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Assessing occupational mercury exposures and behaviours of artisanal and small-scale gold miners in Burkina Faso using passive mercury vapour badges

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ABSTRACT

Artisanal and small-scale gold mining (ASGM) is a crucial economic activity in Burkina Faso, however it is associated with significant mercury exposure and health concerns. The aim of the present study was to assess the level of mercury (Hg) vapour exposures and occupational behaviours at a representative site using Hg vapour monitor badges and questionnaires. To our knowledge this is the first time that personal exposure to Hg vapour during ASGM activities has been reported. The study population were ASGM workers who completed a questionnaire (n=100) or participated with an occupational exposure assessment using commercially available passive Hg vapour samplers (n=44). Occupational exposure to Hg was high during open-air burn events with a time weighted average (TWA) exposure of 7026±6857 μg/m^3 for burners, and 1412±2870 μg/m^3 for bystanders. Most (82%) of the people present at the burn exceeded the Permissible Exposure Limit (PEL) of 100 μg/m^3, and 11% exceeded the level considered to be Immediately Dangerous to Life and Health (IDLH) of 10,000 μg/m^3. Even control workers who were not present at the burn exceeded the PEL (24%), likely due to legacy Hg contamination producing latent Hg releases to the atmosphere. Similarly, 86% of the miners at the burn and 59% of control workers had an 8-h TWA that exceeded the Recommended Exposures Limit (REL). Several occupational behaviours that may contribute to Hg exposures were documented. This study corroborates previous studies suggesting that Hg exposure during amalgam burning is very high, and demonstrates the plausibility of using passive vapour monitoring badges rather than costly and logistically difficult biomonitoring methods. Mercury reduction and elimination interventions are strongly needed to reduce Hg exposure in ASGM communities, particularly as countries come into compliance with the Minamata Convention.

1. Introduction

Artisanal and small-scale gold mining (ASGM) is the labour-intensive extraction of gold using rudimentary technology. There are an estimated 15 million ASGM miners across the globe who produce 400–700 t of gold per year, and also release up to 1600 t of elemental mercury (Hg) into the environment (AMAP/UNEP, 2013). The ASGM sector is responsible for the largest anthropogenic release of Hg (UNEP, 2013a) and is subject to the Minamata Convention, which aims at reducing such Hg releases in ratified countries. One of the stipulations of the Minamata Convention is for countries with ASGM to monitor and reduce Hg exposure and to devise a public health strategy to protect ASGM communities; Article 7 and Annex C (UNEP, 2013b).

Gold is the largest export of Burkina Faso, accounting for 12.2% of the national GDP (Lankoande and Maradan, 2013). It is roughly estimated that the ASGM sector in Burkina Faso produces 15–25 metric tonnes of gold per annum, directly employs 400,000 miners, and supports an estimated 4 million people in the secondary economy (UNEP, 2013c). The ASGM process widely used in Burkina Faso involves the following steps:

1. Excavating – gold bearing rock is extracted from underground shafts.
2. Crushing – the rock is crushed into gravel, often manually with hammers.

Abbreviations: ASGM, artisanal and small-scale gold mining; GM, geometric mean; Hg, mercury; ICP-MS, Inductively coupled plasma mass spectrometry; IDLH, immediately dangerous to life and health; PEL, permissible exposure level; REL, recommended exposure limit; TWA, time weighted average; 8-h TWA, 8 h time weighted average

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3. Milling – the gravel is milled into a sand or powder, often with rudimentary disk or ball mills.
4. Concentrating – the gold and other heavy minerals are separated from the waste rock by washing the milled slurry over an incline lined with towels, carpets, or blankets.
5. Amalgamating – the concentrated material is mixed with Hg, often by bare hand. The excess Hg is removed from the mercury-gold amalgam by wringing it through fabric and/or aspirating by mouth.
6. Burning – the amalgam is heated to vapourize the Hg, often in pans in the open air, leaving behind sponge gold. Retorts or personal protection equipment are rarely used.
7. Melting – the sponge gold is further melted to produce a solid gold doré which releases residual Hg – usually at least 5% - and prepares the gold for sale to gold buyers.

The miners who participate in the amalgamating and burning are exposed to high levels of elemental Hg mainly through inhalation (Tomicic et al., 2011). Several studies have documented elevated Hg in blood or urine of ASGM miners who use Hg throughout Latin America, Asia and Africa (Reviews: Gibb and Leary, 2014; Kristensen et al., 2014). The health effects related to elemental Hg exposure are well documented, where the kidneys and central nervous system are most commonly affected (Asano et al., 2000). Common symptoms of Hg exposure includes tiredness, depression, agitation, a metallic taste in the mouth, and irritability (ATSDR, 1999; UNEP and WHO, 2008). Later symptoms can become more pronounced such as sleep disruption, memory loss, muscle tremors, and altered personality (Clarkson et al., 2003). High levels of Hg vapour may harm the lungs, causing burning sensation in the throat or lungs, and unconsciousness (ATSDR, 1999; UNEP and WHO, 2008). Although thorough clinical assessments of ASGM populations are lacking, several of these symptoms have been associated with Hg exposure specifically within this sector (Tomicic et al., 2011; Veiga and Baker, 2004; Yard et al., 2012).

According to occupational standards, a worker should not exceed the ceiling Permissible Exposure Limit (PEL) of 100 $\mu g/m^3$ of Hg vapour, and levels above 10,000 $\mu g/m^3$ are considered to be Immediately Dangerous to Life or Health (IDLH) (ATSDR, 2014; OSHA, 2016). A worker's 8-hour time weighted average (TWA) air Hg concentration should not exceed the Recommended Exposure Limit (REL) of 50 $\mu g/m^3$ (OSHA, 2016).

The assessment of Hg vapour exposure may be done with biomonitoring in blood or urine or by directly measuring Hg in the air of the breathing zone. Exposure to Hg vapour correlates well to urine Hg levels in some occupational settings (Decharat et al., 2014), and is logistically, economically, and ethically more feasible in some situations. An under-studied method is to measure Hg vapour using personal passive Hg vapour badges, rather than with active monitors that require bulky and often expensive equipment, technical skills, and a reliable power source (McLagan et al., 2016). As countries come into compliance with the Minamata Convention, it is expected that the number of studies that assess Hg vapour exposure in ASGM communities will increase. The main objectives of this study were to assess the personal Hg exposure and occupational behaviours within an ASGM community in Burkina Faso, and to determine if this method of personal Hg exposure could be reliably utilized.

2. Materials and methods

2.1. Subjects

This study was conducted in a rural ASGM community called Zopal, in the Ioba province of Burkina Faso. This community has over 20 years of continual informal ASGM activity and a population of approximately 3000 people during the peak dry season. This study was conducted in the 2015 dry season. It is estimated that 300 people are directly employed in ASGM activities at this site, with the remainder participating within the secondary economy (ie. restaurants, supply stores, mechanics). A total of 162 miners participated in this study, representing 54% of the total miner population in Zopal. Inclusion criteria were men or women, over the aged of 18, who were working on the mine site doing one of the main mining activities on site; excavating, crushing, milling, concentrating, amalgamating, and burning. We used a convenience sampling approach and attempted to include participants from each employment category and from both genders.

2.2. Data collection

Participating individuals gave informed consent and answered an occupational health questionnaire administrated by a healthcare professional/student who was trained on non-biased interview approaches. The questionnaire included information on demographics, occupational activities, and general health as described and validated elsewhere (Tomicic et al., 2011; Veiga and Baker, 2004; Yard et al., 2012) Participants were given a small sum of money to compensate them for their time and a small kit of personal protective equipment items. Hg amalgam burning has been identified as the primary source of Hg exposure in similar ASGM systems (Tomicic et al., 2011). Participants who were involved with Hg amalgam burning were further invited to participate in a personal assessment of occupational Hg vapour exposure ($n=27$) during 3 separate burn events. A convenience opportunistic sampling approach was used because these burn events occur without schedule or announcement due to security concerns. As a control, participants who were not involved with Hg related activities; excavating, crushing, milling, and concentrating, were invited to participate in a personal assessment of occupational Hg vapour exposure ($n=17$) while no amalgam burning was occurring on site.

2.3. Personal Hg vapour exposure

The personal exposure to Hg vapour was assessed with personal Hg vapour badge (SKC Inc., model # 520-03, 520-02A), according to a previously validated method (OSHA ID140, 1991). Briefly, Hg vapour passively absorbs into a sorbent capsule held in a plastic diffusion case, which was attached to the participant's clothing nearest their breathing zone. A total of 27 miners wore badges during 3 different amalgam burn events on different days. A total of 17 miners wore badges during non-Hg related mining activities. Each personal assessment lasted 1–4 h, upon which time the badge was collected, recapped, the time noted, and the sorbent capsule was immediately removed and sealed in a plastic bag as per the manufacturers' instructions. As a further precaution to avoid cross-contamination during transportation and storage, the plastic bags were then placed into individual labeled glass tubes with tight fitting plastic lids. A field blank ensured quality control (26.13 ng Hg) and was used to correct Hg exposure calculations. The sorbent capsule holders were then triple washed with detergent and diluted nitric acid to remove any residual Hg, air dried, and reused for subsequent assessments. The badges' limit of detection is 0.04 μg with a maximum load of 30 μg per badge, and validated for ranges of 61–200 $\mu g/m^3$ (OSHA ID140, 1991). Two duplicate personal exposure assessments were made on site to test the reproducibility with 2% and 12% variability, which was viewed as within the acceptable experimental error reported by the manufacturer ($\pm$8.6%). The person's time weighted average (TWA) was calculated from the total Hg on the badge, divided by