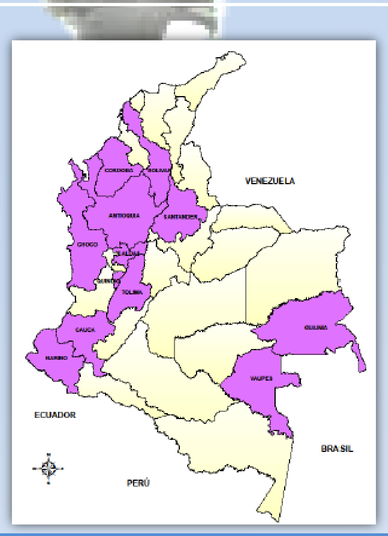
PROBABILISTIC ASSESSMENT OF RISK FROM THE EXPOSURE TO MERCURY IN ARTISANAL GOLD MINING COMMUNITIES IN COLOMBIA

Eduardo De Miguel[a,*], Diana Clavijo[a], Marcelo F. Ortega[a], Enrique Chacón[a], Jorge Loredo[b] , Almudena Ordóñez[b]

[a] Environmental Geochemistry Research and Engineering Laboratory, Universidad Politécnica de Madrid, Alenza 4, E-28003 Madrid, Spain ([*]eduardo.demiguel@upm.es)
[b] Oviedo School of Mines, University of Oviedo, Independencia 13, 33004 Oviedo, Spain

INTRODUCTION

Colombia is one the largest per capita mercury polluters as a consequence of its artisanal gold mining operations, which are steadily increasing following the rising price of this metal. Compared to gravimetric separation methods and cyanidation, the concentration of gold using **Hg amalgams** presents several advantages: the process is less time-consuming and minimizes gold losses, and Hg is easily transported and inexpensive relative to the selling price of gold. Very often, mercury amalgamation is carried out on site by unprotected workers. During this operation large amounts of mercury are **discharged to the environment** and eventually reach the fresh water bodies in the vicinity where it is subjected to methylation. Additionally, as gold is released from the amalgam by heating on open charcoal furnaces in small workshops, **mercury vapors** are emitted and inhaled by the artisanal smelters and the general population.



Map 1: Provinces with significant gold mining activity

METHODOLOGY

The assessment of risk has been carried out independently for each of the 12 Colombian provinces where gold artisanal mining is most intense (Map 1). The conceptual model for the risk assessments considers two main exposure pathways: **Inhalation of Hg vapor** arising from the burning of the amalgam, in workshops and outside and inside the residence; and **ingestion of MeHg-contaminated fish**.

Quantitative toxicity values for both mercury species were obtained from the USEPA's IRIS database:

- Inhalation Reference Concentration: 0.0003 mg/m^3
- Oral Reference Dose: 0.0001 mg/Kg/day.

A total of 70 values of concentration of MeHg in fish, ranging from 0.001 to 3.3 mg/Kg, were used to generate the probability function distributions of exposure to contaminated fish. The number of measurements of Hg in air was considerably higher: 555 inside workshops and 274 in outdoor air.

For ingestion of MeHg in fish, exposure was calculated as:

$$for(i\ in\ 1{:}100000)\begin{cases} C_f = sample(\bar{x}_p, size = 1) \\ CR = sample(uniform(min(cr), max(cr)), size = 1) \\ I[i] = \dfrac{C_f \times CR \times ET \times EF \times ED}{BW \times AT} \end{cases}$$

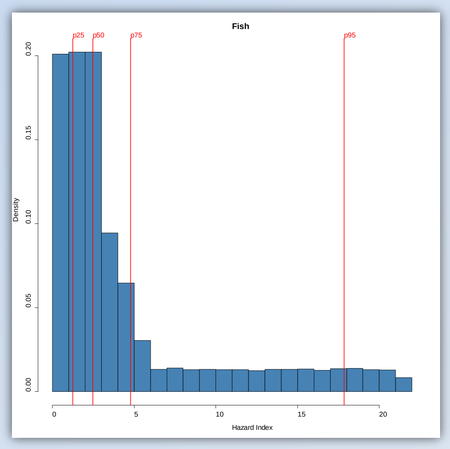
For inhalation of Hg vapors, exposure was calculated as a weighted average for the workshop and the outdoor/indoor environments :

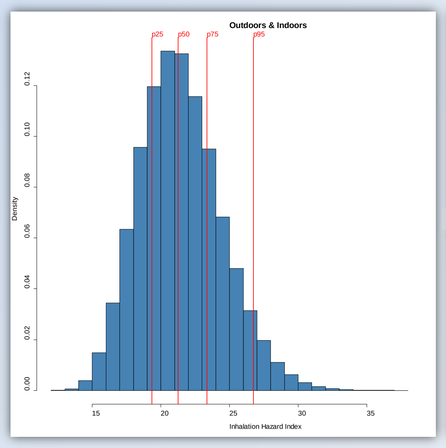
$$for(i\ in\ 1{:}100000)\begin{cases} C_w = mean(sample(x_n, size = n, replacement = TRUE)) \\ C_{out} = mean(sample(x_m, size = m, replacement = TRUE)) \\ EC[i] = \dfrac{C_w \times ET_w \times EF_w \times ED_w + C_{out} \times (\sum_{j=1}^{3} ET_j \times EF_j \times ED_j)}{AT} \end{cases}$$

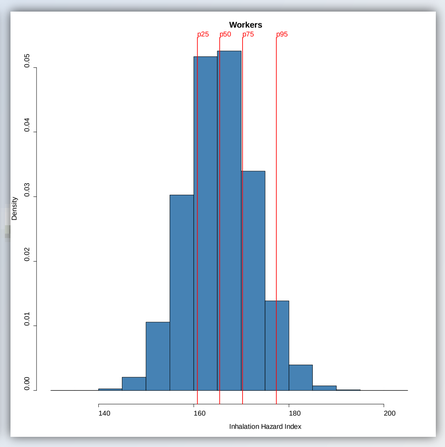
RESULTS AND DISCUSSION

Tables 1 and 2 present a summary description of the resulting HQ distributions for the 12 departments (ingestion) and 3 towns (inhalation) included in this study.

- The elevated rates of fish consumption (fishing communities) and high MeHg concentrations result in HQ distributions whose median values exceed the threshold level of 1 in 10 of the 12 provinces included in the study.
  - All **p95** values are higher than 1, those for the provinces with the highest fish consumption rates range between **HQ=45** and **HQ=90**.
  - A sensitivity analysis reveals that given the relative homogeneity of MeHg in fish across the 12 provinces the rate of fish consumption is the variable that controls the risk output.
  - The estimate of that rate, however, is affected by a high degree of uncertainty.







		min	1 Qu	Median	Mean	3Qu	p95
Miners smelters	Remedios	102.5	138.1	145.2	145.4	152.6	163.6
	Segovia	147.7	180.5	186.9	187.1	193.5	203.4
	Bagre	25.4	42.6	47.8	48.3	53.4	62.4
General population	Remedios	8.6	13.3	14.3	14.3	15.2	16.7
	Segovia	11.2	23.2	26.7	27.1	30.6	36.8
	Bagre	12.4	22.1	23.8	23.8	25.5	27.8

Table 1: Distribution of HQs - Inhalation (outdoor and indoor air, incl. workshops)

	min	1 Qu	Median	Mean	3Qu	p95
Antioquia	2.7E-05	1.2	2.4	4.5	4.8	17.8
Santander	4.7E-06	0.2	0.6	1.7	1.5	9.0
Nariño	1.0E-06	0.1	0.5	1.1	1.7	4.4
Cauca	1.1	2.5	3.6	4.2	5.6	8.7
Caldas	0.2	0.8	2.7	4.5	7.1	13.9
Guainía	1.1	2.3	3.3	4.0	5.8	8.0
Vaupés	1.1	2.3	3.3	4.0	5.7	8.0
Quindío	1.3	3.1	4.3	4.8	6.1	8.6
Bolívar	0.02	2.7	8.8	21.4	24.6	90.5
Chocó	0.5	2.9	11.2	16.1	28.3	46.9
Córdoba	2.6	7.1	9.6	15.7	12.5	78.4
Tolima	0.998	1.9	3.3	8.6	4.4	56.1

Table 2: Distribution of HQs – Ingestion of MeHg-contaminated fish.

- Exposure to mercury vapors in **workshops** where the amalgam is burnt results in HQ distributions for workers with median values ranging from 48 to 187 and **minimum** values **higher than 100** in two of the three towns investigated.
- The risk from inhalation for the **general population** is approximately one order of magnitude lower than for miner-smelters in two of the three towns investigated (and approx. half that HQ in the third), but the **minimum** values are all **higher than the threshold value of 1**.
- For the general population the contribution to the **aggregate risk** of ingestion of MeHg-contaminated fish is lower than that of inhalation of Hg vapor, with differences between both exposure pathways within one order of magnitude.
  - For **miners-smelters** exposed to Hg vapors during the burning of the amalgam, the contribution of **inhalation is 2 orders of magnitude higher** than that of **ingestion**.

CONCLUSIONS

Probabilistic risk assessment is a useful tool to give quantitative meaning to problems of environmental and occupational exposure to pollutants, to categorize these problems, and to prioritize remedial actions.

The general population in Colombia's artisanal gold mining communities is exposed to exorbitant levels of risk resulting from ingestion of Hg-contaminated fish and inhalation of Hg-laden outdoor air.

For miner-smelters who burn the amalgam in artisanal workshops the risk of developing adverse health effects is even higher, reaching levels 200 times higher than what is deemed acceptable.

Environmental HEALTH 2013
Science and Policy to Protect Future Generations
3-6 March 2013 Boston, USA