UNIVERSITY OF BRITISH COLUMBIA
NORMAN B. KEEVIL Institute of Mining Engineering

tel: 604 822 2540 fax: 604 822 5599 517, 6350 Stores Road, Vancouver, BC V6T 1Z4 www.mining.ubc.ca

Changes in Urban Mercury Vapour in Colombia, 2010-2011

By

Paul Cordy, MSc
PhD Candidate

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Executive summary

Atmospheric mercury concentrations [Hg] in the urban core of Segovia, Colombia have remained stable or decreased in the past 16 months, despite a 30% increase in gold production. From September 21 to October 7, 2011, a follow up mercury mapping field campaign was conducted to assess changes in mercury concentrations since the spring of 2010. The 2011 dataset is approximately double the size of that from 2010. Analysis of these data show increases in temporal average [Hg] in the neighboring towns of Remedios and La Cruzada. By contrast, a conservative estimate of roughly 10% reduction in Segovia could be the result of the UNIDO Colombian Mercury Project interventions of the past two years. Differences in bulk temporal [Hg] were verified by comparison with separate averages for each day of the week, spatial averages, extreme values, and cross-validated averages. A map of spatial averages shows the distribution of mercury in both years (Figure 1). Though results in Segovia are encouraging, there is considerable uncertainty given the short and isolated measurement campaigns. Unknown temporal variability of gold production and amalgam burning are also significant sources of uncertainty. There is much greater uncertainty in assessments of changes in mercury contamination in La Cruzada and Remedios because mercury measurements are fewer and cover a much smaller area.

If future measurements confirm these reductions in mercury contamination it would be a significant achievement for UNIDO and Segovia's mining community. Any such improvement in Segovia is likely attributable to the use of retorts in the processing centres. Retorts recover mercury for re-use, thereby vastly decreasing the amount of mercury evaporated in open burning. Further improvement efforts should focus on installing high temperature glass doors on gold shop fume hoods (thus allowing operators to close the door without miners worrying that they are being cheated), and decreasing the milling speeds to increase grinding efficiency and reduce evaporation due to frictional heat generation. Long term goals should be set to ban amalgam burning in the urban core and relocate processing centres away from residential/commercial areas. Even if all contemporary sources of mercury were eliminated, concentrations would persist for some time as a result of evaporation from contaminated soils and surfaces.

Table 1: Changes in average mercury concentration [Hg] *in the urban cores of Antioquia.*

[Hg] Time Averages (ng/m^3)	2010	2011	% change
Segovia	1244.9	976.5	-22
Remedios	244.9	322.9	+32
La Cruzada	556.8	817.9	+47

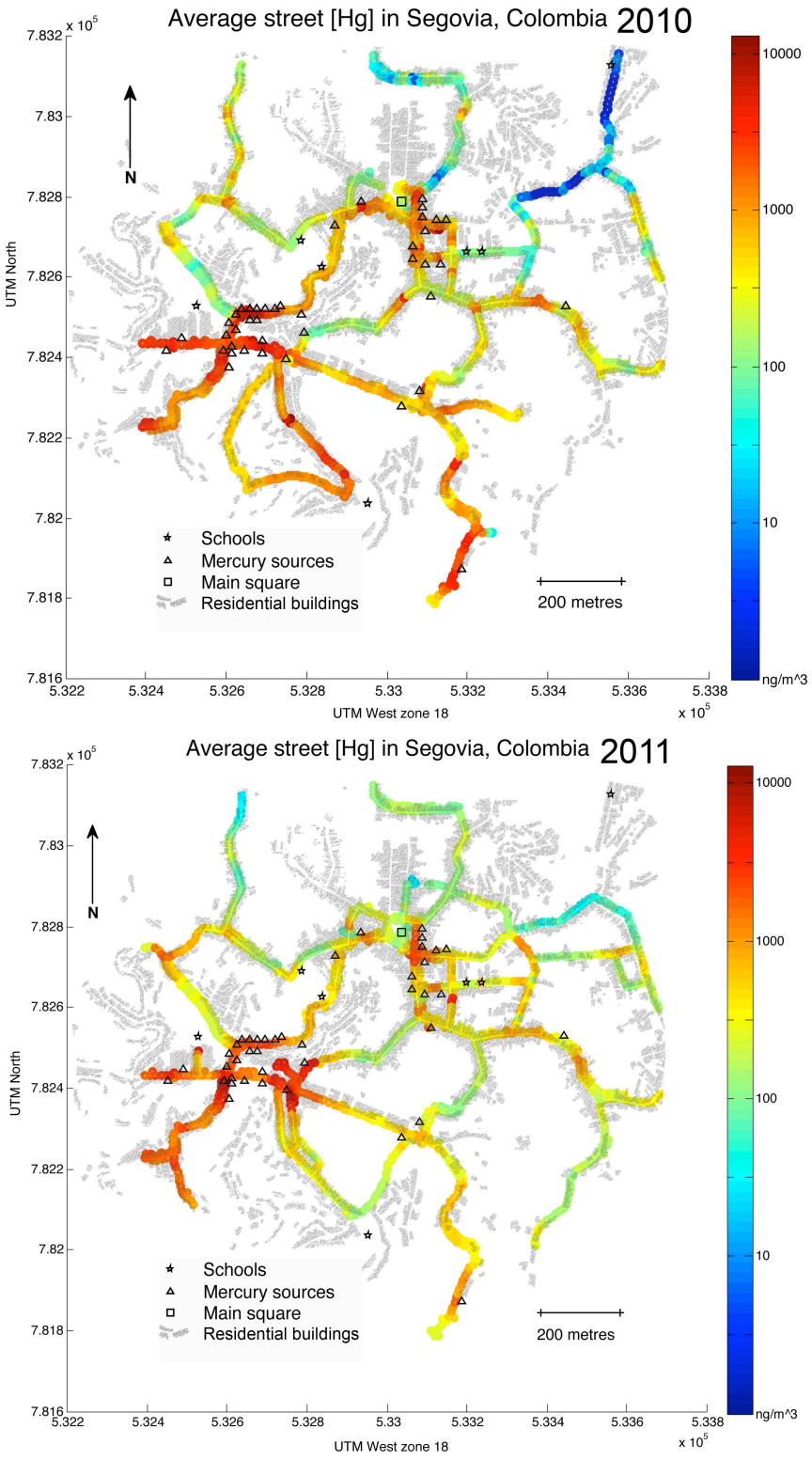

Figure 1: Mercury concentrations in the urban core of Segovia. Each colour represents the average of all concentrations measured within 10 metres of that point.

Average concentrations greater than 1000 ng/m^3 are hazardous according to the World Health Organization (2000).

Not all mercury sources are shown.

Introduction

This report focuses entirely on mercury vapour emissions from artisanal mining activities in the province of Antioquia, Colombia. According to a recent census conducted by the UNIDO Global Mercury Project, it is estimated that there are between 15000 and 30000 artisanal gold miners in 17 mining towns in Antioquia, Colombia. The five core municipalities of Segovia, Remedios, Nechi, El Bagre, and Zaragoza produce between 10 and 20 tonnes of gold per annum. Local authorities revealed that the total gold production of the Department of Antioquia in 2008 was around 26 tonnes from companies and artisanal miners. The official gold production in Colombia in 2008 was 41.5 tonnes (Bernstein 2009). Numbers are still very fuzzy in Antioquia since a mining census has not been implemented yet.

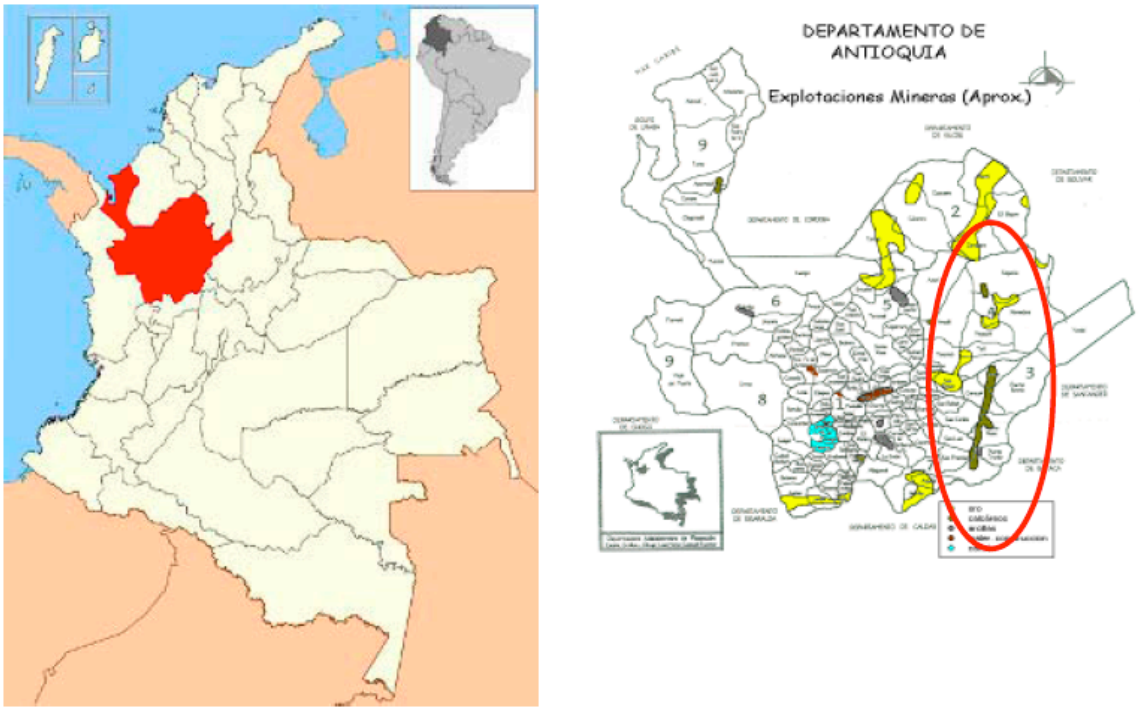

Figure 2: Index map showing the province of Antioquia, Colombia, with target municipalities circled in red.

As a result of the presence of guerrilla groups in the rural area, most gold ore is processed in the urban environment of Remedios, Segovia and Zaragoza. These processing centres known as "entables" are located beside schools, residences, grocery stores, pharmacies, etc. The amount of mercury being used and lost in Colombia is not well known. A study conducted by Telmer and Veiga (2008) estimated that the annual mercury emissions/ releases from artisanal gold miners (AGM) in Colombia can be between 50 and 100 tonnes, but it seems that this can reach as much as 150 tonnes/a, according to local sources. In this case Colombia occupies the 3rd place in mercury emissions from AGM just after China (240 to 650 tonnes of Hg/a) and Indonesia (130 to 160 tonnes of Hg/a). In terms of mercury emissions per capita from AGM, Colombia is likely the world's main polluter. Full details of mercury use and mining practices in Colombia are included and described in Cordy et al. (2011).

Methodology

Mercury concentrations were measured using the LUMEX RA 915+ ('Lumex' from the University of British Columbia, CERM3) and the Jerome 431X ('Jerome' from CORANTIOQUIA) spectrometers. The lower detection limit of the Lumex and Jerome are 2 ng/m^3 and 3000 ng/m^3 respectively. The LUMEX uses a Zeeman process (Zeeman Atomic Absorption Spectrometry with high frequency modulation of light polarization ZAAS-HFM) that eliminates interference and does not use a gold trap. The Jerome analyzer uses a thin gold film whose resistance changes relative to the concentration of mercury in sample air stream. The Jerome was used to measure concentrations inside gold shops, entables, and some non-mining buildings. The Lumex was used for long term monitoring of mercury in the church tower near the central plaza, and for mercury mapping.

Spatial mercury measurements were taken while driving around the urban areas with the Lumex inlet at a height of 2 metres. Positions were taken using a recreational grade GPS device, and both the Lumex and GPS logged data at a frequency of one second. In order to reduce spatial averaging, the target sampling speed was 20 km/h, however the actual speed varies depending on traffic.

The maps in Figure 1 (see executive summary) show the average concentration at each point along the roads of Segovia, as measured by operating the Lumex from a vehicle. Since concentrations vary over 4 orders of magnitude, a logarithmic scale was used. On the colour bar scale, 1 ng/m^3 (near background), 1 = 10 (normal), 2 = 100 (tolerable), 3 = 1000 (hazardous), and 4 = 10000 (extreme). Keep in mind that because of the logarithmic scaling, the variability in the lower values is exaggerated relative to the variability among higher values. Comparative analysis of the spatial averages were done using only road lengths that were common to both sampling years.

Mercury observations from a high tower were made in both 2011 and 2010, however unfavorable winds meant the tower was always upwind of sources in 2011. Therefore no comparison of tower data is provided here, other than to note that they all show a local background [Hg] of 10-30 ng/m^3 when the source air is coming from less urban areas free of Hg sources.

Analytical tools

Day matched averages

The 2010 sampling campaign did not obtain data from all days of the week, and amalgam burning activities vary on different days of the week (for instance, weekends are thought to be more active because the miners are extracting ore during the week). Furthermore, the amount of sampling done on any given day of the week varies between the two datasets, so the day matched average method was developed to reduce possible biases that might arise from these differences.

First, all data are separated into the day of week into which they occurred. Then for each day of the week, a random sample of the data is taken and the average mercury concentration is found. These samples are smaller than the minimum size of either 2010 or 2011 dataset for that day of the week. If there is no data from a given day of the week in either 2010 or 2011 then that day is not included. Averages for each day were

calculated by resampling 50 times (taking a different random sample of the data each time). The mean of these day averages give the day matched average.

Cross-validated averages

The 2010 dataset is half the size of the 2011 dataset. To test whether this size effect impacted the results, a random subsample of each year's data was taken that was smaller than the 2010 dataset. This process was repeated 50 times to see how the average value varied with sample size. The averages for each year were stable (variability was less than 5%).

Extreme value analysis

Extreme values can skew averages, so both low and high values were averaged separately to see how the relative change in bulk averages differed. The WHO health hazard limit for Hg in air is 1000ng/m^3, so this was used as the boundary between low and high.

Results

Table 2 shows that mercury concentrations in Segovia have decreased for all temporal analyses, suggesting that UNIDO interventions have reduced airborne mercury contamination by 10% despite a 30% increase in gold production in the same time period. Given that different analyses for Segovia yield similar results we can be reasonably confident in the assessment of changes in mercury levels there.

Table 2: Changes in average mercury concentration [Hg] *in the* **Segovia** *urban core; in bulk and separated by hazard level.*

	2010	2011	% change
% of observations >1000* ng/m^3	24%	18%	-6
Total observation time (hh:mm)	26:18	56:10	+113
Time Averages (ng/m^3)			
[Hg]	1244.9	976.5	-22
Day matched Average [Hg]	1197.3	1088.3	-9
[Hg] >1000	4321.2	4243.8	-2
[Hg] <1000	285.5	265.2	-7
Spatial Averages (ng/m^3)			
Bulk [Hg]	558.9	404.5	-28
[Hg] >1000	2717.6	2117.9	-22
[Hg] <1000	323.5	299.9	-7

**1000 ng/m^3 is the World Health Organization health hazard limit.*

Assessments of mercury changes in Remedios and La Cruzada (Table 3) are much less confident. Though they suggest that contamination has increased in proportion to gold production, neither the spatial nor temporal coverage of the data are sufficient to confidently assess changes in contamination. In particular, the small roadside sampling region for these towns contain mostly gold shops and few entables, and it is in the entables that the greatest mercury interventions have taken effect (most notably, the use of retorts). Increasing confidence in the assessments of all three municipalities requires that further data be taken in the same way over time to see if there are consistent patterns.

Gold shop and entable owners were all informed of mercury mapping research before each campaign, but by 2011 they had seen the maps that resulted from the 2010 work. There is therefore a small chance that they changed their behaviour in order to make it look like they were producing fewer emissions. This is considered unlikely because the miners themselves sell gold as soon as they obtain it, and shops were probably not going to turn them away for an entire week. Furthermore, all entable mills were running constantly during the entire study, so there appeared to be no decrease in mineral processing.

It is important to acknowledge the openness and participation of the gold trade community in the five municipalities studied, and especially in Segovia. Meetings I had with them were always well attended and jovial, and cleaner technologies like retorts are being installed and used as requested by UNIDO. Furthermore they are welcoming to frequent external mercury use observation and reporting by UNIDO staff. This is a vital element in tracking the effectiveness of remediation measures and resulting declines in mercury vapour emissions. If the observed reduction in mercury vapour in Segovia can be replicated in follow up studies that include reliable mercury use and gold production data it would be a significant achievement in a relatively short time. These are laudable efforts by the gold trade community and UNIDO. They must be continued, praised, and advanced, however it must always be kept in mind that mercury emissions in urban centres must eventually be banned altogether.

Table 3: Changes in average mercury concentration [Hg] *in* Segovia, Remedios, *and* La Cruzada*.*

	2010	2011	% change
Time Averages [Hg] (ng/m^3)			
Segovia	1244.9	976.5	-22
Remedios	244.9	322.9	+32
La Cruzada	556.8	817.9	+47
Total observation time (hh:mm)			
Segovia	26:18	56:10	+113
Remedios	7:56	9:37	+21
La Cruzada	0:56	4:59	+435
% of observations >1000* ng/m^3			
Segovia	24%	18%	-6
Remedios	5%	5%	0
La Cruzada	7%	11%	+4

**1000 ng/m^3 is the World Health Organization health hazard limit.*

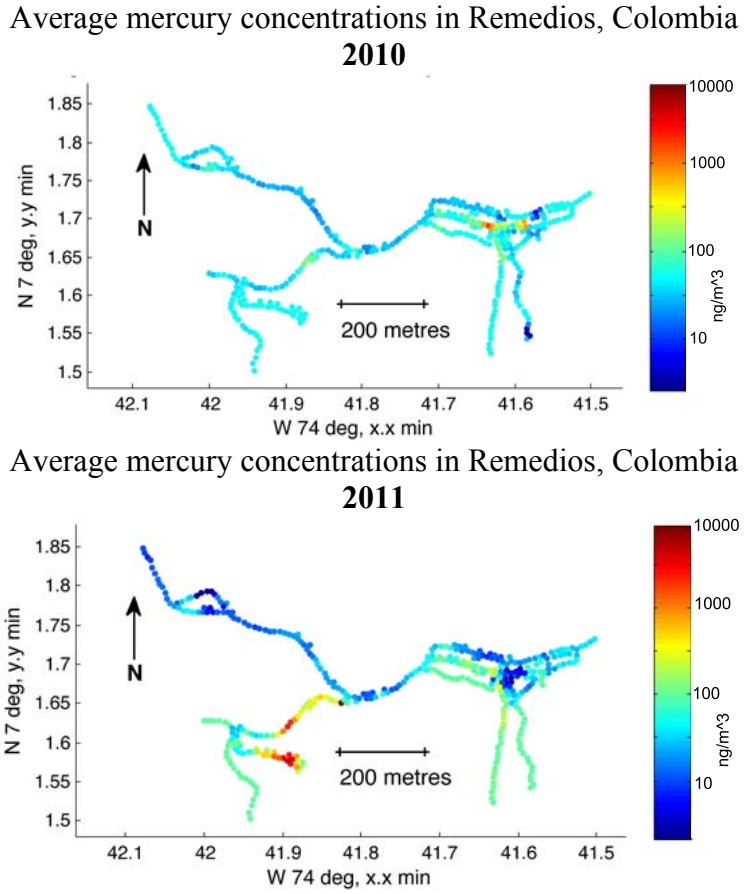

Figure 2: Mercury distributions in Remedios show quite different patterns, with more signals captured near gold shops (in 2010, previous page) and more signals found near the closest entables (in 2011, above.)

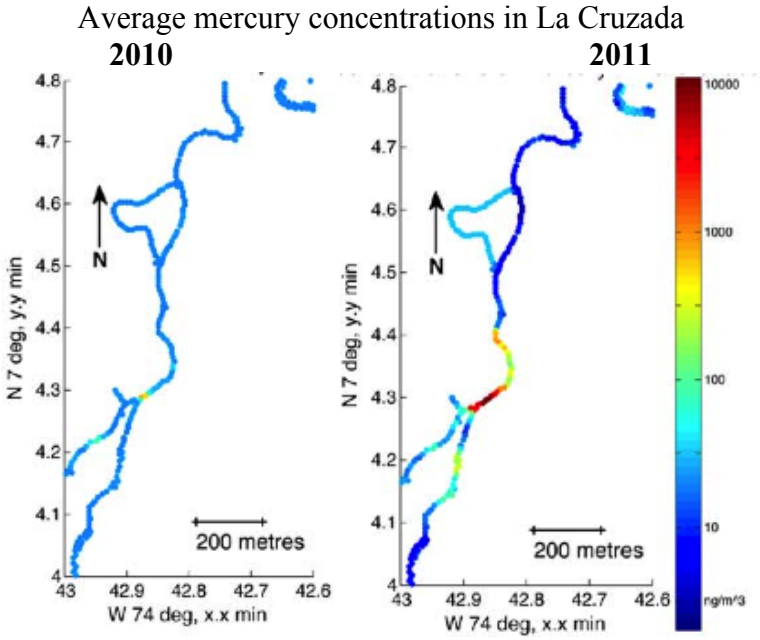

Figure 3: Few data exist for 2010, however they show the same main source as in 2011.

Lectures and meetings

Mr Oseas Garcia (Field Manager of the UNIDO Colombian Mercury Project) and the author of this report had several meetings in which he explained the goals of the UNIDO Colombian Mercury Project and I explained the mercury vapour monitoring that was taking place. Several Segovia municipal workers, Corantioquia staff, and University of Medellin researchers participated in a Lumex training session, and one Corantioquia employee was trained over several days to conduct mercury mapping transects independently. In Medellin, a meeting was held at the University of Medellin explaining the preliminary results of the comparative mercury contamination in 2011 vs. 2010, and ongoing efforts at mitigation.

Recommendations

The ultimate goal for any initiative in this region must be the complete elimination of all gold shops and entables from populated areas. There is no system for filtration of mercury vapours that is sufficiently efficient to burn amalgam without adversely affecting human health; therefore amalgam burning must not be permitted in the urban core. It would still be worthwhile to improve or replace locally developed mercury capture devices, and an immediate solution could be to add glass doors on the fume hoods so that the miner can still see the amalgam being burned, but the vapour is forced to escape via the filters.

Figure 4: Using a glass door on the fume hood on the left could stop people from burning with the door open as shown to the right. They do this so that miners can see their amalgam during the entire burn.

Adults seem to be reasonably tolerant of mercury vapour, and this leads many to doubt the severity of the contamination and risk. However, both Segovia and Remedios' mayors remarked to us that there is an unusually high incidence of kidney failure in their towns. Children and pregnant women are especially vulnerable however and municipal officials noted that there is a high incidence of cerebral palsy in Segovia. School teachers notice that Segovian students have greater learning difficulties and poorer memory than students in other towns. These claims need to be investigated further, and researchers

from the University of Antioquia have indicated interest in carrying out such a study. For the sake of the children, mercury burning activities must be banned or relocated. Even after this happens it is likely that shop walls and other surfaces will emit their mercury burden for months to years after relocating mercury sources.

Conclusions

Mercury contamination continues to be a serious problem in the towns of Antioquia. In 2010 and 2011 the average concentration in the Segovia urban core was close to 1000 ng/m^3, which is hazardous according to the World Health Organization (WHO 2007). Concentrations exceeding the WHO lowest observed effect limit of 20,000 ng/m^3 were encountered frequently in all towns that were sampled, therefore residents are at risk in terms of health and further action must be taken. Recent remediation efforts in Segovia seem to have reduced time-averaged concentrations by about 10%, but addition of new sources have led to increases in spatial average concentration. In Remedios and La Cruzada mercury contamination has increased proportionally to regional production (+30%), even though reduction efforts have been ongoing in these towns also.

Observed reductions in Segovia are likely attributable to use of retorts in entables. In order to make confident claims as to the effectiveness of interventions, this study must be run several more times to produce a time series. If observations of different seasons over several years show consistent decline or stability relative to changes in regional gold production, then there will be firm evidence for the effectiveness of interventions. These data need to be corroborated using accurate estimates of mercury purchasing and use in entables. Ultimately, all mercury use and burning must be banned in urban areas, and many urban and indoor surfaces may have to be decontaminated in order to prevent passive emission of accumulated surface burdens.

Acknowledgements

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References

Bronstein, H. (2009). Gold Production in Colombia. http://poorbuthappy.com/colombia/post/colombia-goldproduction-1463-million-ounces/

Gonzales, V., Velasquez, C., Olivero, J., Pajaro, N. (2011). Air mercury contamination in the gold mining town of Portovelo, Ecuador. Bulletin of Environmental Contamination and Toxicology. 87:3, pp 250-253.

Telmer,K. & Veiga,M.M. (2008). World emissions of mercury from small scale artisanal gold mining and the knowledge gaps about them. In: Mercury Fate and Transport in the Global Atmosphere: Measurements, Models and Policy Implications. Pirrone, N. and Mason, R. (Eds). Chapter 6. p. 96-129. UNEP-United Nations Environment Programme.

Veiga,M.M. and Baker, R. (2004). Protocols for Environmental and Health Assessment of Mercury Released by Artisanal and Small-scale Gold Miners. Published by GEF/UNDP/UNIDO Global Mercury Project. Vienna, ISBN 92-1-106429-5, 289p.

WHO – World Health Organization (2000). Air Quality Guidelines for Europe. 2nd Edition. WHO Regional Publications, European Series, N. 91. http://www.who.dk/document/e71922.pdf

WHO – World Health Organization (2007) pamphlet. Exposure to mercury, a major health concern. www.who.int/phe/news/Mercury-flyer.pdf