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A Combined Ecological and Epidemiologic Investigation of Metals Exposure amongst Indigenous Peoples Near the Marlin Mine in Western Guatemala

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Abstract

In August 2009 a combined epidemiological and ecological pilot study was conducted to investigate allegations of human rights abuses in the form of exposures to toxic metals experienced by mine workers and Indigenous Mam Mayan near the Marlin Mine in Guatemala. In the human study there were no differences in blood and urine metals when comparing five mine workers with 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 had significantly 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 (aluminum, manganese, cobalt) were found significantly elevated 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 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. The authors conclude that more robust studies are needed while parallel efforts to minimize the ecological and human impacts of mining proceed. This is critical particularly as the impact of the exposures found could be greatly magnified by expected increases

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in mining activity over time, synergistic toxicity between metals, and susceptibility for the young and those with pre-existing disease.

Keywords

field study; exposure assessment; metals; ecological health; human health; indigenous peoples; human rights; mining

1.0 INTRODUCTION

The Marlin Mine is the largest gold and silver mine in Central America, located approximately 300 kilometers northwest of Guatemala City. The mine was commissioned in 2005 and commenced commercial production that same year (Marlin Mine 2009). It is owned by the Canadian mining company Goldcorp and operated locally by Montana Exploradora de Guatemala, S.A (Montana). The mine is approximately 5km^2 in area but located in a 1,000km^2 parcel of land that is actively being prospected (73 exploratory holes drilled in 2008). The mine consists of two open pits and one underground facility. It 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 (Gómez and Wade 2005). In brief, ore is removed via explosives and then crushed into sand and smaller sized grains. The grains are next leached with cyanide to precipitate out gold, silver, and other elements. The residual waste is contained within a tailings storage facility which continues to expand in size. Cyanide leaching is a common practice in such facilities (Eisler and Wiemeyer 2004; U.S. Environmental Protection Agency 1995). There are many cases where tailings storage facilities at gold and/or silver mines have leaked or accidently discharged waste materials, thus contaminating the local environment (U.S. Environmental Protection Agency 1995). Environmental degradation, including contamination of groundwater, surface water, soil and air with complex metals mixtures, as well as damage to wildlife, is commonly found near mining facilities and the impacts are known to last for decades (U.S. Environmental Protection Agency 1995).

In recent years the mine has been the subject of widespread protest despite the mine’s claim of local support for the project. Last year the Human Rights Office of the Archbishop of Guatemala received several allegations by area residents (mainly Mam Mayan Indigenous Peoples) that the Marlin Mine has caused negative human health effects, broad environmental degradation, and social unrest. Part of this evidence comprised of photographs claiming that indigenous residents, especially young children and the elderly, residing near the Marlin Mine are suffering from skin rashes, hair loss, respiratory difficulties, and other disorders, and that these are due to the mine’s pollution (Guindon and Springs 2009). Area residents claim they did not have these ailments until after the mine commenced operations, and have requested investigative assistance.

At the request through the Archbishop of Guatemala’s office, a multi-disciplinary team of investigators was assembled by Physicians for Human Rights and deployed to Guatemala to conduct a field mission between Aug 17 and 24, 2009. The goal of the three-member field team was to determine in an impartial and transparent manner whether there was science-based evidence of any adverse impact on ecological health (e.g., contamination of water and soil) and human health, as alleged. The primary aims of this study were to: 1) determine if mine workers had higher levels of metals than non-mine workers; 2) determine if levels of metals in humans and the environment varied according to their proximity to the mine; and 3) determine if levels of metals were related to self-reported health effects. To address these aims, a combined epidemiological and ecological study was conducted.

2.0 MATERIAL AND METHODS

2.1 Field Sites

A three-member research team conducted a field mission between Aug 17 and 24, 2009. To address the study aims, attention was focused on four communities located at varying distances from the mine in the San Marcos department in Western Guatemala. The targeted communities included (Figure 1): 1) San José Ixcaniche, adjacent to the mine; 2) Salitre, 3km north of the mine; 3) Siete Platos, 2km northeast of the mine; and 4) Chininguitz, 7km from the mine. Chininguitz is considered upstream of the mine and the furthest away, whereas the other three sites are located adjacent (San José Ixcaqniche) or downstream (Siete Platos, Salitre) of the mine. Operations were based out of San Miguel Ixtahuacán.

2.2 Human Subjects Interactions

Institutional Review Board (IRB) approval was obtained from the University of Michigan (HUM00031341) to protect the rights and welfare of the human research subjects. Prior to the visit, leaders (e.g., teachers, government officials) in each of the four communities were notified. Verbal 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. Aggregated results were disseminated back to community members in May 2010 via a meeting at the local parish center which was recorded and broadcast on the local radio station. It is noted that this study was not designed (and did not seek IRB approval) to include infants and children.

2.3 Surveys and Biological Samples

An oral survey was administered to gather self-reported information on participant demographics, occupation, and diet. The survey also captured self-reported measures of general and specific health status. Participants were first asked to assess their general health as “poor”, “average” or “excellent”, and then asked polar yes-no questions about physiological systems. Participants were allowed to elaborate upon all responses in a qualitative manner and responses were hand recorded by members of the research team.

Biological samples were collected from each participant for metals analysis. Blood was collected following sterile procedures via venipuncture of the antecubital fossa into BD Vacutainer tubes certified for trace metals analysis. Urine was collected in 120mL sterile plastic cups. About 30-50 strands of hair from the occipital region were cut close to the scalp. All 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 laboratory facility.

2.4 Community and Ecological Samples

In three of the communities surface soil (10-20g) was collected from prominent sites including school yards, soccer pitches, and agricultural fields. Communal drinking water (250mL) was also collected and acidified as described below. For reference, a bottle of commercially purchased water and drinking water from tap in the San Miguel Ixtahuacán parish were sampled.

Four river sites of varying distances from the mine and/or previously studied by the nonprofit agency, COPAE (2009) and the independent, community-based monitoring association (AMAC; http://commdev.org/section/projects/participatory_environmental_mo) were sampled (Figure 1; Table 1). The sites sampled included: A) Rio Tzala, 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 to the mine.

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. Water quality readings were taken at each river site by a YSI 556MPS probe (Yellow Springs, OH). Water was obtained from three springs located near the mine that were of use by community members, especially when communal 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.

2.5 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 U.S. EPA accredited methods (Method 7473) as previously published in our laboratory (Basu et al. 2009). Briefly, urine and blood samples were vortexed. Five hundred μL of sample was then placed into a quartz sampling. Hair (~2-5mg) was cleaned with acetone and milli-Q water, dried, weighed and directly placed into a nickel boat. Following introduction of samples into the machine's decomposition furnace, mercury vapour was liberated from the sample and carried to an absorbance cell by oxygen. Absorbance was 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 pressurized with either a hydrogen (H_2) or helium (He) reaction gas as previously described (Bazzi et al. 2008). Briefly, 100μL 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, 500 μL 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. 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.

For both the DMA-80 and the ICPMS, a series of rigorous analytical quality control measures were used (Table A.1). All biological samples were handled in a Class 100 and 1000 clean lab. 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 U.S. 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 (U.S. Environmental Protection Agency 2000). 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.

2.6 Statistical Analyses

Biomarkers of metals exposures were generally not normally distributed and as transformation schemes did not achieve normality for most metals, biomarkers were analyzed and reported without any transformations to maximize their interpretability. Tests for statistical significance included t-tests, analysis of variances (ANOVAs, including Brown-Forsythe), and spearman correlations. The primary relationships of interest were associations between biomarker of metals exposures with respect to occupation, geographical proximity to mine, self-reported measures of health, and other key covariates (age, gender, diet). For 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 as outlined in the text. All results are presented as mean values ± standard deviation, unless indicated.

3.0 RESULTS

3.1 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 fewer 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 (12±0 years) and miners (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.

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 of their household location in relation to the mine, 8/23 were categorized as “far” (households located >5km from the mine), 4/23 were categorized as “middle”, and 11/23 were categorized as “near”, living in communities adjacent to the mine (<2km from 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, $p<0.01$).

3.2 Metal Exposure Biomarkers

The exposure biomarker assessment focused on metal levels in blood and urine. The limit of detection (LOD) for each metal was calculated and deemed acceptable (Table A.1). 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. For all blood samples (except for one nickel reading), quantifiable results were obtained. For urine, several samples fell below detection limits and were thus assigned a value of one-half the detection limit.

Total mercury (0.10±0.10 μg/g; range 0.05 to 0.52 μg/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. Significant gender-related effects were found and included higher blood levels of manganese and aluminum in females and higher zinc and lead in males (data not shown). 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 A.2). 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. In general, most blood metals were within reference, 'normal' ranges reported elsewhere (focused on the U.S. population; Table 2). 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, and thus are of unclear significance.

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 (data not shown). Like the biomarker results from blood, there were no significant changes in urinary metals with respect to occupation (Table A.3). In contrast, 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 2). When urinary metals were compared according to household distance to the mine, several significant differences were found (Figure 2). Those residing closer to the mine had higher concentrations of urinary mercury, arsenic, copper and zinc. It should be noted, however, that none of the levels exceeded reference range values, and that urinary copper and zinc are seldom used as biomarkers of exposure.

3.3 Dietary Survey

The survey instrument was designed to capture broadly the dietary habits in the region, which to the team's 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 A.6). Notable was their significantly higher intake of high protein foods, such as eggs, chicken, and beef. Miners also consumed greater amounts of rice and cheese. The 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).

3.4 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 A.4). 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 A.5). 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. Individuals living the furthest distance from the mine tended to report more 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).

In the 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 (i.e., 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.

3.5 Community Water and Soil

Samples of drinking water were collected from neighborhood springs, community taps and residences, and from a commercial vendor. Several elements, including chromium, 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 (Table A.8). 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 U.S. EPA's National Drinking Water Regulations, although 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 A.9).

3.6 River Water Quality

Four river sites of varying distances from the mine were sampled (Table 1). 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 had significantly higher water pH, conductivity, and temperature when compared to the other two sites. It should also be noted that Sites B and C were also identified as creeks and thus contained shallow water with less flow.

In river water, 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 consistent patterns for metals in water (Figure 3). 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 imply that water metal concentrations are highest in sites directly beneath the mine. When compared to U.S. 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.

3.7 River Sediment

Sediment samples were collected from each of the four river sites (Table A.7). 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. 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 U.S. 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.

4.0 DISCUSSION

Owing to the need to collect rapidly high quality, scientifically robust evidence, the study was designed and deployed in a 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 a 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), thus resulting in a holistic examination of the situation. 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 upwards of 80 people attended each of our various community outreach events. Despite these limitations, the primary aims of this study were addressed by use of diverse and scientifically robust methods both in the field and the laboratory. The outcomes provide qualitative and generalized trends that enable conclusions to be drawn and the results can be used as a foundation to develop a more extensive investigation.

The first aim of the project was to determine if mine workers (n=5) have higher exposures to metals than non-mine workers (n=18). The results of this study indicate no difference in the concentrations of blood and urinary metals between mine workers and non-mine workers. The mine mandates regular blood testing for metals (e.g., mercury, lead, copper) for employees. A qualitative review of reports provided by two mine employees revealed high correspondence between our measurements and those conducted by the laboratory contracted by the mine. 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 report being in better general health than the other occupational groups, and were more likely to indicate “No” when asked about specific physiological issues. This may be related to the “healthy worker effect” - employed individuals, on average, tend to be in better health than those not employed (Li and Sung 1999). As indicated in the mine’s 2008 Annual Monitoring Report, all employees undergo regular safety training including regular (daily) safety updates and these practices were verified by each of the five miners that participated in this study (Marlin Mine 2009). Mine workers also receive health insurance and free access to the mine’s clinic. Associated with the “healthy worker effect”, the 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 (i.e., blood lead, urine mercury, arsenic, copper, zinc), concentrations were higher in residents that lived closest to 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. Further, significant differences in water quality measurements among the four ecological sites could be separated based on proximity to the mine. The combined results from the epidemiological and the ecological study suggest that geographic proximity to the Marlin mine is an important predictor of metals exposure.

Such an observation (i.e., elevated metals exposures) has previously been made in other communities that live close to large-scale mining operations (Banza et al. 2009; Hu et al. 2007; Bao et al. 2009).

The third aim of this study was to determine if human exposure to toxic metals is related with self-reported health effects. The purported health effects that initially drew attention were skin rashes, hair loss, and respiratory difficulties, particularly in the elderly and children. No clinical medical tests were used to assess these outcomes. While the researchers did not actively engage the elderly (although four participants >60 years old) and children (youngest was 20 years old), during the field study (which included visits to 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 were prevalent. Further, there was no clear relationship between self-reported health measures with a participant's household location or 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 (beyond the blood and urine metal levels) or diagnostic interpretations were made on individual participants.

While no striking associations were found between chemical exposures and health measures the results of this study demonstrate that individuals near the Marlin Mine may have higher exposures to some metals compared to those living farther away. As highlighted in Table 2, 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 (Carpenter et al. 1998; Grandjean and Landrigan 2006; Fowler et al. 2004). 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 cyanide or its metabolite, thiocyanate, 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 and should be further investigated (ATSDR 2006).

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 may occur through water rather than atmospheric deposition onto soils or general contamination of soil, but further work is required to substantiate this conclusion. Inhalation exposures are plausible and require further study.

Water quality and quantity in the region surrounding the Marlin mine are of concern. Many community members described how communal water taps and local springs run dry, which may result in the seasonal use of river water for cleaning or consumption. Many voiced concern in using river water owing to fears of contamination. The mine acknowledges that its practices include use of copious amounts of water (but that a high percentage is recycled), and that the region already suffers from limited water availability (Gómez and Wade 2005). The results from the study demonstrate that water resources in the area below the mine contain 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 region's water quality and quantity. 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 (U.S. Environmental Protection Agency 1995). There are many cases in the U.S. where tailings storage facilities at gold and/or silver mines (e.g., Rube Heap Leach Mine, Basin Creek Mine, Brewer Gold Mine, American Girl Mine, Carson Hill Gold Mine, Grey Eagle Mine, Jamestown Mine) that employ various cyanide leaching methods have leaked or accidently discharged waste materials, thus contaminating the local environment.

Though this investigation 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 (Edelstein 1998; Lima 2004; Unger et al. 1992). One participant commented "if the mine is contaminating us, then we need to leave our home and our lands." Another stated poignantly "if cattle die from using the river then who knows what will happen to us."

A brief perusal of the available information (e.g., news articles, photoblogs, annual reports from the Marlin Mine) indicates that much distrust and miscommunication exists among stakeholders (area residents, non-governmental organizations, representatives of the Marlin mine, government officials). This was evident to the research field team on numerous occasions as the term 'misinformacion' was heard every day. 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 in which 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 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” and “3-4 years ago crops - apricot, avocado, maize - started to not do well”. 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 (e.g., hunting, medicine gathering) that play integral roles in the community’s culture, spirituality, economy, and diet are limited (Kuhnlein and Chan 2000; Wheatley 1998). 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 (Mohai and Saha 2006; Elliott et al. 2004).

5.0 CONCLUSIONS

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. Using diverse scientific methods in epidemiology and ecology, some evidence of metals contamination was found in relation to the mine. While further research is clearly needed, this study responds to community concerns and helps to establish important baseline data. The findings of this study should be leveraged into a rigorous, prospective epidemiological study to assess comprehensively and characterize in detail pollutant exposures and potential human health effects in relation to the mine. Further, a carefully planned ecological study is needed to help monitor environmental quality on spatial and temporal scales. Finally, owing to the distrust and miscommunication that exists among and between stakeholders, 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. The panel should 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.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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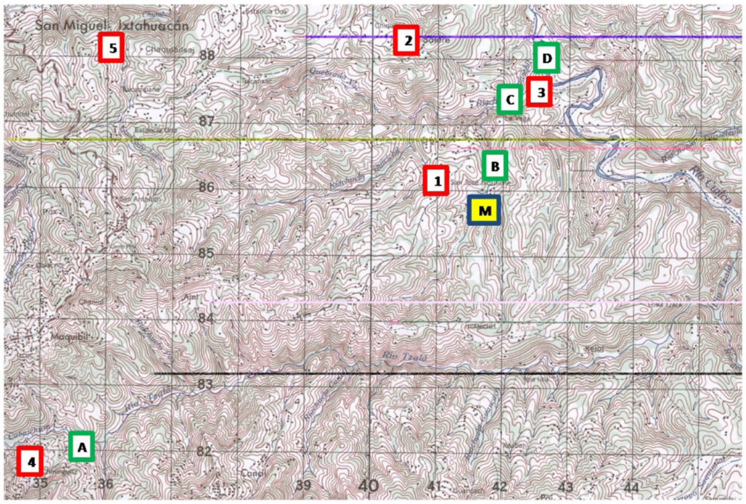

Figure 1.

Map of study area. Key: 1=San José Ixcaniche; 2=Salitre; 3=Siete Platos; 4=Chininguitz; 5=San Miguel Ixtahuacan; A=Rio Tzala; B=Tailings Creek; C=Quivichil Creek; D=Rio Cuilco; M=Marlin Mine. Map Source: Santa Barbara, Guatemala 1861 I E754 Edition 2DMA (Scale 1:50,000, Grid 1000m).

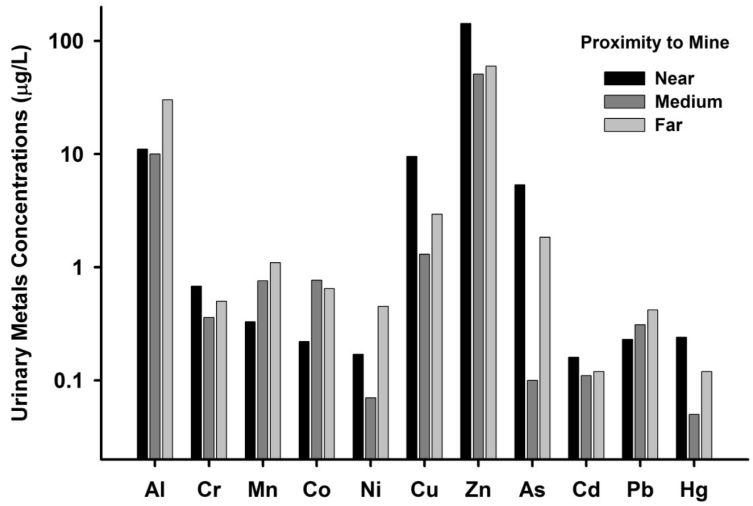

Figure 2.

Concentrations (µg/L) of metals in urine of participants (n=23) 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) were significantly higher in those living closest to the Marlin Mine compared to those living furthest away. Refer to Supplementary Table A.3 for additional information such as sample size and variance.

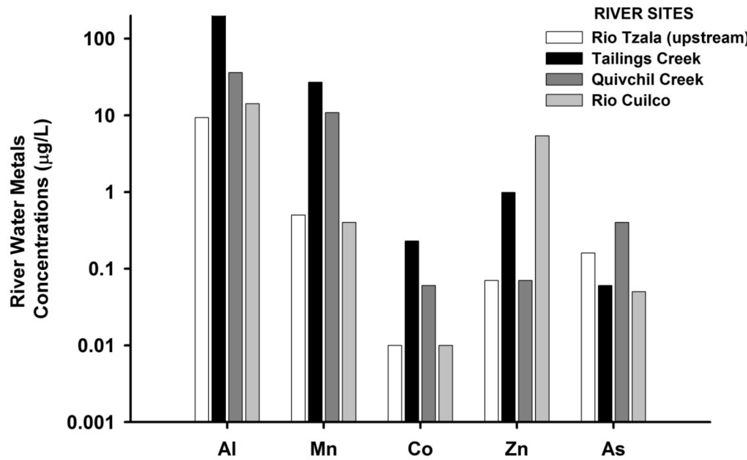

Figure 3.

Concentrations (µg/L) of metals in river water based on two samples collected per site. 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) were significantly elevated ($p<0.001$) in the sites below the Marlin Mine when compared to the reference upstream site (Rio Tzala).

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Table 1

Overview of river sites. Water quality parameters were significantly different ($p<0.001$) across sites as indicated by letters within a given column.

Site ID	Site Name	Description	GPS N	GPS W	Alt	Temp (°C)	pH	Cond. (ms/cm)
A	Rio Tzala	above the mine	15.21328	91.74979	7370	20.1±0.3[c]	7.47±0.04[b]	0.12±0.04[c]
B	Tailings Creek	located below tailings pond, flows into Quivichil Creek	15.251979	91.679244	5987	31.5±0.3[a]	7.84±0.03 [a]	0.38±0.01[a]
C	Quivichil Creek	below the mine, flows in Rio Cuilco	15.26447	91.67357	5317	26.5±0.4[b]	7.77±0.05[a]	0.31±0.00[b]
D	Rio Cuilco	below the mine in the town of Siete Platos	15.259885	91.667426	5322	20.3±0.8[c]	7.19±0.05[c]	0.13±0.02[c]

Table 2

Reference (normal) range or threshold values for metals in relation to concentrations measured in the current study. Cited references are indicated in the Table's footnote.

	Blood Concentrations (μg/L)		**Urine Concentrations (μg/L)**		**Toxic effects when present in excess**
	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 (upper reference; T); 160 (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)	<1 (T)	Central nervous system, respiratory inflammation
Cobalt (Co)	0.4 (0.2-1.5)	0.5 (T)	0.24 (0.03 - 2.52)	<2 (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 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 (A); <50 (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 (T)	Central nervous system

A - compiled from U.S. 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.