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Toxic Metals and Indigenous Peoples Near the Marlin Mine in Western Guatemala

Potential Exposures and Impacts on Health

An Expert Scientific Report by
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with the assistance of the International Forensic Program
of Physicians for Human Rights

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Physicians for Human Rights

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Cover Photo:

Sampling the water at Rio Tzala, Site A. *(Credit: Dr. Niladri Basu)*

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Map from http://brendaandbrent.com/Guatemala.html *and* http.geographicguide.net/america/guatemala.htm.

Executive Summary

In the summer of 2009, a multi-disciplinary team of investigators was assembled by Physicians for Human Rights and deployed to Guatemala for one week to investigate allegations of human rights abuses in the form of exposures to toxic metals experienced by mine workers and Indigenous Peoples living near the Marlin Mine. The primary specific aims of this study were to use rigorous scientific methods to:

1) determine if mine workers have higher exposures to toxic metals than non-mine workers;
2) determine if levels of toxic metals in humans and the environment varied according to their proximity to the mine; and
3) determine if human exposure to toxic metals was related to self-reported health effects.

Given the limitations of what the team was able to accomplish on the one week visit, the work should be viewed as a preliminary, baseline investigation. Nevertheless, several trends were observed and three main recommendations are offered. In the human study, there were no differences in exposures to toxic metals in comparing samples from the five mine workers studied with those of eighteen non-mine workers, and there were no discernible relationships between metals exposures and self-reported health measures in any study group.

On the other hand, individuals residing closest to the mine, generally communities adjacent to or downstream from the mine, had higher levels of certain metals — urinary mercury, copper, arsenic, zinc — when compared to those living further away. Levels of blood aluminum, manganese, and cobalt were elevated in comparison to established normal ranges in many individuals; however, there was no apparent relationship to proximity to the mine or occupation, and thus are of unclear significance.

In the ecological study, several metals such as aluminum, manganese and cobalt were found at elevated levels in the river water and sediment sites directly below the mine when compared to sites elsewhere. When the results of the human and ecological results are combined, they suggest that human exposures to certain metals may be elevated in sites near the mine but it is not clear if the current magnitude of these elevations poses a significant threat to health.

Given that the Marlin mine is a relatively new operation, the negative impacts of the mine on human health and ecosystem quality in the region have the potential to increase in the coming years and last for decades, as commonly occur near other mining facilities worldwide. Furthermore, beyond exposure to chemical stressors, it was clear during our visit that many area residents suffer from psychosocial stress and that much distrust and miscommunication exists amongst and between the various stakeholders — area residents, non-governmental organizations, representatives of the Marlin mine, government officials.

Based on the site visit, the analysis and interpretation of the scientific evidence collected, as well as the constraints of the limited investigation we are able to perform, the authors of this report offer the following three recommendations.

Recommendations

1. There is a need for a rigorous human epidemiological study to comprehensively assess and characterize pollutant exposures and potential human health effects in relation to the Marlin Mine. A new study should build upon the current report and be focused on both occupational exposures — that is, compare mine workers and non-mine workers, and environmental exposures — that is, study several communities at varying distances from the mine. Such a study should consider children's exposure and health in particular. Given that prospecting activities are spreading across the region, establishing baseline data in several communities is warranted. Ideally, for both the human and ecological work, this would be prior to the mine's operation to be considered truly baseline. The epidemiological study should also be longitudinal in design so that prospective trends can be evaluated.

2. There is a need for an enhanced and expanded ecological research study to monitor environmental quality on spatial and temporal scales. Such a study should include several monitoring sites, more than are currently being tracked by various organizations; each site should be monitored regularly — several times per year — and over many years; and monitoring sites should include both ecological sites as well as human communities. At each monitoring site a variety of samples should be collected to investigate both ecological concerns — for example, river water, sediment and soil — and human health concerns — such as drinking water and locally grown foodstuffs. All samples should be analyzed using established analytical methods and rigorous quality control measures. Chain-of-custody procedures should be used to collect samples, and all samples should be securely banked and made available for other investigators.

3. There is a need to create an independent oversight panel that may provide objective and expert guidance concerning the risk and benefits of the Marlin mine in relation to social, economic, environmental, and human health. This is crucial owing to the distrust and miscommunication that seems to exist among stakeholders: area residents, non-governmental organizations, representatives of the Marlin mine, and government officials. The panel would allow for a forum that is transparent and inclusive, and it would facilitate dialogue amongst the stakeholders.

Preface

This study was conducted in response to allegations of human rights abuses in the form of exposures to toxic metals experienced by mine workers and residents living near the Marlin Mine in Western Guatemala. These concerns were voiced to the Human Rights Office of the Archbishop of Guatemala in 2008. In late 2008, Douglass Cassel, Professor of Law and Director, Center for Civil and Human Rights, Notre Dame Law School, was invited by the Archbishop of Guatemala, Cardinal Rodolfo Quezada Toruño, to chair a four-member Independent International Panel and conduct a Human Rights Impact Assessment. The Independent International Panel engaged Physicians for Human Rights and University of Michigan researchers to provide independent, expert professional judgment in the collection, analysis, and interpretation of science-based, medical and ecological evidence.

These results should be viewed as preliminary and baseline, that may be leveraged into a more extensive investigation. Though a moderately extensive and diverse set of human and ecological samples were collected and analyzed based on a research plan that was a rigorous as possible, the conclusions of this study are limited, as the study was designed and deployed in a very short period of time — in order to be responsive to the received allegations — with limited resources, in a region where the research team had limited prior field experience and access to a relatively constrained statistical sample size. Despite such limitations, the outcome of this study resulted in several scientifically determined, qualitative and generalized trends.

The authors of this report intend to publish the findings in the scientific, peer-reviewed literature during summer 2010.

Financial support for this project was received from Due Process of Law Foundation and the University of Michigan's School of Public Health. In-kind support was received from Physicians for Human Rights and the Independent International Panel.

Problem Statement

In 2002, the mining company Glamis acquired the Marlin mine in the Western Highlands of Guatemala. The mine is now owned by the Canadian mining company Goldcorp and operated locally by Montana Exploradora de Guatemala, S.A., Montana. The mine is situated approximately 300 kilometers northwest of the capital Guatemala City and spans the boundary of two municipalities, San Miguel de Ixtahuacán in San Miguel, and Sipacapa, both located in the Department of San Marcos, population 766,950; area 3,596km^2 [1]. The actual mine is approximately 5km^2 in area but is located in a 1000km^2 parcel of land that is actively being prospected; e.g., 73 exploratory holes drilled in 2008[2]. The mine purportedly drains into the Rio Tzala and the Quivichil Creek in a north-south orientation, with eventual discharge into Rio Cuilco.

The mine was commissioned in 2005 and commenced commercial production that same year[3]. The mine consists of two open pits and one underground facility. The mine is estimated to contain 2.4 million ounces of gold, and over its projected 10-year life span is expected to yield about 250,000 ounces of gold per year and 3.6 million ounces silver per year. The gold and silver is extracted using a cyanide leaching process as described by the mine[4]. In brief, the extraction process consists of ore removal via explosives and mining practices followed by crushing into sand or smaller sized grains. The grains are next leached with cyanide to facilitate the precipitation of gold, silver, and other precious elements. The residual waste from the cyanide leaching process is contained within a tailings storage facility which continues to expand in size. Cyanide leaching is a common practice in many mining facilities[5]. There are many cases in the US where tailings storage facilities at gold and/or silver mines that employ cyanide as a means to leach elements have leaked or accidently discharged waste materials, thus contaminating the local environment[5] — for example, Rube Heap Leach Mine, Basin Creek Mine, Brewer Gold Mine, American Girl Mine, Carson Hill Gold Mine, Grey Eagle Mine and Jamestown Mine. Environmental degradation, including contamination of groundwater, surface water, soil and air, as well as damage to wildlife, is commonly found near mining facilities and the impacts are known to last for decades.

Despite the mine's claim of local support for the project, the operation has been the subject of widespread protest. In recent years, the Human Rights Office of the Archbishop of Guatemala has received several alleged claims that the Marlin

1. Water Resources Assessment of Guatemala. US Army Corps of Engineers. June 2000.
2. Environmental and Social Performance - 2008 Annual Monitoring Report. Montana Explorada de Guatemala, S.A.
3. same as 2
4. Environmental Management Plan - Fauna. Marlin Project. Montana Explorada de Guatemala, S.A. June 1, 2005
5. US Environmental Protection Agency. 1995. Human Health and Environmental Damages from Mining and Mineral Processing Wastes. Office of Solid Waste.

mine has caused negative human health effects, broad environmental degradation, and social unrest. Photographic evidence was also received claiming that indigenous residents, especially young children and the elderly, living near the Marlin mine, are suffering from severe skin rashes, hair loss, respiratory difficulties and other ill health ailments, and that these are due to the mine's pollution[6]. Area residents claim they did not have these ailments until after the mine commenced operations, and have requested investigative assistance.

In late 2008, Douglass Cassel, Professor of Law and Director, Center for Civil and Human Rights, Notre Dame Law School, was invited by the Archbishop of Guatemala, Cardinal Rodolfo Quezada Toruño, to chair a four-member Independent International Panel and conduct a Human Rights Impact Assessment of Goldcorp's Marlin Mine in Guatemala. The Independent International Panel engaged the not for profit organization, Physicians for Human Rights (PHR), and University of Michigan researchers to collect science-based, medical and ecological evidence and to provide independent, expert professional judgment on potential impacts of the mine.

In the summer of 2009, a multi-disciplinary team of investigators was assembled by PHR and deployed to Guatemala for one week. The goal of the team was to determine whether there was science-based evidence of any adverse impact on ecological health and human health in a manner that is impartial and transparent. The main objective of this mission was to improve understanding of whether toxic metals purported to be released from the mine may be impacting the health of residents living near the mine and workers at the mine, as alleged.

The primary specific aims of this study were to:

1) determine if mine workers had higher exposures to toxic metals than non-mine workers;
2) determine if levels of toxic metals in humans and the environment varied according to their proximity to the mine; and
3) determine if human exposure to toxic metals was related with self-reported health effects.

To address these aims, a combined epidemiological and ecological study was conducted.

6. 'Health harms in San Miguel Ixtahuacan where Goldcorp Inc. operates an open-pit, cyanide leeching gold mine' Photo Essay by Francois Guindon and Karen Springs, Rights Action, published February 20, 2009 [*http://www.rightsaction.org/articles/San_Miguel_022009.htm*]

Research Methods

General Overview of Study

This proposed study was initiated in response to health concerns voiced by local Indigenous Peoples, mainly Mam Mayan, to the Human Rights Office of the Archbishop of Guatemala. A four-member Independent International Panel was assembled in late 2008 to conduct a Human Rights Impact Assessment of Goldcorp's Marlin Mine in Guatemala.

While the International Independent Panel and Physicians for Human Rights provided advice into study design as well as financial and in-kind support, the actual research activities and analyses were conducted objectively by University of Michigan researchers in a manner that is impartial and transparent as outlined here.

To address the objectives of the study, a combined epidemiological and ecological study was conducted in the area surrounding the Marlin mine. As elaborated below, the epidemiological study aimed to characterize metals exposures, via biomarker analysis of blood and urine, by studying people that live/work at varying distances from the mine and by comparing mine workers with non-mine workers, and to also determine if there were associations between metals exposures and self-reported health outcomes, via survey. The ecological study aimed to address the extent of metals pollution by sampling community drinking water sources, river water and sediment, and soil from various sites surrounding the Marlin mine.

In both the human study and the ecological study, the sites located nearest the mine are also considered to be downstream of the mine whereas the site located furthest away is considered to be upstream of the mine. Though, it is not clear if the hydrogeology of the region is well-established and thus the use of the terms 'upstream' and 'downstream' should be interpreted with caution.

While the aims of this study were addressed by use of diverse and scientifically robust methods, this project should be viewed as a preliminary, baseline investigation. With limited resources available, a small window of time to prepare for the deployment of the mission, and limited prior research field experiences in Western Guatemala by team members, the conditions necessary to implement a comprehensive epidemiological and ecological study were not present.

However, the results of this work enabled us to address the aforementioned primary study aims, and these outcomes may provide qualitative and generalized trends that can be leveraged into a more extensive investigation as outlined in the Recommendations (page 17).

Research Team Members

Members of the primary field team included:

- Dr. Niladri Basu, Assistant Professor of Environmental Health Sciences, University of Michigan;
- Stefan Schmitt, Director, International Forensics Program, Physicians for Human Rights; and
- Marce Abare, Medical Student, University of Michigan Medical School and PHR Student Chapter member.

The activities of the primary field team were supported by Dr. Howard Hu, Department Chair of Environmental Health Sciences, Professor, Physician, University of Michigan; and Susannah Sirkin, Deputy Director, Physicians for Human Rights.

Laboratory analyses for metals, data synthesis, interpretation of results and study recommendations were performed by Dr. Basu and his students, and overseen by Dr. Hu. This study team is multi-disciplinary and consists of skilled, experienced investigators with the requisite knowledge of environmental health sciences (Basu, Hu), medicine (Hu, Abare), ecosystem health (Basu), and human rights (Schmitt, Sirkin) to conduct a successful mission.

On-site field assistance was provided by two university students and a Mam-Spanish translator who were hired by the Independent International Panel and supervised by Mario Domingo who acted as the field coordinator in Guatemala for the Independent International Panel.

Field Sites and Logistics

An eight day mission was conducted between August 17 and 24, 2009. The daily activities are listed in Table 1.

TABLE 1. General timeline of field activities

Date	Itinerary
Aug 17	-depart to Guatemala; overnight in Antigua
Aug 18	-travel to San Marcos -travel to San Miguel Ixtahuacan
Aug 19	-field site #1 - Chininguitz
Aug 20	-field site #2 - San José Ixcaniche
Aug 21	-field site #3 - Siete Platos
Aug 22	-field site #4 - Salitre
Aug 23	-organize samples; transit to Guatemala City
Aug 24	-return to U.S.A.

To address the study aims, we focused attention to four communities that were located at varying distances from the mine, both located upstream and downstream of the mine. The targeted communities included (Figure 1):

1) San José Ixcaqniche, which is adjacent to the mine;
2) Salitre, which is 3km north of the mine; and
3) Siete Platos, which is 2km northeast of the mine;
4) Chininguitz, which is 7km from the mine.

Chininguitz would be considered upstream of the mine and the furthest away, whereas the other three sites are located adjacent to (San José Ixcaqniche) or downstream (Siete Platos, Salitre) of the mine. Our operations were based in San Miguel Ixtahuacan.

Prior to our visit, leaders in each of the four communities were engaged by the university students hired by the International Independent Panel. Community leaders took necessary steps to advertise our project in their districts and to arrange for a location for researcher-participant interactions (explanation of study, informed consent process, sample collection). Twenty three participants were recruited in total, and the overview talks delivered in each of the communities drew between 20 and 80 members. In Siete Platos, community support was evident but the Mayoral Council was not in agreement with our project and out of respect we did not actively engage any members of Siete Platos.

Permits and Security

Institutional Review Board (IRB) approval was obtained from the University of Michigan (HUM00031341) to protect the rights and welfare of the human research subjects. Permits from the US Department of Agriculture (USDA) and US Centers of Disease Controls (CDC) were obtained to import samples from Guatemala.

All samples (biological, ecological, surveys) were secured in the field and during transit by use of signed, sealed evidentiary tape. Upon return of samples to the University of Michigan, all samples have been stored in a secure, key-access facility.

Human Epidemiological Study

Institutional Review Board (IRB) approval was obtained from the University of Michigan (HUM00031341) to interact with human research subjects. Each individual who was interested in participating was first provided with a 30-45 min overview of the study. Oral informed consent was obtained from each willing participant and noted. Owing to the sensitive nature of our mission, a variety of schemes was used to protect the identity of human subjects. No unique identifiers were collected and we only interacted with self-selected participants. An oral survey was administered to gather self-reported information on participant demographics, including

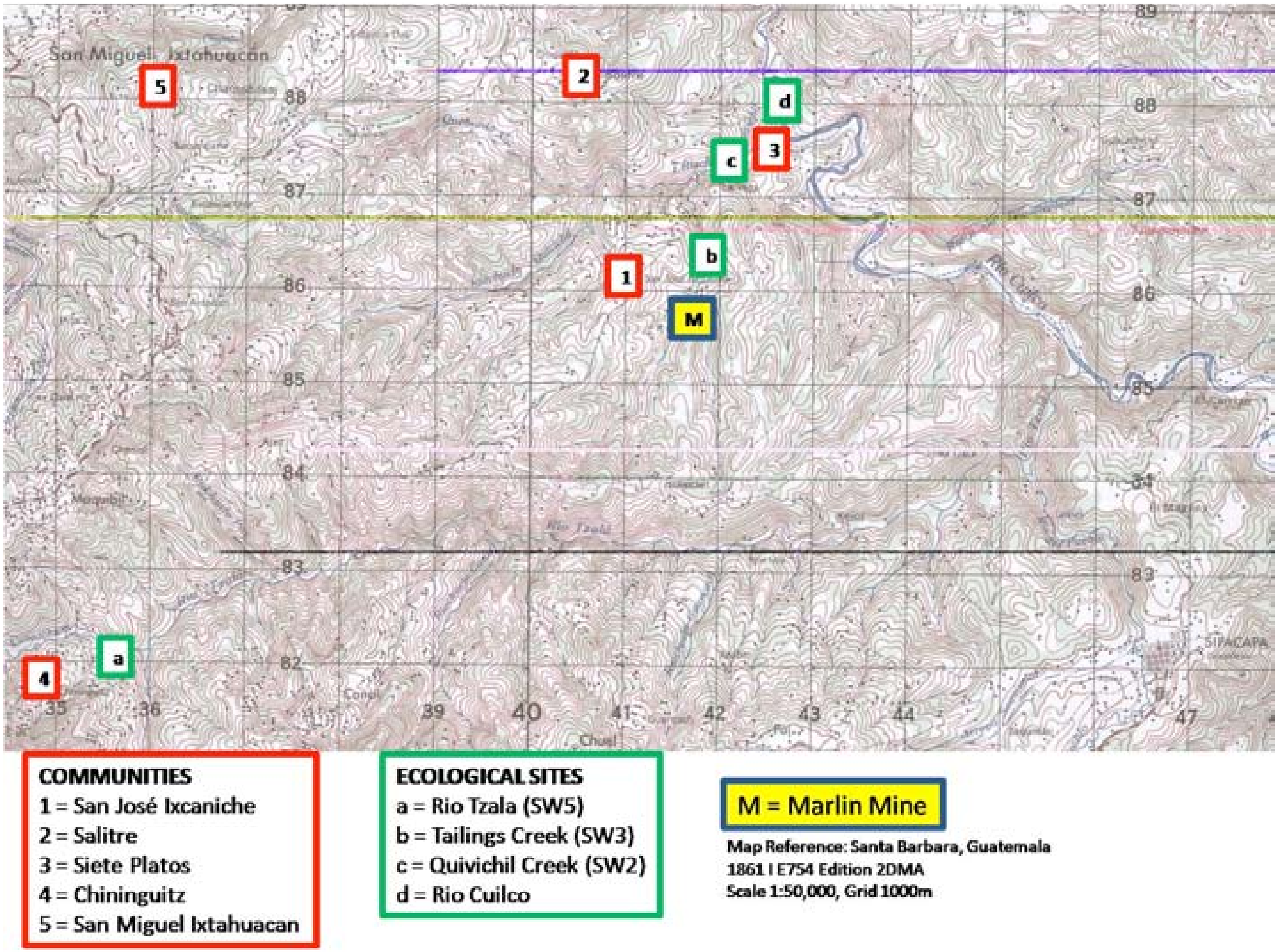


FIGURE 1. *Map of Study Area and Sampling Sites*

gender, age, education and residence; occupation — type, number of weekly hours, number of years; and diet, such as weekly servings of key foodstuffs.

The survey was also designed to capture self-reported measures of general and specific health status. Participants were first asked to assess their general health as "poor", "average" or "excellent". Participants were then asked polar yes-no questions about the health of specific physiological systems (hearing, vision, gastrointestinal neurological, respiratory, renal, dermal). Participants were allowed to elaborate upon their responses. In general, questions were gauged to address health over the past three months. The survey was designed and scribed in English, translated into Spanish and delivered by a Spanish-Mam translator.

Biological materials were collected from each participant. Two tubes of venous blood (~5mL/tube) were collected into BD Vacutainer® glass sterile tubes certified for trace metals analysis. Each tube contained 143 USP units of sodium heparin and was enclosed with a royal blue Hemogard™ enclosure. Approximately 20-60mL of urine was collected in 120mL sterile BD Vacutainer® plastic urine collection cups. For analysis of total Hg, approximately 30-50 strands of hair from the occipital region were cut close to the scalp and placed cut-side down onto sticky paper and wrapped. Finger nail clippings were opportunistically collected for research purposes into coin envelopes but not analyzed for this report. The entire process took about 20-30 minutes per participant. All human samples were stored at ambient temperatures until returned to the University of Michigan upon which they were stored frozen at -20°C in a secured, card-access laboratory facility.

Ecological Study

In three of the four principal communities, at least one sample of soil was collected from a prominent site; that is, seven samples were collected from school yards, soccer pitches, agricultural fields. At least one sample of common drinking water was collected from each community, thus five drinking water samples were collected in total. For reference, a bottle of commercially purchased drinking water and the community drinking water from the San Miguel church were sampled.

In additional to environmental samples from each of the communities, four river sites of varying distances from the mine and/or previously studied by the non-profit agency, COPAE[7] and the independent, community-based monitoring association, AMAC[8] were sampled (Table 2, below; Figure 1, page 7). The sites sampled included:

A) Rio Tzala, at a site located above the mine that corresponds to COPAE's SW-5 site and AMAC's SW-1 site;
B) Tailings Creek, located below tailings pond, flows into Quivichil Creek and corresponds to COPAE's SW-3 and AMAC's MW-3 or MW-4;
C) Quivichil Creek, located below the mine, flows in Rio Cuilco, corresponds to COPAE's SW-2 and AMAC's SW-3; and
D) Rio Cuilco, below the mine in the town of Siete Platos which corresponds to AMAC's SW-5.

It should be emphasized that, similar to the selection of sites for the human study, these ecological sites were chosen to explore for potential differences in sites that are located downstream and upstream of the mine, and also to explore for potential differences according to varying geographic proximity – near the Marlin mine versus further away. This approach tests the assumption that the sites closest to the mine and also downstream of the mine will contain levels of metals that are higher than sites located further from the mine and also upstream of the mine. Also, the use of the term 'downstream' is based upon literature discussed in reports published by AMAC, COPAE, and the Marlin mine, though it is not clear if the region's hydrogeology (including groundwater flow) is well-characterized and thus one of this report's recommendations (Recommendation #2) calls for an expanded monitoring study.

At each river site, water quality readings and samples were collected about 15 meters downstream from an entry point and 15 meters upstream, thus resulting in two collections per site. At each site, a 250mL grab sample of surface water was collected in HDPE vials certified trace-metals free (Preserved HDPE containers, EP Scientific) and subsequently acidified to 1% nitric acid (Merck 'Pro Analysis Grade') to assess concentrations of total (not dissolved) metals. A corresponding sediment sample (~50g) was collected in a sterile 4-oz Whirlpak® bag. Water quality readings (i.e., temperature, pH, conductivity) were taken at each river site by use of a YSI 556MPS probe (Yellow Springs, OH). Water was also obtained from three springs located near the mine, that were in use by community members, especially when community taps ran dry. The GPS coordinates of each ecological site was obtained using MotionX-GPS for the iPhone and verified with a Garmin Gecko GPS. Also, several photographs were taken at each site for reference (Appendix B: Supplementary Photos).

7. Segundo informe annual del monitoreo y analisis de la calidad del agua. Comision Pastoral Paz y Ecologia (COPAE), Diocesis de San Marcos, Guatemala. Julio de 2009

8. *http://commdev.org/section/projects/participatory_environmental_mo*

Laboratory Metals Analyses

Analysis of total mercury in hair, urine, and blood was performed using a Direct Mercury Analyzer 80 (DMA-80, Milestone Inc, CT) according to US EPA accredited methods (Method 7473) as previously published for biological tissues[9]. Briefly, urine and blood samples were vortexed. Five hundred uL of sample was then placed into a quartz sampling tube. Hair (~2-5mg) was weighed and directly placed into a nickel boat. Sampling boats were introduced into the DMA-80 by means of an autosampler. Following introduction of samples into the machine's decomposition furnace, mercury vapour is liberated from the sample and is carried to an absorbance cell by oxygen. Absorbance is measured at 253.65 nm as a function of mercury concentration.

All other metals were detected using an Inductively Coupled Plasma Mass Spectrometer (ICPMS; Agilent 7500c, Agilent Technologies, Palo Alto, CA) equipped with a quadrupole analyzer and octopole collision/reaction cell which are pressurized with either a hydrogen (H2) or helium (He)

9. Environmental Toxicology and Chemistry. 28(1): 133-140.

TABLE 2. Descriptive overview of river sampling sites.

ID	Name	Description	GPS N	GPS W	Alt	COPAE Ref	AMAC Ref
A	Rio Tzala	above the mine	15.21328	91.74979	7370	SW-5	SW-1
B	Tailings Creek	located below tailings pond, flows into Quivichil Creek	15.251979	91.679244	5987	SW-3	MW3 or MW4
C	Quivichil Creek	below the mine, flows in Rio Cuilco	15.26447	91.67357	5317	SW-2	SW-3
D	Rio Cuilco	below the mine in the town of Siete Platos	15.259885	91.667426	5322		SW-5

reaction gas to chemically eliminate polyatomic interferences. One-hundred uL of blood samples were diluted 45-fold with milli-Q water (>18 megohm/cm resistivity) containing 1% nitric acid (Optima grade, Fisher Scientific) and 0.01% TritonX-100, and allowed to digest overnight at room temperature.

The following morning, 500uL hydrogen peroxide (30% Suprapur grade, Sigma-Aldrich) was added to each digest and allowed to sit for at least one hour prior to analysis. For urine, 1mL of sample was digested overnight with concentrated nitric acid, and then diluted five-fold to achieve a final acid concentration of 2%. Acidified water samples were directly analyzed without any sample preparation. Soil and sediment samples (~5-10 grams each) were first dried for 72 hours at 60°C, and then ~1 gram of the dried product was digested with 10mL concentrated nitric acid and heated for 10 min at 95°C. After allowing the digest to cool to room temperature, another 5mL concentrated nitric acid was added to the digest and then refluxed for 30 min at 95°C. After an additional cooling cycle, a final volume of 5mL concentrated nitric acid was added to the digest and then refluxed for 2 hrs at 95°C. The final digest was diluted with milli-Q water to 2% nitric acid, which was then analyzed by ICPMS.

All samples were batch processed according to sample type — that is, all urine run together — using a CETAC ASX-500 autosampler (CETAC Technologies, Nebraska). All analyses were completed within a two week period. Data output was acquired and processed using the Agilent ChemStation software under quantitative analysis modes. The ICPMS was run with argon (Ar) plasma and helium gas for certain elements. Sample uptake was 0.4 mL/min from a peristaltic pump with 1.2 L/min Ar carrier gas through a Babbington-style nebulizer into a Peltier-cooled double-pass spray-chamber at 2°C; 1.0 L/min auxiliary Ar and 12.0 L/min plasma gas Ar were added for a total of 14.2 L/min separated from nickel cones by a sampling depth of 8.5 mm. The ICPMS was tuned under standard settings by running the manufacturer's recommended tuning solution of 10ppb of Li, Y, Ce, Tl, and Co (Agilent internal standard mix) for resolution and sensitivity. Interference levels were reduced by optimizing plasma conditions to produce low oxide and doubly charged ions (formation ratio of <1.0%) and residual matrix interferences were removed using the collision/reaction processes in the Octopole Reaction System. This particular ICPMS instrumentation platform has been used previously to determine trace metals in diverse samples[10].

For both the DMA-80 and the ICPMS, a series of rigorous analytical quality control measures were used (Table S1 [see Appendices for Supplementary Tables]). All biological samples were handled in a Class 100 and 1000 clean room at the University of Michigan's Environmental Toxicology Laboratory. Glassware, plasticware, and Teflon-coated tubes were acid-washed (cleaned, soaked in 10% nitric acid for 24 hours) prior to use. Accuracy and precision were measured by use of several certified reference materials, including US National Institute of Standards and Technology (NIST; 1643 – trace elements in water), the Institut national de santé publique du Québec (INSPQ; QMEQAS09 blood, QMEQAS09 urine), and the Canadian National Research Council (NRC) DOLT-3. In addition, each batch run contained procedural blanks and replicate runs. Samples for which a contaminant was detected but the concentration was below the analytical detection limit was assigned a value of one-half the detection limit (US EPA 2000[11]). For each particular element, the analytical detection limit was calculated as the concentration of the element which gave a detectable signal above the background noise at greater than the 99% confidence level, so that the detection limit was calculated as 3 times the standard deviation of the mean blank value.

The following is a list of abbreviations used in the report, in relation to the metals analyzed:

- aluminum (Al),
- arsenic (As),
- cadmium (Cd),
- chromium (Cr),
- cobalt (Co),
- copper (Cu),
- lead (Pb),
- manganese (Mn),
- mercury (Hg),
- nickel (Ni), and
- zinc (Zn).

Statistical Analyses

Results were analyzed using a variety of statistical schemes, but owing to low statistical power the outcomes of this work should be viewed as qualitative, preliminary and descriptive. Nonetheless, for a study that was deployed with limited resources, an extensive and diverse set of human and ecological samples were collected to address the main stated aims, and the results provide a good basis to draw scientifically defensible conclusions (i.e., diverse samples collected, rigorous analytical quality control measures used, range of values obtained, both human and ecological studies show metals variation may be related to geographic proximity to mine, similar metals flagged in both human and ecological studies) and have the potential to be leveraged into a more extensive study.

For all measures, preliminary data analysis included tabulation of descriptive statistics. Biomarker of metals exposures in urine and blood were generally not normally distributed and since transformation schemes (i.e., log-10, ln) did not achieve normality for most metals, biomarker levels were analyzed and reported without any transformations to maximize their interpretability. Tests for statistical significance included t-tests, analysis of variances (ANOVAs), Brown-Forsythe ANOVA, and spearman correlations. The primary relationships of inter-

10. Journal of Environmental Monitoring 10, 1226-1232; Journal of Exposure Science and Environmental Epidemiology 18, 149-157.

11. US EPA. 2000 Guidance for assessing chemical contaminant data for use in fish advisories. Volume 2: Fish sampling and analysis 3rd ed.

est were associations between biomarker of metals exposures with respect to occupation (mine workers versus other groups), geographical location (proximity to mine), self-reported measures of health (general health, specific physiological systems, and other key covariates) age, gender, diet. For the ecological results, concentrations of metals were compared across sites using ANOVAs. For both the human and ecological results, comparisons against benchmark values were made in a comparative manner. All results are presented as mean values ± standard deviation, unless indicated.

Results

Demographic Overview

For the human epidemiological study, 23 participants were recruited. Sixty-five percent of the participants (15/23) were male. A majority of the recruited participants (12/23) had less than 3 years of formal education, while 7/23 had more than 9 years of education. Five of the 23 participants were miners, 11 were farmers, 4 were teachers, and 3 were unclassified (non-workers). Education in teachers (mean 12±0 years) and miners (mean 8.6±4.1 years) was significantly ($p<0.001$) higher than the other two groups. The average number of years worked by all participants was 17.6±19.8, and the average number of hours worked per week was 32.9±18.6. The age range of the participants was 20 - 71, including four individuals over the age of 60. The study was not designed (and did not seek IRB approval) to engage infants and children, though future epidemiological studies should consider these sensitive age groups.

Five miners self-selected to participate in the study. All were male and their mean age was 35.2±11.4. The average number of years they worked at the mine was 4.9±1.3 and each individual worked on average 55.2±17.1 hours per week. The miners worked significantly ($p<0.001$) longer hours per week than all other occupational groups.

When all participants were stratified according to the distance that their household was located in relation to the mine, 8/23 were categorized as "far", 4/23 were categorized as "middle", and 11/23 were categorized as "near", living in communities adjacent to the mine. A statistical comparison of participant demographics in relation to their distance to mine revealed that participants located closer to the mine were younger (32.0±11.4, $p<0.01$), more educated (mean number of years schooled was 10.1±3.2, $p<0.001$), and had fewer years of work experience (4.8±3.3, $p<0.01$).

Exposure Biomarkers

The focus of the exposure biomarker assessment was on metal levels in blood and urine. Owing to differences in toxicokinetics (how the body absorbs, distributes, metabolizes, and excretes) for a given metal, blood and urine levels often do not correlate with each other. The limit of detection (LOD) for each metal was calculated and such values are considered acceptable (Table S1). For all blood samples (except for one nickel reading), quantifiable results were obtained (Tables S2, S3). For urine, there were several samples that fell below detection limits and were thus assigned a value of one-half the detection limit (Tables S4, S5). The number of samples that were below detection limits for the urinary biomarkers is as follows: aluminum (17/23), chromium (13/23), manganese (12/23), nickel (19/23), copper (4/23), and arsenic (11/23). For most analysis of metal biomarkers, in general the accuracy and precision was within ±20% of expected and no results were adjusted based on recovery rates (Table S1).

Total mercury (0.10±0.10 ug/g; range 0.05 to 0.52 ug/g) was measured in each hair sample. Hair mercury did not relate with any variable, including fish consumption ($r_S = 0.23$, $p = 0.3$) which is usually the strongest predictor of environmental mercury exposure.

Concentrations of ten metals were measured in each blood sample, except for one participant whose blood nickel levels were below LOD. Significant gender-related effects were found and included higher blood levels of manganese and aluminum in females and higher zinc and lead in males (Table S6). No age-related effects on blood metal levels were found. When results were stratified and analyzed with respect to occupation there were no apparent differences among the groups (Table S2). When comparisons were made according to household distance to the mine, blood lead was significantly lower (~25%) in the group located furthest from the mine (Table S3). In general, most blood metals were within reference, 'normal' ranges reported elsewhere (Table 3). For blood aluminum, every participant had levels that were higher than reference range values, though most epidemiological studies utilize urinary aluminum as a biomarker of exposure given that urine accounts for >95% of aluminum excretion – and only 6/23 individuals had detectable aluminum in urine. Also, several individuals had blood manganese and cobalt exceeding reference range values. For blood aluminum, manganese, and cobalt there were no clear relationships with occupation or household distance to the mine.

The mine mandates regular blood testing for metals such as mercury, lead and copper, for employees. A review of reports provided by two mine employees revealed high correspondence between our measurements and those conducted by the laboratory contracted by the mine.

For urine, several of the measurements for aluminum, chromium, manganese, nickel, copper, and arsenic were below detection limits and thus their results should be interpreted with caution. There were no gender-related differences in urinary metal levels, but a significant positive correlation was found between urinary manganese and age and negative, age-related correlations were found with zinc, arsenic, and mercury (Table S7). Like the biomarker results from blood, there were no significant changes in urinary metals with respect to occupation

TABLE 3. Reference (normal) range or threshold values for metals in blood and urine in relation to concentrations measured in the current study. Cited references are indicated in the Table's footnotes. The final column provides a general overview of the main toxic effects associated with chronic exposure to elevated levels of each metal.

	Blood Concentrations (ug/L)		Urine Concentrations (ug/L)		Toxic effects (assuming excess concentrations in the case of nutrients rather than deficiencies)
	Median (Range), Current Study	Reference Range or Threshold	Median (Range), Current Study	Reference Range or Threshold	
Aluminum (Al)	52 (16.5 - 107.1)	0 - 6.2 (A)	2.71 (2.71 - 113.44)	16 ug/L (upper reference; T); 160ug/L (Finnish action level; T)	Central nervous system, gastrointestinal, pulmonary (restrictive, obstructive) disease
Manganese (Mn)	13.2 (7.3-24.3)	4 -15 A; 7 - 12 (T)	0.05 (0.04 - 4.34)	<1ug/L (T)	Central nervous system, respiratory inflammation
Cobalt (Co)	0.4 (0.2-1.5)	0.5 (T)	0.24 (0.03 - 2.52)	<2ug/L (T)	Respiratory system (asthma, lung cancer, fibrosing alveolitis)
Nickel (Ni)	1.80 (0.07-13.50)	limited data (A)	0.07 (0.04 - 2.63)	0.5-4 ug/L (T)	Carcinogen, contact allergen, respiratory toxicant
Copper (Cu)	828 (566 - 1347)	not good indicator (A)	3.07 (0.15 - 19.01)	not good indicator (A)	Pulmonary, gastrointestinal
Zinc (Zn)	6735 (4885 - 9050)	7000 (A)	83.8 (11.7 - 352.0)	limited information (A)	Deficiency and toxicity result in varied health effects
Arsenic (As)	3.9 (3.2 - 8.5)	0 - 5 A; not good indicator (A)	0.06 (0.04 - 16.7)	<100 ug/L (A); <50 ug/L (T)	Multiple organ systems
Cadmium (Cd)	1.20 (0.74 - 2.40)	<1 (T); action level is 5.5 (Sweden; (T))	0.11 (0.05 - 0.27)	<1 (T)	Pulmonary, renal, gastrointestinal, bone, hematological
Lead (Pb)	26.7 (3 - 44)	<100 (A)	0.23 (0.12 - 1.47)	0.69 (2001-2002 NHANES geometric mean)	Central nervous system
Mercury (Hg)	2.4 (0.6 - 13.0)	<20	0.11 (0.04 - 0.70)	<10 ug/L (T)	Central nervous system

A. US CDC's Agency for Toxic Substances and Disease Registry "*Toxicological Profiles*" series [*http://www.atsdr.cdc.gov/toxpro2.html*]
T. *'Handbook on the Toxicology of Metals 3rd Edition'* Edited by G.F. Nordberg, B.A. Fowler, M. Nordberg, L. Friberg. 2007. Academic Press.

(Table S4). Though, arsenic levels were detected in each of the five mine workers and were noticeably higher when compared to the other groups where many of the individuals had urinary arsenic levels below detection limits. Urinary arsenic is considered the most reliable indicator of exposure, but all values measured here were within reference ranges (Table 3 – page 9). When urinary metals were compared according to household distance to the mine, several significant differences were found (Table S5; Figure 2 (page 12), note that the y-axis scaled to log10). Those residing closer to the mine had higher concentrations of urinary mercury, arsenic, copper and zinc. Though, it should be noted that none of the levels exceeded reference range values, and that urinary copper and zinc are seldom used as biomarkers of exposure.

Dietary Survey

The survey instrument was designed to broadly capture dietary habits in the region, which to our knowledge have never been documented. The instrument collected information on key foodstuffs and tracked the number servings consumed over the preceding week. It was not designed to account for portion size and is subject to a participant's recall bias. In general, the miners consumed the most foods across all categories

(Table S8). Notable was the significantly greater intake of high protein foods, such as eggs, chicken, and beef, in relation to the other occupational classes. Miners also consumed greater amounts of rice and cheese. The Marlin mine has a canteen available to workers and this likely represented a major source of nutrition to the workers.

When the dietary results were compared among participants living at varying distances to the mine, there were no significant differences for a given food category (data not shown). There were no gender-related differences in number of servings consumed (data not shown).

When number of servings was correlated (Spearman rank) with exposure biomarkers, significant relationships were found but these should be interpreted with caution as their meaning is limited by low statistical power (n=23), skewed distribution of the exposure biomarkers, and several values below detection limits. Concentrations of urinary mercury correlated with milk powder ($r=0.44$, $p<0.05$), beef ($r=0.43$, $p<0.05$), rice ($r=0.42$, $p<0.05$), fish ($r=0.50$, $p<0.05$), and beans ($r=0.48$, $p<0.05$). Concentrations of urinary arsenic correlated with vegetables ($r=0.52$, $p<0.05$), beef ($r=0.42$, $p<0.05$), and fish ($r=0.46$, $p<0.05$). Concentrations of urinary zinc correlated with chicken ($r=0.55$, $p<0.01$) and beans ($r=0.66$, $p<0.001$). Intake of corn atol was related with urinary cobalt ($r=0.50$, $p<0.05$). For exposure biomarkers in blood, intake of cow's milk was correlated with blood manganese ($r=0.52$, $p<0.05$). Consumption of fruits was correlated with blood aluminum ($r=0.47$, $p<0.05$). Blood lead was correlated with ingestion of chicken ($r=0.43$, $p<0.05$), while blood arsenic was correlated with beef ($r=0.58$, $p<0.005$) and fish intake ($r=0.53$, $p<0.005$).

Human Health Survey

The health portion of the survey instrument was designed to gather self-reported information on general and physiologically-specific health status. There were no associations between any of the self-reported measures and urinary or blood biomarker values. When the 23 participants were asked to categorize their overall health into one of three categories, nine chose "poor", ten chose "average" and four chose "excellent" (Table S9).

Notably, of the four that indicated "excellent", three were mine workers and on average mine workers responded to being in better general health than the other occupational groups. This observation was extended to other questions regarding specific physiological systems as the mine workers generally indicated "No" when asked about issues related to hearing, vision, digestive/GI, neurological, respiratory, renal, and dermal health (Table S10). When the information on self-reported health measures was compared across locations, there were no discernable trends with respect to the question concerning general health (Table S10). Individuals living furthest away from the mine tended more to report issues related to vision, digestion, and respiration. When the self-reported health responses were compared against levels of metals in blood and urine, there were no significant associations measured (data not shown).

The purported health effects that initially drew attention were skin rashes, hair loss, and respiratory difficulties, particularly in the elderly and children. While we did not actively engage the elderly — though four participants were over 60

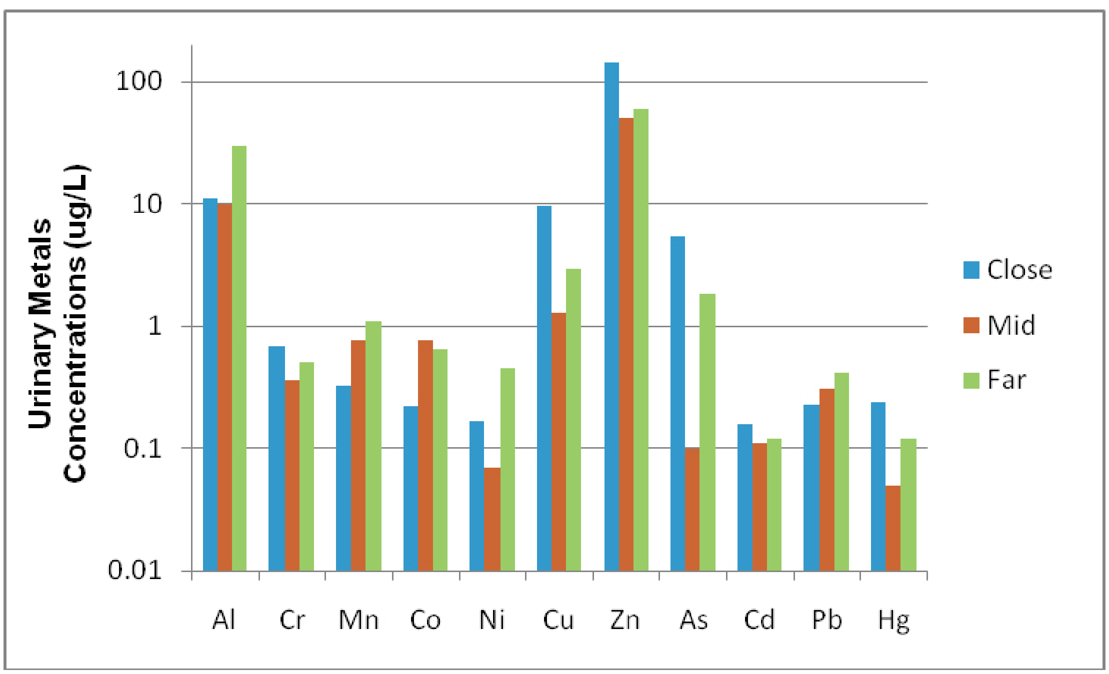


FIGURE 2. *Urinary metals concentrations in relation to household distance to the mine. Note that the Y-axis is on a log-scale as concentrations of metals span several orders of magnitude. Levels of urinary arsenic (As), cupper (Cu), mercury (Hg), and zinc (Zn) are significantly higher in those living closest to the Marlin Mine. Raw data are provided in Supplementary Table S5.*

years old — or children (youngest was 20 years old), during our field study, which involved visiting two schools when children were in attendance in the towns of San José Ixcaqniche and Chininguitz, it was not obvious that skin rashes and hair loss was prevalent.

In our study, about one-fifth of the participants indicated skin-related problems but none of them specifically indicated chronic dermal rashes or lesions as being of concern. One miner specifically indicated skin issues — that is, white spots and discoloration – and attributed this to regular direct contact with chemicals in the workplace, such as sodium cyanide and copper sulfate, which he mentioned splashed/spilled on him on a near-daily basis. Note, this particular mine worker also mentioned that his health — mainly respiratory and neurological — has been deteriorating since early 2008. About two-fifths of the participants indicated respiratory and breathing difficulties, with the greatest responses occurring in participants that lived furthest away from the mine. No participant indicated hair loss to be of concern. It should be noted that 12 of 23 individuals reported difficulties with vision, and 5 of these 12 indicated that these visual problems were relatively new, having started within the past 5 years. Also, vision was the only health measure that was negatively associated with age. It needs to be emphasized that this study used general survey methods to assess human health, and while the research team consisted of individuals with medical experience no clinical tests or diagnostic interpretations were made.

Ecological Health Comments

In addition to human health concerns voiced by the area residents, several participants commented on the likely impacts of mining pollution on the environment. During surveys, notable comments included "river is dangerous", "stopped using the river completely three years ago", "when taps run dry we use the river but are too scared to let our son use the river". One participant commented "3-4 years ago crops — apricot, avocado, maize — started to not do well". Another stated poignantly "if cattle die from using the river then who knows what will happen to us".

River Water

Four river sites of varying distances from the mine and/or previously studied by the community agencies COPAE and AMAC were sampled (Table 2 [page 8]; Figure 1 [page 7]). The sites sampled included:

- Site A: Rio Tzala, at a site located above the mine;
- Site B: Tailings Creek, located below tailings pond, flows into Quivichil Creek;
- Site C: Quivichil Creek, located below the mine, flows in Rio Cuilco; and
- Site D: Rio Cuilco, below the mine in the town of Siete Platos.

At each site, two samples were taken, each about 15 m downstream and upstream of our entry point which was usually a bridge. In general, there were significant differences in water quality measurements among the four sites that could be separated based on proximity to the mine and/or downstream versus upstream location. The two sites immediately located below the tailings pond (Sites B and C) had significantly higher water pH, conductivity, and temperature when compared to the other two sites (Table 4). It should also be noted that Sites B and C were also identified as creeks and thus had water that was shallow and with less flow.

TABLE 4. Water quality measurements. Letter within a column denotes significant differences.

Site	Name	Temp (°C)	pH	Cond. (ms/cm)
A	Rio Tzala	20.1±0.3c	7.47±0.04b	0.12±0.04c
B	Tailings Creek	31.5±0.3a	7.84±0.03a	0.38±0.01a
C	Quivichil Creek	26.5±0.4b	7.77±0.05a	0.31±0.00b
D	Rio Cuilco	20.3±0.8c	7.19±0.05c	0.13±0.02c
	ANOVA, p-value:	<0.001	<0.001	<0.001

For trace metals analysis, river water was collected and acidified from each of the four sites. Several elements (chromium, nickel, copper, cadmium, lead) were below detection limits, though aluminum, manganese, cobalt, zinc, and arsenic were detected. Similar to the differences in water quality across the four sites, there were some consistent patterns for concentrations of metals in water (Figure 3 [page 14]; Table S11). Levels of aluminum, manganese, and cobalt were significantly higher in Site B (Tailings Creek) and elevated in Site C (Quivichil Creek) when compared to the other two sites. Water concentrations of arsenic were significantly higher in Quivichil Creek.

These results generally imply that water metal concentrations are highest in sites directly beneath the mine. When compared to US benchmarks, the concentrations of aluminum in surface water approached and exceeded (i.e., Site B) guideline values. Though COPAE and AMAC, as well as the Marlin Mine and the Guatemalan Ministry of Natural Resources, have also published reports detailing water chemistry values in the area, we did not have resources to carry out a rigorous, quantitative comparison of all the datasets but such an activity is recommended.

River Sediment

Sediment samples were collected from each of the four river sites. All metals screened were detected with the exception of nickel and cadmium. Similar to the river water data, concentrations of metals in sediments were generally higher in the sites below the mine when compared to Site A which was located above the mine, but the differences were not as strong (Table S12). While trends exist in the data, there are no significant differences in sediment concentrations of aluminum, manganese, zinc, arsenic, and lead among the river sites. Rio Cuilco (Site D) generally had the highest sediment concentrations of chromium, cobalt, and copper. Concentrations of metals sediments were lower than US regulatory benchmark values but levels of zinc and arsenic were within 50% of regulatory benchmark values. There were no relationships (Spearman) between concentrations of metals in sediment with concentrations in water as follows: aluminum (r_S=0.46, p=0.26), manganese (r_S=0.61, p=0.12), cobalt (r_S=0.51, p=0.22), zinc (r_S=0.41, p=0.30), and arsenic (r_S=-0.29, p=0.49).

Community Water and Soil

Samples of drinking water were collected from neighborhood springs, community taps and residences, and from a commercial vendor (Table S13). Several elements, including chromium, nickel, copper, and nickel were not detected in any drinking water sample, and of the elements measured there were many that were below detection limits and thus assigned a value of half the LOD. In general, the concentrations of aluminum and manganese were highest in the spring samples and zinc was highest in the community taps. Concentrations of metals in the commercially purchased water bottle were generally lowest, except for arsenic which was present in the highest concentration in the commercially purchased water. There were no samples that exceeded the US EPA's National Drinking Water Regulations, though levels of aluminum and manganese were within five-fold of the benchmark values in some cases. Soil was also sampled in each of the communities, but levels were within background ranges (Table S14).

Discussion

Study Limitations

This study was conducted in direct response to allegations of human rights abuses voiced by individuals living near, or working at, the Marlin mine through the Human Rights Office of the Archbishop of Guatemala. Owing to the need to rapidly collect high quality, scientifically robust evidence, the study was designed and deployed in a very short period of time, with limited resources, and to a region where the research team had limited prior field experience. As such, the outcome of this work should be viewed as a preliminary, baseline investigation. Statistical sample size was the major limitation of the study but a diverse array of samples was collected from both humans (blood, urine, survey answers) and the environment (drinking water, river water, sediment, soil).

Another limitation was sampling and reporting bias as the twenty-three individuals self-selected to participate and provided self-reported health measures, though it should be noted that our study was advertised to the broader community and between 20 and 80 people in each of three communities attended our seminars.

Despite these limitations, the primary aims of this study were addressed by use of diverse and scientifically robust methods. The outcomes provide qualitative and generalized trends that enable conclusions to be drawn and the results can be leveraged into a more extensive investigation as outlined in the Recommendations of this report.

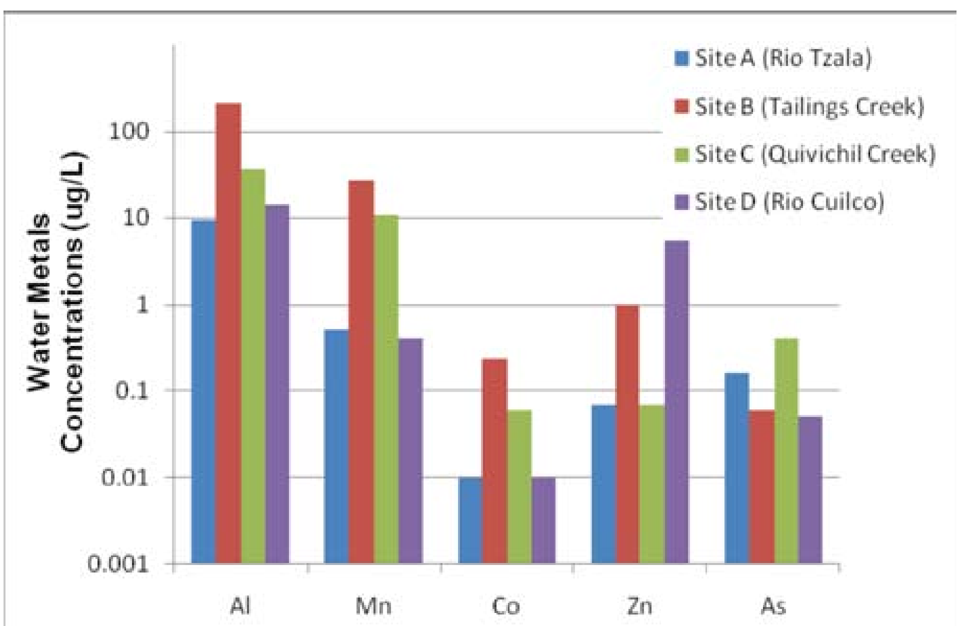


FIGURE 3. *Concentrations of metals in river water. Note that the Y-axis is on a log-scale as concentrations of metals span several orders of magnitude. Levels of aluminum (Al), manganese (Mn), and cobalt (Co) are significantly elevated in the sites below the Marlin Mine. Raw data are provided in Supplementary Table S12.*

Human Health - Chemical Exposures and Survey Outcomes

The first aim of this project was to determine if mine workers have higher exposures to toxic metals than non-mine workers. The results of this study indicate no difference in the concentrations of blood and urinary metals between mine workers and non-mine workers. Blood level of metals measured here were similar to values documented by the mine's employee testing program. In the miners, there were no associations between any of the self-reported health measures and urinary or blood biomarker values. In fact, the mine workers tended to respond to being in better general health than the other occupational groups, and were more likely to indicate "No" when asked about issues related to hearing, vision, digestive/GI, neurological, respiratory, renal, and dermal health. Such may be related to the "healthy worker effect" which states that employed individuals tend to be in better health than those not employed.[12]

As indicated in the mine's 2008 Annual Monitoring Report, all employees undergo regular safety training including weekly/daily safety updates and these practices were verified by each of the five miners that participated in this study. Mine workers also receive health insurance and free access to the mine's clinic. Associated with the "healthy worker effect", our dietary survey indicated that mine workers had a more varied and plentiful diet (i.e., greater intake of eggs, chicken, beef, rice, cheese) when compared to others.

The second aim of this project was to determine if levels of toxic metals in humans vary according to their proximity to the mine. For several metals — that is, blood lead, urine mercury, arsenic, copper, zinc — concentrations were higher in residents that lived closest to the mine (these are generally sites adjacent or downstream of the mine) when compared to individuals living further away. Environmental sites located directly below the mine tended to have the highest levels of metals in water and sediment when compared to sites located upstream of the mine. The combined results from the human epidemiological study and the ecological study suggest that geographic proximity to the Marlin mine is an important predictor of metals exposure. Such an observation — elevated metals exposures — has previously been made in other communities that live closest to large-scale mining operations.[13]

The third aim of this project was to determine if human exposure to toxic metals is related with self-reported health effects. The purported health effects that initially drew attention to the community were skin rashes, hair loss, and respiratory difficulties, particularly in the elderly and children. While we did not actively engage the elderly and children, during our field study, which involved visiting two schools when children were in attendance, it was not obvious that skin rashes and hair loss was prevalent. Further, there was no clear relationship between self-reported health measures such as general health and specific, physiological systems, with a participant's household location and occupation. When the self-reported health measures were tested against urinary or blood biomarker values, no significant associations were found. This study used general survey methods to assess human health, and while the research team consisted of individuals with medical experience no clinical tests or diagnostic interpretations were made.

While no striking associations were found between chemical exposures and health measures the results of this study demonstrate that individuals near the Marlin mine are exposed to complex mixtures of metals via occupational and environmental routes. As highlighted earlier (Table 3), all the metals investigated here are, for example, potent neurotoxicants, carcinogens, and/or respiratory irritants. Most of the metals were detected at concentrations below values associated with clinical harm, but little is known about their cumulative and combined health impacts on humans (especially children) following chronic exposures to complex, real-world mixtures particularly near toxic waste sites. Position papers on this matter generally conclude that the adverse health outcomes associated with exposures to multiple chemicals may be greater than expected owing to synergistic interactions among individual chemicals.[14] Elevated levels of aluminum and manganese were found in certain human and ecological samples and warrant further investigation. While metals pollution was the focus of this study, other chemicals such as cyanide may contaminate the region, and future studies should investigate the concentrations of cyanide in the environment (air, water, soil) and in humans (area residents, mine workers). The primary health complaints voiced by indigenous residents, namely skin rashes and respiratory ailments, are known to be consistent with those caused by cyanide exposure.[15]

Non-Chemical Stressors

A brief perusal of the available information; for example, news articles, photoblogs, annual reports from the Marlin mine, highlights that much distrust and miscommunication exists among stakeholders — area residents, non-governmental organizations, representatives of the Marlin mine, government officials. This was evident to us on numerous occasions during our mission, as the term 'misinformacion' was heard every day. For example, many individuals that hold a governing position, that is, those in the town's developmental council or mayoral council, whether in support of our study or not, hoped that our work would be done in an objective manner and help clarify misinformation. Several residents complained of poor communication between the mine and the broader community. According to some area residents, three years ago the mine sponsored a children's epidemiological study

12. 1999. Occup Med (Lond) 49: 225-229.
13. 2009. Environ Res. 109(6):745-752; 2007. Pediatr Clin North Am. 54(1): 155-175; 2009. BMC Public Health. 9:217.
14. 1998. Environ Health Perspect. 106 Suppl 6:1263-1270; 2006. Lancet 368(9553): 2167-2178; 2008. Toxicol Appl Pharmacol 233: 92-99.
15. Toxicological Profile for Cyanide. Agency for Toxic Substances and Disease Registry. US Department of Health and Human Services. July 2006.

where blood samples were collected for baseline contaminant analyses but results have never been communicated back to residents. It was not clear whether such a study had an acceptable informed consent process and IRB approval. Likewise, there was mention that a psychosocial study was recently performed by an American researcher on mine workers, but plans for dissemination of results were not clarified. In both instances certain study participants and community members expressed concerns related to the consent process and dissemination plans.

Like populations of Indigenous Peoples across the world, the cultural practices of the Mam Mayan that reside in Western Guatemala are heavily dependent on the environment. Chemical pollution not only impacts human health but has deeper impacts on the cultural fabric. During surveys, notable comments included “river is dangerous”, “stopped using the river completely three years ago”, “when taps run dry we use the river but are too scared to let our son use the river”. Another stated poignantly “if cattle die from using the river then who knows what will happen to us”.

It was also mentioned that many residents in the area anticipate future ill health and luck given that the degradation of mountains via mining activities conflicts with Mayan’s reverence of mountains and the ritualistic and spiritual role that mountains play in Mayan culture. In other Indigenous communities plagued with toxic pollution, traditional outdoor activities, for example, hunting and medicine gathering, that play integral roles in the community’s culture, spirituality, economy, and diet are limited.[16] The disproportional placement of industry based on ethnic and socioeconomic factors is found in many parts of the world and exemplifies a common form of environmental injustice.[17]

Though our investigation was focused on the health impacts of chemical (metals) pollution, stressors that are non-chemical or psychosocial may have an equally, or even greater, impact on human health. One participant commented “if the mine is contaminating us, then we need to leave our home and our lands”.

Ecological Exposures

Similar to the results from the human exposure portion of this study, levels of certain metals were elevated in water and sediment samples collected from the sites directly located below the mine. In general, concentrations were within background ranges except for aluminum which approached, or even exceeded, guideline values in some river water and community tap water. Levels of metals in soil were at background levels.

These results suggest that exposures to metals are likely through water rather than atmospheric deposition onto soils or general contamination of soil, but further work is required to substantiate this conclusion.

Water quality and quantity in the region surrounding the Marlin mine are of concern. Many community members described how shared community tap waters and local springs run dry, and also mentioned increased hesitation in using river water owing to fears of contamination. The mine acknowledges that its practices use copious amounts of water, but that a high percentage is recycled, and that the region already suffers from limited water availability.[18]

The results from our study demonstrate that water resources in the area below the mine have levels of metals that may be higher than the site upstream of the mine. The presence of metals pollution in water resources is expected to further increase in scope and magnitude given that the mine’s operation is in an early phase, additional wastes will be generated and stored in the tailings pond, and that to our knowledge no long-term sustainability plan exists once the mine’s ten-year activity period is over. Furthermore, the mine is actively prospecting dozens of other sites in the region near the Marlin mine, and any future mining operation may further compromise the quality and quantity of water in the broader area.

Environmental degradation, including contamination of groundwater, surface water, soil and air, as well as damage to wildlife, is commonly found at mining facilities and the impacts are known to last for decades.[19] There are many cases in the US where tailings storage facilities at gold and/or silver mines, for example, Rube Heap Leach Mine, Basin Creek Mine, Brewer Gold Mine, American Girl Mine, Carson Hill Gold Mine, Grey Eagle Mine and Jamestown Mine, that employ various cyanide leaching methods, have leaked or accidently discharged waste materials, thus contaminating the local environment.

16. 1991. Environ Health Perspect 95: 61-66; Annu Rev Nutr 20, 595-626; 1998. Int J Circum Health 57 Suppl 1, 537-542.
17. 2006. Demography 43, 383-399; 2004. J Epid Comm Health 58, 24-30.
18. Environmental Management Plan - Fauna. Marlin Project. Montana Explorada de Guatemala, S.A. June 1, 2005
19. US Environmental Protection Agency. 1995. Human Health and Environmental Damages from Mining and Mineral Processing Wastes. Office of Solid Waste.

Recommendations

1 - Need for a rigorous human epidemiological study

This study established baseline data and explored potential differences across key variables. The results have the potential to be, and in our opinion, should be leveraged into a rigorous, statistically-validated epidemiological study to comprehensively assess and characterize pollutant exposures and potential human health effects in relation to the Marlin Mine as well as other future-planned mining activities in the area. A new study should build upon the current report and be focused on both occupational, that is, compare mine workers and non-mine workers, and environmental — study several communities at varying distances from the mine — exposures.

Given that prospecting activities are spreading across the region, establishing baseline data in several communities is warranted, and actually, should have been performed both human and ecological exposures prior to the mine's operation to be considered truly baseline. The study should also be longitudinal in design so that over-time trends can be tracked. Selection bias and reporting should be reduced by random sampling and the use of objective human health measures. Developing babies and young children are most sensitive to toxic chemicals, and additional focus should be made on this susceptible group. Medically upheld methods should be used to validate allegations of hair loss and skin rashes. Similar to the current study, a dietary and demographic/lifestyle survey should be utilized as well as a more comprehensive survey to better gauge any possible influence of non-chemical (psychosocial stress) stressors on health outcome and exposure measures. Like the current study, all steps need to be taken to protect human subjects via IRB (or equivalent) approval and oversight.

Community participation and education will be an important component to any future-planned epidemiological study, as will involvement of all key stakeholders including mining officials, non-governmental organizations, governmental officials, and independent, multi-disciplinary scientific researchers.

2 - Need for an enhanced and expanded ecological study

Similar to Recommendation #1, a carefully planned, rigorous ecological study is needed to help monitor environmental quality on spatial and temporal scales. The work by independent, community-based organizations COPAE and AMAC should continue and it is recommended that with additional resources that these efforts be expanded. The number of sites sampled should be increased to improve spatial coverage and resolution. Such an expansion is warranted owing to the possibility that mining activities may spread across the region. In addition to water samples, sediment should also be collected from each river site. It is not clear if the metal composition in the ore and tailings have been reported. In conjunction with a human epidemiological study, strong consideration should be given to the collection of community soil, locally grown agriculture, and water samples from taps and springs from each engaged community as this will improve understanding of pertinent source-fate-exposure pathways for human residents. Chain-of-custody methods should be used to collect samples. All ecological samples should be banked frozen in a secured facility for future, retrospective studies by third-parties or for screening additional contaminants.

Several groups — COPAE, AMAC, Marlin Mine, Guatemalan Ministry of Natural Resources, and the current study — have now published reports detailing water chemistry values in the area. While we did not have the resources to conduct a rigorous, quantitative comparison of all datasets, such an activity is warranted to gain a broader understanding of water quality issues in the region. The quality of these various studies should be compared, contrasted, and scrutinized. It would be expected that any scientifically defensible study concerning water quality be conducted with utmost consideration of quality control steps to ensure the consistency and reliability of results. Requisite quality control steps in any assessment of water chemistry include, for example, the use of certified blanks to determine limit of detection, replicate analyses to determine analytical precision, and certified standard reference materials to determine accuracy. Furthermore, contemporary methods for the analysis of trace metals now call for the use of ultra-clean facilities (i.e., class100 and 1000 rooms) and sensitive analytical machinery (i.e., inductively coupled plasma mass spectrometers, atomic absorption spectrometers).

In addition to the ecological studies reviewed above, steps should be taken to launch a study using resident sentinel organisms. The mine previously conducted a very limited inventory of flora and fauna,[20] but the exposure of the region's fish, wildlife, domestic, and farm organisms to toxic chemicals

20. Environmental Management Plan - Fauna. Marlin Project. Montana Explorada de Guatemala, S.A. June 1, 2005

and a study of possible health effects in these organisms (by means of established molecular and physiological biomarkers) has not been investigated. There is ample evidence from many mining regions that wildlife are excellent sentinels of toxic exposures and effects.[21]

3 - Establishment of an Independent Oversight Panel

The present study was conducted as an independent, impartial study in the collection, analysis, and interpretation of medical and ecological evidence. Owing to the distrust and miscommunication that exists among and between stakeholders (area residents, non-governmental organizations, representatives of the Marlin mine, and government officials), it is recommended that an independent oversight panel be assembled to provide objective and expert guidance. Such a panel should consist of specialists across the natural, medical, and social sciences and humanities. Such a panel should also be in a position to offer broad-ranging advice concerning the risk-benefits of the Marlin mine in relation to social, economic, environmental, and human health. The panel would allow for a forum that is transparent and inclusive, and facilitates trusted dialogue among stakeholders.

21. Schmitt et al., 2006. Environ Geochem Health. 28:445-471; Rabinowitz et al., 2005. Ecohealth. 2: 26-37.

Members of the research team observe the mine. (PHR)

Appendix A: Supplementary Tables

Table S1

Analytical methods and quality control outcomes. The limit of detection (LOD) was calculated as the mean value of several blank samples plus 3x the standard deviation of the mean. Accuracy (closeness to actual value) was determined by use of standard reference materials (SRM) obtained from the US National Institute of Standards and Technology (NIST; 1643 - trace elements in water) and the Institut national de santé publique du Québec (INSPQ; blood and urine standards). Precision was determined from the replicate analysis of a certain sample.

				Accuracy and Precision of Methods					
				NIST1643 Water SRM		QMEQAS09 Blood SRM		QMEQAS09 Urine SRM	
Element	**Method**	**Mode**	**LOD (ug/L)**	**Accuracy**	**Precision**	**Accuracy**	**Precision**	**Accuracy**	**Precision**
Al	ICPMS	He	5.42	113.5%	18.5%	111.5%	19.6%	93.1%	13.6%
Cr	ICPMS	He	0.73	103.5%	n/a1	n/m2	n/m	98.3%	11.7%
Mn	ICPMS	He	0.10	107.4%	7.1%	108.1%	15.6%	83.5%	13.8%
Co	ICPMS	He	0.03	111.1%	8.3%	132.4%	14.3%	94.8%	10.2%
Ni	ICPMS	No Gas	0.15	111.5%	n/a	87.3%	8.8%	102.6%	8.4%
Cu	ICPMS	No Gas	0.30	103.4%	n/a	98.5%	19.0%	104.3%	7.7%
Zn	ICPMS	No Gas	1.34	119.6%	1.9%	106.8%	18.1%	106.4%	7.2%
As	ICPMS	No Gas	0.08	114.3%	3.2%	139.6%	12.1%	61.1%	23.5%
Cd	ICPMS	He	0.07	105.9%	12.9%	132.1%	22.8%	111.5%	9.8%
Pb	ICPMS	No Gas	0.89	119.3%	n/a	103.4%	6.5%	63.7%	8.5%
Hg	DMA	Normal	0.10 ng	n/m	n/m	93.6	2.4%	93.5%	2.4%

1. n/a refers to not applicable as precision was calculated from replicate analysis of actual samples, and Cr, Ni, Cu, and Pb were not detected in any collected sample of water
2. n/m refers to a sample that was not measured

Table S2

Blood metal concentrations in relation to occupation.

		Blood Metal Concentrations (µg/L)									
		Al	**Mn**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Cd**	**Pb**	**Hg**
ALL (n=23)	Mean	51.90	13.81	0.50	2.40	855.93	6818.50	4.18	1.35	26.76	3.09
	Std Dev	23.00	3.77	0.33	2.70	174.10	1170.87	1.14	0.42	10.20	2.59
	Median	52.00	13.20	0.40	1.80	828.00	6735.00	3.90	1.20	26.70	2.40
	Min	16.50	7.30	0.20	0.07	566.00	4885.50	3.20	0.74	3.00	0.60
	Max	107.10	24.28	1.50	13.50	1347.00	9050.00	8.50	2.40	44.00	13.00
Results Stratified According to Occupation											
Miner (n=5)	Mean	37.56	12.92	0.36	1.01	764.70	7407.00	5.06	1.44	32.54	2.82
	Std Dev	19.96	1.90	0.09	0.88	76.34	1429.94	2.05	0.58	11.82	1.18
	Min	16.50	11.20	0.30	0.07	691.00	5120.00	3.30	0.80	19.20	1.50
	Max	63.30	16.00	0.50	2.10	856.00	9050.00	8.50	2.30	44.00	4.40
Farmer (n=11)	Mean	54.10	14.04	0.59	3.17	882.23	6610.05	4.13	1.27	26.48	3.68
	Std Dev	24.77	4.96	0.42	3.58	222.78	1216.90	0.69	0.47	8.68	3.54
	Min	28.90	7.30	0.26	0.70	566.00	4885.50	3.20	0.74	14.90	0.60
	Max	107.10	24.28	1.50	13.50	1347.00	8460.00	5.77	2.40	43.20	13.00
Teacher (n=4)	Mean	59.23	14.15	0.40	2.68	883.25	6300.00	3.65	1.45	25.60	2.50
	Std Dev	25.46	1.77	0.22	1.23	73.81	438.81	0.59	0.21	8.79	1.42
	Min	29.90	13.10	0.20	1.50	828.00	5690.00	3.20	1.20	15.90	1.20
	Max	91.00	16.80	0.70	4.10	987.00	6735.00	4.50	1.70	34.50	4.50
Other (n=3)	Mean	57.97	14.00	0.50	1.53	875.17	7293.33	3.63	1.40	19.70	2.13
	Std Dev	16.68	4.35	0.26	1.63	196.94	1147.65	0.38	0.26	14.54	0.90
	Min	42.60	11.10	0.20	0.10	652.50	6135.00	3.20	1.10	3.00	1.10
	Max	75.70	19.00	0.70	3.30	1026.50	8430.00	3.90	1.60	29.50	2.70
Brown-Forsythe test[1]	F-value	1.00	0.15	1.18	1.72	0.78	1.08	1.51	0.35	0.81	0.84
	p-value	0.43	0.93	0.36	0.21	0.54	0.40	0.31	0.79	0.52	0.49

1. owing to differential variances in metal biomarker results, a Brown-Forsythe ANOVA was performed to assess the deviations from the group medians and not means.

Table S3

Blood metal concentrations in relation to household distance to mine.

		Blood Metal Concentrations (µg/L)									
		Al	**Mn**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Cd**	**Pb**	**Hg**
ALL (n=23)	Mean	51.90	13.81	0.50	2.40	855.93	6818.50	4.18	1.35	26.76	3.09
	Std Dev	23.00	3.77	0.33	2.70	174.10	1170.87	1.14	0.42	10.20	2.59
	Median	52.00	13.20	0.40	1.80	828.00	6735.00	3.90	1.20	26.70	2.40
	Min	16.50	7.30	0.20	0.07	566.00	4885.50	3.20	0.74	3.00	0.60
	Max	107.10	24.28	1.50	13.50	1347.00	9050.00	8.50	2.40	44.00	13.00
Results Stratified According to Distance to Mine											
Close (n=11)	Mean	51.69	13.06	0.39	1.92	851.95	6784.14	4.29	1.42	27.88	3.37
	Std Dev	24.41	2.87	0.14	1.11	119.02	1140.76	1.53	0.39	9.48	3.39
	Min	16.50	7.30	0.20	0.07	708.00	4885.50	3.20	0.90	15.90	1.20
	Max	91.00	16.80	0.70	4.10	1129.50	9050.00	8.50	2.30	44.00	13.00
Mid (n=4)	Mean	47.10	15.35	0.80	5.23	911.75	7785.00	4.08	1.63	35.48	2.38
	Std Dev	14.67	3.48	0.50	5.62	99.81	680.42	0.28	0.59	6.26	1.94
	Min	28.90	11.10	0.40	1.60	825.50	6930.00	3.80	1.00	28.20	0.60
	Max	63.20	19.60	1.50	13.50	1006.00	8460.00	4.40	2.40	43.20	5.00
Far (n=8)	Mean	54.59	14.07	0.49	1.65	833.50	6382.50	4.09	1.13	20.86	3.05
	Std Dev	26.42	5.04	0.36	1.42	261.49	1224.06	0.83	0.30	9.83	1.60
	Min	26.70	9.60	0.20	0.10	566.00	5075.00	3.20	0.74	3.00	1.10
	Max	107.10	24.28	1.28	4.00	1347.00	8430.00	5.77	1.60	34.80	6.30
Brown-Forsythe test	F-value	0.16	0.52	1.64	1.39	0.28	2.59	0.14	1.73	4.19	0.27
	p-value	0.85	0.60	0.27	0.36	0.76	0.10	0.87	0.25	0.03	0.76

Table S4

Urine metal concentrations in relation to occupation.

		Urinary Metal Concentrations (µg/L)										
		Al	**Cr**	**Mn**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Cd**	**Pb**	**Hg**
ALL (n=23)	Mean	17.55	0.56	0.67	0.47	0.25	5.82	97.62	3.22	0.14	0.31	0.17
	Std Dev	32.89	0.42	1.19	0.64	0.57	5.88	80.89	4.81	0.06	0.27	0.17
	Median	2.71	0.36	0.05	0.24	0.07	3.07	83.84	0.06	0.11	0.23	0.11
	Min	2.71	0.02	0.04	0.03	0.04	0.15	11.74	0.04	0.05	0.12	0.04
	Max	113.44	1.75	4.35	2.52	2.63	19.01	352.00	16.71	0.27	1.47	0.70
Results Stratified According to Occupation												
Miner (n=5)	Mean	14.87	0.48	0.45	0.14	0.07	5.69	114.49	8.00	0.10	0.28	0.25
	Std Dev	22.76	0.37	0.90	0.09	0.00	4.12	48.73	3.15	0.04	0.10	0.25
	Min	2.71	0.02	0.05	0.04	0.07	1.61	66.88	4.86	0.07	0.15	0.10
	Max	55.06	1.00	2.07	0.24	0.07	10.03	182.02	12.40	0.16	0.41	0.70
Farmer (n=11)	Mean	18.27	0.68	0.60	0.55	0.11	6.25	69.86	2.60	0.14	0.27	0.13
	Std Dev	33.80	0.54	1.11	0.62	0.13	7.17	50.60	5.47	0.07	0.13	0.17
	Min	2.71	0.36	0.04	0.03	0.04	0.15	11.74	0.04	0.05	0.12	0.04
	Max	113.44	1.75	2.91	2.22	0.51	19.01	142.38	16.71	0.27	0.55	0.63
Teacher (n=4)	Mean	2.71	0.54	0.22	0.25	0.34	7.24	189.93	1.33	0.18	0.23	0.21
	Std Dev	0.00	0.24	0.29	0.08	0.53	6.53	138.04	1.51	0.06	0.10	0.09
	Min	2.71	0.36	0.05	0.16	0.07	0.57	31.18	0.04	0.10	0.12	0.11
	Max	2.71	0.87	0.65	0.32	1.13	14.53	352.00	2.95	0.24	0.32	0.30
Other (n=3)	Mean	39.16	0.32	1.92	0.99	0.93	2.56	48.23	0.04	0.12	0.62	0.11
	Std Dev	63.13	0.06	2.16	1.32	1.48	2.20	14.24	0.00	0.05	0.74	0.08
	Min	2.71	0.25	0.23	0.21	0.07	0.15	37.34	0.04	0.09	0.17	0.06
	Max	112.06	0.36	4.35	2.52	2.63	4.45	64.34	0.04	0.17	1.47	0.21
Brown-Forsythe test	F-value	0.52	1.13	1.07	0.95	0.83	0.53	2.68	2.99	1.89	0.69	0.83
	p-value	0.70	0.37	0.46	0.53	0.57	0.67	0.17	0.06	0.18	0.63	0.51

Table S5

Urine metal concentrations in relation to household distance to mine.

		Urinary Metal Concentrations (µg/L)										
		Al	**Cr**	**Mn**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Cd**	**Pb**	**Hg**
ALL (n=23)	Mean	17.55	0.56	0.67	0.47	0.25	5.82	97.62	3.22	0.14	0.31	0.17
	Std Dev	32.89	0.42	1.19	0.64	0.57	5.88	80.89	4.81	0.06	0.27	0.17
	Median	2.71	0.36	0.05	0.24	0.07	3.07	83.84	0.06	0.11	0.23	0.11
	Min	2.71	0.02	0.04	0.03	0.04	0.15	11.74	0.04	0.05	0.12	0.04
	Max	113.44	1.75	4.35	2.52	2.63	19.01	352.00	16.71	0.27	1.47	0.70
Results Stratified According to Distance to Mine												
Close (n=11)	Mean	11.07	0.68	0.33	0.22	0.17	9.56	142.27	5.35	0.16	0.23	0.24
	Std Dev	17.36	0.47	0.61	0.14	0.32	6.31	91.36	5.63	0.07	0.09	0.22
	Min	2.71	0.02	0.05	0.04	0.04	0.57	31.18	0.04	0.07	0.12	0.04
	Max	55.06	1.75	2.07	0.56	1.13	19.01	352.00	16.71	0.27	0.41	0.70
Mid (n=4)	Mean	10.03	0.36	0.76	0.77	0.07	1.30	50.73	0.10	0.11	0.31	0.05
	Std Dev	14.63	0.00	1.43	1.02	0.00	2.30	51.28	0.13	0.06	0.17	0.01
	Min	2.71	0.36	0.04	0.03	0.07	0.15	11.74	0.04	0.05	0.16	0.04
	Max	31.98	0.36	2.91	2.22	0.07	4.75	121.34	0.29	0.19	0.55	0.07
Far (n=8)	Mean	30.22	0.50	1.10	0.65	0.45	2.94	59.68	1.84	0.12	0.42	0.12
	Std Dev	50.94	0.44	1.62	0.79	0.90	2.54	38.50	3.55	0.04	0.44	0.06
	Min	2.71	0.25	0.05	0.10	0.07	0.15	13.12	0.04	0.08	0.17	0.06
	Max	113.44	1.59	4.35	2.52	2.63	8.34	116.98	9.58	0.20	1.47	0.21
Brown-Forsythe test	F-value	0.97	1.42	0.78	1.04	0.89	10.28	5.64	4.21	1.90	1.01	4.69
	p-value	0.41	0.27	0.48	0.41	0.45	0.00	0.01	0.03	0.19	0.40	0.03

Table S6

Influence of age and gender on blood metals.

		Al	Mn	Co	Ni	Cu	Zn	As	Cd	Pb	Hg
AGE	Spearman's rho	-0.14	-0.19	-0.03	0.04	-0.31	0.01	-0.03	-0.09	-0.16	-0.07
	P-value	0.52	0.39	0.91	0.87	0.16	0.96	0.89	0.68	0.45	0.74
GENDER	Total (n=23)	51.90	13.81	0.50	2.40	855.93	6818.50	4.18	1.35	26.76	3.09
	Male (n=15)	43.68	12.63	0.51	2.48	812.93	7184.67	4.19	1.37	29.72	3.36
	Female (n=8)	67.31	16.03	0.47	2.25	936.56	6131.94	4.16	1.32	21.21	2.58
	P-value	0.02	0.04	0.76	0.85	0.11	0.04	0.95	0.77	0.05	0.50

Table S7

Influence of age and gender on urine metals.

		Al	Cr	Mn	Co	Ni	Cu	Zn	As	Cd	Pb	Hg
AGE	Spearman's rho	0.27	-0.22	0.46	0.14	0.17	-0.26	-0.54	-0.58	-0.33	0.11	-0.55
	P-value	0.22	0.32	0.03	0.52	0.44	0.23	0.01	0.00	0.13	0.63	0.01
GENDER	Total (n=23)	17.55	0.56	0.67	0.47	0.25	5.82	97.62	3.22	0.14	0.31	0.17
	Male (n=15)	18.08	0.49	0.70	0.51	0.31	5.17	100.76	2.82	0.13	0.34	0.14
	Female (n=8)	16.55	0.69	0.63	0.38	0.12	7.05	91.74	3.96	0.16	0.26	0.21
	P-value	0.92	0.29	0.89	0.63	0.46	0.48	0.81	0.60	0.28	0.54	0.34

Table S8

Dietary survey results stratified by occupation. Values listed are number of servings per week, except for tortillas which are number per day. No attempt was made to account for portion sizes.

	No. of Servings (All Participants)					Mean No. of Servings (Stratified According to Occupation)					
Food Item	Mean	St Dev	Median	Min	Max	Miner	Farmer	Teacher	Other	F-value	P-value
Milk, cow	0.6	1.6	0	0	7	0.4	1.0	0.0	0.0	0.57	0.64
Milk, powder	2.0	4.3	0	0	14	6.0	0.2	3.5	0.0	3.26	0.04
Cheese	1.0	2.4	0	0	7	2.8	0.3	1.8	0.0	1.73	0.20
Cream	0.5	1.2	0	0	4	1.4	0.1	0.8	0.0	1.91	0.16
Eggs	4.9	5.2	3	0	21	10.0	3.7	4.0	1.7	2.73	0.07
Fruits	18.7	17.8	14	0	60	20.8	13.6	29.0	20.3	0.75	0.54
Vegetables	3.8	3.9	2	0	17	4.4	4.6	3.5	0.0	1.23	0.33
Beans	5.3	4.1	4	1	14	7.2	4.2	7.5	3.0	1.37	0.28
Fish	0.2	0.5	0	0	2	0.2	0.1	0.5	0.0	0.80	0.51
Chicken	0.8	1.3	0	0	4	2.4	0.2	1.0	0.0	8.57	0.00
Beef	1.4	1.0	1	0	4	2.8	1.0	1.3	1.0	9.53	0.00
Rice	3.3	2.2	3	0	7	6.2	1.8	3.5	3.3	0.39	0.76
Tortilla	16.1	5.8	15	9	36	16.8	15.2	18.8	15.0	2.57	0.08
Corn Atol	10.8	7.3	10	0	21	6.2	10.6	18.3	9.3	5.41	0.01
Alcohol	0.8	2.2	0	0	9	3.6	0.0	0.0	0.3	0.57	0.64

Table S9

Self-reported general health assessment. Individuals reported their health as either 'poor', 'average', or 'excellent', and data are stratified according to occupation and household distance to the mine.

	Poor	**Average**	**Excellent**
TOTAL (n=23)	39.1%	43.5%	17.4%
Occupation			
Miner (n=5)	20.0%	20.0%	60.0%
Farmer (n=11)	64.5%	45.5%	0%
Teacher (n=4)	50.0%	50.0%	0%
Other (n=3)	0%	66.7%	33.3%
Household Distance to Mine			
Close (n=11)	36.4%	45.5%	18.1%
Mid (n=4)	50.0%	50.0%	0%
Far (n=8)	37.5%	37.5%	25.0%

Table S10

Self-reported health assessment of physiological systems. Individuals self-reported specific health issues (data coded as 'yes' or 'no' for a particular physiological system) with respect to occupation and household distance to the mine. Values refer to percent within a group indicating yes to that particular health issue (for example, 13% of all participants complained of issues related to 'hearing' while 87% did not).

	Hearing	**Vision**	**Gastro-intestinal**	**Neurological**	**Respiratory**	**Renal**	**Dermal**
ALL (n=23)	13%	52%	48%	70%	39%	65%	22%
Stratified According to Occupation							
Miner (n=5)	0%	0%	20%	40%	20%	60%	20%
Farmer (n=11)	9%	73%	55%	91%	45%	64%	27%
Teacher (n=4)	25%	25%	25%	50%	25%	75%	0%
Other (n=3)	33%	100%	100%	67%	67%	67%	33%
Stratified According to Household Distance to Mine							
Close (n=11)	18%	27%	18%	64%	27%	64%	18%
Mid (n=4)	0%	50%	50%	100%	0%	75%	0%
Far (n=8)	12%	87%	87%	62%	75%	62%	37%

Table S11

Metal concentrations in river water. Concentrations represent mean (ug/L) ± standard deviation of two readings. Benchmark concentrations were obtained from NOAA SQuiRTs.

Site ID	**Name**	**Al**	**Mn**	**Co**	**Zn**	**As**
A	Rio Tzala	9.30±0.15b	0.50±0.06c	0.01±0.00a	0.07±0.00	0.16±0.03b
B	Tailings Creek	208.60±51.05a	26.99±1.44a	0.23±0.06b	0.99±0.37	0.06±0.03b
C	Quivichil Creek	36.18±7.34b	10.8±3.48b	0.06±0.01a	0.07±0.00	0.40±0.03a
D	Rio Cuilco	14.20 ± 16.26b	0.40±0.49c	0.01±0.00a	5.40±7.54	0.05±0.01b
	ANOVAs	<0.005	<0.001	<0.01	0.51	<0.001
Benchmark concentration (ug/L) for inorganics in surface water (freshwater, chronic)						
		87	80	3	120	150

Table S12

Metal concentrations in river sediment. Concentrations represent mean (ug/g) ± standard deviation of two readings. Benchmark concentrations were obtained from NOAA Squirts (*response.restoration.noaa.gov/cpr/sediment/squirt/squirt.html*).

Site ID	**Name**	**Al**	**Cr**	**Mn**	**Co**	**Cu**	**Zn**	**As**	**Pb**
A	Rio Tzala	176.78±5.96	0.06±0.06 b	35.24±9.30	0.26±0.04b	0.07±0.01 b	2.73±1.01	0.83±1.07	0.56±0.40
B	Tailings Creek	267.78±75.05	0.12±0.01 b	72.74±5.13	0.75±0.05a	0.27±0.00 a	4.08±0.51	0.52±0.12	0.74±0.08
C	Quivichil Creek	180.84±52.21	0.01±0.00b	46.13±32.19	0.36±0.16a,b	0.04±0.03b	2.20±1.23	0.31±0.35	0.65±0.62
D	Rio Cuilco	195.53±54.52	0.54±0.09a	51.98±18.09	0.65±0.09 a,b	0.39±0.09a	3.10±0.98	0.55±0.24	0.72±0.09
	ANOVAs	0.42	0.02	0.42	0.04	0.02	0.41	0.88	0.97
Benchmark concentration (ug/g) for inorganics in freshwater sediments									
	Squirt Regulatory Value Sediment(ug/g)	0.26%	7-13	400	10	10-25	7-38	1.1	4-17

Table S13

Metal concentrations in community water (taps and springs). Concentrations are listed as ug/L. Note that several of the water samples were below limit of detections, and were assigned a value of ½ LOD. Note, Cr, Ni, Cu, and Pb not detected in any tap water sample and are not listed below. Benchmark concentrations were obtained from EPA's National Secondary Drinking Water Regulations.

A) COMMUNITY DRINKING WATER SOURCES						
Description	Location	Al	Mn	Co	Zn	As
Tap, Church	Chininguitz	2.70	0.05	0.01	19.75	0.04
Tap, School	Chininguitz	10.79	0.04	0.01	1.06	0.06
Tap, School	SJX	2.70	0.05	0.01	62.50	0.04
Tap, Residential Home	SJX	2.70	0.05	0.01	51.02	0.04
Tap, Community Hall	SLT	37.35	10.35	0.10	0.07	0.04
Tap, Church	San Miguel	2.70	0.05	0.01	163.70	0.04
Bottled Water	San Miguel	2.70	0.05	0.01	0.07	0.22
	Mean	8.81	1.52	0.02	42.59	0.07
	Std Dev	12.94	3.89	0.03	59.16	0.07
	Median	2.70	0.05	0.01	19.75	0.04
B) SPRING WATER SOURCES						
Description	Location	Al	Mn	Co	Zn	As
Spring	CHI	9.54	0.09	0.01	0.07	0.04
Spring	STP	19.16	0.11	0.01	0.07	0.08
Spring	SLT	39.55	10.85	0.11	0.07	0.04
	Mean	22.75	3.68	0.04	0.07	0.05
	Std Dev	15.33	6.21	0.06	0.00	0.02
	Median	19.16	0.11	0.01	0.07	0.04
C) EPA's National Secondary Drinking Water Criteria value						
		50-200 ug/L	50 ug/L	1000 ug/L	5000 ug/L	10 ug/L

Table S14

Metal concentrations in community soil. Concentrations are listed as ug/g. Benchmark concentrations were obtained from NOAA Squirts (*response.restoration.noaa.gov/cpr/sediment/squirt/squirt.html*).

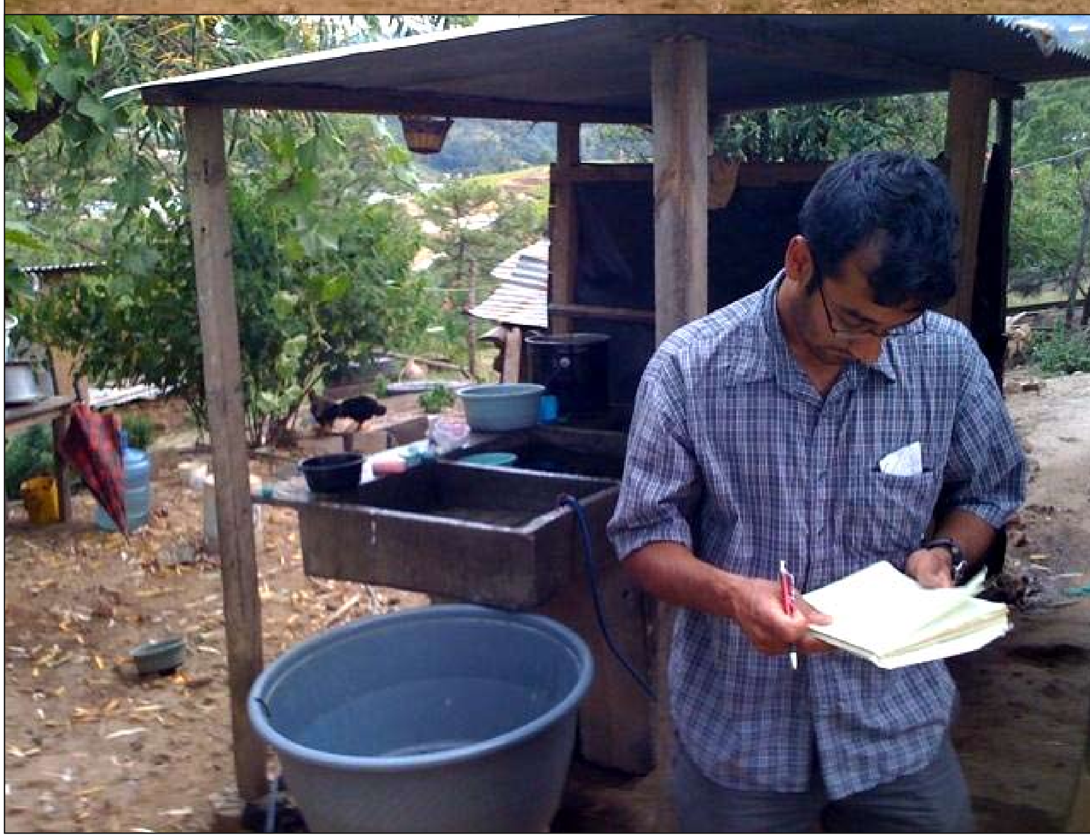
Description	**Location**	**Al**	**Cr**	**Mn**	**Co**	**Cu**	**Zn**	**As**	**Pb**
Church yard	Chininguitz	242.53	0.09	31.37	0.36	0.01	1.86	0.07	0.27
Football pitch	Chininguitz	158.14	0.03	38.45	0.45	0.01	2.09	0.07	0.40
Cornfield	Chininguitz	175.99	0.06	19.95	0.30	0.01	5.12	0.04	0.32
School yard	Chininguitz	242.18	0.03	56.39	0.61	0.14	0.65	0.14	0.39
Football pitch	SJX	232.69	0.03	19.64	0.21	0.20	2.12	0.12	0.56
Cornfield	SJX	391.25	0.04	33.01	0.24	0.37	3.70	0.16	0.54
Football pitch	Salitre	144.50	0.41	17.91	0.65	0.06	1.41	0.09	0.54
	Mean	226.75	0.09	30.96	0.40	0.12	2.42	0.10	0.43
	Std Dev	83.30	0.13	13.70	0.18	0.14	1.51	0.04	0.12
	Median	232.69	0.03	31.37	0.36	0.06	2.09	0.09	0.40
Mean background soil concentrations (SQUIRTS)									
		4.7%	<37	330	6.7	17	48	5.2	16

Appendix B: Supplementary Photos

Sampling soil in Chininguitz

Water from church tap, Chininguitz

Sampling in San José Ixcaqniche - School Soccer Field.



Water at a San José Ixcaqniche house.

Cattle browse near Tailings Creek, Site B.

Sampling at Quivichil Creek, Site C.

Rio Cuilco, Site D.

Gear used for sampling at Rio Cuilco.

Water tap in Church at San Miguel Ixtahuacan.

Leaving the area.