World emissions of mercury from small scale and artisanal gold mining and the knowledge gaps about them

Kevin Telmer
University of Victoria, Canada

ASGM Mercury Consumption - World
The mercury and gold problem

 Indonesia, 2008, K. Telmer
Mercury Use in ASGM Globally

• Artisanal and Small Scale Gold Mining (ASGM) occurs in at least 70 countries and is growing
• As a consequence of poor practices, 650 to 1350 tonnes of mercury per year are released – an average of 1000 tonnes/a
• This is roughly 1/3 of all global anthropogenic releases
• ASGM is the single largest intentional-use source of mercury pollution in the world
Impact Summary

- 333 tonnes of mercury per annum are volatilized directly to the atmosphere
- 667 tonnes are discharged into soils, rivers and lakes but much of this may be later emitted to the atmosphere – “latent emissions”
- Severe occupational hazards – Mercury vapour
- Tens of thousands of permanently polluted sites – for centuries
- Long-term environmental health hazards to populations and ecosystems
- Perhaps 15 Million people are directly employed by ASGM including 4 million women & 1 million children – all potentially exposed
- Gross revenue is 10.7 billion USD or 715 $ per person
- 100 million people are indirectly involved and potentially exposed to mercury vapours
- Many more people are potentially exposed if the global impact is considered – global contamination of fish
- Neurological damage to people and animals
- Decreased capacity for innovation and prosperity – societal regression
How is Mercury Used?

Gold + Sand → Add mercury to dissolve gold → Tailings

Form Amalgam: 50% Au, 50% Hg → Apply Heat → Sponge Gold Residual
Where is Mercury Lost?

Gold + Sand

Add mercury to dissolve gold

Tailings

Form Amalgam

Apply Heat

Sponge Gold

60% Au, 40% Hg

Hg into water

Hg into air

Hg into air

Hg into air
Mercury Losses Vary With Style of Operation

- Much more mercury lost when **whole ore** is amalgamated
- Even worse when CN is also used!

Eliminating whole ore amalgamation can reduce Hg consumption globally by 45% but it is relatively complicated

BAD

Whole Ore

Gravity Separation

BETTER

Gravity Concentrate

Tailings
Amount of Mercury Used

Amounts of mercury consumed in ASGM can be determined primarily in 5 ways

1. Direct measurements – using a balance to directly weigh amounts of mercury used
2. Applying a mercury:gold (Hg:Au) ratio based on the style of operation (gravity concentrate or whole ore amalgamation) to estimates of gold production
3. To get to number 2, estimate the number of miners actively mining and their average gold production
4. Interviewing miners and gold merchants who buy or sell mercury
5. Official trade data
The Current Estimate is Based On

- Relatively good estimates of gold production and mercury use from pilot studies in 2 countries, Brazil and Indonesia – multiple sites per country
- Reasonable information from 7 more countries
- Some but poor information (mostly anecdotal) from 14 more countries
- Enough information to hazard a guess at a specific level of mercury consumption for 24 more countries
- The identification of the presence of ASGM camps in the remaining 22 countries. These were assigned a fixed minimum amount of mercury consumption. This amount does not significantly alter the estimated total release, and has no effect on the estimated minimum of 640 tonnes/a, but seems reasonable in order to identify potential localities of release.
- Independent analysis of officially recorded trade in mercury and gold
Some outcomes of trade analysis

- Transfer of mercury from the developed countries and northern hemisphere to less developed countries and southern hemisphere
- 13 countries with no mercury using chloralkali plants that import significant amounts of mercury: Australia, Azerbaijan, China, Hong Kong SAR, Guatemala, Guyana, Kenya, Malaysia, Mexico (has plants), Singapore, South Africa, Syria, Thailand, Zimbabwe. Of these, Mexico and Singapore are by far the largest, importing 221 and 138 tonnes/a, respectively.
- Between 2000 and 3000 tonnes/a Hg consumed by all users
- There are 16 main mercury exporting countries (more than 50 tonnes/a): Algeria, Czech Rep., France, Germany, Italy, Japan, Kyrgyzstan, Malaysia, Netherlands, Peru, Russian Federation, Singapore, Spain, Switzerland, United Kingdom, USA
- Value of mercury trade per year is about 30 Million US$
Current Estimate and Distribution

- 333 tonnes of mercury per annum are volatilized directly to the atmosphere.
- 667 tonnes are discharged into soils, rivers and lakes but much of this may be later emitted to the atmosphere.
- Sources of Information: More than 100 documents + other sources

### ASGM Mercury Consumption - World

<table>
<thead>
<tr>
<th>Legend</th>
<th>Tonnes/a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>0.00 to 0.00</td>
</tr>
<tr>
<td>Dark Red</td>
<td>0.01 to 4.99</td>
</tr>
<tr>
<td>Red</td>
<td>5.00 to 9.99</td>
</tr>
<tr>
<td>Dark Orange</td>
<td>10.00 to 29.99</td>
</tr>
<tr>
<td>Orange</td>
<td>30.00 to 49.99</td>
</tr>
<tr>
<td>Light Orange</td>
<td>50.00 to 99.99</td>
</tr>
<tr>
<td>Pink</td>
<td>100.00 to 250.00</td>
</tr>
</tbody>
</table>
Why is Mercury Used?

• Very easy
• Very independent – 1 person can do it
• Highly effective under field conditions
• Accessible
• Cheap:
  – Jan 22, 2008, mercury US$0.017/g; gold US$28/g
  – 1:1650
  – (local prices are different)
  – Worst prices 1:125 – still cheap
• Miners are not aware of the risks
• No choice

Brazilian miner with Tremors, 1996
When is Mercury used

- Used when simple gravity methods cannot produce concentrates greater than 10-20% gold
  - Many sluicing operations
- When a supply is available (almost always)
- When capital is needed quickly (subsistence)
  - Sophisticated processing takes too long
  - 1 or 2 months is too long
  - Can you wait more than a month to be paid?
  - Without a credit card?
Three Case Studies, Three Different Mercury Scenarios

• Primary Mining and Whole Ore Amalgamation in Sulawesi, Indonesia
  – (Hg:Au 20:1 or worse)

• Alluvial Mining and Gravity Concentrate Amalgamation in Kalimantan, Indonesia
  – (Hg:Au = 1.3:1)

• River Dredging and Gravity Concentrate Amalgamation: Pará, Brazil & Kalimantan, Indonesia
  – (Hg:Au = 2:1 to 4:1)
Case 1: ASM in Colluvial and Primary Ores and Whole Ore Amalgamation, Sulawesi, Indonesia
Case 1: ASM in Colluvial and Primary Ores and **Whole Ore Amalgamation**, Sulawesi, Indonesia
Hand Dug Underground Shafts
Very Dangerous, Very far from Health and Safety Compliance
Ore
Crushing
Milling
Preparing to Amalgamateur
750 Grams of Mercury
Amalgamating the Whole Ore
Creating a Slurry and Amalgamating the Whole Ore
Extracting the Slurry and Amalgam
Producing the Amalgam
Amalgam
Amalgam Burning
Amalgam burning

Mercury loss from burning 1 unit Hg, for 1 unit Au
Capturing the Mercury Rich Slurry

- 60-70% of gold remains in slurry
- 20 to 50g mercury per gram of gold is lost to the slurry (A 50:1 ratio!)

As high as 20:1 or 50:1
Mercury Rich Slurry Goes to Cyanidation Process
Cyanide Use After Mercury!
Gold adsorbed on carbon is recovered by burning, mercury emitted to atmosphere

- Adsorbed gold and lots of adsorbed mercury!
- Carbon is burnt releasing mercury and leaving the gold as a residual ash
- The ash is amalgamated again with mercury
- So in the end, even with this method of using CN, the minimum Hg emission is Hg:Au 1:1
- Need to learn “elution” to recover gold and carbon and save money
Slurry Disposal

Very High in Cyanide and Mercury!
Cyano-Mercury Complexes Released into Environment

- Enhanced Transport
- Enhanced Bio-Availability
- Enhance Volatilization

Atmospheric Evasion
Widespread Phenomena

The misuse of mercury and cyanide has been observed in:

- Brazil
- China
- Ecuador
- Indonesia
- Peru
- Phillipines
- Zimbabwe
Case II: Alluvial Ore in Kalimantan
Was habitat for Orangutans

• Only 5000 wild ones left
Galangan – 200 km²
One of many growing operations

City of Palangkaraya

Galangan

Other Growing Sites

Aerial Survey
Mining Pits & Amalgamation Ponds
On the ground
Ignorance
Rates and Amounts

1989 - zero

Primary forest cover is extensive

24km x 18km = 432km²

Processed Landsat 5 TM Image: R=5, G=4, B=3
Huge changes!
Extensive forest removal and vast area of mined sands.

1999

Processed Landsat 7 ETM+ Image, R=5, G=4, B=3
Image classification reveals mined area = 78 km$^2$ in 1999

Classification:

Sand from Mining (cyan) 78km sq, 18% ± 2%;

Exposed Soil (brown) 64km sq, 15% ± 2%;

Agriculture/disturbed (grey) 117km sq, 27% ± 2%
2002 – 102 km$^2$

Classification:

Sand from Mining (cyan) 78km sq, 18% ± 2%;

Exposed Soil (brown) 64km sq, 15% ± 2%;

Agriculture/disturbed (grey) 117km sq, 27% ± 2%
Since 1990 – 16 years

- Rate of Mining – 8 km$^2$/y
- Gold recovered = 11.9 t
- Value of gold$^1 = $210 Million US Dollars
- $13 Million/year
- $35 Million/year for Galangan Area including Dredges
- Directly supports about 40,000 people – 875 $/year
- Any alternative needs to be this big

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1. Determined using gold price variations over time since 1990
Set up and operating costs of operating in Galangan

- Pump + sluice + carpets = 10,000,000 Rp = 1000 USD
- Dredge = 15,000,000 Rp = 1500 USD
- Simple Zircon setup = 2,200,000 Rp = 220 USD
- Generally make back investment in 1 year
- Main cost is fuel (diesel; 4-5000 Rp/L = $0.50/L)
  - 200,000 Rp/day for sluice; 20USD
  - 400,000 Rp/day for dredge; 40USD
Salaries in Galangan

• Basic labourer makes 25,000 to 50,000 Rp/day
  – 2 to 5 USD
• Foreman, perhaps 10 times more; 20 to 50 USD
• Land holder, perhaps 5 times that but varies with holdings
• Mercury Mafia – 1,000,000 USD/year (unknown how many people)
Fume Hood Introduction GMP, 2006
35 USD
Captures 90%
Hg
Activities to reduce mercury consumption

- Reselling Mercury
- Great Financial Incentive
- Prevents Further Imports
- Establishes Relationship with Community
Activities to reduce mercury consumption

2. Awareness campaign

- Primary target and secondary target
- Saturation style media campaign: billboards, posters, flyers, stickers, broadcast media, and UNIDO booklets
- Direct consultation
- Film screening

Budi Susilorini, GTFM, GMP, Vienna, 2007
Measured Success

• Increased awareness of mercury hazard
  – Public 41 to 83%
  – Gold Shop Owners 83% to 100%
  – Women 14% to 91%
  – Miners 21% to 93%

• Reduced Mercury Consumption
  – 35 out of 35 gold shops have installed the water condenser fume hood to capture and recycle mercury
  – The hoods are even being used out in the mine fields

• They are being used because, they make money reselling the mercury!
Case III: Amazon Basin River Dredges
K. Telmer, Tapajos River Basin, 1997
Dimension of artisanal gold mining in Brazil and in Tapajós region

- 100,000 artisanal gold miners (garimpeiros)
- 40,000 in the Tapajós region. Reached 200,000 miners - mining peak in 1990
- 2,000 mining sites (garimpos)
- 432 air strips
- 6 to 8 tonnes/year of gold in the Tapajós region
- Major costs: Diesel, transportation, tools, Mercury (US$200/kg) and food
Bausa

K. Telmer, Tapajos River Basin, 1997
One man operation

Had Malaria

K. Telmer, Tapajos River Basin, 1997
Fume hood installed by USEPA

Rodolfo Neiva de Souza, GTFM, GMP, Vienna, 2007
Argonne National Lab Program with USEPA

Economics of Mercury: Case I

- **Case I: Amalgamation of whole ore followed by cyanidation**
  - Greatest mercury consumption per unit of gold (20:1 to 50:1)
  - Mercury is currently 10% of direct operating costs; and perhaps another 5% due to increased labour costs
  - To increase profits, miners with sufficient capital already do not use mercury
  - Technologically and socio-economically, it is possible that mercury consumption can be drastically reduced quickly and ultimately, completely replaced
  - Eliminating mercury would not eliminate the local gold economy
  - An increased mercury price will help drive this change
Economics of Mercury: Case II

- Case II: Amalgamation of gravity concentrate from alluvial workings
  - Consumption is about 1.3 units of mercury per unit of gold produced
  - Cost of mercury is less than 1% of gold revenue and the amount used is not controlled by the miners directly
  - 1% of a 50 million dollar per year economy is $500,000 dollars
  - Gold shop owners have been eager to recover and recycle mercury for profit
  - An increased mercury price will increase incentives to recover and recycle mercury
Economics of Mercury: Case III

- Case III: River Dredges, Kalimantan and Brazil
  - Consumption is about 1.3 units of mercury per unit of gold produced
  - But the once the mercury becomes “dirty” it is discarded raising the consumption rate to 3 to 5 units of mercury per unit of gold recovered
  - The mercury is purchased directly by miners
  - Cost of mercury is less than 2% of gold revenue but these operations run at near the break even point and so buying mercury is considered a significant cost by the miners
  - Each miner makes $12 to $30 per week
  - Mercury costs per miner are around $2.5 dollars per week (10 to 20% of earnings)
  - An increased mercury price will increase incentives to recover and recycle mercury
Determined Mercury Conservation
Is It Possible to Limit Supply Locally?

- Almost no success across ASM sector over 30 years
- It should be viewed as any other contraband
- Stringent policy sounds good but drives it underground and out of reach – has occurred due to international interventions
- Regulating imports is more difficult than regulating exports from developed countries
- Export bans from main sources will be easier and more effectively control mercury trade
But there are other important considerations

• A huge price increase or rendering all mercury contraband may have unpredictable outcomes
  – Increased incentive to smuggle
  – Underground mercury trade
  – Already occurring in some places
• It is easier to eliminate mercury from some ASM operations than others
  – A very high price ($2000/kg) will still only represent 10% of costs for some operations so price alone will not solve the problem
• Field based intervention programs must also continue
Ethics

• Increased costs are passed on to the poorest
• Export bans represent a unilateral action which arguably can impoverish or further indenture the poor
• By most human rights criteria, we should not knowingly induce small scale miners to take a pay cut
• An export ban therefore needs to be accompanied by the development and implementation of viable replacement technologies or replacement economies for small scale miners
• Don’t squeeze people to change but rather help them to change
• Field based intervention programs must remain a priority
The keys to eradicate mercury in ASM

- Making Hg less available
- This is equivalent to making it more expensive
  - Trade Bans
- Providing an alternative
  - Alternative method of small scale gold mining
  - Alternative economy
Knowledge Gaps

Amalgam burning: Adsorption behaviour to local surfaces like the wooden beam, have large health implications

Air-surface exchange
- Halogen depleted atmosphere

Atmospheric transport
- How far?

Deposition or emission to the canopy over 10 years?

Gold Shop Chimney Emissions. Urban surfaces?

Amazon Rainforest Canopy

Indonesian Rainforest Burning

• Air-Surface Exchange?
• Speciation?
• Magnitude?
• Fate?
Knowledge Gaps

Mercury – Cyanide Interactions

Atmospheric Evasion
Mining into high DOM waters

- Floodplain Inundation
- Methylation
Landuse and Remediation

- Prevention: Landuse Improvements
- Less than 20% of the total area has been effectively mined.
- 90% of the gold is being left behind
- The already destroyed area could be mined for another decade
- No further land degradation or river siltation
Filling Knowledge Gaps

• There are many more gaps – (see Telmer and Veiga, 2008)

• Small scale mining is a good place to build this knowledge about mercury

• It would bring needed resources, raise awareness, and undoubtedly produce some innovative ideas.

• The current lack of understanding about mercury in ASGM puts a limitation on the development of innovative solutions towards prevention and remediation.
Limiting Supply – Trade Bans

• Miners are sensitive to the price of mercury and already seize any opportunity to conserve it
• Therefore a ban on mercury trade will stimulate mercury conservation at ASM operations
• Limiting supply is an important step in reducing mercury consumption in ASM but is not a silver bullet to the problem
• There are ethical considerations about unilateral action that causes pay cuts to the poor
• Field based intervention programs must also remain a priority
Possible Reductions

• If miners adopted emission control measures (fume hoods and retorts) mercury consumption globally could be reduced by a maximum of 27%

• Learning how to re-activate or clean used mercury could reduce mercury consumption by a maximum of 25%

• Elimination of whole ore amalgamation could reduce mercury consumption by 45% or more
Perspective

- If the top 10 countries using mercury in ASGM, excluding China, were just to adopt fume hoods and retorts and learn how to re-activate mercury, then roughly 210 tonnes less mercury per annum would be consumed.
- If China participated then the reduction in mercury consumption would increase to 420 tonnes of mercury per annum.
- For every 10% of the whole ore amalgamation operations that convert to either (a) first producing a gravity concentrate before amalgamation, or (b) using mercury free technology, 50 tonnes less mercury would be consumed per annum.
Conclusions

Realistically by working towards the three approaches
  – emission control
  – Recycling
  – elimination of whole ore amalgamation

a 50% reduction in mercury use in ASGM globally over 10 years could be obtained through intervention efforts

Reasonable because the first two are profitable to miners
  – an important criterion for sustainable change.
Decadal Reduction Scenarios

Current - 2008

Amalgamation of concentrate: 50%
Amalgamation of whole ore: 50%
1000 tonnes

2018

300 tonnes: also a 50% reduction of whole ore amalgamation

550 tonnes: fume hoods + retorts

91% 9%
83% 17%

Final Word

- The database on ASGM remains poor
- How many people are mining, how much gold they are producing, how much mercury they use, what happens to the mercury, and how much habitat (land and water) has been impacted remains poorly known
- The available data has been used to make a first estimate of these quantities, and to point out the knowledge gaps surrounding mercury use in ASGM
- Inputs that will improve the database or innovations that can contribute to solutions are needed and welcome
Thank you!

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