Bull Environ Contam Toxicol (2011) 87:250–253
DOI 10.1007/s00128-011-0345-5

Air Mercury Contamination in the Gold Mining Town of Portovelo, Ecuador

Víctor González-Carrasco · Patricio C. Velasquez-Lopez · Jesús Olivero-Verbel · Nerlis Pájaro-Castro

Received: 6 January 2011 / Accepted: 13 June 2011 / Published online: 17 July 2011

Abstract Portovelo is one of the oldest gold mining towns in Ecuador. Artisanal gold mining still uses mercury in the process of gold recovery. In this study, mercury concentrations in the air of Portovelo were evaluated. High mercury levels in the ambient were found in El Pache sector, where most gold mining processing plants are located. These varied between 2,356.7 ± 1,807.6 and 3,699.5 ± 1,225.3 ng/m^3 during the rainy and dry seasons, respectively. Lower levels were detected in the urban (central) area of Portovelo, with 214.6 ± 43.7 ng/m^3 in the rainy season and 574.2 ± 72.8 ng/m^3 in the dry season, exceeding the Agency for Toxic Substances and Disease Registry minimum risk level of 200 ng/m^3. Average mercury concentrations in exhaled air from miners, measured before and after amalgam burning ranged between 179–1,352 and 2,007–3,389 ng/m^3, respectively. These data suggest Portovelo air is polluted with mercury and humans are being dangerously exposed. Therefore, strong actions must be undertaken to protect human and environmental health, including changing gold recovery systems.

Keywords Mercury · Artisanal-small-scale gold mining · Amalgamation · Southern Ecuador

V. González-Carrasco (✉) · P. C. Velasquez-Lopez
Faculty of Chemical Sciences, Technical University of Machala, Machala, Ecuador
e-mail: vhg22@yahoo.es

J. Olivero-Verbel · N. Pájaro-Castro
Environmental and Computacional Chemistry Group, Faculty of Pharmaceutical Sciences, University of Cartagena, Campus of Zaragocilla, Cartagena, Bolívar, Colombia

Artisanal and small-scale gold mining is an important economic activity in over 55 developing countries across Africa, Asia and South America, often providing the only income to local people (Li et al. 2009; Eisler 2004). Worldwide, 10–15 million artisanal gold miners in more than 70 countries extract on average 350 tons of gold, and in the process, 640–1,350 tons of mercury (Hg) are released into the environment. Hg use in artisanal and small-scale gold mining accounts for one-third of all global anthropogenic Hg consumption. It has been estimated that 300 tonnes of Hg are volatilized directly to the atmosphere per year, while 700 tonnes are discharged in mine tailings, which pollute soil, rivers and lakes. As a result of Hg exposure, severe health impacts are often experienced by miners, gold processing workers as well as communities downstream (Spiegel and Veiga 2010).

In Ecuador, gold mining has been carried out from the pre-Inca era in different parts of the country such as the provinces of Cañar, Azuay and El Oro. Extensive gold mining is concentrated in the Portovelo mine, located in the upper part of the Oro Province, where more than 20,000 people depend directly or indirectly from artisanal and small scale gold mining activities. Gold mining has been a source of environmental problems, such as Hg contamination of biota, air, soil and water, and of course, it has impacted human health (Tarras-Wahlberg 2002; Velásquez et al. 2010). Although in Ecuador, artisanal and small-scale gold mining is the main source of Hg pollution, this activity is also the most important, and sometimes the only, income for many people who live in the area (Pantoja 2001; Tarras-Wahlberg 2002). Therefore, the massive use of this metal has transformed Portovelo in an area with serious air pollution. Portovelo is a small city on the Southeast of the El Oro province of Ecuador, 105 km far from its capital Machala. This town is one of the 14

cantons of El Oro Province, with an area of approximately 35 km^2. It is crossed by El Amarillo and La Calera Rivers. It maintains most of the year warm weather (18–21°C) with little wind presence.

Given the magnitude of this problem, and considering that Hg is a metal of high human and environmental impact (Paruchuri et al. 2010), as it is easily absorbed on gas state (Sandborgh-Englund et al. 1998) the main aim of this study was to measure Hg levels in the environment of the canton Portovelo, Ecuador, in particular around processing plants located in El Pache sector, as well as in the urban (central) area of the town.

Materials and Methods

Air samples were collected from two sites. (1) El Pache, a sector located along La Calera River, possesses most of the gold mining plants and mills in Portovelo. (2) The central or urban area of Portovelo (3°43′13″S and 79°37′14″O), where people have their houses and no gold mining processes are found. The town is located at an altitude of 650 m above sea level, with a population of 13,800 inhabitants.

Nine different sites of the sector El Pache and eleven from the urban zone in Portovelo were sampled in this study (Fig. 1). Sampling was carried out during both dry season (July to December 2007) and rainy season (January to March 2008). Sampling sites were selected considering the location of several gold processing plants distributed along El Pache sector, being sites 4–7 the places with greater number of amalgamation and burning units in the area.

Measurements of Hg in the urban and gold processing areas of Portovelo were performed using a spectrometer with background correction—Zeeman atomic absorption mercury spectrometer RA-915 + (Lumex Ltd, Russia) as described elsewhere (Olivero-Verbel et al. 2006). This equipment has a detection limit of 1 ng Hg/m^3 in air. Hg measurements were carried out during rainy and dry seasons with at least 10 readings (by triplicates) throughout the month during morning hours.

Measurements of Hg concentrations in exhaled air of artisanal miners were carried out on miners that work on Hg amalgamation in El Pache area of Portovelo. Readings were acquired five times, 5 min before and after amalgam burning was performed.

Mercury concentrations were reported as mean ± sem (standard error of the mean), and examined using descriptive statistics. The differences between groups were analyzed by one-way ANOVA ($p < 0.01$), and the Student–Newman–Keuls test for all pairwise comparisons after log data transformation. The results of a statistical test were considered statistically significant if $p < 0.05$. GraphPad Prism was used for data analyses.

Results and Discussion

Average air Hg concentrations found during the dry and rainy seasons in the urban area of Portovelo are presented in Fig. 2. As expected, in almost all stations (10/11), as

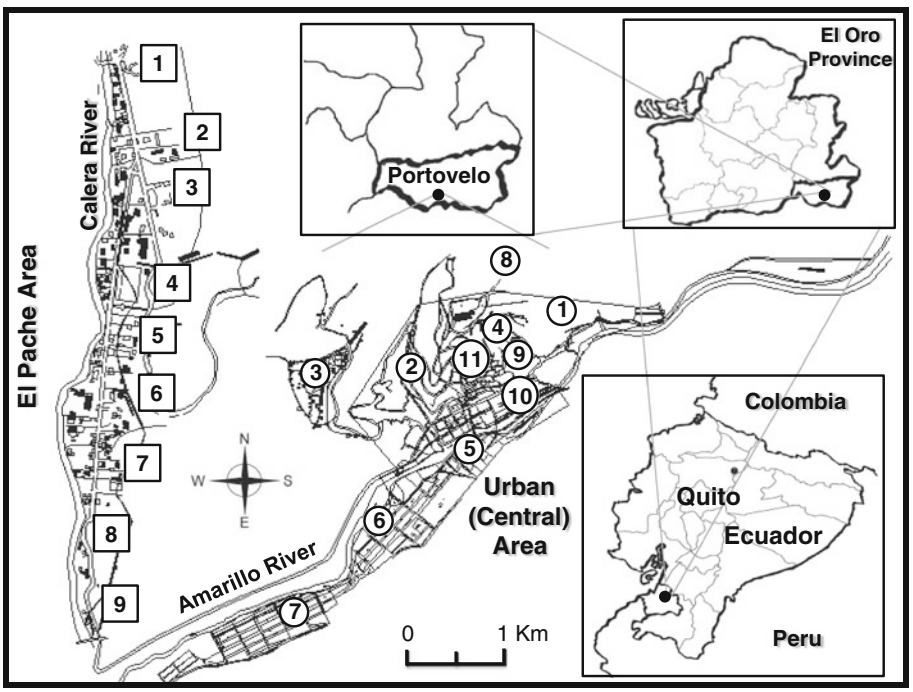

Fig. 1 Location of sampling sites in the urban (*circled numbers*) and the gold processing area (*squared numbers*) of El Pache in the city of Portovelo, Ecuador. Neighborhoods located in central area: *1* Ciudadela el Paraíso, *2* Ciudadela Cima o Machala, *3* Barrio el Osorio, *4* Sector del Antiguo Hospital Curipamba, *5* Ciudadela el Oro, *6* Barrio 28 de Noviembre, *7* Barrio Florida, *8* Barrio el Soroche, *9* Barrio Plaza Central o Sector del Municipio, *10* Barrio Av. del Ejército o Sector del Estadio, *11* Barrio 1 de Mayo

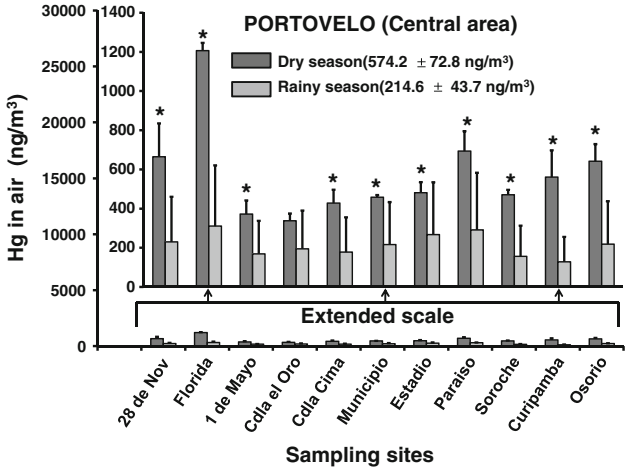

Fig. 2 Mercury concentrations in air from sampling stations at urban (*central*) area of Portovelo during dry and rainy seasons. *Significantly different when comparing seasons

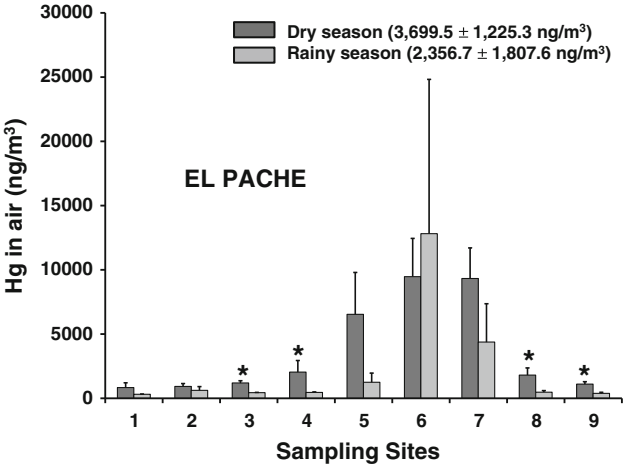

Fig. 3 Mercury concentrations in air from sampling stations at El Pache area during dry and rainy seasons. *Significantly different when comparing seasons

well as in terms of average values, air Hg levels were greater during the dry season when compared to the rainy season (574.2 ± 72.8 ng/m^3 vs. 214.6 ± 43.7 ng/m^3). This season-dependent behavior has also been observed after measurement campaigns in a Hg cell chlor-alkali complex (Gibicar et al. 2009).

The maximum Hg concentrations in air from Portovelo area were found around the Florida neighborhood, the closest site to El Pache area. During the dry season, the average value for this station was significantly different when compared to others ($p < 0.05$). This indicates that gold extracting processes are impacting the air of the urban area of Portovelo. Therefore, this town should be a priority for health and environmental authorities, who must develop programs to prevent adverse effects on Hg-exposed children, in particular neuro-, nephro-, and immune-toxicity (Bose-O'Reilly et al. 2010). Simultaneously, the community should receive educational campaigns to isolate Hg-related processes from the population.

Mercury concentrations in air from El Pache area are presented in Fig. 3. Results revealed that air Hg concentrations in El Pache area are greater than in the urban zone of Portovelo, in at least one or two orders of magnitude. In average, Hg levels during the dry season in El Pache (3,699.5 ± 1,225.3 ng/m^3) are significatively greater than those found in the rainy season (2,356.7 ± 1,807.6 ng/m^3). At stations 1, 2, 5, 6 and 7, no statistical differences were found for Hg levels between seasons. Maximum Hg concentrations in air were detected at sampling points 5, 6, and 7, locations near processing plants.

The dry season in Portovelo is characterized by a warm environment with temperatures around 25°C, and high humidity and evaporation. This may explain the high levels of Hg obtained in the different sites in Portovelo during July 2007 to March 2008. In comparison, Hg concentrations detected from November to April were lower, suggesting that Hg either can be precipitated by the rain or less evaporated from the soil. This seasonal variability is similar to that reported in China, where lower Hg levels were observed in summer (wet season) as a result of rainfall scavenging and lower Hg emissions (Wan et al. 2009). However, wind dispersion and other meteorological parameters are also important issues that can modify Hg fate behavior in the local polluted environment (Yang et al. 2009), where cycling of atmospheric Hg is likely to occur (Eckley et al. 2011).

Results from this work have pointed out that in Portovelo, specifically at El Pache sector, Hg vapor emissions are extensive and permanent. This may be a consequence of the fact that El Pache possesses almost 70% of all amalgam-related processing plants in the region, and therefore this place is particularly dangerous for human health.

As presented here, independent from the sampling location (El Pache or the urban area of Portovelo), average elemental Hg levels measured in air exceeded the Agency for Toxic Substances and Disease Registry minimum risk level of 200 ng/m^3 (ATSDR 2010), although this value has been recently revised and a new lower value has been suggested as a reference (Beate et al. 2010). In addition to atmospheric Hg release, the Portovelo district is causing other environmental impacts, such as release of Hg-related and metal rich tailings into rivers of the Puyango catchment area (Tarras-Wahlberg et al. 2001). These practices contribute to increase Hg levels in fish and humans in the region (Appleton et al. 2001). In Ponce Enriquez, a city near Portovelo, where gold mining also occurs, pollutants have accumulated in agricultural areas (Velásquez et al. 2010).

Table 1 Mercury in exhaled air from artisanal miners of Portovelo

Miner	Hg concentration before burning (ng/m^3)	Hg concentration after burning (ng/m^3)
1	731.8 ± 37.4	3,388.6 ± 1,147.2
2	179.4 ± 12.3	2,007.4 ± 115.8
3	433.0 ± 49.5	2,350.6 ± 174.94
4	667.8 ± 14.0	2,706.4 ± 285.8
5	300.4 ± 21.9	3,081.2 ± 232.9
6	1,351.8 ± 6.7	3,241.4 ± 292.2

Mercury levels in exhaled air of miners working in El Pache sector before and after burning gold-amalgams in different mining plants are reported in Table 1.

Mercury concentrations in exhaled air of miners were always greater after performing amalgam burning, suggesting that people are highly exposed to Hg vapors through breathing. This is the result of the lack of protective equipment during the processing operations. A study by Velásquez et al. (2010) reported that only 51–59% of Hg used in amalgamation processes is recovered when miners squeeze the excess of Hg from the amalgam, around 29% of is lost when burned, and 15% is lost with the tailings. Approximately 1.5 tonnes of Hg per year are released in Portovelo-Zaruma, from which 70% is evaporated and 30% being released with tailings. The massive Hg release in Portovelo and other gold mining areas of Ecuador could be producing neuro-cognitive deficits in visual-spatial reasoning (Counter et al. 2006), neuro-otological symptoms and abnormalities in children (Counter et al. 2002). As in these places Hg pollution is also concomitant with an extensive use of cyanide, this last chemical may explain the effects observed in children with low blood Hg levels.

A campaign for reducing Hg emissions must focus on the use of individual retorts, or any other Hg pollution control devices, as well as on the elimination or substitution of whole ore amalgamation processes (Velásquez et al. 2010). These are urgent measures that need to be implemented not only to protect human health, but also to avoid Hg accumulation in the ecosystem, leading to human exposure through food consumption.

References

Appleton JD, Williams TM, Orbea H, Carrasco M (2001) Fluvial contamination associated with artisanal gold mining in the Ponce Enriquez, Portovelo-Zaruma and Nambija areas, Ecuador. Water Air Soil Pollut 131:19–39

ATSDR—Agency for Toxic Substances and Disease Registry (2010) Minimal Risk Levels (MRLs) for Hazardous Substances. Available http://www.atsdr.cdc.gov/mrls/mrllist.asp. Accessed 02 Sep 2010

Beate L, Stephan BO, Gustav D (2010) Proposal for a revised reference concentration (RfC) for mercury vapour in adults. Sci Total Environ 408:3530–3535

Bose-O'Reilly S, McCarty KM, Steckling N, Lettmeier B (2010) Mercury exposure and children's health. Curr Probl Pediatr Adolesc Health Care 40:186–215

Counter SA, Buchanan LH, Ortega F, Laurell G (2002) Elevated blood mercury and neuro-otological observations in children of the Ecuadorian gold mines. J Toxicol Environ Health A 65(2): 149–163

Counter SA, Buchanan LH, Ortega F (2006) Neurocognitive screening of mercury-exposed children of Andean gold miners. Int J Occup Environ Health 12:209–214

Eckley CS, Gustin M, Marsik F, Miller MB (2011) Measurement of surface mercury fluxes at active industrial gold mines in Nevada (USA). Sci Total Environ 409:514–522

Eisler R (2004) Mercury hazards from gold mining to humans, plants, and animals. Rev Environ Contam Toxicol 181:139–198

Gibicar D, Horvat M, Logar M, Fajon V, Falnoga I, Ferrara R, Lanzillotta E, Ceccarini C, Mazzolai B, Denby B, Pacyna J (2009) Human exposure to mercury in the vicinity of chlor-alkali plant. Environ Res 109:355–367

Li P, Feng XB, Qiu GL, Shang LH, Li ZG (2009) Mercury pollution in Asia: a review of the contaminated sites. J Hazard Mater 168: 591–601

Olivero-Verbel J, Ropero-Vega J, Ortiz-Rivera W, Vera-Ospina P, Torres-Fuentes N, Montoya-Rodriguez N (2006) Air mercury levels in a pharmaceutical and chemical sciences school building. Bull Environ Contam Toxicol 76:1038–1043

Pantoja F (2001) Tecnologías apropiadas para disminuir la contaminación ocasionada por mercurio en la minería del oro. Available via: Jornada internacional sobre el impacto ambiental del mercurio utilizado por la minería aurífera artesanal en Iberoamérica. www.gama-peru.org/jornada-hg/pantoja.pdf. Accessed 10 Jul 2010

Paruchuri Y, Siuniak A, Johnson N, Levin E, Mitchell K, Goodrich JM, Renne EP, Basu N (2010) Occupational and environmental mercury exposure among small-scale gold miners in the Talensi-Nabdam District of Ghana's Upper East region. Sci Total Environ 408:6079–6085

Sandborgh-Englund G, Elinder CG, Johanson G, Lind B, Skare I, Ekstrand J (1998) The absorption, blood levels, and excretion of mercury after a single dose of mercury vapor in humans. Toxicol Appl Pharmacol 150:146–153

Spiegel S, Veiga M (2010) International guidelines on mercury management in small-scale gold mining. J Clean Prod 18:375–385

Tarras-Wahlberg N (2002) Environmental management of small-scale and artisanal mining: the Portovelo-Zaruma gold mining area, southern Ecuador. J Environ Manage 65:165–179

Tarras-Wahlberg N, Flachier A, Lane S, Sangfors O (2001) Environmental impacts and metal exposure of aquatic ecosystems in rivers contaminated by small scale gold mining: the Puyango River basin, southern Ecuador. Sci Total Environ 278: 239–261

Velásquez P, Veiga M, Hall K (2010) Mercury balance in amalgamation in artisanal and small-scale gold mining: identifying strategies for reducing environmental pollution in Portovelo-Zaruma, Ecuador. J Clean Prod 18:226–232

Wan Q, Feng X, Lu J, Zheng W, Song X, Li P, Han S, Xu H (2009) Atmospheric mercury in Changbai Mountain area, northeastern China II. The distribution of reactive gaseous mercury and particulate mercury and mercury deposition fluxes. Environ Res 109:721–727

Yang Y, Chen H, Wang D (2009) Spatial and temporal distribution of gaseous elemental mercury in Chongqing, China. Environ Monit Assess 156:479–489