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Gold Mining Community: A Comprehensive Review**

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Mercury Exposure and Health Impacts among Individuals in the Artisanal and Small-Scale Gold Mining Community: A Comprehensive Review

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Abstract

Background: Mercury is used in gold mining to extract gold from ore by forming “amalgam” – a mixture composed of approximately equal parts mercury and gold. Approximately 15 million people, including approximately 3 million women and children, participate in artisanal small-scale gold mining (ASGM) in developing countries. Thirty-seven percent of global air emissions of mercury are produced by ASGM. The recently adopted Minamata Convention calls for nations to gather health data, train health-care workers, and do awareness-raising in regard to ASGM activity.

Objectives: The purpose of this review is to evaluate the current literature regarding the health effects of mercury among those working and/or living in or near ASGM communities.

Methods: PubMed, ScienceDirect and Google were searched for studies relating to health effects and biomarkers of mercury exposure in ASGM communities. Articles published from 1990 through December 2012 were evaluated for relevance.

Discussion: Studies reporting health assessments, kidney dysfunction, neurologic disorders and symptoms, and immunotoxicity/autoimmune dysfunction in individuals living in or near an ASGM community were identified. Over sixty studies that measured biomarkers of mercury exposure in individuals living in or near ASGM communities were also identified. These studies, conducted in 19 different countries in South America, Asia, and Africa, demonstrated that hair and urine concentrations are well above WHO health guidance values.

Conclusions: ASGM workers and their families are exposed to mercury vapor, and workers, workers’ families, and residents of nearby and downstream communities are consuming fish heavily contaminated with methylmercury.

Introduction

In February 2009, the Governing Council of the United Nations Environment Programme (UNEP) began development of a legally binding global instrument on mercury (Hg). In January 2013, governments agreed to text for this instrument thus giving birth to the Minamata Convention on Mercury (UNEP 2013b). In October 2013, the convention was signed in Minamata, Japan. Article 7 and Annex C of the Convention address artisanal and small-scale gold mining (ASGM). Annex C addresses the development of national plans for artisanal and small-scale gold mining. Included in the outline for national plans is development of a public health strategy on the exposure of artisanal and small-scale gold miners and their communities to mercury. Such a strategy should include the gathering of health data, training for health-care workers and awareness-raising through health facilities.

Mercury is used in gold mining to extract gold from ore by forming “amalgam” – a mixture composed of approximately equal parts mercury and gold (UNEP 2013d). The amalgam is heated, evaporating the mercury from the mixture, leaving the gold (UNEP 2013d). This method of gold extraction is used in the ASGM community because it is cheaper than most alternative methods, can be used by one person independently, and is quick and easy (UNEP 2012). The dramatic rise in the cost of gold over the last decade has fueled a gold rush by poverty-driven miners in many countries (UNEP 2008). ASGM occurs primarily in South America, Africa, and Asia, but it can also be found in North America and Australia (UNEP 2013c). Approximately 15 million people, including approximately 3 million women and children, participate in the ASGM industry in 70 countries (UNEP 2012). ASGM is the largest source (37%) of global mercury emissions (UNEP 2013c). Between 2005 and 2010, mercury emissions from ASGM doubled (UNEP 2013a). While most uses of mercury are declining throughout the world, the ASGM

demand for mercury is expected to increase (UNEP 2013c). ASGM accounts for the largest percentage of global mercury demand (UNEP 2013c).

Mercury vapors in the air around amalgam burning sites can be alarmingly high and almost always exceed the WHO limit for public exposure of $1.0 \mu\text{g}/\text{m}^3$ (UNEP 2012). These exposures affect not only the workers but also those in the communities surrounding the processing centers (UNEP 2012). Drake et al. (2001) reported that the range of the 8-h TWA airborne mercury exposure at gold mining operations in Venezuela was 0.1 to $6,315 \mu\text{g}/\text{m}^3$ with a mean of $183 \mu\text{g}/\text{m}^3$. WHO (2000) reported that tremor has been observed in workers exposed to $30 \mu\text{g}/\text{m}^3$ and that renal tubular effects and changes in plasma enzymes are estimated to occur at $15 \mu\text{g}/\text{m}^3$. The vaporized mercury eventually settles in soil and the sediment of lakes, rivers, bays, and oceans and is transformed by anaerobic organisms into methylmercury (MeHg). In bodies of water, the methylmercury is absorbed by phytoplankton, ingested by zooplankton and fish, thereby contaminating the food chain. It especially accumulates in long-lived predatory species including shark and swordfish (WHO 2007).

Elemental mercury and methylmercury are toxic to the central and peripheral nervous system. The inhalation of mercury vapor can produce harmful effects on the nervous, digestive and immune systems, lungs and kidneys, and may be fatal (WHO 2007). Children are especially vulnerable and may be exposed directly by eating methylmercury-contaminated fish. Methylmercury bioaccumulates in fish and when consumed by pregnant women may lead to neurodevelopmental problems in the developing fetus. Transplacental exposure is the most dangerous, as the fetal brain is very sensitive (WHO 2007). Neurological symptoms include mental retardation, seizures, vision and hearing loss, delayed development, language disorders

and memory loss. In children, a syndrome characterized by red and painful extremities called acrodynia has been reported to result from chronic mercury exposure (WHO 2007; WHO 2008).

Elemental mercury, the form of mercury used in gold amalgamation, is a liquid that volatilizes rapidly (WHO 2007). In humans, elemental mercury is typically measured in blood or urine (WHO 2003; WHO 2008). Methylmercury, the form of mercury that contaminates fish, is typically measured in blood, cord blood, or hair. Sample collection of hair is the preferred method of biomonitoring for methylmercury as it is less invasive than blood sampling. Blood mercury concentrations characterize recent or current exposure (WHO 2008). In populations where exposure to mercury occurs primarily through consumption of contaminated fish, most of the total mercury in the blood is organic and can be used as a measure of methylmercury exposure (WHO 2008).

Given the prominence of ASGM as a significant source of global mercury and that national plans, as specified by the Minamata Convention, call for the collection of health data, this review was undertaken to identify studies that describe health effects and exposure in ASGM communities. It is hoped that such information can serve as a resource to health authorities in those countries where ASGM is currently practiced.

Methods

To identify relevant studies, we utilized PubMed, ScienceDirect, and Google. The following search terms were included: mercury, methylmercury, fish consumption, hair, blood, urine, neurologic effects, kidney effects, health effects, and gold mining. The names of numerous countries where ASGM is known to occur were also included in searches. There were 1,317 potentially relevant studies identified. Studies were considered relevant if they identified health

effects or measured hair or urinary mercury concentrations in individuals residing in an area affected by ASGM. Seventy-two studies were identified that fit our criteria for a relevant study. We divided the studies into two categories: 1) studies that identified health effects in ASGM communities (see Table 1), and (2) studies that reported hair or urine mercury in ASGM communities or communities affected by ASGM (see Supplemental Material, Tables S1, S2 and S4). Several studies also included measurements of blood mercury as well as hair mercury (see Supplemental Material, Tables S2 and S3). We included studies published through December 2012.

We compared hair concentrations with 2.5 $\mu\text{g/g}$, the hair concentration associated with the Provisional Tolerable Weekly Intake (PTWI) (Bellanger et al. 2013; FAO/WHO 2003). The PTWI was established to protect the developing fetus from neurotoxic effects (WHO 2007). In 2006, the Joint FAO/WHO Expert Committee on Food Additives (JECFA) concluded that life stages other than the embryo and fetus may be less sensitive to the effects of methylmercury. Available data did not allow JECFA to make firm conclusions with respect to children up to the age of 17 and therefore stated that the PTWI also applied to children (WHO 2007).

Urine concentrations in this study were compared with 50 $\mu\text{g Hg/g-creatinine}$, a concentration where renal tubular effects and changes in plasma enzymes are expected to occur (WHO 2000). Urine concentrations were also compared to 100 $\mu\text{g Hg/g-creatinine}$, a urinary concentration where the probability of developing the classical neurological signs of mercury intoxication is “high” (WHO 1991). For purposes of presentation, only studies that reported ranges as well as mean urinary or hair mercury were included in figures to demonstrate the extremes of mercury exposure. All study results, however, are presented in the supplementary tables that accompany this article.

Results

We identified 17 studies in the literature search that described health effects in ASGM communities (Table 1). The studies were conducted in 10 different countries on three continents (South America, Africa, and Asia). All of the studies are cross-sectional.

Numerous biomarker (hair, blood, urine) studies have been conducted in ASGM populations. Studies were conducted in 19 different countries on three continents. Studies that reported hair mercury concentrations among residents of ASGM communities, miners and environmentally exposed populations are reported in Supplemental Material, Table S1. These studies were conducted in 14 different countries. Supplemental Material, Table S2, includes studies that examined hair and blood mercury in the same population. Eight different countries are represented by these studies. Supplemental Material, Table S3 and Table S4 contain studies that reported mercury concentrations in blood and urine, respectively. The studies on blood and urinary mercury were conducted in 5 and 13 countries, respectively.

Figure 1 describes urinary mercury concentrations where both a mean (horizontal green line) and a range (vertical blue line) were reported. The green and blue line scheme is used to represent means and ranges, respectively, and is employed in Figures 2 and 3 as well. The red line indicating “Neurological signs” designates the 100 $\mu\text{g/g-Cr}$ value for neurological effects identified by WHO (1997). The red line indicating “Kidney effects” designates the 50 $\mu\text{g/g-Cr}$ concentration where renal tubular effects are expected to occur (WHO 2000). Additional information on the studies presented in Figure 1 can be found in the Supplemental Material (see Supplemental Material, Table S4). References that appear on the x-axis more than once indicate that the study included more than one study group (e.g., merchants and miners in Harari et al. 2012).

Figure 2 describes hair mercury concentrations in female residents of ASGM communities where both a mean and a range (where shown) were reported. Most of the means and all of the maximum concentrations reported were above the PTWI. Figure 3 shows mean and ranges of hair mercury of children and infants in ASGM communities. Women and children were selected for Figures 2 and 3, respectively, because the developing fetus and children are considered more vulnerable to the effects of methylmercury. Additional information regarding the studies included in Figures 2 and 3 can be found in Supplemental Material, Tables S1 and S2.

Discussion

The most common health effect reported among workers engaged in the artisanal and small-scale gold mining are neurologic effects (see Table 1). These include tremor, ataxia, memory problems, and vision disorder and were found to occur not just among those engaged in mining activities but also among fish consumers living downstream of mining activities.

Increased urinary excretion of the enzyme N-acetyl- β -D-glucoaminidase (NAG), a biomarker of damage to the proximal tubules of the kidney, was found among those occupationally exposed (Drake et al. 2001) as well as among those living in a community where gold mining had been practiced (Tian et al. 2009). Kidney dysfunction was clinically diagnosed in 9 out of 103 in a gold mining population in Peru (Yard et al. 2012). Those reporting kidney dysfunction had higher urine total mercury concentrations (GM=12.0 $\mu\text{g/g Cr}$) than those not reporting kidney dysfunction (GM=5.1 $\mu\text{g/g Cr}$; $p<0.05$). See Table 1 for further information on kidney effects.

Four studies conducted in Brazil suggest that mercury exposure among gold miners and in gold mining communities is associated with an increase in the prevalence of markers of autoimmune

dysfunction (Alves et al. 2006; Gardner et al. 2010; Nyland et al. 2011; Silva et al. 2004). See Table 1 for the details of each study.

Ten of the study populations in Table 1 are in South America, six in Brazil alone. Only two of the study populations are in Africa; four are in Asia. The number of studies in a geographic region should not be construed to represent the magnitude of the problem in that region, however. The number of artisanal and small scale gold miners and the amount of mercury released from artisanal and small scale gold mining is as great, if not greater, a problem in Asia and Africa as it is in South America (UNEP 2013c).

Harari et al. (2012), Steckling et al. (2011), Tomicic et al. (2011), Paruchuri et al. (2010), Bose-O'Reilly et al. (2010a), Bose-O'Reilly et al. (2008), Counter et al. (2006), and Drake et al. (2001) all report urinary mercury concentrations well above 100 $\mu\text{g Hg/g-Cr}$. See Figure 1 and Table S4 for urinary mercury concentration data. WHO (1991) considers 100 $\mu\text{g Hg/g-Cr}$ to be the level above which the probability of developing classical neurological signs of mercury intoxication is "high." High urinary mercury concentrations were particularly evident among those who amalgamate mercury or heat mercury to remove it from the amalgam. As an example of the elevated urinary concentrations found among small-scale gold mining operations, Tomicic et al. (2011) reported that the mean urinary mercury among gold dealers in Burkina Faso was 299.1 $\mu\text{g Hg/g-Cr}$. Gold dealers were believed to have the most frequent exposure to mercury vapor. Drake et al. (2001) reported that among "self-employed" gold miners in Venezuela, the mean urinary mercury concentration was 148 $\mu\text{g Hg/g-Cr}$; the high end of the range was 912 $\mu\text{g Hg/g-Cr}$. Bose-O'Reilly et al. (2008) reported that the mean urinary mercury concentration among a sample of 80 children who work with mercury was 36.50 $\mu\text{g Hg/g-Cr}$; the high end of the range was 666.87. The children, who worked in small scale gold mining operations in

Indonesia and Zimbabwe, ranged in age from 9 to 17. Umbangtalad et al. (2007) found that Thai school children living near, but not working in, small-scale gold mining operations had increased urinary mercury concentrations.

Hair mercury reflects the ingestion of fish mercury (methylmercury) (WHO 1990). The mean hair mercury concentration in virtually all of the 55 studies conducted in ASGM areas or areas affected by ASGM are above the concentration (2.5 µg/g) associated with WHO's Provisional Tolerable Weekly Intake (PTWI) (See Figures 2 and 3, and Supplemental Material Tables S1 and S2). Many of the studies reported hair concentrations above 14 µg/g which FAO/WHO (2003) considers a No Observed Effects Level (NOEL). The NOEL is based on neurotoxic effects in the fetus; the PTWI was established to protect the fetus from neurotoxic effects (WHO 2007). In 2006, JECFA concluded that life stages other than the embryo and fetus may be less sensitive to the effects of methylmercury. Because of a lack of data on children under the age of 17, JECFA concluded that the PTWI should also apply to children (WHO 2007). Hair mercury concentrations above those that reflect the PTWI and NOEL, should therefore not be indicative of health effects in adults. WHO (1990) concluded that a hair mercury concentration of 50 µg Hg/g would indicate a low (5%) risk of neurological damage to adults. Some of the studies in Table 1 (e.g., Harada et al. 2001; Lebel et al. 1998), however, suggest that neurological effects may be evident in adults at hair mercury concentrations lower than 50 µg Hg/g. Blood concentrations of mercury may reflect exposure to either methylmercury or inorganic mercury (WHO 2003; WHO 1990). The background level of mercury in blood for those who do not eat fish is 2 µg Hg/L (WHO 2003).

Conclusions

Those involved in the gold mining operations, their families, and those in the gold mining communities are exposed to dangerous levels of elemental mercury vapor as evidenced by urinary mercury concentrations. This evidence includes extremely elevated urinary mercury concentrations in children who work in the mines and children who live in the areas where small-scale gold mining occurs. Residents in the gold mining communities and downstream of the gold mining communities consume fish that may be heavily contaminated with methylmercury as demonstrated by hair mercury measurements. Current studies indicate that those in the ASGM communities experience neurologic effects, kidney effects, and possibly immunotoxic/autoimmune effects from mercury exposure. Not only is the danger widespread globally, but the problem is expected to grow. National public health strategies on ASGM, as required by the Minamata Convention, should be implemented immediately.

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Table 1. Health effects observed in ASGM areas.

Source and Country of Origin	Study Population	Observed Effects
Studies that included persons occupationally exposed to mercury from ASGM		
Yard et al. 2012, Peru	103 people living in a gold mining area including 35 who had direct contact with Hg at least once per month	Over 50% reported headache, mood swings or muscle weakness. Previous medical diagnoses included digestive system disorder (n=20), kidney dysfunction (n=9), and nervous system disorders (n= 4). Participants reporting kidney dysfunction had higher urine total mercury concentrations (GM=12.0 µg/g Cr) than those not reporting kidney dysfunction (GM=5.1 µg/g Cr; p<0.05). Urinary Hg concentrations were significantly (p < 0.05) higher among people who heated amalgam compared to those who never heated amalgam.
Harari et al. 2012, Ecuador	200 gold miners; 37 gold merchants; 72 referents	Tremor was found to be associated with blood and urinary mercury. Elimination of Hg appeared to be modified by a polymorphism. The gold merchants had the highest blood and urinary Hg because they burn amalgam on a daily basis.
Tomicic et al. 2011, Burkina Faso	93 gold workers; 779 workers related to gold mining activities	Nearly half of the 93 workers considered most susceptible to mercury exposure reported at least 5 symptoms possibly related to mercury exposure (frequent headaches, sleep disorder, dizziness/fit of giddiness, wounds/irritation of mouth, unusual tiredness, walking difficulty, trembling, pins and needles/tingling in hands or feet, vision disorder, persistent cough, thoracic pain, rhinitis). Gold ore dealers were found to have higher urine Hg than ore washers; dealers heated Hg an average of 13.2 times per day compared to individuals not dealing gold who heated mercury 7.8 times per day.
Bose-O'Reilly et al. 2010a, Indonesia	Group1: 21 Sulawesi residents control group; Group 2: 66 Kalimantan residents living in exposed area with no occupational exposure; Group 3:18 Sulawesi residents living in exposed area with no occupational exposure; Group 4:30 Kalimantan Hg workers – panning, but no smelting; Group 5: 17 Sulawesi, Hg workers – panning, but no smelting; Group 6: 69 Kalimantan Hg workers – smelting; Group 7: 60 Sulawesi, Hg worker – smelting	A determination of Hg intoxication was based on a merging of medical score and biomonitoring results. The following rates of intoxication were observed: Group 1: 0%; Group 2: 31.8%; Group 3: 16.7%; Group 4: 43.3%; Group 5: 23.5%; Group 6: 62.3%; Group 7: 41.6% Mercury-exposed workers showed typical symptoms of Hg intoxication, such as movement disorders (ataxia, tremor, dysdiadochokinesia, etc.).

Source and Country of Origin	Study Population	Observed Effects
Gardner et al. 2010, Brazil	98 gold miners in Rio Rato (Para state); 91 emerald miners (Goias state); 57 diamond miners (Goias state)	Mercury-exposed gold miners had higher prevalence of detectable anti-nuclear autoantibodies (ANA) and anti-nucleolar autoantibodies (ANoA) as compared to diamond and emerald miners with no occupational mercury exposure. Mercury-exposed gold miners with detectable ANA or ANoA in serum had significantly higher concentrations of pro-inflammatory cytokines IL-1 β , TNF- α , and IFN- γ in serum as compared to diamond and emerald miners. The authors concluded that the results suggest that mercury increases autoimmune dysfunction and systemic inflammation.
Bose-O'Reilly et al. 2008, Indonesia Zimbabwe	80 children working with Hg (51 Indonesia, 29 Zimbabwe); 36 children living in Hg-exposed areas (22 Indonesia, 14 Zimbabwe); 50 control group (31 Indonesia, 19 Zimbabwe)	8% of children working with mercury in Indonesia were considered mercury intoxicated. 29% of children living in mercury-exposed areas in Zimbabwe were considered intoxicated. 55% of children working with mercury in Zimbabwe were considered intoxicated. None of the control children were considered intoxicated. Chronic mercury intoxication is a combination of severe and specific symptoms and raised mercury levels in biomarkers.
Silva et al. 2004, Brazil	98 (54 currently working in a gold mine) in Rio Rato, a gold mining community in the mid-Tapajos watershed; 140 in Jacareacanga, a riverine settlement on the mid-Tapajos River (no current occupational exposure; elevated MeHg in fish consumed); 98 in Tabatinga, a riverine community in the lower Amazon (no occupational exposure; low MeHg in fish)	There was a high prevalence of detectable antinuclear antibodies (ANA) (54.1%) and antinucleolar autoantibodies (ANoA) (40.8%) in Rio Rato ($\geq 1:10$ serum dilution). The prevalence was lower in Jacareacanga (10.7% ANA and 18% ANoA) and much lower in Tabatinga (7.1% ANA and 2.0% ANoA).
Drake et al. 2001, Venezuela	21 small-scale gold miners	3 had N-acetyl- β -D-glucoaminidase (NAG), a biological marker of preclinical, nonspecific damage to the kidney's proximal tubule cells in excess of reference values.
Drasch et al. 2001, Philippines	102 occupational exposed ball-millers and amalgam-smelters; 63 inhabitants of Mt. Diwata, environmentally-exposed; 100 individuals residing downstream in Monkayo; 42 controls were inhabitants of Davao	Workers reported fatigue, tremor, memory problems, restlessness, weight loss, metallic taste and disturbances in sleeping. Diagnosis of mercury intoxication in the workers was significantly higher in the downstream community, the Mt. Diwata non-occupational group and in the workers compared to the control group. Median concentrations of mercury in blood, urine, and hair among the workers were significantly different from the concentrations found in the control group.

Source and Country of Origin	Study Population	Observed Effects
Studies of persons not engaged in gold mining but who live in areas affected by ASGM		
Nyland et al. 2011, Brazil	232 persons from the Lower Tapajós River Basin in the Brazilian Amazon, an area with a history of Hg use in small-scale gold mining	Elevated titers of mercury in blood and plasma were associated with anti-nuclear autoantibodies (ANA) but not with anti-nucleolar autoantibodies (ANoA). Pro-inflammatory and anti-inflammatory interleukins and IL-17 were increased with MeHg exposure but were decreased in the subset of the population with elevated ANA. The authors concluded that the data indicate an immunotoxic or immunomodulatory effect of MeHg in the range of exposures found in this population but suggest that there may be a specific phenotype of MeHg susceptibility.
Tian et al. 2009, China	203 persons from area contaminated with mercury due to gold extraction; 191 persons from control area	Urinary mercury was significantly correlated with β_2 -microglobulin and N-acetyl- β -D-glucosaminidase (NAG).
Alves et al. 2006, Brazil	105 adults in 7 riverine communities (104 consumed fish daily); 6 riverine communities were along the mid-Rio Negro; one was located along the tributary Rio Cuiuni; 105 controls (volunteer donors at a blood bank); fish species high in methylmercury was consumed more frequently by the riverine population (45.5%) than by controls (18.8%)	Mean hair mercury of the riverines (34.5 ppm) was significantly higher than controls (1.0 ppm). Positive serum ANA was more frequently observed in riverine fish-eaters (12.4%) than controls (2.9%). There was, however, no significant association between hair mercury and ANA.
Cordier et al. 2002, French Guiana	156 children and their 104 mothers in Upper Maroni communities (high Hg exposure); 69 children and their 51 mothers in Camponi (medium Hg exposure); 153 children and their 115 mothers in Awala (low Hg exposure) *Hg exposure was the result of gold mining activity.	No major neurologic signs were observed in the children examined. After adjustment for potential confounders, a dose-dependent association was observed between maternal hair mercury level and increased deep tendon reflexes, poorer coordination of legs, and decreased performance in the Standard-Binet Copying score which measures visuospatial organization.
Harada et al. 2001, Brazil	132 fishermen and their families (n=182) in three fishing villages along the Tapajós River	General sensory disturbance was observed in 16 of 50 subjects (32%) whose hair mercury was > 20 ppm. Several subjects were diagnosed with Minamata disease.
Akagi et al. 2000, Philippines	162 school children in a community of Mindanao where gold is processed	Predominant findings among the children were gingival discoloration, adenopathy, underweight, and dermatologic abnormalities.

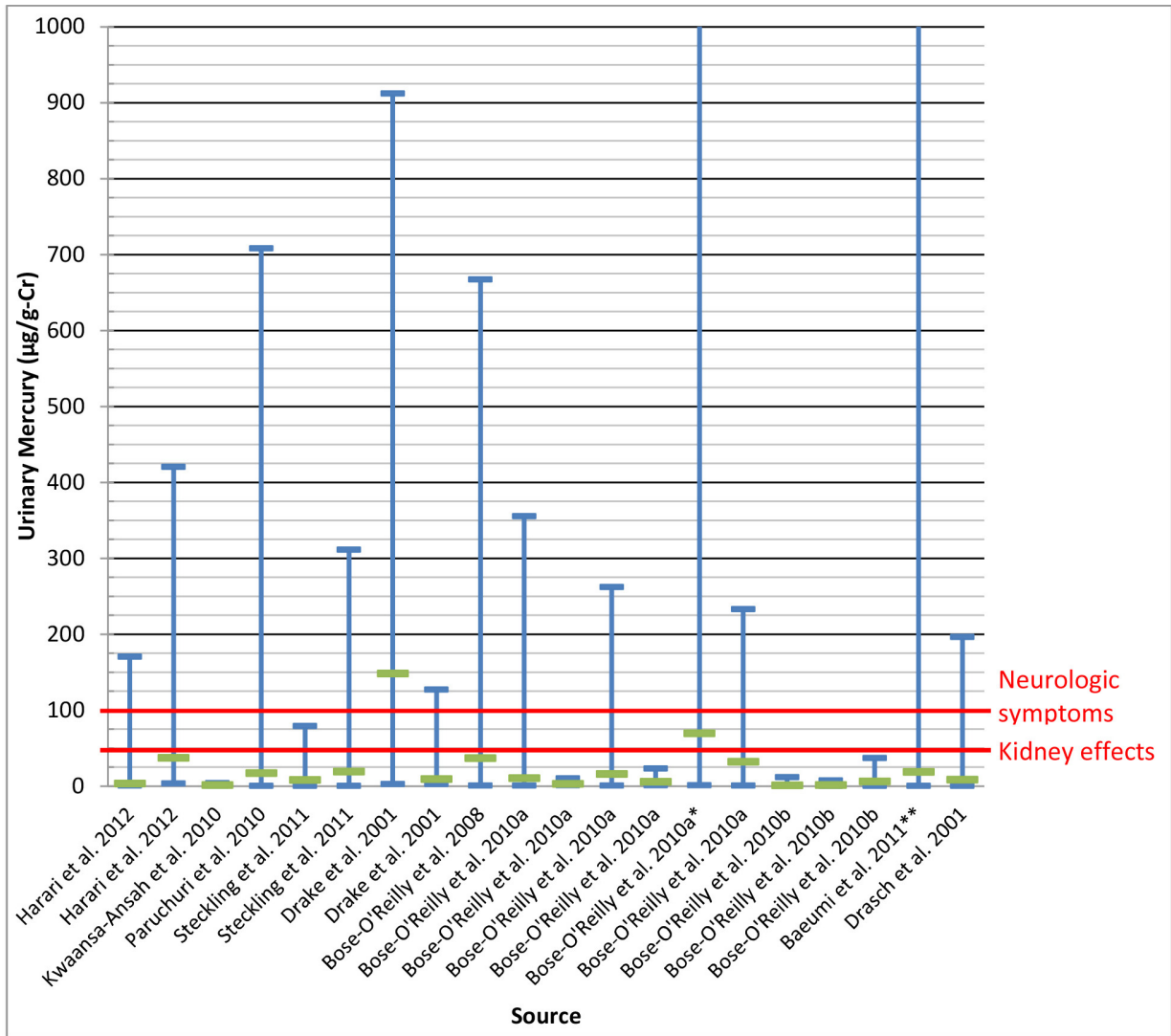
Source and Country of Origin	Study Population	Observed Effects
Grandjean et al. 1999, Brazil	351 school children between the ages of 7 and 12 in four villages along the Tapajos River basin downstream from a gold mining area; 135 mothers of 252 children were examined; hair samples were obtained from 113 mothers of 222 children examined.	Neuropsychological tests of motor function, attention, and visuospatial performance showed decrements with hair mercury concentrations.
Lebel et al. 1998, Brazil	91 adult inhabitants living 250 km downstream from the most extensive gold-mining fields in Brazil. The villagers are not exposed to mercury vapor. The area is accessible only by water.	Near visual contrast sensitivity and manual dexterity, adjusted for age, decreased significantly with hair mercury levels. There was a tendency for muscular fatigue to increase and muscular strength to decrease in women. Hair mercury levels were significantly higher for persons who presented disorganized movements on an alternating movement task and for persons with restricted visual fields. Hair mercury concentrations were less than 50 µg/g.

Figure Legends

Figure 1. Urinary mercury means and ranges found in ASGM populations.

Figure 2. Mean and range hair mercury of women in studies of residents of ASGM communities.

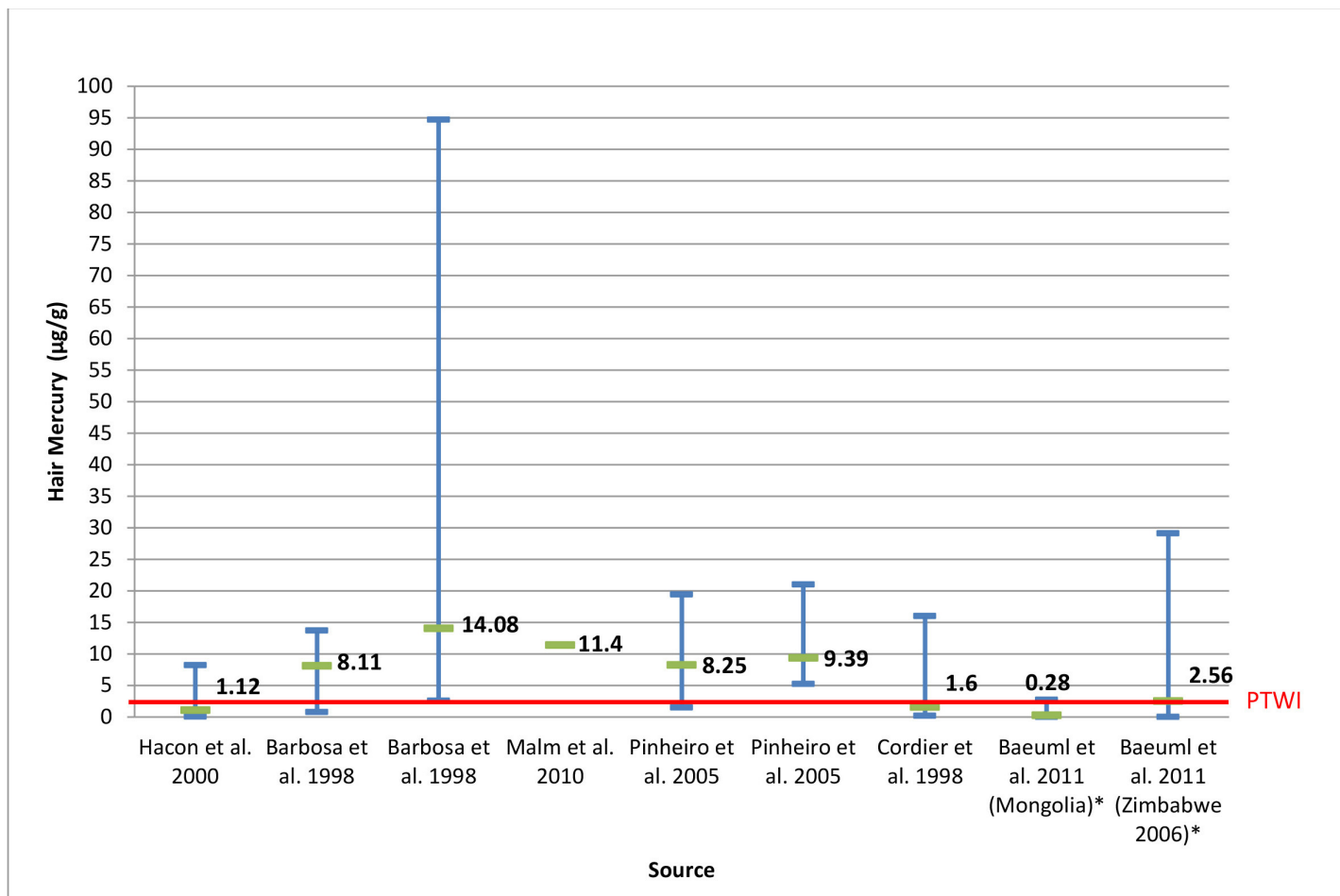
Figure 3. Mean and range hair mercury of children and infants in studies of residents of ASGM communities.



*the highest value for the data in this category was 1,697.39 µg/g-Cr

**the lowest value for the data in this study was less than the LOD; the highest value was 1,697 µg/g-Cr

Figure 1



*the lowest value for these studies was less than the LOD

Figure 2

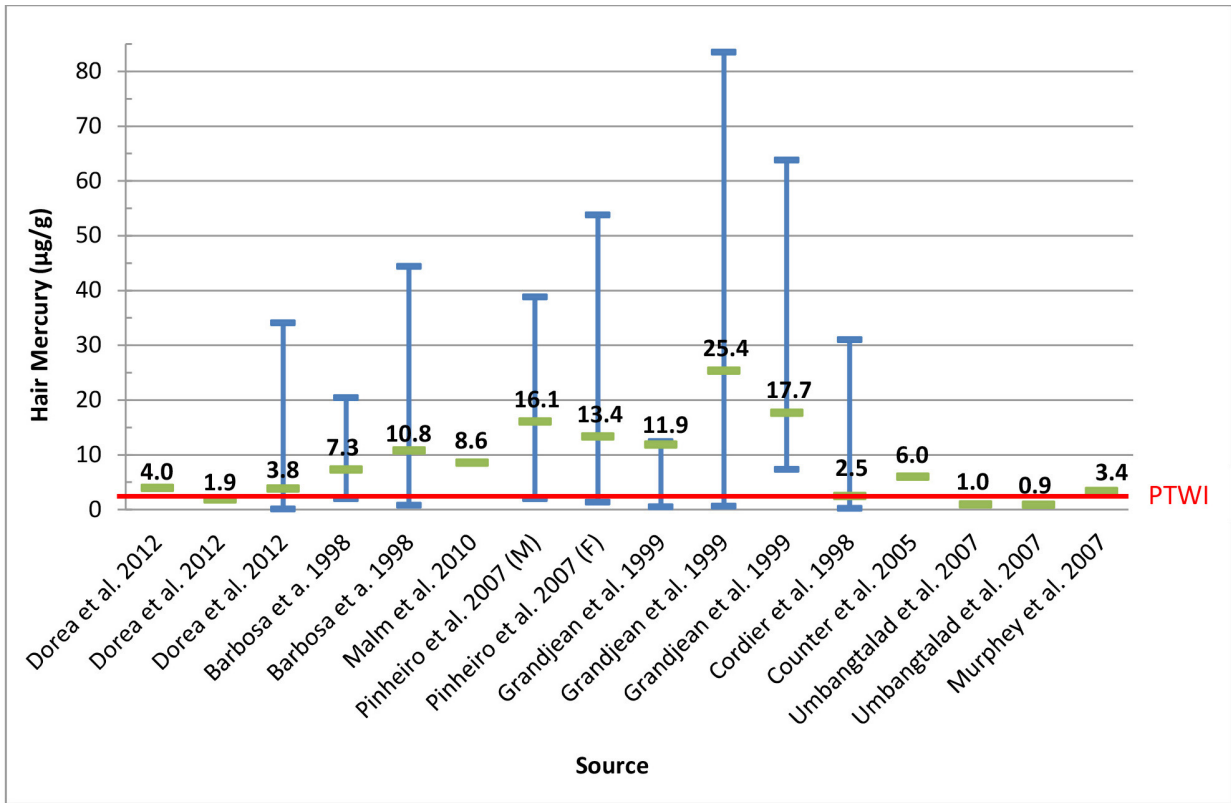


Figure 3