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ORIGINAL RESEARCH

Mercury Mining in Mexico: I. Community Engagement to Improve Health Outcomes from Artisanal Mining

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Mexico

Abstract

BACKGROUND Mercury is an element that cannot be destroyed and is a global threat to human and environmental health. In Latin America and the Caribbean, artisanal and small-scale gold mining represents the main source of mercury emissions, releases, and consumption. However, another source of concern is the primary production of mercury. In the case of Mexico, in the past 2 years the informal production of mercury mining has increased 10-fold. Considering this scenario, an intervention program was initiated to reduce health risks in the mining communities. The program's final goal is to introduce different alternatives in line to stop the mining of mercury, but introducing at the same time, a community-based development program.

OBJECTIVE The aim of this study was to present results from a preliminary study in the community of Plazuela, located in the municipality of Peñamiller in the State of Queretaro, Mexico.

METHODS Total mercury was measured in urine and environmental samples using atomic absorption spectrometry by cold vapor technique. Urine samples were collected from children aged 6-14 years and who had lived in the selected area from birth. Urine samples were also collected from miners who were currently working in the mine. To confirm the presence of mercury in the community, mining waste, water, soil, and sediment samples were collected from those high-risk areas identified by members of the community.

FINDINGS Children, women, and miners were heavily exposed to mercury (urine samples); and in agreement, we registered high concentrations of mercury in soils and sediments.

CONCLUSION Considering these results and taking into account that the risk perception toward mercury toxicity is very low in the community (mining is the only economic activity), an integral intervention program has started.

KEY WORDS mercury, mining, Minamata Convention, children's environmental health, Mexico

INTRODUCTION

In 2003, after having performed a global assessment, the United Nations Environment Program (UNEP) found that there was sufficient evidence of significant global adverse effects from mercury and its compounds to warrant further international action to reduce the risks to human health and the environment from the release of mercury and its compounds to the environment.[1] In January 2013,

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an intergovernmental negotiating committee agreed on the text of the Convention on Mercury, and in October 2013 the Convention was signed in Minamata, Japan, by 128 countries.[1] In its first article, the Minamata Convention states that its objective is to protect the human health and the environment from anthropogenic emissions and releases of mercury and mercury compounds.[1]

In Latin America and the Caribbean, artisanal and small-scale gold mining represents the main source of mercury emissions, releases, and consumption.[2] However, another source of concern is the primary production of mercury. In 2013, the global mining production of mercury was estimated at 1880 tons,[3] with 1600 tons being produced by China and 100 tons by Kyrgyzstan. In the case of Mexico, an average annual production of 13 tons was estimated during the 2007 to 2009 period, from informal primary mercury mining.[4] However, because Mexico has become the region's main supplier of mercury to net importing countries such as Bolivia, Colombia, Guyana, and Peru (countries with a significant presence of artisanal and small-scale gold mining),[2] in the past 2 years the informal production of mercury mining has increased 10-fold ($\geq$5 mining regions are now in operation in Mexico, 4 in the State of Queretaro and 1 in the State of San Luis Potosi).

Regarding mining, the Minamata Convention considers different approaches to reduce not only the use of mercury, but also health and environmental effects due to exposure to this metal. For example, the Convention establishes measures (Article 7 and Annex C) for artisanal mining. Parties who carry out those activities in their territory must take steps to reduce and where feasible, eliminate the use of mercury and mercury compounds, as well as the emissions and releases to the environment in the form of mercury, such as mining and processing. Moreover, Article 12 of the Convention states that each party shall endeavor to develop appropriate strategies for identifying and assessing sites contaminated by mercury. In accordance with these articles, the Convention also considers the promotion of appropriate health care services for prevention, treatment, and care of populations affected by exposure to mercury (Article 16); the promotion of education, training, and public awareness related to the effects of exposure to mercury and mercury compounds on human health and the environment (Article 18); and the promotion of research, development, and monitoring of levels of mercury in vulnerable populations and in environmental media (Article 19).

Mercury mining remains an important activity in Mexico, so much so that it is being extracted by informal miners using low-technology operations. As such, it can be assumed that mining areas are heavily polluted with this metal. In the context of the Minamata Convention, an intervention program was initiated to reduce health risks in mining communities. The program's final goal is to simultaneously introduce different alternatives to stop the mining of mercury and to initiate a community-based surveillance framework for the assessment of exposure sources including abandoned mines, mining wastes, water sources, and recreational areas for children. In this comprehensive program, children, women, miners, and biota have been identified as vulnerable groups. In the present review, we present results from the first pilot study conducted in a mining community (Plazuela) in the State of Queretaro.

METHODS

Site Description. Plazuela is a community located in the municipality of Peñamiller in the State of Queretaro, Mexico. Mercury has been mined in the area since precolonial times (indigenous groups like the Aztecs worked in the region). However, from the 1970s to 1980s, a rotary kiln produced hundreds of tons of mercury annually. Today, mercury is recovered using a low-technology process: After the ore is collected from the mines, it is crushed, screened, and then heated in a furnace; mercury is obtained once the vapors generated in the furnace are cooled. At least 3 mines have been operating using this rudimentary method in Plazuela since 2010. The mines are located within the community limits. It is important to take into account that in the recent past, recovering mercury from the mineral using furnaces placed not only in the mine but also in household backyards was common.

Study Population. Approximately 1000 inhabitants reside in Plazuela. Children attending primary school located in this community were screened for study eligibility through personal interviews. Those who had lived in the selected area from birth and who were between the ages of 6 and14 years at the time of the study were eligible to participate. After informed consent was obtained, a questionnaire was used to help document the history of each child and urinary samples were taken. Only workers currently working in the mine participated in this study. We were not able to collect urinary samples from those working in the furnaces.

Environmental Monitoring. To confirm the presence of mercury in the community, mining waste, water, soil, and sediment samples were collected from those high-risk areas identified by members of the community. Samples from spring and mine water were collected in polyethylene containers and acidified with concentrated nitric acid until a pH <2.0 was obtained. The samples were stored at 4°C until analysis. Surface soil samples (1-5 cm in depth) from recreational areas and sites affected by mine activities were collected in plastic bags. Areas repeatedly used by children either at school or at home (backyards) were included as part of the sampling area. Finally, surface sediment samples were collected in polyethylene containers from the creek where mine water is being pumped.

Analytical Studies. For the analysis of total mercury in soil and sediment samples, 0.5 g of sample were accurately weighed and placed in a teflon vessel, and 20 mL of a solution 25% HNO_3−10% HCl were added. The digestion was performed in a microwave oven (MDS-2000), and allowed to cool to room temperature. The digested sample was filtered using a Whatman filter paper grade 1 (pore size 11 μm) and diluted with deionized water to 25 mL. Then the sample was oxidized with potassium permanganate 5%. Total mercury was measured using atomic absorption spectrometry by cold vapor technique (Perkin Elmer Analyst 100 Atomic Absorption Spectrometer). The quantification limit for mercury was 0.5 μg/L. The digestion procedure for total mercury analysis was verified using the Standard Reference Material 2710a Montana I Soil of the National Institute of Standards and Technology. The recovery percentage was 98%.

For the analysis of mercury in urine and water, urine samples (first void samples) of approximately 100 mL were collected in polyethylene bottles and stored at 4°C until analysis. Then 5 mL of the sample were digested with 3 mL of concentrated nitric acid in a microwave oven (MARS 6), subsequently the samples were oxidized with potassium permanganate 5%. Total mercury was measured using atomic absorption spectrometry by cold vapor technique (Perkin Elmer Analyst 100 Atomic Absorption Spectrometer). The quantification limit for total mercury analysis was 0.5 μg/L. The digestion procedure for total mercury urine analysis was verified using the reference material, ClinCheck Urine Control (D-80992, Munich, Germany). The recovery percentage was 82%. Finally, the levels of mercury in urine were adjusted by creatinine (Cr).

Community-Based Risk Assessment. Community-based risk assessment (CBRA) refers to participatory methods to assess hazards, vulnerabilities, and capacities in support of community-based risk reduction interventions.[5] In compliance with the steps included in this framework, we took transect walks (systematic walks along a defined path across the community together with the local people to identify high-risk areas—areas of mercury exposure); we performed focal group meetings (with miners, women, and children); development of community risk maps were produced; risk perception exercises were implemented with women and children; and collection, analysis, and validation of secondary information was done with community members.

RESULTS

The first step to be able to work in a small rural community, heavily contaminated with toxins, is to involve the inhabitants in the study. The objective is to prepare a risk reduction strategy through the prioritization of environmental threats identified by the community itself, and through environmental assessments performed by the technical group. Therefore, our group is working with representatives of 3 vulnerable groups: miners, women, and children; who have a basic knowledge of the local situation, people, and their livelihoods; the type and extent of threats in the locality (including pathways of exposure); and a traditional preparedness and coping strategy to face existing threats.

Plazuela is classified as a very poor community by Mexican government indicators and the unemployment rate is high. The daily income ranges from US $1 to $3. The only source of employment is the mine, and thus, for children, women, and miners, the risk perception around mining activities is very low. For example, none of the miners or the women in their focal groups was able to identify risks related to the mine or to the extraction of mercury (the only risk identified by the miners was the accidents within the mine). Only 1 child identified a risk related to mining, shown in the drawing of the pumping of water mine into the creek (Fig. 1).

As a result of the focal group meetings and the transect walks, 4 environmental threats not related to mercury extraction were recognized:

1. Indoor pesticide spraying;
2. Use of lead-glazed pottery for cooking;
3. Use of wood as a fuel for indoor domestic cooking; and
4. Use of spring water for drinking and cooking.

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Figure 1. **The "bad" thing in my community.**

Thus, the community is exposed to several toxins in addition to mercury. It is important to mention that fish is not included in the normal diet and rice is not produced in the area. While working with the children, our group identified domestic waste as the most important source of contamination for the community.

Among the social threats, the 3 most important selected by the miners and women included:

1. Migration due to unemployment;
2. Division between the miners and the non-miners because the jobs in the mine are defined by local authorities; and
3. Alcoholism and drug addiction in adolescents.

Furthermore, we were able to identify among the miners, individuals aged between 14 and 18 years. The community identified domestic violence and violence related to gender as the 2 most important issues in the community for children.

Health services are limited; community members only identified 1 health professional (a medical student in social service). Among the most frequent diseases recognized by the community were respiratory infections, diarrhea, and undernutrition in children; whereas diabetes, hypertension, and respiratory infections were prioritized for adults.

For environmental studies, the community selected likely high-risk areas for mercury contamination. In those areas, soil or sediment samples were collected. Results are depicted in Table 1. It can be observed that all the samples were above the Mexican guideline's for mercury in residential soils (23 mg/kg)[6] with concentrations up to 150 times the Mexican guideline. Meanwhile, in the contaminated area where the rotary kiln was once operating, levels of mercury in the soil were found to be up to 340 times higher than the guideline. In sediments, concentrations were found to be up to 1400 times higher than this guideline. In concerning water sources, nondetectable mercury levels were found in the water spring but in the mine water levels of up to 100 ppb were registered (the World Health Organization guideline for drinking water is 6 ppb).[7] Finally, mercury concentrations in mine waste samples were detected at 4500 mg/kg.

Taking into account the levels of mercury found in environmental samples, a preliminary exposure assessment study was performed in the community, with urinary samples from 16 volunteers. Results are shown in Table 2. It can be observed that in all the urine samples, mercury was found to be at levels above the respective action level,[8-10] and at least 50% of the studied population presented levels above their respective risk levels.[8,10,11]

Table 1. **Mercury Levels in Environmental Samples in Plazuela (mg/kg)**

Group	Domestic Soil	Sediments	Contaminated Area*
N	7	5	4
Mean	790.9	9004	5231
Minimum	28.8	107.8	3979
Percentile 25	78.9	166.4	4103
Median	256.2	1239	4541
Percentile 75	915.9	21,724.0	7050
Maximum	3493	33,589.0	7864

Mexican guideline for residential areas: 23 mg/kg.[5]
* Contaminated area is the area where the rotary kyln used to be.

Table 2. Urinary Mercury Levels* in Individuals Living in Plazuela (μg/g Cr)

Group	Children	Women	Miners
N	5	3	8
Mean	22.5	39.7	54.1
Minimum	6.1	20.2	11.5
Percentile 25	13.8	20.2	17.8
Median	22.7	35.5	52.9
Percentile 75	31.1	63.4	70.3
Maximum	37.7	63.4	144.0
Action level	5	5	25
Risk level	20	20	35

* Action level for children and women[8,9]risk level for children and women[8]; action level for workers[10]risk level for workers (occupational guideline).[10,11]

DISCUSSION

Results from this study demonstrate that the site is heavily polluted with mercury attributable to historical (the rotary kiln area) and present (mining activities) activities. Urinary mercury levels showed an important exposure of the population to this metal. As such, mercury can be declared a toxin of high concern for this community. However, the community of Plazuela has further social and environmental threats, which is why a comprehensive intervention program is needed; and thus, to start a risk reduction strategy in Plazuela, we have activated the 5-step CHILD framework that includes:

1. Community-based risk characterization;
2. Habilitation;
3. Intervention;
4. Laws and regulation; and
5. Development.

Community-Based Risk Characterization. In this step, the results are expressed in terms of aggregate and cumulative exposure. Thus, regarding aggregate exposure it is important to take into account that mercury was found in sediments and soil samples, meaning there is risk for ingestion especially by children; whereas because mercury is a volatile compound (miners are obtaining elemental mercury), inhalation might be the most important route of exposure, in this case not only for the general population but also for the miners (particularly in the recovery area where mercury vapors are produced). In agreement with this information, urinary mercury levels found in children, women, and miners were above normal (Table 2). Regarding cumulative exposure, the community might be exposed to other chemicals in addition to mercury. For example:

1. Hexachlorobenzene, formaldehyde, and polycyclic aromatic hydrocarbons due to smoke exposure from indoor cooking fires and smoke from the furnaces in the mercury recovery areas;
2. Lead from lead-glazed ceramics;
3. Pesticides used indoors; and
4. Other toxic elements probably present in the mined mineral (such as arsenic or manganese).

Furthermore, the microorganisms responsible for diarrhea and respiratory infections must be considered. These were identified by the community as diseases of concern. The first priority is to control the pathways of exposure related to mercury, including the development of alternatives to mercury mining as this is the only source of employment in the site. The second priority is to increase the sample of individuals for the analysis of urinary mercury (especially children and workers). Finally, the third priority is to start an exposure assessment to other chemicals and to study the quality of drinking water sources.

Habilitation. The idea behind habilitation is to improve community capabilities to increase the options to deal with environmental, biological, and social threats under a context of poverty and inequity. Thus, capacity-building programs are the elements of the first action plan in this phase of the CHILD framework. To achieve this objective, we have been working in 2 areas: the organization of technical groups and the establishment of community centers. The purpose is to have continuous presence in the regions because the goal is to introduce programs for community development. Regarding professional training, the first phase has consisted on the organization of a telehealth program for clinical toxicology. For this "e-TOX" program, we have organized a Poison Control Center and educational programs for health promotion. Additionally, we have achieved an agreement between the municipality of Peñamiller and the State University of the Region (Autonomous University of Queretaro) to open a facility that will allow the increase of the presence of the academic sector in the region, with the sole goal of increasing the capabilities of the community for its development.

Intervention. Taking the risk characterization results into account, at this point 3 projects are being performed with the help of local authorities:

1. Risk communication programs with children, women, and miners will help increase education, training, and public awareness related to the effects of exposure to mercury and other chemicals.

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2. Environmental intervention actions will decrease the cumulative exposure to pollutants, including site remediation in the most polluted areas of the community.
3. Because there were 632 mercury mines recorded in 1968 in the studied regions, environmental surveillance of abandoned mines is necessary.[4]

Furthermore, different technological alternatives to decrease the presence of mercury in the environment are being developed by 2 Mexican universities.

Laws and Regulations. In this regard, we are working with the state government of Queretaro to develop a risk reduction program in the context of the Minamata Convention. Additionally, we have built a National Children's Environmental Health Network, with the intention of reviewing the national guidelines for lead, arsenic, and mercury. The idea is to work under the concept of the human biological monitoring (HBM) values that have been developed by the Commission on Human Biological Monitoring of the German Government.[8] In principle, 2 different HBM values are recommended by the Commission: HBM I, the concentration of an environmental toxin in human biological material below which there is no risk for adverse health effects in individuals of the general population; and HBM II, the concentration of an environmental toxin in human biological material above which there is an increased risk for adverse health effects in susceptible individuals of the general population. The HBM I value can be considered an alert value (from the toxicologic point of view) that our group has defined as an action level to start prevention actions. The HBM II value represents a risk level at which attempts should be undertaken to reduce the level of exposure immediately and to carry out further medical examinations. It is important to mention that in Plazuela, all individuals within the studied population had urinary mercury levels above the HBM I and that 50% had concentrations above the HBM II.

Development. The final stage of the CHILD framework is sustainable human development, working in 5 areas (taken from the new millennium development goals): environment, economy, health, social issues, and peace. In this scenario 2 alternatives for employment are being studied: further mining (polymetallic deposits) and protected agricultural activities. Moreover, new education activities are being planned by the University of Queretaro.

CONCLUSION

We have shown with a limited sample size that mercury mining in this region of Mexico is a threat for the environment and for human health, as has been reported previously in other countries.[12,13] Therefore, an intervention program under the goals of the Minamata Convention is needed; not only for Plazuela but for all the communities in the region that are exposed to mercury, including those exposed to abandoned mercury mines.

REFERENCES

1. United Nations Environment Program. Minamata Convention on mercury. Geneva, Switzerland: UNEP; 2013.
2. United Nations Environment Program. The Minamata Convention on mercury and its implementation in the Latin America and Caribbean region. Uruguay: United Nations Environment Programme/Regional Office for Latin America and the Caribbean (UNEP/ROLAC); 2014.
3. U.S. Geological Survey. Minerals yearbook, mercury. Washington, D.C.: U.S. Geological Survey; 2013.
4. Commission for Environmental Cooperation. An assessment of primary and secondary mercury supplies in Mexico. Montreal, Canada: Commission for Environmental Cooperation; 2013.
5. Comprehensive Disaster Management Programme. A facilitators guidebook for community risk assessment and risk reduction action plan. Dhaka, Bangladesh: Government of the Peoples Republic of Bangladesh; 2007:60.
6. Mexican Official Standard. NOM-147-SEMARNAT/SSA1-2004. Establishing criteria for determining the concentrations of remediation of contaminated by arsenic, barium, beryllium, cadmium, hexavalent chromium, mercury, nickel, silver, lead, selenium, thallium and/or vanadium soils. Official Journal of the Nation. March 2007.
7. World Health Organization. Guidelines for drinking-water quality. 4th ed. Geneva, Switzerland: WHO; 2011.
8. Schulz C, Angerer J, Ewers U, Kolossa-Gehring M. The German Human Biomonitoring Commission. Int J Hyg Environ Health 2007;210:373–82.
9. Agency for Toxic Substances and Disease Registry. Mercury exposure investigation using serial urine testing and medical records review. Atlanta, Georgia: New Jersey Department of Health and Senior Services Under Cooperative Agreement with the U. S. Department of Health and Human Services Agency for Toxic Substances and Disease Registry; 2007.
10. Hazardous chemicals requiring health monitoring. Mercury (inorganic). Safe Work Australia, 2013. Available at: http://www.safeworkaustralia.gov.au/sites/SWA/about/Publications/

Documents/765/Hazardous-chemicals-requiring-health-monitoring.pdf. Accessed March 21, 2014.
11. American Conference of Governmental Industrial Hygienists. Documentation of the biological exposure indices. 7th ed. Cincinnati, OH: ACGIH; 2011.
12. Qiu G, Feng X. Synthesis of current data for Hg in areas of geologic resource extraction contamination and aquatic systems in China. Sci Total Environ 2012;421–422:59–72.
13. Ordóñez A, Álvarez R, Loredo J. Asturian mercury mining district (Spain) and the environment: a review. Environ Sci Pollut Res Int 2013;20:7490–508.