and with amenable political and security situations.

To date, the TSIP has conducted and validated 406 mining-related waste sites in 45 countries (see Table 1). The sites are divided between 131 artisanal and smallscale gold mining (ASGM) sites and 275 industrial mining and ore processing sites. General observations on each group are supported by case studies at particular sites. The authors argue that the ISS provides an effective instrument for rapidly quantifying health risks posed at screened sites.

The TSIP relies on locally hired investigators to identify potentially contaminated areas and carry out ISSs. Investigators are in-county nationals with advanced degrees in relevant environmental and health sciences. Investigators are overseen by country coordinators who manage the overall national program, including maintenance of government and private sector relationships. Where appropriate, government personnel accompany investigators on site visits and assist them in acquiring relevant data. All individuals engaged in the ISS process attend a two-day training workshop hosted by international Blacksmith staff. Trainings cover a range of topics, including basic toxicology, sampling methodology, and database entry.

Following the training workshop, investigators work with coordinators to develop lists of suspected contaminated sites. Priority is placed on a short list of contaminants with well-documented health effects, including lead, mercury, hexavalent chromium, pesticides, and radionuclides, among others. Lists are then shared with New York-based technical advisors who assist in prioritizing visits.

ISSs are typically conducted in a single day. At a minimum, basic site geography is documented, interviews are carried out, sampling is conducted, GPS coordinates are recorded, and photographs are taken. While visiting a site, the investigator identifies and records potential exposure pathways, such as contaminated drinking water or residential soil. This information then guides the sampling plan and identification of populations at risk.

Certain industries comprise a majority of sites investigated. Areas where the primary contamination source is related to mining and ore processing make up nearly one-quarter of those sites screened between 2009 and 2012. This outcome is in part due to a focus on heavy metals that often result from mining. It is also due in part to a significant increase in mining activity in recent years. Importantly, however, mining and ore processing industries generate very large amounts of waste material that require attentive management and oversight (Lottermoser 2010). In the case of low- and medium-income countries, which are characterized by small tax bases and relatively weak governments, conditions are more conducive to mismanagement of these wastes.

Environmental health risk assessment

In developing an assessment and prioritization instrument, we adjusted the Hazard Ranking System (HRS) which was first developed for the US EPA as a method to assess hazardous waste sites (Kushner 1986). The current HRS characterizes three general criteria: (1) characteristics of the waste (pollutant), (2) likelihood that a site has released or has the potential to release hazardous substances into the environment, and (3) people or sensitive environments affected by the release (population) and use a structured-value numerical algorithm model combining the components above and computes an overall score between 0 and 100, with a score of 28.50, which is presently the cutoff for inclusion on the National Priorities List for cleanup (i.e. listed as a Federal Superfund site) (NRC 1994). While the US EPA's HRS is widely used, it requires extensive data collection and sampling of multimedia environments (air, water, soil, and food). Also, the intent of the HRS was to provide information to be used in the next step of the clean-up process, namely, determining remedial actions. Given that the objective of the TSIP was to identify and screen potential hazardous waste sites, including mining sites, that present clear health implications, the use of US EPA's HRS was unnecessarily complicated. Therefore, a newly created Blacksmith Index, calculated from data obtained in the ISS, was developed to permit simpler and faster calculation of risks and was not intended to be the basis of determining remediation. This index follows the same general guidelines of the HRS with determination of the pollutant, pathway, and population but differs in that it does not assess ecological risks.

It has shown that while toxic waste sites occasionally consist of a complex heterogeneous array of chemical agents, in actuality, many of them exhibit a dominant chemical agent, hereafter described as the key pollutant (KP) (Ericson et al. 2012). The selection of a single contaminant begins at the site visit where investigators evaluate the nature of the site and possible contaminants present based on historical activities (e.g., mining, pesticide manufacturing, tanneries). Composite sampling was conducted with analysis for chemicals associated with the industry or activity, such as heavy metals, pesticide scans, and petroleum hydrocarbons to confirm the key pollutant. Fortunately, environmental agencies, academic institutions, multilateral agencies, and even nongovernmental organizations have occasionally sampled and characterized the site thereby expediting the assessment.

Profile of mining sites, attributes, and environmental health parameters

An analysis of the TSIP inventory revealed a total of 406 mining related waste sites. These sites were distributed as 131 ASGM sites with mercury as the dominant pollutant, 66 lead mining and secondary lead smelting sites, and a total of 209 general mining and ore processing sites. This latter category contained a significant number of sites where waste tailings and slag were the primary environmental health threat (i.e., total and hexavalent chromium in India). While only 86 sites (21 %) were defined as legacy (i.e., abandoned and no longer used), 256 sites were identified that contained both a legacy and active site portion of the waste site.

Figure 1 presents the frequency of chemical agents found at the 406 mining sites in the TSIP. Interestingly, arsenic, lead, and mercury, all strongly associated with adverse health effects, comprise over 75 % of the environmental chemical risks at these sites. This result is likely due to the health bias associated with site selection. The prioritization scheme used by the ISS heavily weighs toxicity and human health exposure as a selection criterion as opposed to ecological risks.

A total of 7.5 million people are estimated to be exposed at these 406 sites. The median population at risk from all pathways per site is 9,200 with a range of 100 to 400,000 people. Figure 2 presents the population at risk per key pollutant.

As a component of the ISS, coordinators and/or investigators assessed a variety of environmental media, such as air, soil (residential, agricultural, and industrial), and water (drinking, bathing, irrigation, and fishing). Periodic sampling of blood, urine, and food was also implemented though not a priority. The dominant sampling media however were residential topsoil with a frequency of over 50 %.

The usefulness of the ISS however rests in the assessment and reporting of exposure pathways. Table 2 lists each key pollutant and the dominant exposure pathway assessed. Such information may prove useful in designing environmental interventions that are tailored to minimizing health risks. Dust and soil dominated in exposure pathways.

Case studies

Case study #1: Gold mining in Kalimantan, Indonesia

Description

ASGM acts as the primary source of income for perhaps 10–15 million people globally (UNEP and Artisanal Gold Council 2012). Estimates indicate that 20 % of global gold supply is provided in this way (ibid). ASGM miners utilize a range of methods to extract gold from ore. Most common among these is mercury amalgamation, which frequently results in significant fugitive emissions to air and surface water. Telmer and Veiga (2009) and Veiga et al. (2006) estimate that an average of 1,000 metric tons per year is released into the environment from ASGM. This represents approximately 1/3 of global anthropogenic emissions (UNEP 2006). As has been observed elsewhere, mercury can migrate considerable distances through the atmosphere once it is released (see Fitzgerald et al. 1998, for example). However, the ASGM areas themselves experience the most significant environmental degradation and the highest levels of environmental mercury (see, for example, Taylor et al. 2005; Limbong et al. 2003; Appleton et al. 1999).

As has been documented elsewhere, ASGM is common in Indonesia. Veiga et al., for instance, estimate that more than one-tenth of global mercury releases from ASGM originate in Indonesia (Veiga et al. 2006). Much of this activity is concentrated in Kalimantan, the Indonesian section of the island of Borneo (Telmer and Veiga 2009). The Martapura River is located in the province of Kalimantan Selatan, one of four Indonesian provinces on the island. It is a tributary of the Barito River and runs through two cities, Martapura and the provincial capital, Banjarmasin.

Pathway assessment

A number of human exposure pathways are present in the river. One such pathway is the consumption of methylmercury contaminated fish. Mercury bioaccumulates and biomagnifies in the food chain, thus presenting a particularly acute risk when such fish are consumed by humans (Morel et al. 1998). The second possible pathway is the ingestion of surface water. However, this was not observed at the site nor it is likely given the relative low depth of groundwater. The third possible pathway is the use of surface water in daily activities such as bathing and clothes washing. This type of activity was widely observed during investigation.

Sampling

The primary exposure pathway in these types of locations is likely the consumption of potentially contaminated fish. However, due to the prohibitive cost of this type of sampling, investigators regularly utilize water samples as a surrogate. In this case, water samples had been collected, analyzed, and published by the regional environment authority. The samples which were collected at various points along the river indicated a mean presence of mercury (nonspeciated) in surface water of 242 μg/l, exceeding the US EPA standard of 2 μg/l by 120 times.

Population at risk
The population estimated to be coming into contact with the contaminant through daily activities such as bathing and clothes washing is estimated to be 50,000 people. Migration from the area is limited; therefore, the risks posed at the site are likely chronic.

Ranking
In this case, the population at risk is quite large (50,000). Additionally, the analyzed samples show a very high level of the contaminant in a human exposure pathway (120 times over the international standard). However, the relevant pathway is not particularly strong (irrigations/ bathing/ washing). Thus, the Blacksmith Index value for this site is 7.

Case study #2: Lead mining in Central Peru
Description
Peru has a long history of mining and many of the oldest mines are still active. However, recent expansions in the sector and related policy changes have resulted in potentially increased human health and ecological risks (Bebbington et al. 2007; Plá et al. 2001). The relevant village is home to approximately 2,000 residents of which nearly all are in some part dependent on the lead mine. Livestock is also maintained by a large number of residents. The village is situated at an altitude of 4,000 m in the Andean mountains about 120 km due east of Lima. Concerns about dust migrating from the mine and processing facilities into the community as well as possible water contamination from leaching led to an investigation in mid-2012.

Pathway assessment
Several potential exposure pathways were identified at the site. The first such pathway was inhalation of contaminated dust that migrated to the community through fugitive emissions and workers' clothing. The second possible pathway was through contact with surface water which was noticeably being contaminated from mine runoff and effluent releases. Groundwater in the region is located at significant depth. As a result, nearly all residents rely on surface water collected at rivers for bathing, agricultural, and livestock purposes, among other uses. Finally, the third possible pathway was through consumption of contaminated livestock that similarly come into contact with contaminated water and soil.

Sampling
A number of contaminants were potentially present in the surface water, including lead, copper, zinc, and iron. Several of these result in well-documented health effects in humans, therefore complicating the choice of KP for sampling.
In this case, soil samples were taken by a Blacksmith investigator and were sent to a certified laboratory. The samples were analyzed for a range of metals and showed very few were present in the soil above international standards. Based on these results, lead was chosen as the KP. A targeted sample from a residential street showed a level of lead in soil at 815 mg/kg. A composite sample from another street resulted in 472 mg/kg. For reference, the US EPA recommended level is 400 mg/kg.

Population at risk
An estimate was determined for the population at risk based in part on census data, aerial photographs, and interviews. It was determined that the entire population of 2,000 people was exposed to the lead in soil which is in a range of 472 to 815 mg/kg

Ranking
In this case, the population at risk was relatively small (2,000). The analyzed pathway, residential soil, presents a clear human health risk through inhalation and ingestion, especially by children. Importantly, however, the analyzed samples showed relatively low levels of lead in soil. Thus, the resulting Blacksmith Index value is 5.

Case study #3: Chromium slag in Southern India
Description

India is one of the largest producers of chromium ore and salts, which are used worldwide as tanning agents (Dubey et al. 2001). Following ore processing, extensive chromium slag is generated requiring disposal. Within the Indian state of Tamil Nadu, there exist numerous processing sites and tanneries where slag piles have accumulated. In one such site, the spent ore totals an estimated 1.5 million metric tons with the waste slag pile towering almost 12 m on a 3-ha footprint. The site occupies a gentle slope whereby rainwater flows to the Palar River which ultimately terminates at Chennai and the Bay of Bengal.

Chromium ore slag can include commonly existing species of chromium including trivalent chromium (Cr(III)), hexavalent chromium (Cr(VI)), and elemental chromium (Cr). Although the adverse health effects of trivalent chromium are still widely debated, it is readily oxidized to the water-soluble and carcinogenic hexavalent chromium, which can contaminate surface and groundwater (US EPA 1998). The extent of hexavalent chromium contamination from chromate ores and tannery processing operations is well studied (Avudainayagam et al. 2003; Kumar and Riyazuddin 2010; Panda et al. 2012).

Pathway assessment

Several potential exposure pathways were identified at the site. Rainwater readily permeates the slag pile where hexavalent chromium can be mobilized. Given the site geography and the height of the slag pile, groundwater flows out from the sides, forms a small stream, and travels downward toward the river. However, interestingly enough, the dominant exposure risk comes from the reuse of slag ore as construction materials for housing and irrigation berms. Local residents confirmed that chromium slag was offered free and readily available for a wide range of uses. Former workers of the abandoned facility took this material and integrated it with concrete for wall construction and other uses. In another case, farmers used the crushed slag to create berms for irrigation control while others used it as a paving/leveling material.

During heavy rains, common during the monsoon season, runoff and stream overflows contaminate local bare streets and distribute the hexavalent chromium. Finally, as the plume of hexavalent chromium-contaminated water flows to the river, it passes through waterlogged lowlands and ponds where agricultural contamination occurs and presents additional exposure pathways.

Sampling

Numerous chromium ore processing plants exist in India and environmental monitoring has been ongoing. At this particular site, chromium slag levels reached 49,500 mg/kg and stream sediment levels of 14,900 mg/kg. The yellow tint of chromium-contaminated water can be seen throughout the area.

Population at risk

Given the prevalence of tanneries and ore processing plants in this geographic area, a precise population at risk for a single facility is difficult to determine. However, the investigator determined that approximately 15,000 local residents are at risk from this individual site.

Discussion

The need for a rapid, cost effective tool to identify populations at risk from environmental agents at abandoned or uncontrolled industrial facilities is pressing and well timed. The rising economies and increased resource demands of the BRICs have been predicted to significantly add to these risks (Crop 2012). In both the extraction and ore processing sectors, the mining industry will be challenged to ensure environmentally sensitive operations and minimal public health impacts. A difficulty in creating an environmental health assessment scheme of this scope is achieving a meaningful balance between breadth, depth and time within an appropriate cost. The Blacksmith process does not claim to be a comprehensive and definitive assessment process but rather a simple, easily administrable protocol that offers essential and meaningful information to pursue more comprehensive inquires. A goal of TSIP is to identify and prioritize where more complete studies should be conducted, based on a general comparative health risk.

The three case studies presented illustrate the nature of assessments at mining and ore processing sites and demonstrate a range of different types of exposures. The data collected as part of the ISS process allow for rapid comparison across a range of parameters. This sort of consistent and credible data are necessary to support arguments for expenditure on interventions. Different ISSs can be compared across these parameters to allow for prioritization of further assessment or remedial activity.

Additionally, the TSIP can provide a useful resource for researchers attempting to better understand the health risks posed by mining locations. The case studies also demonstrate that sites in disparate locations with different types of exposures and sources can be rapidly compared utilizing the ISS.

There are several significant limitations of the ISS. Underlying many of these is the reliance on personal observations. It is possible that the Investigator, however well trained or educated, may incorrectly identify the KP or primary exposure pathway. Similarly she may fail to calculate the total number of people at risk accurately. These errors can further compound, resulting in severe under or over estimates of risk.

The ISS is not an exhaustive characterization of a given site. It does however capture key pieces of information on which to base further action. As such, it can be seen as one tool among many that policy makers and researchers can use in addressing issues at mining locations.

Conclusion

This paper provides an approach to estimating the contribution of mining and metals processing to the overall GBD from legacy and artisanal pollution. The health of more than seven million people was found to be at risk from mining locations globally. This risk was posed by 131 artisanal and small-scale gold mining (ASGM) and 275 industrial mining and ore processing locations in 45 different countries. Sites were evaluated during visits carried out by Investigators hired and trained by Blacksmith Institute. The investigation instrument, the Initial Site Screening (ISS), captured data at each site in a uniform way, allowing for comparison between different types of sites. The ISS is well suited for its intended purpose of prioritizing sites for further investigation or remedial activity.

The ISS is focused on health risks, which provide the basis for prioritizing interventions in the often complex and large scale environmental and social challenges related to legacy and artisanal mining. The data collected as part of the ISS provides the basis for more detailed estimation of the health risks and impacts associated with the mining sites.

The ISS methodology, based on the existing USEPA HRS, provides a scientifically sound and analytically robust basis for making explicit the health risks and for identifying the benefits of different possible interventions.

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Fig. 1 Distribution of key pollutants at 406 mining hazardous waste sites

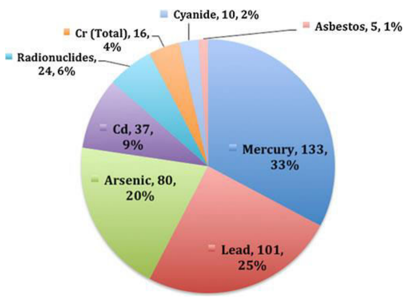

Fig. 2 Population at risk by key pollutants at 406 mining hazardous waste sites assessed

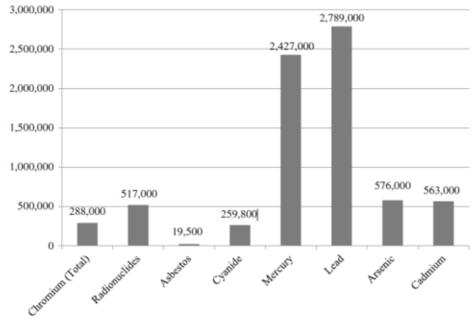

Table 1 Mining waste sites assessed by country (n=45)

Argentina	Indonesia	Serbia/Montenegro
Bangladesh	Jamaica	Slovenia
Bolivia	Kazakhstan	Suriname
Brazil	Kenya	Tajikistan
Cambodia	Kyrgyzstan	Tanzania
Chile	Mexico	Thailand
China	Mongolia	Trinidad/Tobago
Colombia	Mozambique	Uganda
Congo	Nicaragua	Ukraine
Costa Rica	Niger	Uruguay
Ecuador	Nigeria	Uzbekistan
Georgia	Peru	Venezuela
Ghana	Philippines	Vietnam
Honduras	Romania	Zambia
India	Russia	Zimbabwe

Table 2 Key pollutants by exposure pathways

	Dermal contact	Dust/soil/inhalation/ ingestion	Food ingestion	Gases/vapor/ inhalation	Water ingestion	Unknown	Total
Arsenic	8	30	12	3	26	1	80
Asbestos	–	1	–	4	–	–	5
Cadmium	1	19	4	–	12	1	37
Chromium total	6	1	2	1	6	–	16
Cyanide	2	–	2	1	3	2	10
Lead	5	39	13	20	15	9	101
Mercury—elem	20	36	11	14	24	14	119
Mercury—inorg	5	2	–	1	3	–	11
Mercury—org	1	1	–	–	1	–	3
Radionuclides	–	7	1	7	6	3	24
Total	48	136	45	51	96	30	406

Número de registro.
447-1227-1-SM-Caravanos-Peru