Chapter 6
World Emissions of Mercury from Artisanal and Small Scale Gold Mining

Kevin H. Telmer and Marcello M. Veiga

Summary We estimate mercury releases from artisanal and small scale gold mining (ASGM) based on available data about mercury and gold exports and imports by country and from field reports from the countries known to have active ASGM communities. The quality of the estimates ranges from reasonable to poor across the countries. This paper aims to give a first order estimate of the amount and location of mercury being released into the environment globally by ASGM, to motivate stakeholders to improve the quality of these estimates, to illustrate the linkages between global mercury trade and its use in ASGM, and the fourth objective is to provide a practical outline of the options available for reducing mercury use in ASGM. We estimate that artisanal and small scale gold mining releases between 640 to 1350 Mg of mercury per annum into the environment, averaging 1000 Mg yr^{-1}, from at least 70 countries. 350 Mg yr^{-1} of this are directly emitted to the atmosphere while the remainder (650 Mg yr^{-1}) are released into the hydrosphere (rivers, lakes, soils, tailings). However, a significant but unknown portion of the amount released into the hydrosphere is later emitted to the atmosphere when it volatilizes (latent emissions). Considering that ASGM is growing, latent emissions conservatively amount to at least 50 Mg yr^{-1} bringing the total emission of mercury to the atmosphere from ASGM to 400 Mg yr^{-1}. This estimate of emission to the atmosphere differs from the previous one provided in the 2002 UNEP Global Mercury Assessment both in terms of its magnitude (400 Mg yr^{-1}, versus 300 Mg yr^{-1}) and in the way the estimate has been made. The current estimate is based on a better understanding of ASGM and on a wider variety of information sources, more field evidence, better extrapolation methods, and independent testing by analysis of official trade data.

6.1 Introduction

We begin with a presentation of the intricacies of why mercury is used in ASGM and how it is released to the environment. A good understanding of the use of mercury in ASGM is needed in order to evaluate both the emission estimate and the options available for reducing mercury use.

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We then begin to build the database on mercury in ASGM by identifying the known localities of ASGM – documented to occur in 70 countries – by citing reports from governments, international bodies, NGOs, the peer reviewed literature, and from mining companies. This is followed by a section that uses case studies and field data collected from various intervention efforts, as well as arguments from later sections, to make an estimate of the consumption of mercury in ASGM by country. This is further broken down into an estimate of how much mercury is directly released to the atmosphere.

The next section examines the global trade in mercury and gold for the purposes of placing the magnitude of mercury consumption by the ASGM community into perspective. Because reporting is voluntary, this approach is imperfect but does provide some useful information on mercury in ASGM. It also re-enforces the notion that mproved reporting of mercury trade would greatly improve our ability to track flows of mercury around the world. For example, despite having active dental services that undoubtedly use mercury, there are 70 countries that do not report any trade in mercury. Analysing the trade data, allows some crude but independent constraints on the magnitude of mercury consumption in ASGM to be made.

We then explain the current knowledge gaps surrounding mercury use in ASGM. This is to point out that despite being one of the largest sources of mercury to the environment, research on mercury in ASGM has been relatively poorly funded and grossly unsophisticated relative to that carried out in the northern hemisphere, and that small scale mining communities are a good place to build knowledge about mercury. Aside from answering important questions about mercury's behaviour, working in these communities would additionally 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.

The final section examines the options available to reduce mercury use in ASGM and the estimates the magnitude of reductions for each of the options discussed.

6.2 Why Mercury is Used

Mercury is used in ASGM for the following reasons:

1. Mercury use is very easy – the easiest and quickest method to extract gold from many alluvial ores under the existing field conditions. This is sometimes debated by those who have not spent much time in the field, but it is a verity. A simple way to look at this is as follows. In the case study by Telmer and Stapper (2007), the effective ore grade (what is recoverable by the miners) was about 0.1 g Mg^{-1}; the miners processed about 100 Mg of ore per day to produce a gravity concentrate of 10 kg of ore. That represents a concentration factor of 10,000 times. The 10 kg of concentrate contains 10 g gold and so they need to further concentrate

by 1000 times. This can be done by manual gravity methods (like panning) but will require significant time and will risk the loss of some gold (particularly the finer fraction). For example, recreational small scale miners in Canada often spend 2 or more hours panning up their concentrate. Capturing the gold by amalgamating the concentrate takes about 10 minutes and produces more certain results. So in ASGM sites, the 2 hours is instead used to continue mining and produce another 2 g of gold.

2. Mercury is very independent – the whole mining process can be accomplished by just one person thereby eliminating the necessity of participating in undesirable and unfair labour practices (there is no need to be indentured). Often in more mature ASGM sites the bottom of the labour pool are still indentured to middle men or “a syndicate”, but even so, their salaries are inevitably higher than those from their former occupation, and they always have the choice to strike out on their own – an important and desirable psychological condition for most people around the world.
3. Mercury is highly effective at capturing gold under the conditions found in ASGM sites. Again, the verity of this statement is occasionally debated by academics but under the circumstances found in ASGM sites, it is indisputably true. That is not to say it is technically always the “most” effective method to capture gold, but it can often be the “optimal” method under the socio-economic and political conditions found in ASGM sites. For example, in the first point (#1) above, a centrifuge or other technology may be more effective than mercury, but at what cost? and what infrastructure is needed to operate it? Often costs and infrastructure are prohibitive. This is particularly true when operations are illegal, which is most of the cases. Who is going to risk significant investment into an illegal operation?
4. Mercury is typically very accessible – it is as portable and easy to transport as gold and so moves across borders and into camps as easily as or more easily than many other contraband materials. As far as we know, eliminating mercury through local enforcement has never been successful. In fact it often has a detrimental effect on the miners. For example, in Indonesia, mercury was made illegal in 2006. This drove mercury trade underground and doubled the price paid in the ASGM sites but did nothing to stem the flow of mercury – in fact it made selling it more lucrative for merchants. However, it is also true that increased prices may have been an incentive to increase recycling efforts – keeping in mind that the affordable recycling technology was only made available through an intervention program, the GMP.
5. Mercury is relatively very cheap, as explained through the following perspective:

   - As of Jan 22, 2008, prices were: mercury (US$600/76 lb flask; US$17.40/kg); gold (US$874.00/ozt)
   - This is close to historical highs for both mercury and gold.
   - Therefore 1g mercury = US$0.017; and 1g gold = US$28.10
   - The mercury: gold price ratio is therefore 1:1,650
   - If 2 units of mercury were used to produce 1 unit of gold, the cost of the mercury would represent 0.1% of revenue. An invisible amount.

- In the mine fields, the price paid for gold is less than the international price, typically 8 to 10% less (~US$25/ozt) and the price paid for mercury is higher, particularly where it is illegal making gouging by suppliers easier. Some miners have reported paying as high as US$200/kg (US$0.20/g) (Creporizão, Brazil). Under these prices the cost of using 2 units of mercury to produce 1 unit of gold represents a mercury: gold price ratio of 1:125 or 0.8% of revenue – still remarkably cheap.
- However, once expenses are paid (fuel, equipment, food, shelter), and profits are divided – usually very inequitably with the lion's share going towards the top of the labour pyramid – the cost of mercury may become significant for labourers at the bottom, and so despite its apparent cheapness, an economic incentive to conserve mercury does exist for the lowest paid labourers and for those who deal in large quantities of mercury – often gold dealers.

6. Miners are not always aware of the health risks that mercury poses. Images of people carelessly exposing themselves to mercury in Figure 6.1 tragically show the truth of this.
7. Miners have no choice – in many cases miners are not aware of alternatives if they do exist, or do not have the capacity to practice them.
8. Mercury is most commonly used when simple gravity methods cannot produce concentrates greater than 10-20% gold. This is true of many simple hydraulic sluicing operations and many shallow colluvial or hard rock operations. If a concentrate of 20% can be produced, then direct gold smelting is possible.
9. Mercury is used when capital (cash) is needed quickly for subsistence or to purchase materials and supplies required for more sophisticated techniques like leaching with cyanide. This point is often a difficult one for citizens of developed nations to fully grasp. The miners – even the middle men – do not have bank accounts or credit cards or much, if any, access to social assistance like health care, and therefore often cannot wait to get paid. For example, miners who have made the transition to cyanide leaching and whom know that the maximum gold can be obtained through cyanide leaching alone, often return to using mercury when an emergency such as a family illness or wedding comes up, simply because they cannot wait until completion of the more time consuming, albeit more efficient, cyanide processing method (often a 1 month cycle).

In summary, using mercury is cheap, simple, fast, independent, and reliable. And so in many settings, it is hard to beat. That is why, as a first line of intervention, it may be more appropriate to try to reduce mercury consumption through conservation practices like retorting, fume hoods, and mercury re-activation or cleaning (making dirty mercury usable again and thereby preventing it from being discarded into the environment), rather than immediately aiming for the total elimination of mercury use. The introduction of conservation practises can easily reduce mercury consumption by 50 to 90% and it is an easily accepted change in practice – one that can even have the powerful incentive of being profitable (Agrawal, 2007).

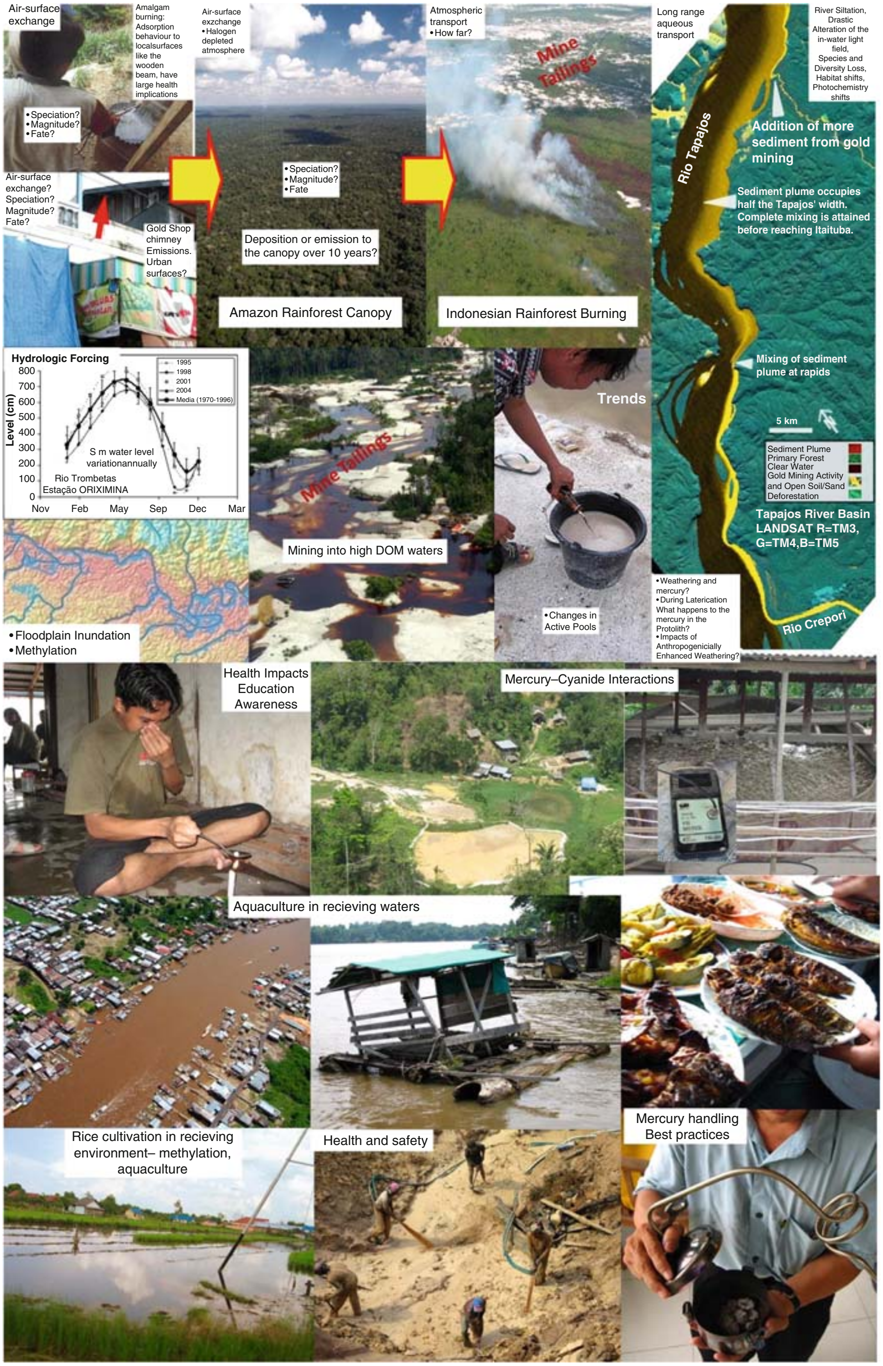

Figure 6.1 Illustration of some of the many knowledge gaps remaining about mercury in ASGM

6.2.1 How Mercury is Released to the Environment

Mercury is released to the environment during artisanal gold mining in a variety of ways. When it is used to amalgamate gold, some escapes directly into water bodies as elemental mercury droplets or as coatings of mercury adsorbed onto sediment grains. The mercury that forms the amalgam with gold is emitted to the atmosphere when the amalgam is heated – if a fume hood or retort is not used. As well naturally occurring mercury in soils and sediments that are eroded by sluicing and dredging becomes remobilised and bio available in receiving waters (Telmer et al. 2006). Finally, where a combination of cyanide and mercury are used, the formation of water soluble cyano-mercuric complexes enhances transport and bio-availability. Albeit the fate of mercury in any of these processes is poorly understood, the interactions of cyanide and mercury are the least understood at this time.

When miners use cyanide, this dissolves not only gold but also mercury, forming cyano-mercury complexes. These complexes are easily mobilized by rain and often, due to poor containment practices, quickly reach stream waters. It is expected that water-soluble mercury cyanide is either more bio available or easier to be biomethylated than elemental mercury. This possibility deserves more investigation, but indirect evidence collected by the Global Mercury Project sites in Indonesia, Zimbabwe and Brazil suggest this is the case. Dangerously high levels of mercury in fish (average 2.53 ± 3.91 mg Hg kg^{-1}; carnivorous fish: 4.16 ± 5.42 mg Hg kg^{-1}) were found in Brazil when mercury and cyanide were used together compared to when only mercury amalgamation was performed (UNIDO, 2006). Other similar investigations were carried out in Indonesia (Castilhos et al., 2006; Baker and Telmer, 2007).

Overall, therefore, the pathway that mercury from ASGM takes into the environment, whether it is emitted to the atmosphere, first released into surface water and soils and later emitted (latent emissions), or exported in products (see later section); as well as the amount of mercury consumed per unit of gold produced, varies greatly across ASGM operations and communities.

6.2.1.1 Whole Ore Amalgamation

Whole ore amalgamation is the process of bringing mercury into contact with 100% of the material being mined. Typically, mercury is either added when the ore is being ground in mills or the slurry produced from grinding is passed over a mercury coated copper plate. Amalgamating the whole ore uses mercury very inefficiently and so between 3 and 50 units of mercury are consumed to produce 1 unit of gold, with an average of around 5. Most of the mercury loss during whole ore amalgamation initially occurs into the solid tailings which are often discharged directly into receiving waters and soils. Importantly, however, it is well documented that this mercury continues to evade into the environment for centuries (Alpers and Hunerlach, 2000; Al et al., 2006; Shaw et al. 2006; Winch, 2006). Further, although little studied, it is certain that mercury in tailings that are subsequently leached with cyanide to recover more gold (a growing trend already observed in 10 countries) undergoes enhanced aqueous transport and emission to the atmosphere. This is because of the complexation of mercury by cyanide. It is well known that mercury and cyanide, like gold and cyanide, readily form soluble complexes, and that when cyano-mercury complexes degrade, mercury readily volatilises.

Immediate emissions to the atmosphere during whole ore amalgamation occur when the recovered amalgam is heated to produce the gold. In the simplest case, such as the use of mercury coated copper plates, immediate losses to the atmosphere are therefore roughly equal to the amount of gold produced. However, there can be significant additional emissions to the atmosphere on a time scale of weeks to months from tailings and in particular from operations that employ cyanide. For example, in a whole ore amalgamation operation like those in Indonesia documented in Sulaiman et al. (2007), if 20 g of mercury are consumed to produce 1 g of gold, then 19 g of mercury are lost to the tailings and 1 g of mercury is immediately emitted to the atmosphere. However, additional mercury is released to the atmosphere shortly thereafter from: (i) volatilisation from cyanide rich tailings; (ii) during cyanidation gold is adsorbed from the solution by activated carbon. Mercury is also unavoidably adsorbed. To recover the gold, the carbon is burnt and so any adsorbed mercury is emitted at that time; (iii) the "ash" produced by burning the activated carbon is often re-amalgamated with mercury and this amalgam is also thermally decomposed to produce the gold, releasing an additional amount of mercury to the atmosphere equal to the total gold produced. In such cases, immediate emissions to the atmosphere are minimally greater than the total gold produced and this includes the amount of gold produced via cyanide leaching.

6.2.1.2 Amalgamation of a Concentrate

In cases where only a gravity concentrate is amalgamated, losses are normally about 1 to 2 units of mercury for each unit of gold produced, but can be significantly lower if a mercury capturing system is used when the amalgam is burnt – retorts or fume hoods. For example, in Central Kalimantan, commonly 1.3 g of mercury is consumed to amalgamate 1 g of gold from a gravity concentrate produced by sluicing alluvial ore (Telmer and Stapper, 2007). In this case 0.3 g of mercury is discharged to water with the tailings and 1 g of mercury is emitted to the atmosphere when the amalgam is burnt. Consumption of mercury in Brazil as recorded by Sousa and Veiga (2007) is similar.

Sometimes the tailings are rich in minerals such as zircon which are valuable to the ceramics and abrasives industries and so the tailings are not discarded but rather are further processed and then export (often to China or Korea). During reprocessing the tailings are often amalgamated a second time to recover any residual gold, and then further processed to produce (i) a high grade heavy mineral concentrate which is contaminated in mercury and export, and (ii) a waste which is discarded. The mercury that is export with the zircon is certain to be emitted to the atmosphere during later industrial use. The fate of the mercury in the residual waste is unknown but may end up in aggregate products such as bricks or be discarded into local waterways. An additional cause of mercury pollution that is frequently overlooked is the discarding of "dirty mercury". When ore is amalgamated with mercury the products are (i) solid amalgam; (ii) tailings; and (iii) residual liquid mercury. For example, a miner may add 100 g of mercury to 10 kg of concentrate and then recover 20 g of amalgam (50% gold, 50% mercury), and 87 g of residual liquid mercury with 3 g lost to the tailings. They would then re-use the residual liquid mercury to amalgamate the next day's concentrate. However, the effectiveness of the liquid mercury is reduced as it becomes oxidized and contaminated with impurities – this is referred to as "dirty mercury". Typically, after 3 or 4 uses, mercury becomes much less effective at amalgamation and so it is discarded. In the case of dredge operations in Kalimantan, dredge operators just throw it into the river. This causes mercury consumption to be higher than the 1.3 units of mercury for every 1 unit of gold described above. When mercury is not recycled through re-activation (described in the final section), consumption is likely to be at least twice the ratio established by recording only the immediate losses that occur during amalgamation.

6.3 Where ASGM is Occurring

There is reasonably good information about where ASGM is occurring. The Information sources are: reports from the MMSD (2002); 16 years of archives from the Northern Miner (1992–2008); reports and conference materials from the World Bank's Secretariat on Communities and Small Scale Mining (CASM, 2007) up to 2007 (7 meetings); 5 years of reports and conference materials form the UNDP/GEF/UNIDO Global Mercury Project (GMP) up to 2007; reports from other intervention programs such as the Swiss Development Agency (SDA), the Canadian International Development Agency (CIDA), the World Wildlife Fund (WWF); reports and abstracts from the International Congresses on Mercury as a Global Pollutant (ICMGP) up to 2006 (8 congresses); numerous articles published in the peer reviewed literature; and personal communications with field operatives of intervention programs and people employed in the ASGM economy – miners and gold and mercury merchants. Table 6.1 (see Appendix 1) lists the countries and column 3 of Table 6.1 lists the sources of information that identify the presence of ASGM by country (note that these information sources are in some cases different from those used later to estimate current mercury consumption – column 7). Accordingly, ASGM has been documented to occur in 70 countries. Figure 6.2 illustrates the global distribution of ASGM based on data from Table 6.1. There are at least 6 more countries that are likely to have ASGM occurring bring the likely total to 76 countries but with no firm documentation for those countries we will use the more conservative number of 70.

6.4 Amount of mercury used in ASGM

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.

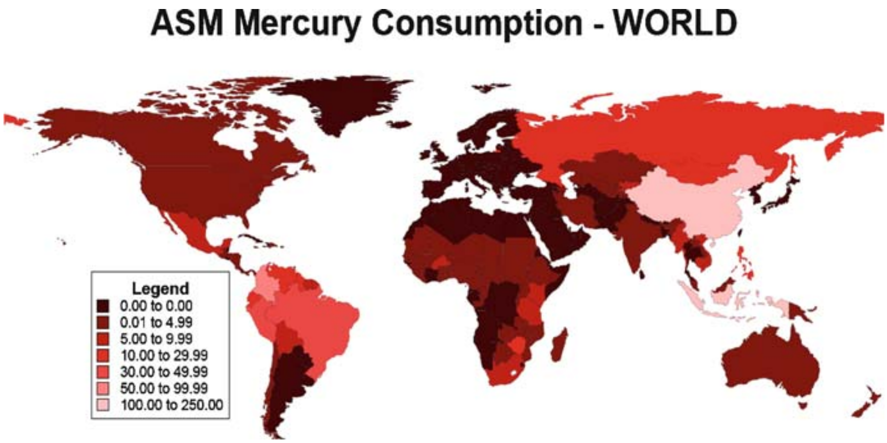

Figure 6.2 Map of mercury consumption by artisanal small scale gold mining globally

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 first four approaches involve directly working with miners and gold merchants and gaining their trust.

Unfortunately, there is very little high quality information on amounts of mercury, size of operations, and what styles of operation are in use around the world in ASGM sites. Much of what exists is anecdotal. In part, this is because of ASGM's highly decentralized and remote nature and because it often exists outside the law. Specifically: (i) there is a lack of interest from governments about ASGM because miners are marginal citizens – they do not pay tax, do not vote, do not have permanent homes, etc.; (ii) miners are subjected to gold price cycles and gold rushes and unfair labour practices and so are very migratory and dispersed; (iii) many ASGM sites are in remote areas where there is no infrastructure and therefore no information; (iv) many clandestine (illegal) activities are involved in ASGM such as money laundering, tax evasion, weapon acquisition, etc., making it sometimes difficult to access miners and making the quality of information they provide sometimes questionable; (v) miners and mining and the use of mercury are often prohibited – perhaps more than 90% of all miners are operating in illegal ways.

But we have found that, in fact, many of these obstacles can be overcome and the lack of information is not only due to these reasons. It is also due to the differing cultures of various intervention efforts. Telmer and Stapper (2007) explain this as follows: "A good knowledge base is the required backbone to formulate solutions to the problems associated with mercury and ASGM. Indeed, many well meaning attempts to improve the livelihoods and living conditions of miners or to reduce the environmental impacts of ASGM have failed because of lack of appropriate knowledge about the ASGM community. There have been attempts to create alternative livelihoods or to introduce mercury-free technologies to miners based simply on the *idea* or *wish* that they should behave differently, rather than starting by understanding the financial burden that such interventions might cause and then building up a solution from there." They go on to explain that "In assessing an ASGM site, there are many useful bits and pieces of information that help constrain the socio-economic and environmental realities of small scale gold mining. Of these, perhaps some of the most useful quantities are: (i) how many people are mining? (ii) how much gold are they producing?; (iii) how much mercury do they use to do so?; and (iv) what is the scale of the impacts they are having on the landscape? – How much habitat (land and water) has been impacted? This basic information can then be used to constrain many other important aspects of ASGM, and then to educate the stakeholders and interest groups involved – including the miners themselves. This in turn helps immensely in guiding the formulation of appropriate intervention strategies, focusing resources, and avoiding costly and frustrating failures." And so unfortunately, despite years of efforts, most interventions in ASGM have either not attempted to, or have not been able to effectively measure the quantity of mercury consumed by miners in ASGM sites. There are however some cases where the amounts of mercury consumed have been well documented.

6.4.1 Indonesia

1. Telmer and Stapper (2007) together with Agrawal (2007) used a scale to directly weigh amounts of mercury used to amalgamate ore, and then extrapolated these statistics to Central Kalimantan by using aerial photography and satellite imagery. The estimate of mercury consumption since 1990 to 2006 for Central Kalimantan not including river dredging was 70 Mg of mercury with the lion's share (10 Mg yr^{-1}) being consumed in more recent times. River dredging consumes more mercury than land based work because the miners throw away the mercury once it becomes oxidized (refered to as "dirty mercury") and is no longer a strong amalgamator of gold – a habit that can be changed by teaching how to clean or re-activate mercury (Pantoja and Alvaarez, 2000; Wuerker, 2008) Sousa and Veiga (2007) estimate how much mercury this prevents from entering the environment for a case study in Brazil. Mercury consumption is estimated to at least double for the region when river dredging is included. Central Kalimantan is about 1/3 of Kalimantan but contains about 1/2 of Kalimantan's ASGM sites, and so by further extrapolation using satellite imagery, it is estimated that 40-60 Mg yr^{-1} of mercury are consumed in Kalimantan. This is a minimum estimate because it does not include any high-grade underground workings which are known to occur in Kalimantan (Mansur Geiger, Kalimantan Gold Corporation, pers. comm., 2008) but difficult to see with publically

available satellite imagery. Further, there are many small operations up the many tributary river channels that cannot be easily seen by satellite imagery. Many of these were seen by low flying aerial survey performed while ground truthing the larger areas with aerial photography – small scale mining was ubiquitous, often appearing in the wake of illegal logging.

2. Sulaiman et al. (2007) examined a whole ore amalgamation operation in North Sulawesi, Indonesia, and also used a balance to directly weigh amounts of mercury used to amalgamate ore per mining operation. Mercury losses per unit of gold amalgamated were extremely high averaging 37.5 g mercury lost per 1 g gold produced. The consumption of mercury in just one small area that contained roughly 100 individual operators was 3 Mg yr^{-1}. [An important additional and worrisome consideration here is that once the ore has been subjected to amalgamation by mercury, it is subsequently leached with cyanide and then the final tailings are crudely disposed of into unlined ponds that leak into rivers and groundwater. It is known that cyanide complexes mercury as well as gold and so it is certain that the cyanide leaching is enhancing the transport and distribution of mercury in the environment. It is also known from large scale mining operations that cyanide leaching enhances mercury evasion to the atmosphere and so that too is certainly occurring.] Two more mining areas in North Sulawesi of equal magnitude were visited making a total of 9 Mg yr^{-1} mercury consumption only for the limited study area. However, it is known that there are more operations in Sulawesi making this a minimum for that island.

The mercury consumption for these two areas is 40-60 Mg yr^{-1} for Kalimantan plus 9 Mg yr^{-1} for a part of Sulawesi with a total between 50 and 70 Mg yr^{-1}. The MMSD report on indonesia by Clive Aspinal (2002) claims much higher losses of mercury in north Sulawesi – a total of 270 kg Hg per day which would make annual losses, based on 260 working days per annum, equal to 70 Mg of mercury – just for one area in North Sulawesi. Further, the report uses that estimate from North Sulawesi to extrapolate and make a hypothetical loss of mercury per annum for all Indonesia of 1400 Mg Hg yr^{-1}. Clearly, this is an overestimate. Nonetheless, the report does help give some useful information on the extent of ASGM in Indonesia claiming that in 2002 small scale gold miners were operating in Kalimantan, Sulawesi, Java, Sumatra, and Irian Jaya (now called Papua) – essentially all of the major islands. Through talking to miners, we learned that it occurs on several other islands as well. Considering the broad distribution of ASGM in Indonesia and the fact that ASGM has grown since the MMSD was completed in 2002 (the price of gold has tripled during that time increasing the incentive to mine), we feel it is reasonable to double the estimates from Kalimantan and Sulawesi for a total mercury consumption for Indonesia equal to 100 to 140 Mg yr^{-1}. To make the quality of this estimate clear, and to illustrate how poor the database on mercury in ASGM is, it is important to understand that despite the obviously loose nature of this estimate, it is perhaps our most certain figure. Scaling up from one operation to the country level inevitably involves significant assumptions; nonetheless, we have begun with quantitative data and used the tools that are available to scale up.

6.4.2 Brazil

Sousa and Veiga, (2007) have estimated that there are 40,000 miners in the Crepori area of the Tapajos basin (Reserva Garimpeira) and that they consume 40 g mercury/month for a total of 19.2 Mg yr^{-1}. Telmer and Stapper (2007) independently looked at a subset of this region representing about 1/2 of the area for the period 1979 to 2006, and only considered land based operations (i.e. no river dredging included) and estimated an annual mercury use of 4 Mg yr^{-1} for 2006 – the closest year to the work of Sousa and Veiga. By extrapolation to the whole area and including dredges an amount of 15 to 25 Mg yr^{-1} is possible, roughly corroborating the results of Sousa and Veiga. Brazil is a vast territory and has several other known ASGM sites including several new areas in the western state of Acre (Blore, 2007) and so we feel that doubling this estimate to 40 Mg yr^{-1} is reasonable.

6.4.3 Other Countries with Documented Estimates

Quantities of mercury have also been relatively well documented in Cambodia 7.5 Mg yr^{-1} (Murphy, 2006); Guyana 15 Mg yr^{-1}; Suriname 7.5 Mg yr^{-1}, French Guyana 7.5 Mg yr^{-1} (Vieira, 2008); and Monglia 11.5 Mg yr^{-1} (Grayson, 2007). As well, quantities of mercury have been estimated in four more countries that participated in the Global Mercury Project: Sudan 0.8 Mg yr^{-1} (Ibrahm, 2003); Zimbabwe 25 Mg yr^{-1}; Laos 1.3 Mg yr^{-1}, and Tanzania 6 Mg yr^{-1}. Gunson and Yue (2002) reported a minimum of 50 Mg yr^{-1} mercury released through ASGM in China, however this estimate was since revised to a min and max of 237 to 652 Mg yr^{-1} through more thorough research (Gunson, 2004) and seems reasonable based on the fact that China became the world's largest gold producer in 2007, much of its production is known to come from small mines, and that much of China's ASGM employs inefficient whole ore amalgamation where the consumption of mercury can be very high. Unfortunately at this time China officially admits no ASGM operations occur in its territory.

6.4.4 Other Countries - Direct Anecdotal Information

We have direct anecdotal information on ASGM operations in another 15 countries (Ghana, Mozambique, Guinea, Uganda, Peru, Colombia, Ecuador, Nicaragua, Bolivia, Venezuela, Suriname, Chile, Costa Rica, Guatemala, and Madagascar). These involved either visits or telephone conversations with various stakeholders and miners and gold merchants who, through personal communications provided estimates of mercury consumption by the ASGM community – listed in Table 6.1. As such these estimates are based entirely on anecdotal information gained through

Appendix 1

Table 6.1 Mercury consumption by country for 2008 in artisanal small scale gold mining (ASGM) estimated by the authors; official imports and exports of mercury and gold as recorded in the UN's COMTRADE database per annum for the five year period 2002-2006; the number of chlor-alkali plants per county in 2004 that use mercury (data from the Chlorine Institute). Note: Iraq and Libya do not report any trade in Hg or Gold. However Iraq has 3 mercury based Chlor-Alkali plants and Libya has 1

			ASGM Mercury (*Mg yr*$^{-1}$)				COMTRADE Data				Chlorine Inst.
	Country	ASGM Presence	min	max	mean	Basis for Estimate	Hg Export (*Mg yr*$^{-1}$)	Hg Import (*Mg yr*$^{-1}$)	Au Export (*Mg yr*$^{-1}$)	Au Import (*Mg yr*$^{-1}$)	Chlor-alk. Plants (#)
Amount			641.9	1352.5	997.2		3227.9	3202.7	5954.9	4884.3	229
Count	163	70	70	70	70	70	65	117	108	124	44
1	Albania							0.05			
2	Algeria						218.38	0.31	0.187	0.567	3
3	Andorra								0.015	0.254	
4	Anguilla										
5	Argentina						0.31	15.18	32.310	0.026	4
6	Armenia							0.00	5.422	4.812	
7	Australia	APLA (2004)	0	2	1.0	Guess	49.96	37.62	258.902	106.918	
8	Austria						1.70	3.84	13.071	20.078	
9	Azerbaijan	?	0.05	0.5	0.3	Min		21.22			
10	Bahrain							0.05	0.109	0.014	
11	Bangladesh							7.93		0.009	1
12	Barbados							0.04		0.005	
13	Belarus							1.06	11.375	2.806	
14	Belgium						17.12	37.23	20.974	12.314	4
15	Benin	Yager et al. (2002)	0.05	0.5	0.3	Min		0.00		0.002	
16	Belize								6.372		
17	Bolivia	Graham (2002); Hentschel et al. (2002)	5	10	7.5	MMSD, GMP, CASM		1.29	6.701	2.378	
18	Bosnia Herzegovina						38.20	0.04		0.055	4

(continued)

Table 6.1 (continued)

			ASGM Mercury (*Mg yr*$^{-1}$)				COMTRADE Data				Chlorine Inst.
	Country	ASGM Presence	min	max	mean	Basis for Estimate	Hg Export (*Mg yr*$^{-1}$)	Hg Import (*Mg yr*$^{-1}$)	Au Export (*Mg yr*$^{-1}$)	Au Import (*Mg yr*$^{-1}$)	Chlor-alk. Plants (#)
19	Botswana	Madawo (2007)	0.5	1	0.8	GMP					
20	Brazil	Blore (2007); Veiga (1997)	30	60	45.0	Sousa and Veiga (2007); Telmer and Stapper (2007)	0.09	54.60	32.009	0.712 0.012	11
21	Bulgaria						0.12	0.44			
22	Burkina Faso	Hiyate (2008); Saywell (2008); ILO (1999)	3	7	5.0	MMSD, Northern Miner		0.001	0.192		
23	Burundi	Cumming (1997) ; Priester and Hentschel (1992)	0.05	0.5	0.3	Min					
24	Cambodia	Sotham (2001)	5	10	7.5	Sotham (2004); Murphy (2006)				1.996	
25	Cameroon	?	0.05	0.5	0.3	Min		0.003			
26	Canada	Basque (1991)	0	2	1.0		8.16	9.03	203.737	150.442	
27	Central Africa Republic	Yager et al (2002); Northern Miner (2001, v87, no.2)	0.05	0.5	0.3	Min					
28	Chad	Mobbs (1996)	0.05	0.5	0.3	Min					
29	Chile	Castro and Sanchez (2003)	3	5	4.0		42.49	1.59	15.230	0.068	
30	China	Saywell (2007); Gunson and Veiga (2004)	237	652	444.5	Gunson (2004)	0.18	188.49	22.642	18.558	6
31	China, Hong Kong AR						11.93	41.79	278.843	132.759	

32	China, Macao SAR							0.00	0.002	0.032	
33	Colombia	Harris (2006); Lacerda (2003)	50	100	75.0	Gov. of Antioquia	0.03	63.18	35.744	0.247	1
34	Cook Isds									0.000	
35	Costa Rica	Northern Miner (1998, v 84, no. 17); Veiga (1997)	0.05	0.5	0.3	Min		0.31	194.969	135.707	
36	Côte d'Ivoire	Mobbs (1998)						0.04	1.518		
37	Croatia						0.46	0.05	0.259	1.907	3
38	Cuba							2.72	0.215	0.081	1
39	Cyprus							0.02	0.037	1.306	
40	Czech Rep.						74.50	3.36	6.006	5.102	2
41	Denmark						9.00	0.42	1.119	2.331	2
42	Dominica							0.002		0.006	
43	Dominican Republic	Veiga (1997)	0.05	0.5	0.3	Min					
44	Democratic Republic of Congo	Vaccaro (2007); ILO (1999)	1	2	1.5	Guess					
45	Ecuador	Robertson (2006); Betancourt et al (2005)	10	20	15.0	GMP	0.03	9.47	285.982	0.922	
46	El Salvador							0.70	0.057	1.488	
47	Estonia						2.79	0.003	0.047	1.589	
48	Ethiopia	Labonne (2002)	0.05	0.5	0.3	Min		0.05	5.278	0.256	
49	Faeroe Isds							0.004		0.005	
50	Fiji							0.19	4.829	0.684	
51	Finland						32.16	0.20	1.221	1.170	5
52	France						56.76	137.93	33.397	41.417	10
53	French Guiana	Fréry et al (2001)	5	10	7.5	Viera (2008)				0.081	
54	French Polynesia										
55	Gambia	Dolley (1996)	0.05	0.5	0.3	Min		0.005			
56	Georgia										

(continued)

Table 6.1 (continued)

	Country	ASGM Presence	ASGM Mercury ($Mg\ yr^{-1}$)			Basis for Estimate	COMTRADE Data				Chlorine Inst.
			min	max	mean		Hg Export ($Mg\ yr^{-1}$)	Hg Import ($Mg\ yr^{-1}$)	Au Export ($Mg\ yr^{-1}$)	Au Import ($Mg\ yr^{-1}$)	Chlor-alk. Plants (#)
57	Gabon	Northern Miner (2003, v. 89, no. 40); Priester and Hentschel (1992)	0.05	0.5	0.3	Min			6.694	0.063	
58	Germany						50.35	52.82	59.861	50.487	21
59	Ghana	Northern Miner (2007, v. 93, no. 39); Babut et al (2003)	3	6	4.5	GMP		5.41	80.243	1.717	
60	Greece							2.79	1.069	28.300	1
61	Guatemala	UNEP (2005)	1	2	1.5	GMP		27.81	0.620	2.327	
62	Guinea	Labonne (2002)	0.05	0.5	0.3	Min			79.313		
63	Guinea-Bissau	Dolley (1996); Bermudez-Lugo (2002)	0.05	0.5	0.3	Min		34.36	7.417	0.028	
64	Guyana	Couture and Lambert, (2003)	10	20	15.0	Viera (2008)					
65	Honduras	Attenborough (1999); Veiga (1997)	0.05	0.5	0.3	Min	0.65	0.51	5.955	0.106	
66	Hungary							4.11	0.764	0.736	2
67	Iceland							0.003	0.008	0.493	
68	India	Duval (2004); Siddaiah (2001)	1	2	1.5	Guess	11.10	186.81	0.594	743.774	48
69	Indonesia	Castilhos et al (2006)	130	160	145.0	Telmer and Stapper (2007)					4
70	Iran	?	0.05	0.5	0.3	Min	0.13	126.19		2.666	7
71	Ireland						0.40	4.91	0.118	2.444	
72	Israel						13.92	24.01	0.444	3.987	2
73	Italy						66.94	39.67	46.578	275.543	11

74	Ivory coast	Yager et al (2002)	0.05	0.5	0.3	Min					
75	Jamaica							0.04		0.037	
76	Japan						108.29	4.58	124.808	67.000	
77	Jordan							0.03	12.989	7.125	
78	Kazakhstan	?	0.05	0.5	0.3	Min	1.24		26.678	0.535	
79	Kenya	Yager et al (2002)	5	10	7.5	GMP	0.93	10.57	558.196	0.765	
80	Kyrgyzstan	Appel et al (2003)	5	10	7.5	Appel	460.48		12.521	0.079	
81	Laos	Boungnaphalom (2003)	0.5	2	1.3	GMP					
82	Latvia						0.00	0.01	0.001	0.147	
83	Lebanon							3.42	17.625	11.290	
84	Lesotho	Coakley (2002)	0.05	0.5	0.3	Min					
85	Liberia	DLI (2003)	0.05	0.5	0.3	Min					
86	Lithuania							0.003		0.012	
87	Luxembourg						0.06	0.11	6.625	6.435	
88	Madagascar	Rajaobelina (2003)	1	2	1.5	Guess	0.00	0.02	0.001	0.002	
89	Malawi	Dreschler (2001)	0.05	0.5	0.3	Min		0.02		0.004	
90	Malaysia	Priester and Hentschel (1992)	2	5	3.5	Google Earth	173.88	42.04	732.191	651.339	
91	Maldives							0.01		0.137	
92	Mali	Northern Miner (2008, v93., no. 47; no. 50); MMSD (2002)	1	2	1.5	MMSD			41.061	2.412	
93	Malta							0.003	0.406	9.461	
94	Mauritius										
95	Mayotte							0.06	0.114	0.778	
96	Mauritania	Mbendi (2004)	0.05	0.5	0.3	Min				0.006	
97	Mexico	Graham (2003); Veiga (1997)	5	10	7.5	Guess	7.64	221.27	138.191	646.113	
98	Mongolia	Grayson (2007)	8	15	11.5	Grayson (2007)			11.503		
99	Montserrat									0.003	
100	Morocco						16.94	2.18	0.915	2.472	3

(continued)

Table 6.1 (continued)

			ASGM Mercury *(Mg yr^{-1})*				COMTRADE Data				Chlorine Inst.
	Country	ASGM Presence	min	max	mean	Basis for Estimate	Hg Export *(Mg yr-1)*	Hg Import *(Mg yr^{-1})*	Au Export *(Mg yr^{-1})*	Au Import *(Mg yr^{-1})*	Chlor-alk. Plants (#)
101	Mozambique	Spiegel et al (2006)	3	5	4.0	GMP		0.004	1.201	0.006	
102	Myanmar	UNESCAP (2003)	5	8	6.5	UNESCAP (2003)			2.956	.454	1
103	Namibia							0.05			
104	Nepal							0.09			
105	Netherlands						198.36	592.26	16.818	20.764	1
106	New Caledonia							0.01		0.077	
107	New Zealand	?	0.05	0.5	0.3	Min	0.04	0.01	18.221	1.067	
108	Nicaragua	Attenborough (1999); Rosario and Ault (1997)	1	2	1.5	Silva (2008)		0.29	4.989	0.021	1
109	Niger	Alfa (2000)	0.05	0.5	0.3	Min			3.218		
110	Nigeria	Vaccaro (2006); Priester and Hentschel (1992)	0.05	0.5	0.3	Min					
111	Norway						0.02	0.08	3.732	2.509	
112	Oceania	?	0	1	0.5	Guess					
113	Oman							0.09	0.367	5.306	
114	Pakistan							34.36		27.650	3
115	Panama	Attenborough (1999)	1	2	1.5	Guess		0.14	0.232	0.572	
116	Papua New Guinea	Crispin (2003)	2	4	3.0	MMSD		3.74	28.230	0.571	
117	Paraguay							0.12	0.051	0.046	
118	Peru	Brooks et al (2006)	20	40	30.0	Brooks et al (2006)	75.46	82.67	415.032	0.026	8
119	Philippines	Israel and Asirot (2000)	20	30	25.0	Israel and Asirot (2000)					1
120	Poland						11.39	9.22	0.482	2.373	3
121	Portugal						15.76	0.28	0.184	2.344	
122	Qatar							0.05	0.016	1.762	

123	Rep. of Korea						8.57	131.15	117.824	156.265	5
124	Rep. of Moldova									0.018	
125	Romania						7.08	18.85	1.223	0.453	1
126	Russian Federation	Stepanov and Yusupov (2001)	7	15	11.0	Stepanov and Yusupov (2001)	138.59	38.45	0.020	0.002	4
127	Rwanda	Priester and Hentschel (1992)	0.05	0.5	0.3	Min					
128	Saudi Arabia						0.00	1.94	234.719	44.816	1
129	Senegal	Savornin et al (2007)	1	2	1.5	Guess		0.04	0.508	0.079	
130	Serbia						0.00	1.18	0.312	0.013	4
131	Sierra Leone	Thonae (2004)	0.05	0.5	0.3	Min					
132	Singapore						84.95	138.74	61.018	116.456	
133	Slovakia						0.90	3.07	0.283	2.993	
134	Slovenia						5.18	0.07	0.456	0.856	2
135	South Africa	Beales (2005); Mahlatsi and Guest (2003)	5	10	7.5	GMP	9.94	11.68	5.999	1.155	
136	Spain						668.75	454.43	7.831	24.311	9
137	Sudan	Ibrahim (2003)	0.5	1	0.8	GMP	0.03	6.01	0.208	7.167	
138	Sri Lanka										
139	Suriname	Heemskerk (2003)	5	10	7.5	Viera (2008)				0.001	
140	Sweden						0.33	4.03	14.461	1.441	5
141	Switzerland						124.07	9.83	42.253	9.038	2
142	Syria							19.96		0.005	
143	Tajikistan	Dawson (1996)	3	5	4.0	Dawson (1996)					
144	TFYR of Macedonia						18.02	0.01	0.016	0.054	
145	Thailand	Umbangtalad et al. (2007)	1	2	1.5	Guess	4.40	12.20	35.851	108.214	
146	Timor-Leste										
147	Togo	Yager et al (2002)	3	5	4.0	Yager et al (2002)	0.97	8.36			
148	Trinidad and Tobago						0.04	0.13	0.127	0.370	

(continued)

Table 6.1 (continued)

			ASGM Mercury ($Mg\ yr^{-1}$)				COMTRADE Data				Chlorine Inst.
	Country	ASGM Presence	min	max	mean	Basis for Estimate	Hg Export ($Mg\ yr^{-1}$)	Hg Import ($Mg\ yr^{-1}$)	Au Export ($Mg\ yr^{-1}$)	Au Import ($Mg\ yr^{-1}$)	Chlor-alk. Plants (#)
149	Tunisia						0.00	0.05	0.409	2.207	
150	Turkey						0.03	5.25	13.413	222.339	2
151	Turks and Caicos Is.										
152	Uganda	World Bank (2003)	0.5	1	0.8	Hinton (2008)		0.05	10.462		
153	United Arab Emirates						1.19	9.70	52.822	117.468	1
154	United Kingdom						56.66	23.08	2.168	347.705	9
155	United Rep. of Tanzania	Kinabo (2003)	4	8	6.0	Kinabo, Ikingura		2.77	50.736	26.600	
156	Uruguay							1.96	3.792	0.100	2
157	USA	Weekend Prospector (2004)	1	2	1.5		319.83	130.75	1330.776	360.750	8
158	Uzbekistan	Trung (2001); Northern Miner (v. 83 no. 41, 1997)	0.05	0.5	0.3	Min				1.002	
159	Venezuela	Veiga et al (2005)	10	20	15.0	Veiga et al (2005)			1.002	0.705	
160	Viet Nam	Trung (2001); Northern Miner (v. 83 no. 41, 1997)	5	10	7.5				0.353	56.863	
161	Yemen								0.824	0.390	
162	Zambia	Kambani (2003)	0.5	1	0.8	Kambani (2003), Nyambe, (2008)		0.12	0.750	0.01	
163	Zimbabwe	Maponga. and Ngorima (2003)	20	30	25.0	GMP		11.12	16.266	41.005	

discussion. We therefore have relatively good information on ASGM mercury consumption from 2 countries, reasonable information from 7 more countries, and some but poor information from 14 more countries amounting to some knowledge by the authors on ASGM sites in 23 countries. These 23 countries represent in excess of 80% of ASGM mercury consumption.

6.4.5 Remaining Countries - Indirect Anecdotal Information

There is further information from the MMSD reports published in 2002 but as mercury was not necessarily a primary focus, the estimates, like the one from Indonesia discussed earlier, are of variable quality. Some seem to exaggerate the amounts of mercury consumed by the ASGM community. For example our estimate of 7.5 Mg yr^{-1} for Bolivia is far lower than the numbers given by the MMSD report (no total is given but 25 Mg yr^{-1} are ascribed to just one area). Some seem to understate the problem - the report on India by Chakravorty (2002), for example, claims that there is no “gold rush” in India and essentially no use of mercury in ASGM in India. However, other anecdotal reports from Indian colleagues claim this is not the case and clearly India is heavily involved in the gold industry.

According to goldnews (http://goldnews.bullionvault.com) India consumes nearly 800 Mg of Gold Bullion/a, accounting for about 20% of world gold consumption. Nearly 600 Mg of it goes into making jewellery representing $13.5 billion in fiscal 2006-07, and accounting for 8.3% of world jewellery sales by value. For the sake of being conservative, we have assigned India an almost impossibly small amount of mercury consumption through ASGM of 0.3 Mg yr^{-1}, however, we imagine that this could be substantially larger. Many of the other MMSD reports mention the use of mercury, even the intensive use of mercury, but do not estimate quantities used.

In total there is some form of information for 48 countries ranging from relatively good to reasonable to poor as described above. Those 48 countries have been assigned value for consumption of mercury by ASGM operations. For the remaining 25 countries, there is only information indicating the presence of ASGM. These countries have been assigned a minimum amount of mercury of 0.3 Mg yr^{-1} equalling a total of 7.5 Mg for those 25 countries.

6.5 Reported Trade in Mercury and Gold

In ASGM, mercury consumption (mercury purchased) is equal to the amount of mercury released to the environment as none that was purchased is ever returned to the commodity market. Notably, although mercury is traded freely as a commodity around the world, it is never officially purchased for gold amalgamation despite the fact that a large amount of what is traded ends up being used for that purpose. For example, Brazil, French Guiana, and Indonesia, despite their large ASGM communities, are countries in which mercury is not allowed by law to be used in gold mining. Here, in order to understand the limits of our estimations on mercury use in ASGM, we analyse the existing global trade data on mercury and gold to make some crude observations and also to show how invisible the trade in mercury and gold from ASGM is.

The following analysis is based on the data in Table 6.1 which lists global trade in mercury and gold per annum using data from the United Nations Commodity Trade Statistics Database (COMTRADE*)* covering the five year period 2002-2006. The table also contains the number of chlor-alkali plants that use mercury per country as reported by the Chlorine Institute (2006), and the estimate of mercury consumption by ASGM made by the authors that is discussed later.

Figure 6.3a shows total reported global mercury trade by country for the years 2002 through 2006 (a 5 year period) as recorded by COMTRADE. The database relies on voluntary reporting and so is incomplete. For example, the number of years reported varied between 5 and 1 for the countries listed. Figure 6.3b shows trade for the same period but per annum by normalising to the number of years reported (mass of mercury/years reported). For some determinations, it is better to use Figure 6.3a, for other determinations, it may be more appropriate to use Figure 6.3b. For example, to determine the average price paid for mercury, it is better to use only the reported data, but the incomplete reporting in Figure 6.3a would underestimate the total trade in mercury. The data in Figure 6.3b, on the other hand, may over-estimate total mercury trade if some countries imported less mercury during the years for which no reporting was done. The trade data from COMTRADE is therefore, to some degree, complicated to interpret. Nonetheless, the following conclusions can be reached:

1. The number of countries that actively trade in mercury is 119 but there are 190 countries listed in the UN's COMTRADE database. Therefore there are 71 countries that either do not consume any mercury or do not report consumption. Due to dental practices alone (300 to 400 Mg mercury consumed per annum for amalgam fillings, Maxson, 2008a; P. Maxson, Concorde Cons., Belgium, 2008, pers. Comm.), it is unlikely that these 71 countries do not trade in mercury at least for dental use. This suggests that the database represents a minimum amount of trade.
2. The total reported mercury trade for the 5 year period of reporting from 2002 to 2006 (Figure 6.3a) is 12,750 Mg exported (2550 Mg yr^{-1}), and 14,870 Mg imported (2970 Mg yr^{-1}). Amounts of "re-export" (57 Mg or 11.5 Mg yr^{-1}) and "re-import" (0.04 Mg or 0.008 Mg yr^{-1}) are insignificant. This implies a surplus amount of import of 2120 Mg over the 5 year period. Under any trade or consumption scenario, this is unlikely. The reason for the discrepancy is unknown - perhaps tax avoidance, perhaps incomplete reporting, or both. As it is unlikely that importing is over-reported, this, as above in point 1, again suggests that mercury trade is underestimated by the UN COMTRADE database. Therefore, it is reasonable to assume that, a minimum of 2970 Mg of mercury per annum on average was imported during the years 2002-2006. Normalising by years reported (Figure 6.3b) the exports of mercury become 3,230 Mg yr^{-1} and imports 3,200 Mg yr^{-1}. The discrepancy is lessened and direction of imbalance reversed to surplus exports

Figure 6.3 (**a**) International exports and imports of mercury by country in Mg for the 5 year period 2002-2006 (UN Comtrade, 2008). All reporting countries are listed. (**b**) Same in (**a**) but per annum by normalizing to the number of years reported – many countries did not report for all years

(30 Mg per annum greater export). The improved balance and more reasonable direction of surplus (more export than import) suggests that this is a better estimate, although by no means robust. It is also important to note that trade does not imply consumption as some of the trade represents recycled mercury, perhaps 5 to 10% globally (Maxson, Concorde Cons., Belgium, 2008, pers. comm.).

3. The total value of reported exports (based on Figure 6.3a) was US$113,587,000 or US$22,717,000 per annum; the total value of imports was US$132,593,000 or US$26,519,000/a. Although, for the above reasons, the totals are minimums, the average price may still be representative. The average selling price of mercury was US$8.91/kg, the average buying price was US$8.92/kg. The current average dealer price is US$18.33/kg (Northern Miner, 2008). For reference, Figure 6.4 shows the price of mercury over the last 108 years. Normalising by years reported (Figure 6.3b) the value of exports per annum becomes US$26,690,000, and imports US$28,567,000. Again the improved balance suggests that this is more reasonable estimate but must be a minimum.
4. The minimum consumption of mercury by human endeavours can only be approximated by this database - but not robustly. For example, during this 5 yr period, the Netherlands exported 198 Mg per annum and imported 592 Mg yr^{-1}. It is unlikely that the Netherlands consumed the difference of 394 Mg yr^{-1} as they only have 1 chlor-alkali plant (Table 6.1) and so their stock must have grown during this period. Rather the data gives some idea of the main mercury dealers globally, the average amount of trade per annum (the mass and value of mercury moving around), the main mercury importers, the countries that must be engaged in mercury trade but do not report it (e.g. Philippines), and puts some constraints on the amount of mercury that could possibly be used for ASGM – i.e. it must

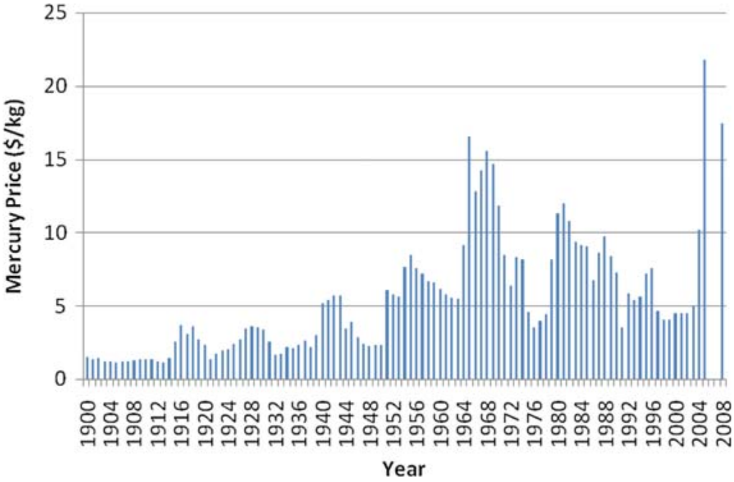

Figure 6.4 Price of mercury over the last 108 years (sources: Northern Miner, 2008; Reece, 2006)

be significantly lower than global trade. Figure 6.5a and 5b illustrate exporters and importers by country. There are 54 countries that only import mercury – these are clearly visible in Figure 6.5a – and there are 2 countries that only export mercury, Kyrgyzstan and Kazakhstan – visible in Figure 6.5b.

5. The minimum consumption of mercury by human endeavours can only be approximated by this database - but not robustly. For example, during this 5 yr period, the Netherlands exported 198 Mg per annum and imported 592 Mg yr^{-1}. It is unlikely that the Netherlands consumed the difference of 394 Mg yr^{-1} as they only have 1 chlor-alkali plant (Table 6.1) and so their stock must have grown during this period. Rather the data gives some idea of the main mercury dealers globally, the average amount of trade per annum (the mass and value of mercury moving around), the main mercury importers, the countries that must be engaged in mercury trade but do not report it (e.g. Philippines), and puts some constraints on the amount of mercury that could possibly be used for ASGM – i.e. it must be significantly lower than global trade. Figure 6.5a and 5b illustrate exporters and importers by country. There are 54 countries that only import mercury – these are clearly visible in Figure 6.5a – and there are 2 countries that only export mercury, Kyrgyzstan and Kazakhstan – visible in Figure 6.5b.
6. There is clearly a transfer of mercury from the developed countries and northern hemisphere to less developed countries and southern hemisphere. Veiga et al., (2006) also discuss this trend. Because overall, industrial consumption of mercury is dropping (Maxson, 2008a), consumption of mercury by ASGM is the most logical explanation for the direction of this transfer.
7. The non-ASGM consumption of mercury for 2005 is estimated to be a minimum of 2385 Mg yr^{-1}, and a maximum of 3365 Mg yr^{-1} (Maxson, 2008a; P. Maxson, Concorde Cons., Belgium, 2008, pers. Comm.). If the global trade data from COMTRADE represents a minimum of 2970 Mg yr^{-1}, and we assume that the 2005 data is a good average for the period 2002-2006 (reasonable), then that suggests that the minimum amount of mercury available for ASGM ranges between 585 Mg yr^{-1} and negative 395 Mg yr^{-1} – hardly a satisfying result. Obviously ASGM consumption is not zero and so perhaps the maximum non-ASGM mercury consumption estimate of 3365 Mg yr^{-1} is too high. That leaves us with a minimum ASGM consumption supported by official data of somewhere between 100 (arbitrary non-zero value) and 585 Mg yr^{-1} with an average minimum of 345 Mg yr^{-1} mercury consumed by ASGM. This is a hypothetical minimum based on available but clearly incomplete official trade data – a starting place. The real amount of mercury consumed by ASGM must be higher as becomes clear when field data is considered – discussed below.
8. The price of mercury has risen sharply since 2003 from ~US$5.00/kg to the current price in 2008 of US$18.33/kg, slightly down from a 2006 peak of around ~US$23.00/kg. That is, on average, a quadrupling of price. From 1975 until 2005, the price of mercury and gold correlated well, but this relationship broke in 2007 when the price of gold sharply increased and the price of mercury actually decreased. The increase in price of mercury to a peak in 2006 was likely a response to the announcement of mercury mine closures and an expectation that supplies would

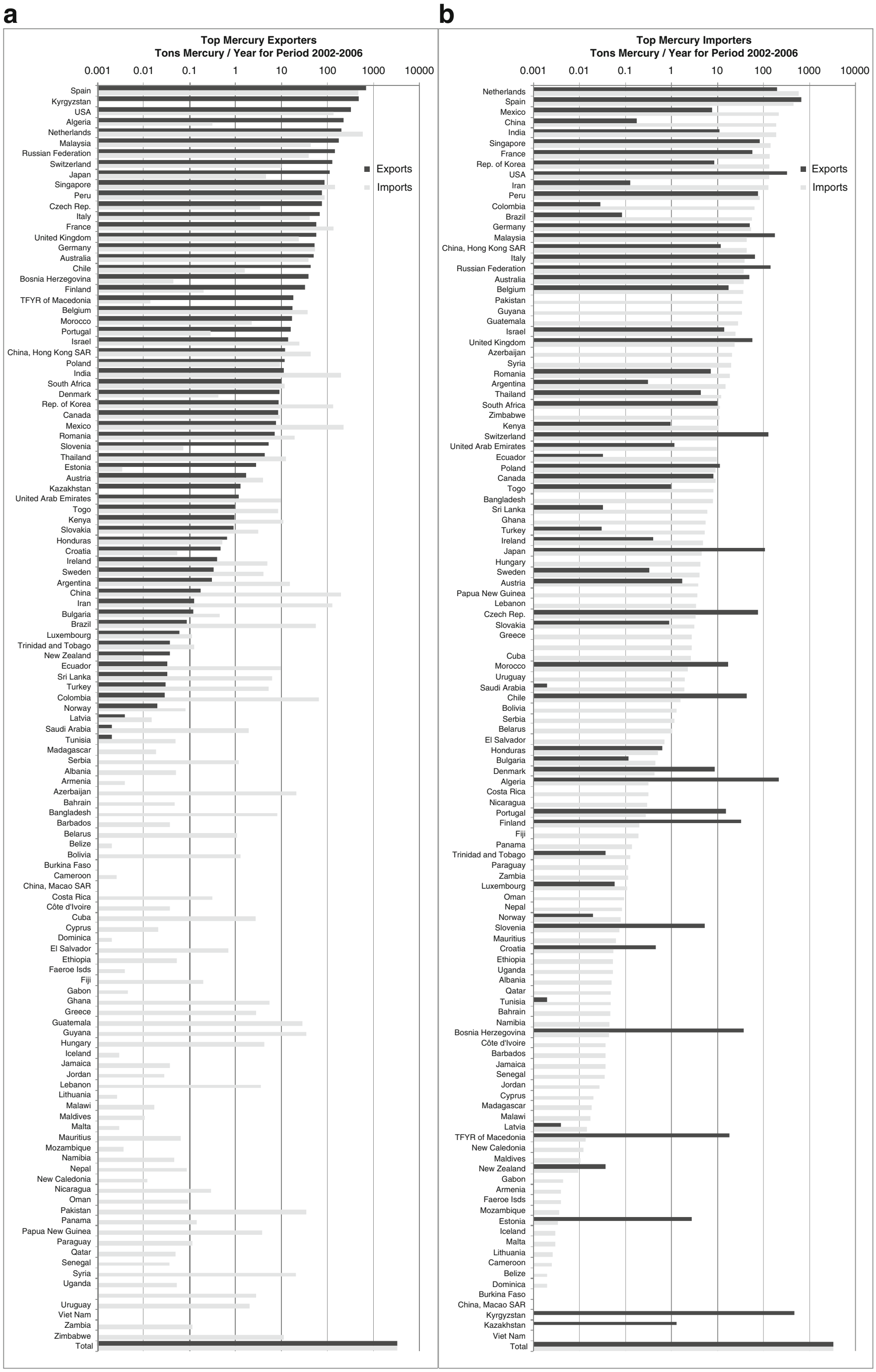

Figure 6.5 (**a**) International exports and imports of mercury per annum sorted by top exporters and (**b**) importers for the 5 year period 2002-2006 (UN Comtrade, 2008). All reporting countries are listed.

be short (Maxson, pers. Comm.). Demand for mercury for ASGM and VCM production in China (vinyl chloride monomer – a feedstock for polyvinyl chloride plastics (PVC)) also likely contributed to supporting higher prices. VCM use of mercury is large and growing (Maxson, 2008b).

9. There is a set of further observations that can be drawn from Table 6.1 as follows:

   - There are 28 countries with known ASGM sites that do not officially export any gold: Azerbaijan, Benin, Botswana, Burundi, Cambodia, Cameroon, Central Africa Republic, Chad, Dominican Republic, DRC, French Guiana, Gambia, Indonesia, Iran, Ivory coast, Laos, Liberia, Malawi, Mauritania, Nigeria, Oceania, Philippines, Rwanda, Sierra Leone, Suriname, Tajikistan, Togo, Uzbekistan
   - There are 16 countries with known ASGM sites that do not officially record any mercury or gold transactions whatsoever: Botswana, Burundi, Central Africa Republic, Chad, Dominican Republic, DRC, Indonesia, Ivory coast, Laos, Liberia, Nigeria, Oceania, Philippines, Rwanda, Sierra Leone, Tajikistan. Two of these countries, Indonesia and the Philippines, are known to have very large ASGM activities (see refs in Table 6.1).
   - There are 4 countries that only export gold: Belize, Guinea, Mongolia, Niger
   - There are 16 main mercury exporting countries (those who export more than 50 Mg yr^{-1}): Algeria, Czech Rep., France, Germany, Italy, Japan, Kyrgyzstan, Malaysia, Netherlands, Peru, Russian Federation, Singapore, Spain, Switzerland, United Kingdom, USA
   - Officially there are 54 countries that only import mercury (a total of 190 Mg yr^{-1}): Albania, Armenia, Azerbaijan, Bahrain, Bangladesh, Barbados, Belarus, Benin, Bolivia, Burkina Faso, Cameroon, China, Macao SAR, Costa Rica, Côte d'Ivoire, Cuba, Cyprus, Dominica, El Salvador, Ethiopia, Faeroe Isds, Fiji, Gambia, Ghana, Greece, Guatemala, Guyana, Hungary, Iceland, Jamaica, Jordan, Lebanon, Lithuania, Malawi, Maldives, Malta, Mayotte, Mozambique, Namibia, Nepal, New Caledonia, Nicaragua, Oman, Pakistan, Panama, Papua New Guinea, Paraguay, Qatar, Senegal, Syria, Uganda, United Rep. of Tanzania, Uruguay, Zambia, Zimbabwe.
   - In terms of countries that are potentially significant distributors of mercury for use in ASGM, there are 13 countries with no or few mercury using chloralkali plants that import significant amounts of mercury: Australia, Azerbaijan, China, Hong Kong SAR, Guatemala, Guyana, Kenya, Malaysia, Mexico, Singapore, South Africa, Syria, Thailand, Zimbabwe. Of these, Mexico and Singapore are by far the largest, importing 221 and 138 Mg yr^{-1}, respectively.
   - There are 14 countries that import more than 50 Mg yr^{-1} of mercury: Brazil, China, Colombia, France, Germany, India, Iran, Mexico, Netherlands, Peru, Rep. of Korea, Singapore, Spain, USA
   - Estimates of ASGM mercury consumption is greater than official mercury imports in 53 countries of the 70 known to have ASGM sites. The opposite is true for the other 21 (imports>ASGM consumption) indicating that the official imports of mercury to these countries is sufficient to meet ASGM demand.

6.5.1 Using Gold Production to Estimate Mercury Consumption in ASGM

Regarding the use of gold production to estimate ASGM consumption of mercury, this also is controversial. There have been unofficial estimates by gold dealers that ASGM gold production is around 150 Mg per annum. However, this is very difficult to know because the gold market is unlike most other commodity markets in that 80% of gold produced over the past 6000 years is still in existence today and available to be traded – a total amount of approximately 135,000 Mg (Schofield, 2007). Official gold production per annum is around 2500 Mg yr^{-1} (Schofield, 2007). So gold traded and gold produced officially by large scale mines do not have to match up and this makes it very difficult to constrain the amount of ASGM gold entering the market each year. This is particularly true because the vast majority of gold trade is done on an unallocated basis meaning that it is held in a vault in common with other gold and the customer has a general entitlement only. Essentially this means that gold from many sources is mixed into one pool by holding companies.

However, even if ASGM production were only 150 Mg per annum, considering that a significant portion of that is estimated to be produced using whole ore amalgamation (around 50%) which uses large amounts of mercury, then globally with a Hg: Au ratio of at least 3:1, a production of 150 Mg of gold per annum would imply 450 Mg yr^{-1} of mercury consumed in ASGM. This calculation is made as yet another hypothetical minimum and to further support later arguments that mercury consumption by the ASGM community must be significantly higher.

Others lines of evidence discussed in the MMSD (2002) and GMP (2007) documents, as well as some earlier work (Veiga, 1997) that used patterns of production per miner per region, suggest that global gold production by ASGM is much higher – 400 to 600 Mg Au per annum. At this level, the consumption of mercury must be near to 1000 Mg yr^{-1} as reflected in Table 6.1. In a reverse argument, if the estimate of mercury consumption in Table 6.1 is reasonable, then global gold production by ASGM must be about 1/3 of 1000 Mg = 350 Mg of gold/year, a value in-between that of gold traders and MMSD estimates.

6.6 Knowledge Gaps about Mercury in ASGM

In order to evaluate the significance of mercury emitted from ASGM, and to enable discussion about how best to reduce emissions, it is useful to elaborate the current gaps in our understanding about it.

The fate of mercury in the environment released from ASGM remains poorly understood. For example, of the portion emitted to the atmosphere, how much falls out locally, and how much travels long distances and over what time scale has never been adequately investigated and so remains poorly known. This is despite the fact that the long range transport of these emissions and subsequent deposition in other countries is a key interest of the UNEP Mercury Program and other parties concerned about global mercury pollution.

Further, what happens to the mercury emitted from ASGM following deposition is also not well known as most of the high calibre research that has been done on atmospheric mercury and its fate has been done in temperate or polar environments whereas most ASGM occurs in the tropics where hydrology, soils and vegetation, productivity, and rates of biogeochemical cycling are vastly different. The fate of the mercury from ASGM that is directly discharged into water is equally poorly known. How it is transported, how far it travels, how and where it becomes methylated, and ultimately how much of it enters the local versus global fisheries is poorly known.

In fact many of the general knowledge gaps about mercury that were highlighted by the plenary panellists at the 8th ICMGP (International Conference on Mercury as a Global Pollutant, "Mercury 2006") apply directly to mercury and gold mining. Some of the relevant gaps identified at that congress are:

- Air-surface exchange
- Role of Halogens
- Trends in active pools
- Hydrology
- How to scale up
- The role of dissolved organic matter (DOM)
- Modelling challenges
- Inorganic mercury vs. Methyl mercury contamination in fish
- Mercury in aquaculture

For a variety of reasons, small scale mining is a good place to build this knowledge. Perhaps even the best place as it would additionally 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. Table 6.2 lists the knowledge gaps highlighted by the plenary panellists at the 8th International Congress on Mercury as a Global Pollutant (Mercury 2006 in Madison, Wisconsin) and how they relate to ASGM as well as some additional important knowledge gaps that were not highlighted. A large part of mercury emitted to the atmosphere from ASGM has been thought to be deposited locally around gold shops and mining sites where amalgam is burnt. Part of the argument used to support this idea, are halos or "bulls eyes" around amalgamation burning centres. Using data from CETEM (1992), Telmer et al. (2006), made some mass balances for soils around gold shops in Alta Floresta, and found that the amount of mercury in the observed bulls eye may be as low as 1% of that emitted, suggesting that in fact, mercury emitted to the atmosphere is travelling long distances. This interpretation is supported by measurements of mercury in the atmosphere made by airplane over the Amazon Basin (Artaxo et al., 2000). They concluded that gold mining areas contribute 63% of the total atmospheric Hg over the Amazon. Telmer et al. also speculate that

Table 6.2 Knowledge gaps about mercury use in ASGM

	General relationship to ASGM	Specific example
Knowledge gap highlighted		
1. Air surface exchange	How far is mercury vapour from ASGM transported? How much mercury enters the global mercury cycle through the atmosphere? How much mercury from ASGM is emitted to the atmosphere? What are the latent emissions of mercury from ASGM to the atmosphere (other than directly during amalgam burning)? What is the fate of mercury emitted to the atmosphere from amalgam burning?	How does the tropical rainforest canopy and or thick clay rich tropical soils interact with atmospheric mercury released from ASGM? How do atmospheric conditions and processes in the tropics cause mercury transport to differ from conditions in the temperate and polar environments? Are the tropics a net source or net sink for atmospheric mercury?
2. The role of halogens	What role do halogens play in the fate of mercury released from ASGM?	The atmosphere is highly depleted in halogens in the middle of the Amazon basin and in other equatorial sites where much ASGM occurs. Does this effect long range transport?
3. Trends in active pools	Which active pools are growing due to ASGM?	Commodity storage? Elemental Mercury in soils? Adsorbed mercury in soils? Methyl Mercury in Floodplains?
4. The role of hydrology	How do annual inundation events in the world's tropical floodplains interact with mercury released from ASGM?	How much does inundation of floodplains downstream of mining operations cause methylation? Does annual inundation enhance or suppress mercury bioavailability?
5. Scaling up	How can the fate of emissions from one ASGM site be extrapolated to other sites and other regions in the world	Do emissions in rainforest ASGM behave similarly to semi-arid ASGM? How can global ASGM emissions be modelled?
6. The role of dissolved organic matter (DOM)	How does DOM interact with mercury released by ASGM?	The draining and burning of tropical peat lands which releases vast amounts of DOM directly interacts with mercury released from ASGM. How does this effect transport and fate?
7. Modelling	How to include mercury releases from ASGM into models of the global mercury cycle?	
8. Inorganic versus organic mercury contamination in fish	Is inorganic mercury a significant vector of mercury into fish exposed to ASGM discharges?	
9. mercury in aquaculture	Many aquaculture operations are in the receiving waters of ASGM. Are these fish impacted?	

Knowledge gaps that are important but not highlighted		
10. Human Health	Long term vapour mercury exposure	How persistent are mercury vapours in ASGM communities? How can locally made chelating agents detoxify contaminated people?
11. Mercury and Cyanide interactions	Many ASGM operations have begun to use cyanide to extract gold and this often occurs in conjunction with mercury use.	What are the Cyanide-Mercury complexes? How long do they persist? How can they most efficiently be destroyed? What are the fate of the decay products? Can they exacerbate methylation?
12. Best practices regarding the handling of mercury	Use of retorts and fume hoods, storage and disposal of mercury and mercury wastes	Retorts reduce emission of mercury to the atmosphere but do not always significantly reduce human exposure due to operation and handling practices. How can design, operation, and education be improved?

Note: It must be mentioned that there are many equally important knowledge gaps that are unrelated to mercury regarding best practices in ASGM, most importantly those involving health and safety.

factors such as atmospheric conditions at the site and time of amalgam burning play an important role in controlling entry of mercury into the regional or global atmospheric cycle. For example, if amalgam is burnt on a hot tropical afternoon when the atmosphere is turbulent well mixed, the likelihood of mercury entering higher levels of the atmosphere and being transported long distances will be greater than if the amalgam is burnt in the evening or early morning, when the atmosphere is less well mixed. It is also possible that mercury deposited locally at one time is quickly desorbed and transported at another as the tropical atmosphere is very energetic. As no firm scientific evidence has yet been provided to prove the distance mercury emitted from amalgam burning travels (Veiga and Baker, 2004), clearly more research on this topic is needed.

To illustrate this knowledge gap and others, Figure 6.1 shows examples of mercury being emitted into the environment from ASGM (some tragic) and how these relate to the identified knowledge gaps. Filling these gaps is required if we are to understand the impacts and costs of mercury emissions from ASGM at local, regional, and global scales.

6.6.1 River Siltation in ASGM

Another significant environmental impact caused by ASGM is river siltation. It is mentioned here because it does have a direct and large impact on mercury transport. Dredging and sluicing sediment and soils for gold extraction causes the discharge of huge amounts of sediment into rivers, lakes and oceans. For example, small scale mining is now the main source of sediment to Brazil's Tapajos River which is one of the Amazon's largest tributaries and one of the world's largest rivers (Telmer et al., 2006b). The Tapajos is about twice the size of Europe's largest river, the Danube. In the tropics sediments are very fine because they are rich in clays and amorphous oxides (mostly iron oxy-hydroxides). This is due to the nature of soil formation in the tropics. When discharged into rivers, a significant portion of these clay rich sediments remain in suspension indefinitely. Sediment discharged from ASGM is consequently transported hundreds to thousands of kilometers downstream and into the ocean.

These sediment discharges have severe environmental impacts. The increases in suspended sediment reduce the penetration of light into waters and change the nutrient supply. This drastically alters the natural habitat (Costa, et al., 2008):

- Biological productivity and diversity is reduced
- Shifts in species composition are extreme

However this also directly relates to mercury. The process of soil formation naturally concentrates and sequesters mercury. Soils around gold mining areas are both naturally rich in mercury (Jonasson and Boyle, 1972) and receive mercury released from amalgam burning.

The erosion of soils by mining releases mercury accumulated during soil formation into water bodies at hugely accelerated rates (Telmer et al., 2006) where it likely becomes available to be methylated and bioaccumulated in downstream floodplains. Forest clearing in the Amazon is also thought to contribute to this process (Roulet et al., 1998). Therefore mercury released into water bodies by soil erosion represents a large anthropogenic source of mercury into waters. The amount of mercury released by this process includes that added by miners but also the mercury that was naturally accumulated in the soils. In some cases, the latter can be the larger number.

6.7 Reducing Mercury use in ASGM

The amount of mercury consumed by artisanal small scale gold mining (ASGM) depends on three main factors: (i) the type of ore being mined; (ii) the technique used to process the ore; and (iii) the technique used to process amalgam to produce gold. To varying degrees, these factors are interdependent.

6.7.1 Reducing Emissions

In a few cases, mercury consumption has been significantly reduced through the use of fume hoods, retorts, and by re-activating dirty mercury. In Brazil and Indonesia, simple fume hoods have been adapted by some gold shops that trap about 90% of former atmospheric emissions (Sousa and Veiga, 2007; Agrawal, 2007; Chouinard, 2007, Argonne National Laboratory, 2008). The fume hoods in Indonesia are very cheap ($US35) and allow gold shop owners to recover and re-sell mercury, thereby recycling it and greatly reducing overall mercury consumption (Agrawal, 2007). They need to recover only 1kg of mercury in order to recover the cost of buying a fume hood. Brazilian efforts in collaboration with the USEPA, are producing similar results (Argonne National Laboratory, 2008). The USEPA led efforts have produced a detailed accounting of the functioning and efficiency of fume hoods constructed in some of the Brazilian Amazon gold mining communities.

As well, importantly, additional reductions in mercury consumption are occurring by teaching simple mercury re-activation and cleaning methods (Pantoja and Alvarez, 2000; R. Wuerker pers. comm., 2007). Using these methods, so called “dirty mercury” is never discarded and this reduces overall consumption and contamination. Pantoja and Alvarez (2000) use a simple electrochemical cell to operated with a 12 volt battery to reduce oxidized mercury to its elemental form. Ralph Wuerker is an astronomer with experience running liquid mercury telescopes which suffer surface oxidation that occasionally needs to be removed. The astronomers (as well as many chemists studying electrochemistry with mercury drop electrodes) simply pass the liquid mercury through a coffee filter to clean it. It is also worth mentioning that retorting mercury (evaporating and then condensing it) produces relatively clean mercury that is able to effectively amalgamate gold. For example, the gold shop owners who operate fume hoods in Kalimantan, sell their recovered mercury with no further cleaning procedure for direct use in mining and this is accepted by the miners.

Retorts also significantly reduce mercury consumption by facilitating mercury recycling. Rickford Vieira, a key person involved with the World Wildlife Fund's efforts to combat environmental degradation due to small scale mining in the Guyanas and Suriname has stated that overall mercury consumption has been reduced to 1:1 by use of retorts. UNIDO's Global Mercury Project, as well as other intervention efforts, have also introduced retorts in an effort to reduce mercury releases to the atmosphere. Although, even with a reduction of 90%, the levels of mercury released by ASGM are still quite unacceptable by modern environmental laws, such a reduction represents a vast improvement from the status quo.

Capturing direct emissions to the atmosphere is a positive development, but in order to have a more significant impact on mercury consumption in ASGM, the practice of whole ore amalgamation must be eliminated or reduced. That is because whole ore amalgamation is (i) the least efficient way to use mercury and so causes the greatest losses; and (ii) is likely to grow as the exploitation of colluvial and bedrock ores becomes more common – these types of ores are the ones that are wholly amalgamated. Eliminating whole ore amalgamation is a much more complicated endeavour than capturing direct mercury emissions to the atmosphere with fume hood and retorts. Most concepts about how to eliminate it involve: (i) introducing efficient processing which involves increasing the sophistication of the processing technology; (ii) increasing initial capital investment; and (iii) increasing the organisation of the labour pool – all big challenges for poor and transient communities that reside at the margins of legal society. However, if these steps can be accomplished, it is possible that more gold can be captured, or less mercury would be consumed, both of which would have monetary value to the miners and so there potentially are underlying economic incentives for such change. It is also important to mention that an increased mercury price, perhaps driven by legally binding export bans from the big exporters such as the European Union and the United States, would likely induce miners to use less mercury in order to reduce costs. Simply put, as the price of mercury rises, the economic feasibility of whole ore amalgamation is reduced.

In order to conceptualise possible reductions in mercury use in ASGM, it is useful to break down the possible approaches as follows:

1. We estimate that if fume hoods and retorts are adopted by any singular ASGM site, immediate emissions to the atmosphere can be reasonably reduced by 90% – less for operations that use cyanide. So where 1 g of mercury was emitted to the atmosphere for every g of gold produced, then only 0.1 g of mercury would be emitted.
2. If mercury re-activation or cleaning methods were adopted for any singular operation, then mercury consumption would be reduced by 50%. So where 2 g of mercury were used to capture 1 g of gold, only 1 g of mercury would be used.
3. If an operation is able to stop amalgamating the whole ore, then mercury consumption can be reduced by 90%. So where 10 g of mercury were used to capture 1 g of gold, only 1 g of mercury would be used.

Overall, if 50% of ASGM mercury use (50% of 1000 = 500 Mg yr^{-1}) is consumed through the amalgamation of concentrate (2:1 Hg: Au ratio – this includes losses incurred when dirty mercury is disposed); and 50% (50% of 1000 = 500 Mg yr^{-1}) is consumed through whole ore amalgamation (5:1 Hg: Au ratio – this is an average based on a mix processing with copper plates and milling with mercury in the grinding circuit), and for every unit of gold produced a unit of mercury is directly emitted to the atmosphere then, (i) 350 Mg of gold are produced by ASGM each year; (ii) 350 Mg of mercury consumed by ASGM are directly emitted to the atmosphere (35% of total mercury consumption), (iii) 250 Mg yr^{-1} of mercury (25%) are discarded because the mercury is dirty, and (iv) 400 Mg yr^{-1} (40%) are lost directly to tailings during whole ore amalgamation. Of these latter two (25% + 40% = 65%), some portion would be latently emitted to the atmosphere from tailings and waters, and some portion would remain in the hydrosphere. The rate of latent emission is unknown but is particularly high where mercury is used in combination with cyanide processing. Considering the growth in ASGM, the growth in the use of cyanide in ASGM, and the growth in the production of mercury contaminated waste from ASGM (multi-year accumulation of tailings), latent emissions conservatively amount to at least 50 Mg yr^{-1} bringing the total emission of mercury to the atmosphere from ASGM to 400 Mg yr^{-1}. Under such a scenario, then adoption of #1 (emission control that captures 90% of emissions) could reduce mercury consumption globally by a maximum of 0.9*35% = 31.5% or more with better emission capturing technology; adoption of #2 (mercury re-activation or cleaning) could reduce mercury consumption by a maximum 25%; and adoption of #3 (elimination of whole ore amalgamation) could reduce mercury consumption by 0.9*40% = 36%. The latter assumes that 10% of mercury used to amalgamate gravity concentrates (rather than whole ore) will still be lost to tailings. Also, note that the estimated reduction for emission control includes capturing 90% of the emissions caused by the burning of amalgam produced at whole ore amalgamation operations – i.e. 100% of ASGM sites. If all three of these approaches were adopted universally, mercury consumption by ASGM globally could be reduced by 96% (from 1000 to 40 Mg yr^{-1}), emissions to the atmosphere could be reduced by 90% (from 350 to 35 Mg yr^{-1}), and losses to tailings, rivers, lakes and soils, could be reduced by 99.2% (from 650 to 5 Mg yr^{-1}).

To put this further into perspective, if the top 10 countries using mercury in ASGM minus China, which are: Indonesia, Colombia, Brazil, Peru, Philippines, Zimbabwe, Ecuador, Guyana, Venezuela, and Mongolia, that together emit around 400 Mg mercury per annum, were to adopt emissions control measures (fume hoods and retorts, #1), and learn how to clean mercury (#2) then roughly 240 Mg less mercury per annum would be consumed. If China is included, the reduction in mercury consumption would increase to 500 Mg of mercury per annum. China is separated to highlight its importance. Considering that these two approaches are vastly simpler than #3 - elimination of whole ore amalgamation - and have been effectively demonstrated to be profitable for miners, their adoption by mining communities should be relatively simple and successful – perhaps even quick if governments cooperate. The elimination of whole ore amalgamation must also remain a focus, as the current trend is that this practice is increasing. We suggest that by working towards the three approaches above, it is reasonable to expect a 50% reduction in mercury use in ASGM globally on a time scale of perhaps 10 years.

6.8 Conclusions

In summary, the impacts of mercury use in artisanal and small scale gold mining (ASGM) are as follows:

- 400 Mg yr^{-1} of mercury per annum are volatilized to the atmosphere (350 directly; 50 through latent emissions).
- 650 Mg yr^{-1} are discharged into rivers, lakes, floodplains, soils, and tailings (50 Mg yr^{-1} of these are volatilized to the atmosphere).
- Global food chain contamination is likely to be occurring through long range atmospheric transport, deposition, and accumulation in global fisheries - global ecosystem damage is likely to be occurring
- Severe occupational hazards occur – mercury vapour
- Intense local food chain contamination is occurring
- Intense local ecosystem damage is occurring
- Neurological damage to people and animals is occurring
- Tens of thousands of polluted sites have been created that are long-term (centuries) health hazards to populations and ecosystems
- Overall the emissions of mercury from ASGM are leading to decreased capacity for innovation and prosperity for people at local regional and global levels – societal regression

The most significant environmental issues are: (i) mercury emissions to the atmosphere, transport of these emissions locally, regionally and globally, and ultimately leading to aquatic food chain contamination and human health impacts through fish consumption; (ii) health impacts through direct mercury vapour exposure, (iii) release of mercury into aquatic systems and the consequential development of mercury hotspots that last for centuries, and (iv) land-degradation and river siltation and the associated deforestation, loss of organic soil, modification of hydrologic regimes and loss of aquatic habitat.

Finding a resolution to mercury use in ASGM is complicated by the characteristics of the informal gold mining sector including that ASGM remains illegal in many of the areas where it operates; ASGM communities are remote and have a transient nature; miners move quickly when better gold areas are found; different mine types and gold purifying methods are used in different regions; and the general lack of communication within and between artisanal miners and society and government authorities. An approach that links field knowledge, a field presence, and community economic considerations with international stakeholders may have a chance at success where other efforts have failed. A key to this approach is building a reliable knowledgebase about ASGM communities, particularly how and why they operate as they do, and the economic drivers behind these operations. A good knowledge base is the required backbone to formulate solutions to the problems associated with mercury and ASGM.

One important function of this knowledgebase is to enable the determination of the financial implications that proposed changes in practice will cause. These are an important primary criterion for finding sustainable solutions. At the global level, 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? Here, in recognition of the importance of good information in bringing the issue into focus and finding solutions, we have used the available data to make a first estimate of these quantities, and to point out the knowledge gaps surrounding mercury use in ASGM. We welcome any inputs that will improve the database or innovations that can contribute to solutions.

References

Agrawal S., 2007. Final Report, UNIDO Project No. EG/GLO/01/G34, Contract No. 16001054/ML, Community Awareness on Hazards of Exposure to Mercury and Supply of Equipment for Mercury-cleaner Gold Processing Technologies in Galangan, Central Kalimantan, Indonesia.

Al T.A., Leybourne M.I., Maprani A.C., MacQuarrie K.T., Dalziel J.A., Fox D. andYeats P.A., 2006.Effects of acid-sulfate weathering and cyanide-containing gold tailings on the transport and fate of mercury and other metals in Gossan Creek: Murray Brook mine, New Brunswick, Canada.Applied Geochemistry, 21:1969-1985.

Alfa, S., 2000. Child labour in Small-scale Mines in Niger. International Labour Organization, Sector Publications: Available at: www.ilo.org/public/english/dialogue/sector/papers/ childmin/137e1.htm#1

Alpers, C.N. and Hunerlach, M.P., 2000. Mercury Contamination from Historic Gold Mining in California. USGS FS062-00, May 2000, 6 p.

APLA - Amalgamated Prospectors and Leaseholders Association of Western Australia (Inc), 2004.

Appel, P.W.U.; Dyikanova, C.; Esengulova, N.; Tagaeva, A., 2003. Baseline Survey of Artisanal and Small-scale Mining and Teaching Seminars for Small scale miners in Kyrgyz Republic. Report from Geological Survey of Denmark and Greenland, n.2004/11. Copenhagen, 27 p.

Appleton, J.D.; Taylor, H.; Lister, T.R.; Smith, B., 2004. Final Report for the Assessment of Environment in the Rwamagasa area, Tanzania. UNIDO Project EG/GLO/01/34. British Geological Survey, Commissioned Report CR/04/014. Nottingham, UK.159 p.

Argonne National Laboratory draft report 2008. "Technology Demonstration for Reducing Mercury Emissions From Small-Scale Gold Refining Facilities" prepared for U.S. Environmental Protection Agency

Artaxo, P.; Campos, R.C.; Fernandes, E.T.; Martins, J.V.; Xiao, Z., Lindqvist, O.; Fernandez-Jimenez, M.T.; Maenhaut, W., 2000.Large Scale Mercury and Trace Element Measurements in the Amazon Basin.Atmospheric Environment, 34:4085-4096.

Attenborough M., 1999. Social problems in developing countries pose challenge - Canadian companies learning that it pays to be a friendly neighbour The Northern Miner, Volume 85, Number 4.

Babut, M.; Sekyi, R.; Rambaud, A.; Potin-Gautier, M.; Tellier, S.; Bannerman, W.; Beinhoff, C., 2003.Improving the Environmental Management of Small-scale Gold Mining in Ghana: a Case of Dumasi.Journal of Cleaner Production, v.11, p.215-221.

Baker R. and Telmer K., 2007. Summary of Fish Mercury Data from Tanoyan Mining Area, Bolaang Mongodow North Sulawesi. UNIDO, Project EG/GLO/01/G34.

Basque, G., 1991.Gold Panner's Manual.Sunfire Pub. Ltd., Langley, BC, 108 p.

Beales P., 2005. Busy Indaba showcases African mining industry, Northern Miner, Volume 91 Number 1.

Bermudez-Lugo, O., 2002. The Mineral Industries of Gambia, Guine-Bissau, and Senegal. U.S. Geological Survey Minerals I

Chouinard R., 2007. Results of the Awareness Campaign and Technology Demonstration for Artisanal Gold Miners, Summary Report, Brazil – Indonesia – Laos – Sudan – Tanzania – Zimbabwe. UNIDO, Project EG/GLO/01/G34.

Coakley, G.J., 2002. The Mineral Industry of Lesotho and Swaziland. U.S. Geological Survey-Minerals Information. Available at: minerals.er.usgs.gov/minerals/pubs/country/africa. html#ir

Costa, M.P.F., Telmer, K., and Novo, E.M.L.M., 2008. Spectral light attenuation in Amazonian waters. Submitted to Limnology and Oceanography.

Couture, R. and Lambert, J.D., 2003. Source of Mercury in Small scale Mining Communities of Guyana. Presented at the GGMC Mining Week conference. August 2003. Georgetown, Guyana.

Crispin, G., 2003.Environmental Management in Small-scale Mining in PNG.J. Cleaner Production, v.11, n.2, p.175-183

Cumming J., 1997. Banro Resource on hold in eastern Zaire after purchase of Sominki, Northern Miner, Volume 83, Number 2.

Danielson V., 1992. Tanzania opens its doors to foreign investment. Northern Miner, Volume 78, Number 7.

Dawson S., 1996. Nelson mining gold along historic Silk Road. Northern Miner. Volume 82, Number 6.

DLI – Defense Language Institute, 2003. Liberia in Perspective. Available at: www.lingnet.org/areaStudies/perspectives/liberia/liberia.pdf.

Dolley, T.P., 1996. The Mineral Industry of Senegal, the Gambia, and Guinea Bissau. U.S. Geological Survey—Minerals Information. minerals. usgs.gov/ minerals/pubs / country/1994/9233094.pdf

Drasch, G.; Boese-O'Reilly, S.; Beinhoff, C.; Roider, G.; Maydl, S., 2001.The Mt. Diwata Study on the Philippines 1999 – Assessing Mercury Intoxication of the Population by Small-scale Gold Mining.The Science of the Total Environment, v.267, p.151-168.

Dreschler, B., 2001. Small-scale Mining and Sustainable Development within the SADC Region. MMSD Report 84. Available at: www.iied.org/mmsd/mmsd_pdfs/asm_southern_africa.pdf

Ecosystems Contamination Assessment. In: Mercury in the Tapajos Basin. p.75-94. Villas Boas, Beinhoff, Silva(eds.). GEF/UNIDO/CYTED/CETEM/IMAAC publication. Rio de Janeiro.

Fréry, N; Maury-Brachet, N.; Maillot, E.; Deheeger, M.; de Mérona, B.; Boudou, A., 2001.Gold-Mining Activities and Mercury Contamination of Native Amerindian Communities in French Guiana: Key Role of Fish in Dietary Uptake.Environmental Health Perspectives, v.109, p.449-456.

GMP, 2007. Partnership on Mercury Reductions in Artisanal and Small Scale Gold Mining (ASGM). Available at : www.chem.unep.ch/Mercury/partnerships/

Graham R., 2002. Eaglecrest advances San Simon, Northern Miner, Volume 88, Number 40.

Graham R.. 2003. Juniors eye Mexican gold prospects. The Northern Miner, Volume 89 Number 42.

Grayson, R. 2007.Anatomy of the Gold Rush in Modern Mongolia.World Placer Journal, v.7, p.1-65.

Gunson and Yue, 2002. Artisanal Mining in the People's Republic of China. Mining, Minerals and Sustainable Development (MMSD) report 74.

Gunson, A.J., 2004.Mercury and Artisanal and Small-scale Gold Miners in China. MASc Thesis. Dept. Mining Engineering, University of British Columbia, Vancouver, Canada.154 p.

Gunson, A.J. andVeiga, M.M., 2004.Mercury and Artisanal Gold Mining in China.Environmental Practice, v.6, n.2, p.109-120.

Heemskerk, M. 2003.Risks, Attitudes and Mitigation among Gold Miners and Others in the Suriname Rainforest.Natural Resources Forum, v.27, p.267-278.

Hentschel T., Hruschka,F., Priester M., 2002. Global Report on Artisanal & Small-Scale Mining. MMSD Summary Report.

Hinton, J.J.; Veiga, M.M.; Beinhoff, C., 2003.Women and Artisanal Mining: Gender Roles and the Road Ahead. In:The Socio-Economic Impacts of Artisanal and Small-Scale Mining in Developing Countries. Chapter 11.G. Hilson (ed.),Pub. by A.A. Balkema, Swets Publishers, Netherlands.

Hinton, J.J.; Veiga, M.M.; Veiga A.T., 2003.Clean Artisanal Mining, a Utopian Approach? Journal of Cleaner Production, v.11, p.99-115.

Hiyate A., 2008. Semafo banks on Mana Gold Mine to Take Company from Red to Black. Northern Miner, Volume 93 Number 51.

Hunerlach, M.P.; Rytuba, J.J; Alpers, C.N., 1999. Mercury Contamination from Hydraulic Placer-Gold Mining in the Dutch Flat Mining District, California. U.S. Geological Survey Water-Resources Investigations Report 99-4018B, p. 179-189.

Ibrahm, M.S., 2003. Information about the Project Sites in Sudan. Report to GEF/UNDP/UNIDO Global Mercury Project. October, 2003. 10 p.

Ikingura, J. R. andAkagi, H., 1996.Monitoring of Fish and Human Exposure to Mercury Due to Gold Mining in the Lake Victoria Goldfields, Tanzania.The Science of the Total Environment, v.191, n.1-2, p.59-68.

Ikingura, J.R.; Mutakyahwa, M.K.D.; Kahatano, J.M.J., 1997.Mercury and Mining in Africa with Special Reference to Tanzania.Water, Air & Soil Pollution, v.97, p.223-232.

Ikingura, J.R., 1998.Mercury Pollution Due to Small-scale Gold Mining in Tanzania Goldfields. In:Small-scale Mining in African Countries: Prospects, Policy and Environmental Impacts. p.143-158.Ed L. Landner, Dept. Of Geology, Univ.Dar es Salamm, Tanzania.

International Labour Office (ILO), 1999. Social and Labour Issues in Small-scale Mines, Report for the Tripartite Meeting on Social and Labour Issues in Small-scale Mines, Geneva 17-22 May, 1999.

Israel, D.C. and J.P. Asirot. 2000. Mercury Pollution in Small-Scale Gold Mining in the Philippines. Philippine Institute for Development Studies, Discussion Paper Series No. 2000-06. Economy and Environment Program for Southeast Asia, 2000.

Israel D.C., 2000. Mercury Pollution Due to Small-Scale Gold Mining: A Serious Menace. Philippine Institute for Development Studies, Policy Notes, No. 2000-03

Jonasson, I.R. and Boyle, R.W., 1972. Geochemistry of mercury and origins of natural contamination of the environment. Canadian Mining and Metallurgical Bulletin 65.

Kambani S.M., 2003.Small-scale mining and cleaner production issues in Zambia.Journal of Cleaner Production, 11; 141–146

Kinabo, C.P., 2002.Comparative Analysis of Mercury Content in Cosmetics and Soaps Used in the City of Dar Es Salaam. In:Proc. International Workshop on Health and Environmental Effects of Mercury: Impacts of Mercury from Artisanal Gold Mining in Africa. p.173-186. Tanzania, Nov. 19-20, 2002.Ed. National Institute of Minamata Disease, Japan.

Kinabo, C., 2003.Women Engagement and Child Labour in Small-scale Mining – Tanzanian Case Study.Urban Heath and Development Bull., v.6, n.4, p.46-56.South Africa.

Labonne, B., 2002. Seminar on Artisanal and Small-scale Mining in Africa: Identifying Best Practices and Bulding the Sustainable Livelihoods of Communities. Synthesis Report: Available at: www.naturalresources.org/minerals/smscalemining/docs.htm

Lacerda, L.D., 2003.Updating global Hg Emissions from Small-scale Gold Mining and Assessing its Environmental Impacts.Environmental Geology v.43, p.308–314

Madawo I., 2007. Canadians lead new Scramble for Africa. Northern Miner, Volume 93, Number 42.

Mahlatsi, S. andGuest, R., 2003.The iGoli Mercury-free Gold Extraction Process.Urban Heath and Development Bull., v.6, n.4, p.62-63.South Africa.

Maponga, O. andNgorima, C.F., 2003.Overcoming Environmental Problems in the Gold Panning Sector through Legislation and Education: the Zimbabwean Experience.Journal of Cleaner Production v.11, p.147–157

Maxson, P., 2004. Mercury flows in Europe and the world: The Impact of Decommissioned Chlor-alkali Plants.Prepared by Concorde EasMg/West Sprl for the European Commission (Environment Directorate), final report, Feb 2004, Brussels, Belgium. Available at: europa.eu.inMg/comm/environmenMg/chemicals/mercury/index.htm

Maxson, P., 2008a. AMAP study of air emissions & transport. Preliminary draft report for UNEP.

Maxson, P., 2008b. Global atmospheric Hg emissions from incineration of mercury products in the waste stream. Preliminary draft report for the Mercury Policy Project, February 2008.

Mbendi Information for Africa, 2004. Mauritania Mining Overview. Available at: www.mbendi.co.za/indy/ming/ af/mu/p0005.htm

MMSD – Mining, Minerals and Sustainable Development, 2002. Breaking New Ground. International Institute for Environment and Development and World Business Council for Sustainable Development. London, UK. 441 p.

Mobbs, P.M., 1996. The Mineral Industry of Chad. U.S. Geological Survey-Minerals Information. minerals.usgs.gov/minerals/ pubs/ country/1996/9206096.pdf -

Mobbs, P.M., 1998. The Mineral Industry of Côte D'Ivoire. U.S. Geological Survey-Minerals Information. Available at: minerals.er.usgs.gov/minerals/ pubs/country/1997/9208097.pdf

Murphy T., 2006. Mercury Contamination along the Mekong River, Cambodia. In: Book of Abstracts of the 8th International Conference on Mercury as a Global Pollutant. Madison, Wisconsin, USA. Aug 6-11, 2006.

Northern Miner, 1997. Gold output from East to rise in '98, FACTS 'N' FIGURES, Volume 83, Number 41.

Northern Miner, 2001. Vaaldiam raises Boungou funds, Volume 87, Number 2.

Northern Miner ,2003. SouthernEra advances Messina, raises CUS$77m Volume 89 Number 40.

Northern Miner, 2007. Exploration Annual Review, Artisanals point the way for African Gold Group, Volume 93 Number 39.

Northern Miner, 2008. Delta drills high-grade gold in Mali , Volume 93 Number 50.

Northern Miner, 2008. Delta drills high-grade gold in Mali. Daily News, Volume 93, Number 47.

Nyambe I., 2008. pers. Comm.

Pantoja F. And Alvaarez R., 2000. Decrease of pollution by mercury in gold mining in Latin Amercia. In: Mine Closure in Iberoamerica., eds.) Villas Boas R.C., Berreto M.L., CYTED/IMAAC/UNIDO: Rio de Janeiro, pp. 178-190.

Priester, M. and Hentschel, T., 1992. Small-scale Gold Mining: Processing Techniques in Developing Countries. GTZ/GATE, Vieweg, Eschborn, Germany, 96 p.

Rajaobelina, S., 2003. Biodiversity and Small Scale Gold Mining in Madagascar. Paper presented at 3rd CASM Annual General Meeting and Learning Event, Elmina, Ghana, September 7-10, 2003. Available at: www.casmsite.org/events_Elmina.html

Robertson R., 2006. Aurelian Gold Discovery Takes Centre Stage Drilling Continues to Show Expansion Potential to the South. Northern Miner, Volume 92 Number 39.

Rosario J. And Ault S.K. 1997. Environmental and Health Impacts of Mercury and Cyanide in Gold-Mining in Nicaragua. Environmental Health Project, Contract No. HRN-5994-C-00-3036-00, Project No. 936-5994, sponsored by the Bureau for Global Programs, Field Support and Research, Office of Health and Nutrition, U.S. Agency for International Development, Washington, DC, ACTIVITY REPORT, No. 33.

Roulet, M., Lucotte, M., Canuel, R., Rheault, I., Tran, S., De Freitos Gog, Y.G., Farella, N., Souza do Vale, R., Sousa Passos, C.J., DeJesus da Silva, E., Mergler, D., Amorim, M., 1998.Distribution and partition of total mercury in waters of the Tapajos River Basin, Brazilian Amazon.The Science of the Total Environment 213, 203–211.

Savornin, O.; Niang, K.; Diouf, A., 2007. Artisanal Gold Mining in the Tambacounda Region of Senegal. Report to Blacksmith Institute. 16p.

Schofield N.C., 2007.Comodity Derivatives, Markets and Applications.John Wiley and Sons Canada, Mississauga, pp.315.

Shaw S.A., Al T.A., and MacQuarrie K.T.B., 2006. Mercury mobility in unsaturated gold mine tailings, Murray Brook Mine, New Brunswick, Canada. Applied Geochemistry, 21: 1986-1998.

Siddaiah, N.S., 2001. Mercury and Arsenic Pollution Dues to Gold Mining, Milling and Smelting in India: A Need to Assess Its Impact on Human Health and Ecosystem. . In: Book of Abstracts of the 6th International Conference on Mercury as a Global Pollutant. Minamata, Japan, Oct.15-19, 2001.

Silva A.C., 2008. pers. Comm.. based on Ph.D. work on community mining in Nicaragua.

Sotham, S., 2001.Artisanal Gold Mining in Cambodia. In:Small-scale Mining in Asia. p.31-40.S. Murao, V.B. Maglambayan, N. Cruz (eds.).Mining Journal Books Ltd., London, UK.

Sotham, S., 2004. Small-scale gold mining in Cambodia, a Situation Assessment. Ed. Dr. Carl Middleton, Additional research contributed by the NGO Forum on Cambodia's Environmental Forum Core Team. Oxfam, America.

Sousa and Veiga, 2007. Brazil Country Report, UNDP/GEF/UNIDO Project EG/GLO/01/G34. Final Report.

Spiegel, S.J.; Savornin, O.; Shoko, D.; Veiga, M.M., 2006.Mercury Reduction in Munhena, Mozambique: Homemade Solutions and the Social Context for Change.International Journal of Occupational and Environmental Health, v.12, n.13, p.215-221.

Stepanov, V.A. and Yusupov, D.V., 2001. Mercury Contamination of Soil-vegetative Cover in Zone of Influence of a Gold-concentration Enterprise. In: Book of Abstracts of the 6th International Conference on Mercury as a Global Pollutant. Minamata, Japan, Oct.15-19, 2001.

Sulaiman R., Baker R., Susulorini B., Telmer K., and Spiegel S., 2007. Indonesia Country Report, UNDP/GEF/UNIDO Project EG/GLO/01/G34. Final Report.

Telmer K., Stapper D., Costa M.P.F., Ribeiro C., Veiga M.M., 2006. Knowledge Gaps in Mercury Pollution from Gold Mining. In: Book of Abstracts of the 8th International Conference on Mercury as a Global Pollutant. Madison, Wisconsin, USA. Aug 6-11, 2006.

Telmer K., Costa M.P.F., Angélica R.S., Araujo E.S., andMaurice Y., 2006b.The source and fate of sediment and mercury in the Tapajós River, Pará, Brazilian Amazon: ground and space based evidence. Journal of Environmental Management, 81: 101-113.(invited, special issue)

Telmer K. and Stapper D., 2007. Evaluating and Monitoring Small Scale Gold Mining and Mercury Use: Building a Knowledge-base with Satellite Imagery and Field Work UNDP/GEF/UNIDO Project EG/GLO/01/G34 Final Report.

Thomae B., 2004. Mano River's Pampana yields more gold. Northern Miner, Volume 90, Number 25.

Trung, N.X., 2001.Small-scale Gold Mining in Vietnam. In:Small-scale Mining in Asia. p.41-45. S. Murao, V.B. Maglambayan, N. Cruz (eds.).Mining Journal Books Ltd., London, UK.

Umbangtalad S., Parkpian P., Visvanathan C., Delaune R.D., andJugsujinda A. 2007.Assessment of Hg contamination and exposure to miners and schoolchildren at a small-scale gold mining and recovery operation in Thailand.Journal of Environmental Science and Health Part A:42:2071-2079.

UNEP – United Nations Environment Programme, 2002. Global Mercury Assessment

UNEP – United Nations Environment Programme, 2005. Strategic Approach to International Chemicals Management (SAICM). Status Report on Partnerships as One Approach to Reducing the Risks to Human Health and the Environment from the Release of Mercury and Its Compounds to the Environment. Vienna, 19–24 September 2005. Available at: www.chem.unep.ch/SAICM/ meeting/prepcom3/ en/INF18%20mercury.pdf

UNESCAP – United Nations Economic and Social Commission for Asia and the Pacific, 2003. UNESCAP Assists Myanmar in Formulating Environmental Policy and Guidelines for the Mining Industry. Available at: www.unescap.org/esd/water/mineral/2003/26_6February.asp

UNIDO, 2006. Summary of the Environmental and Health Assessment Reports. The Global Mercury Project. Compiled by A.J.Gunson et al. Available at: www.globalmercury project.org.

Vaccaro A., 2007. After surviving DRC's dog days, Banro nears its payday – Site Visit. Northern Miner, Volume 93, Number 42.

Veiga, M.M., 1997, Introducing New Technologies for Abatement of Global Mercury Pollution in Latin America. Ed. UNIDO/UBC/CETEM, Rio de Janeiro, 94 p.

Veiga M.M. and Baker R.F., 2004. Protocols for Environmental and Health Assessment of Mercury Released by Artisanal and Small-Scale Gold Miners. Vienna, Austria: GEF/UNDP/UNIDO, ISBN 92-1-106429-5, 294p.

Veiga, M.M.; Bermudez, D.; Pacheco-Ferreira, H.; Pedroso, L.R.M.; Gunson, A.J.; Berrios, G.; Vos, L.; Huidobro, P.; Roeser, M. 2005.Mercury Pollution from Artisanal Gold Mining in Block B, El Callao, Bolívar State, Venezuela. In:Dynamics of Mercury Pollution on Regional and Global Scales, Atmospheric Processes and Human Exposures Around the World. p.421-450.Pirrone, N.; Mahaffey, K.R. (Eds.)ISBN: 0-387-24493-X, July 2005, Springer, Norwell, MA, USA

Veiga M.M., Maxson P., andHylander L., 2006.Origin of Mercury in Artisanal Gold Mining.Journal of Cleaner Production, 14:436-447.

Vieira R., 2008. WWF Guinas, Goldmining Pollution Abatement. World Wildlife Federation.

Weekend Proespector, 2004. Available at: www.geocities.com/Yosemite/Trails/1849/

Wickre J.B., Karagas M.R., Folt C.L., andSturup S., 2004.Environmental exposure and fingernail analysis of arsenic and mercury in children and adults in a Nicaraguan gold mining community Archives of Environmental Health, 59:400-409.

Winch S., Parsons M., Mills H., Fortin D., Lean D., Kostka J., 2006. Mercury Speciation and Sulfate-Reducing Bacteria in Mine Tailings. In: Book of Abstracts of the 8th International Conference on Mercury as a Global Pollutant. Madison, Wisconsin, USA. Aug 6-11, 2006.

Wuerker, 2008. The cleaning of mercury by filtration during the use of liquid mercury telescopes, (Personal communication).

World Bank, 2003. Project Information Document: Sustainable Management of Mineral Resources Project, Uganda, Report 90 p.

Yager, T.R.; Coakley, G.J.; Mobbs, P.M., 2002. The Mineral Industries of Benin, Cape Verde, the Central African Republic, Côte D'Ivoire, and Togo. U.S. Geological Survey-Minerals Information. Available at: minerals.er.usgs.gov/minerals/pubs/country/africa.html