
Mercury exposure and risk among women of childbearing age in Madre de Dios, Peru

David J.X. Gonzalez, MESc 2015

Abstract

The rapid growth of artisanal small-scale gold mining (ASGM) in Madre de Dios, Peru, has led to widespread mercury (Hg) use throughout this Amazonian state. Mercury that is released into the environment through ASGM is converted through natural processes to methylmercury (MeHg), a highly toxic and bioavailable form that accumulates in fish. People who eat fish contaminated with MeHg are at risk of mercury intoxication, which can damage the neurological system. Fetuses and infants are particularly susceptible, and mothers of childbearing age are considered a population of concern as they may pass Hg on to their children during pregnancy or through breastfeeding. Previous studies have found elevated mercury in residents of Madre de Dios, but there is a gap in understanding the Hg risk factors and level of knowledge of Hg risk among the population most affected by mercury contamination.

This study examines mercury exposure and risk factors among women of childbearing age (18–49 years old) living in three cities in Madre de Dios (n = 170). Study participants were selected randomly and asked for their informed verbal and written consent. Each study participant responded to a qualitative survey, which covered personal information and risk factors associated with Hg exposure. Hair samples were collected from each study participant and analyzed for total mercury content (THg). The study population had an average of 1.97 ppm THg (range: 0.01 ppm to 8.11 ppm), nearly two times the World Health Organization reference limit of 1 ppm. Some 78% of the study population had THg levels > 1 ppm. Elevated mercury levels were found outside of the mining zone in Iberia, where residents had an average of 2.37 ppm THg. Many study participants were worried about mercury contamination but had highly limited understanding of the health risks associated with mercury exposure. An immediate health response is needed to reduce the risk of Hg exposure in Madre de Dios, and an educational campaign could have immediate benefits.

El mercurio (Hg) es un contaminante global que tiene efectos dañinos para la salud humana y el medio ambiente. El crecimiento de la minería aurífera artesanal y a pequeña escala en Madre de Dios, Perú, ha subido el uso del mercurio (Hg) en este estado amazónico. Comunidades que viven in áreas afectadas de la minería, incluidas las comunidades de la cuenca Amazónica, tienen un nivel de riesgo elevado de exposición al mercurio. El mercurio contamina el medio ambiente y a través de procesos naturales para el metilmercurio (MeHg), una forma altamente tóxica y biodisponible que se acumula en los peces. Las personas que comen pescado contaminado con MeHg corren el riesgo de intoxicación por mercurio que puede dañar el sistema neurológico. Los fetos y los recién nacidos son particularmente susceptibles, y las madres pueden pasar el Hg a sus hijos durante el embarazo o la lactancia. Estudios previos han encontrado niveles elevados de Hg en los residentes de Madre de Dios, pero hay una brecha en la comprensión de los factores de riesgo de Hg y el nivel de conocimiento del riesgo Hg entre la población más afectada por la contaminación por mercurio.

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Este estudio examina la exposición al mercurio y factores de riesgo entre las mujeres en edad fértil (18-49 años) que viven en tres ciudades de Madre de Dios (n = 170). Los participantes del estudio fueron seleccionados al azar y les pide su consentimiento informado verbal y escrito. Cada participante del estudio respondieron a una encuesta cualitativa, que cubría la información y los factores de riesgo personales asociados a la exposición Hg. Las muestras de cabello fueron recogidas de cada participante del estudio y los contenidos de mercurio total (THg) fueron analizados. La población del estudio tuvo un promedio de 1.97 ppm THg (0,01 ppm a 8,11 ppm), dos veces más del límite de referencia Organización Mundial de la Salud (OMS) de 1 ppm. El 78% de la población estudiada tenía niveles de THg en exceso de 1 ppm. Se encontraron niveles elevados de mercurio fuera de la zona minera de Iberia, donde los residentes tenían un promedio de 2.37 ppm THg. Muchos participantes en el estudio están preocupados por la contaminación por mercurio, pero ellas tienen muy un nivel baja de comprensión de los riesgos que Hg presenta para la salud. Se necesita una respuesta de salud pública para reducir el riesgo de la exposición al Hg en Madre de Dios. Una campaña de educación podría tener beneficios inmediatos.

Introduction

Mercury (Hg) contamination in the Peruvian Amazon is a growing health and environmental concern (Driscol et al. 2013, Swenson et al. 2011). The single most significant source of Hg contamination throughout the world is artisanal and small-scale gold mining (ASGM), which accounts for approximately 37% of total Hg released into the atmosphere each year (Gibb & O’Leary 2013). As the global demand for gold rose in the wake of the 2008 global financial crisis, there was increased pressure to exploit existing gold resources, such as those in the Peruvian Amazon (Swenson et al. 2011). Artisanal and small-scale gold miners have been active for decades in Madre de Dios, an Amazonian state in southeastern Peru (Gutleb et al. 1993, CAMEP 2013). However, there has been a drastic increase in ASGM activity in recent decades—between 1999 and 2012 the geographic extent of ASGM in Madre de Dios spread by 400% (Swenson et al. 2011, Asner et al. 2013).

Though alternative methods exist, workers in ASGM commonly use mercury to extract gold through the amalgamation process (Gibb & O’Leary 2013). Miners mix elemental mercury with a slurry that contains gold flecks to produce a gold-mercury amalgam. The amalgam is then heated to vaporize the mercury, which enables recovery of the gold. The tailings, which still contain mercury, are often dumped into waterways, and as much as 60% of mercury used in ASGM may be released into the environment (Diringer et al. 2015, Maurice-Bourgoin et al. 1999).

There are generally two pathways that mercury released from ASGM can enter the human body. The first pathway is the inhalation of mercury vapors, which are produced when miners or gold shop proprietors heat the gold-mercury amalgam. Without proper safety measures in place, such as a retort, the mercury vapors may enter the lungs of workers and other people nearby (UNEP 2012). The second pathway is the consumption of food, usually fish, contaminated with mercury. Mercury released from in ASGM in makes its way into rivers and other waterways, where it is biochemically converted into methylmercury (MeHg), a highly toxic and bioavailable form (Barbosa et al. 1995). Once in waterways, MeHg accumulates in fish (Gibb & O’Leary 2013). People who eat contaminated fish can be exposed to potentially dangerous levels of MeHg (UNEP 2012). This is a population of special concern, as pregnant and nursing mothers can pass mercury to their infants during gestation or while breastfeeding (UNEP 2012). Serious birth defects may result when pregnant women are exposed to high levels of mercury. Mercury may also be passed from mother to child through breast milk, which can also impact neurological development.

Mercury is a toxic substance that, at high levels of exposure, can cause serious and irreversible damage to human health. The World Health Organization (WHO) sets the mercury acceptable limit for concentration in fish at 1 ppm (WHO 2008). Individuals exposed to levels of Hg above the this limit
are at risk of suffering from a range of health effects. At low levels of exposure, Hg can cause muscle damage, chronic headaches, mood swings, learning disabilities and sensory impairment (UNEP 2012). At high levels, Hg can cause birth defects, respiratory failure, kidney damage, coma, and death (UNEP 2012).

Mercury contamination appears to be a widespread and long-term issue in Madre de Dios. The most common way people become exposed to methylmercury is by eating contaminated fish (Clarkson et al. 2003). The U.S. Environmental Protection Agency sets the reference limit for the maximum at 0.3 ppm (U.S. EPA 2001). Studies dating back to the early 1990s have found fish contaminated with mercury in several Madre de Dios watersheds, some as far as 100 km away from the nearest gold mine (Gutleb et al. 1993, Gutleb et al. 1997).

There is limited understanding of the extent of Hg exposure in the human population of Madre de Dios, but the four studies that exist suggest that Hg presents a widespread risk (Yard et al. 2012, Ashe 2012, CAMEP 2013, Grandez-Urbina et al. 2014). Both Ashe (2012) and the Carnegie Amazon Mercury Ecosystem Project (CAMEP 2013) found elevated Hg levels in residents of Puerto Maldonado, the capital of Madre de Dios and its largest city. Between these two studies, hair samples from 430 adults were analyzed for THg concentration. Both studies report that the majority of the study population had THg levels above the WHO reference limit, with an average of 1.9 ppm reported by Ashe (2012) and 2.7 ppm reported by CAMEP (2013). Grandez-Urbina and colleagues (2014) studied Hg exposure in 60 women of childbearing age living in an indigenous community, also using hair as a biomarker. Most study participants were above the reference limit and the average exposure was 1.8 ppm THg. Residents of the mining communities have elevated Hg levels as well, as reported by Ashe (2012) and Yard et al. (2012). These initial exposure studies indicate that the human population of Madre de Dios is exposed to excess Hg wherever studies have been conducted. However, in a region with a population of 130,000 and widespread mercury contamination, less than 600 individuals have been tested for Hg exposure. There is currently no local capacity to test human Hg exposure in Madre de Dios. Furthermore, there is limited understanding of the factors that increase the risk of Hg exposure in Madre de Dios.

This study focuses on adult women of childbearing age, between 18 and 49 years old, living in urban communities of Madre de Dios, Peru. The aims of this study are threefold. First, I quantify the level of mercury exposure in women of childbearing age residing in Madre de Dios by analyzing hair samples collected from each study participant. Second, I examine risk factors associated with mercury exposure, including personal background and behaviors, as ascertained through in-depth qualitative interviews with each study participant. Finally, I qualify the level of understanding of health risks associated with mercury exposure within the target population. Interview data was matched with levels of mercury exposure for each individual and with mercury levels reported in local wild-caught fish.

Methods

Study Site

Madre de Dios spans 85,300 km² in southeastern Peru and has a population of approximately 130,000 residents. Three urban areas were selected along a gradient of proximity to ASGM activity: Mazuco, which is in the zone where most mining occurs; Puerto Maldonado, which is downstream from the mining zone; and Iberia, which is outside the mining zone. Mazuco has approximately 3,000 residents and is located along the Huepetuhe River, which has been a center of intensive ASGM activity where high levels of Hg were previously found in the human population (Yard et al. 2012). Puerto Maldonado is the capital of Madre de Dios and, with nearly 70,000 residents, its largest city (INEI 2012). Situated at the confluence of the Madre de...
Dios and Tambopata Rivers, Puerto Maldonado is removed from ASGM activity but located in the same watershed. Iberia has approximately 4,000 residents and is located outside the mining zone in a watershed without ASGM activity.

**Sampling**

All study participants were women between the ages of 18 and 49 who had resided in their respective communities for at least six months. To select study participants, residences were selected at random and individuals living in each residence who met the selection criteria were asked whether they’d like to participate in the study. Written and oral informed consent was obtained for each study participant.

Each participant took part in a qualitative interview, which consisted of questions about basic personal information, including age, occupation, and level of education. Each participant was also asked about her level of concern of mercury contamination, level of knowledge of the health risk associated with mercury exposure, and symptoms that may be related to mercury exposure. A sample of hair was taken from each participant to assess mercury exposure.

<table>
<thead>
<tr>
<th>Descriptor</th>
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<tbody>
<tr>
<td>N</td>
<td>170</td>
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<tr>
<td>Puerto Maldonado</td>
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<tr>
<td>Iberia</td>
<td>30</td>
</tr>
<tr>
<td>Mazuco</td>
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<tr>
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<td></td>
</tr>
<tr>
<td>Age Range</td>
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</tr>
<tr>
<td>18–29 yrs</td>
<td>73 (43%)</td>
</tr>
<tr>
<td>30–39 yrs</td>
<td>52 (31%)</td>
</tr>
<tr>
<td>40–49 yrs</td>
<td>45 (26%)</td>
</tr>
<tr>
<td>Pregnant</td>
<td>12 (7%)</td>
</tr>
<tr>
<td>Breastfeeding</td>
<td>33 (19%)</td>
</tr>
<tr>
<td>Pregnant or breastfeeding</td>
<td>45 (26%)</td>
</tr>
</tbody>
</table>

**Table 1.** Descriptive data of the study population

**Laboratory Analysis**

Hair samples were analyzed for total mercury at the Environmental Science Center, Yale University, USA. Each hair sample was cut to 4 cm length for the portion of hair closest to the scalp. This approximates 4 months of mercury exposure, as hair grows an average of 1 cm mo\(^{-1}\) (WHO 2008). The samples were then dried in an oven at 40°C. After dry weight was obtained, each sample was analyzed using the Direct Mercury Analyzer 80 device following EPA Method 1631. Mercury standards PACS and MESS3 were used to ensure quality control.

**Statistical Analysis**

Analyses were conducted using the statistical software R (R Core Team 2015). Levels of mercury exposure were tested against the following risk factors: place of residence, age, level of education, and frequency of fish consumption. Single linear regression was computed for each factor.

**Results**

The majority of the study population in each of the three cities included in this study had high levels of mercury exposure. More than one in four (26%) women who took part in the study were either pregnant or breastfeeding, and thus at risk of passing mercury onto their children if they themselves have elevated levels of exposure (Table 1). The majority of study participants had limited understanding of the health risks associated with mercury exposure, and misconceptions were common.

Across the entire study population, the mean level of total mercury (THg) exposure was 1.97 ppm (range = 0.01–8.11 ppm). The majority (78%) of study participants had levels of mercury exposure above the 1 ppm WHO reference limit.

Mean total mercury exposure varied across the three study sites (Fig. 1). Study participants in Mazuco had a mean THg exposure of 1.90 ppm (0.38–4.78 ppm), and 70% had levels above 1 ppm. In Puerto Maldonado, study participants had a mean THg exposure of 1.89 ppm (0.01–5.22 ppm),
and 76% had levels above 1 ppm. In Iberia, study participants had a mean THg exposure of 2.37 ppm (0.39–8.11 ppm), and 93% of residents had levels above 1 ppm.

The frequency of fish consumption varied widely, from no fish consumption to daily fish consumption. The majority of study participants eat locally caught fish at least once per week. Higher frequency of fish consumption appears to be associated with higher levels of mercury exposure (Fig. 2).

Though the majority of the study population was concerned about mercury exposure, most respondents were misinformed or underinformed about health risks (Table 2). Nearly three in four study participants said they were worried or very worried about mercury contamination (73%). However, just slightly more than one in four study participants (26%) had some knowledge or were knowledgeable about the health risks associated with mercury exposure.

The flow of relevant public health information about mercury exposure is limited. Misperceptions about mercury were common among the study population. Some participants expressed concern that mercury exposure contributes to higher risk of cancer, though no such link has been established (EPA 2015). Many study participants had general knowledge of mercury-related health risks, for example, that mercury can damage the brain. However, very few study participants had an understanding of the symptoms of mercury exposure. Most of the study population had not seen the educational materials about mercury published by the Ministry of Health, universities, or NGOs. The most common way study participants learned about mercury and associated health risk was through popular media, including television, radio, and newspapers.

<table>
<thead>
<tr>
<th>Category</th>
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<tr>
<td>Very Worried</td>
<td>19 (11%)</td>
</tr>
<tr>
<td>Worried</td>
<td>106 (62%)</td>
</tr>
<tr>
<td>Somewhat Worried</td>
<td>13 (8%)</td>
</tr>
<tr>
<td>Neutral</td>
<td>5 (3%)</td>
</tr>
<tr>
<td>Not Worried</td>
<td>17 (10%)</td>
</tr>
<tr>
<td>No Response</td>
<td>10 (6%)</td>
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</table>

Table 2. Responses to the question, “Are you worried about mercury contamination?”
Discussion

Women of childbearing age throughout Madre de Dios are exposed to high levels of mercury. Young children are at risk of mercury passed on from their mothers during pregnancy or breastfeeding.

Previous studies dating back to 1993 from Madre de Dios that have sought to quantify mercury contamination indicate that mercury contamination is widespread. The four previous studies of human exposure all report mercury levels in above the 1 ppm WHO reference limit (Fig. 3). The results from my study match previous findings, with similarly high levels of mercury exposure. Surprisingly, the highest levels of mercury exposure in my study were in Iberia, a community outside the mining zone. This is the first report from Madre de Dios of elevated mercury exposure in a community outside of the mining zone. Most women living in Iberia expressed little to no worry about mercury. Iberia is far removed from most ASGM activity by river, from major sources of Hg, suggests that Hg exposure may be a widespread problem throughout the region and the greater watershed. This area could stretch into Bolivia. The lack of awareness and concern regarding mercury exposure outside the mining zone may present an obstacle to health officials and researchers, who require public participation in order to conduct effective research and health interventions.

Mercury levels in my study were highest in Iberia, but earlier researchers found even higher averages in residents of Puerto Maldonado and the mining zone. This suggests that, though residents in Iberia are exposed to mercury, it likely is not the most contaminated city in the region. My result from Iberia indicates that populations outside the mining zone are also at risk of mercury exposure. More work is needed to quantify the levels of exposure outside the mining zone. Furthermore, public health officials may need to broaden their work to communities not previously thought to be at risk of mercury exposure.

There is a gap between how worried study participants were about mercury and how much they knew about the actual health risks mercury poses. Though approximately 3 in 4 women expressed concern about mercury, only 4 in 10 had at least some level of understanding of mercury’s health risks. Women who are concerned about protecting their own health and that of their families do not have access to the information they need to make informed decisions about their health. Local health officials, as well as NGOs and universities, have produced educational posters and other materials designed to educate the local population about the risks of mercury exposure. Most of the participants in this study had not seen these materials. Local organizations interested in public health education around mercury may benefit from engagement with community groups that can distribute educational materials to members of the community.

Women of childbearing age are a population of concern, and most of the respondents were worried about mercury and were interested in taking measures to protect their and their family’s health. A targeted educational intervention could have far-reaching benefits in protecting not only the health of these women, but also that of their children. Ashe (2012) found a correlation between high levels of fish consumption and higher levels of exposure to mercury. Health workers and others have called for reduced consumption of contaminated fish to reduce the risk of exposure. I collected data on the frequency of fish consumption, which species of fish study participants consume, and alternative sources of animal protein that are already a part of the local diet. Preliminary results indicated that though fish are an important component of the local diet, other protein sources including chicken and eggs also figure prominently. Concerns that women who reduce their intake of fish will not have adequate protein may be unfounded, but we need a more in-depth understanding of how habits of animal protein consumption vary seasonally.

We are still assembling the picture of where mercury contamination exists in Madre de Dios and what can be done to reduce or prevent it,
or at least reduce or prevent one’s exposure to it. What is known is that mercury contamination is widespread, and the more places we look for mercury, the more of it we find. Policymakers may do well to consider three routes to ensure that mercury intoxication does not become a major public health issue in Madre de Dios (and it is important to note that these routes are not mutually exclusive). First, at the national level, the Peruvian legislature is considering ratification of the Minamata Convention on Mercury, which would curb the import of mercury and restrict its use in ASGM. Preventing mercury from entering the country, or at least making it prohibitively difficult, would be beneficial. Second, the introduction of appropriate technologies that replace mercury in ASGM or that capture mercury before it is released into the environment can mitigate further harm. Third, a culturally appropriate educational campaign about mercury, its health risks, and how to reduce or prevent one’s exposure to mercury can have an immediate benefit.

Though the scientific picture of mercury contamination in Madre de Dios is yet incomplete, there is no reason for government officials at the national, state, and local levels not to take action to curb mercury contamination and exposure in the human population.

**Fig. 2.** Mercury exposure by age (left) and average number of fish consumed a month (right). The WHO reference limit of 1 ppm is indicated by the horizontal dashed red line.

**Fig. 3.** A comparison of the level of mercury exposure from previously published studies from Madre de Dios. Vertical lines represent the maximum value for each study. The dashed red line represents the reference limit of 1 ppm.
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