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MERCURY POLLUTION IN THE AMAZON BASIN

Scientific research and related National and International control policies

Norbert Fenzl[1]

Fernanda S. Nascimento[2]

ABSTRACT

As a result of effective policies, Hg fungicides and organic Hg compounds used in industries and agriculture disappeared in many countries, including Brazil. At the same time the use of Hg in Amazonian gold mining increased drastically since the gold rush of the 80`s and again the high gold prices related to the global financial breakdown which started mainly 2007/2008. The present paper shows how Mercury Pollution has been object of scientific research and influenced public awareness and policies intending to control the use of Hg and the resulting impact on public health of the regional population. But despite the worldwide recognized danger of widespread Mercury pollution of Amazon Rivers, and an important scientific production concerning Mercury related issues, consistent and effective control policies are still lacking. The main reasons for the difficulties to apply regulations are due to the immensity of the Amazon region, massive unemployment, high immigration rates to the region and high international gold prices.

Keywords: Amazon Basin, Mercury, Policies, Water Resources, Environment

INTRODUCTION

During the last decade, increasing concern about Mercury (Hg) pollution in the Amazonian ecosystems encouraged numerous research groups to study the causes, the real extension and the social consequences of the problem. Despite the great volume of data and information collected during the last years, the biogeochemical cycle of mercury it is still poorly understood.

Earlier research groups concentrated their attention primarily on gold-mining areas, because it was thought that they are the main responsible for the Hg contamination of aquatic ecosystems (Malm et al., 1990; Nriagu et al., 1992, Pfeiffer et al., 1993; Malm et al., 1995; Maurice-Bourgoin et al., 1999).

More recently it showed that Hg dissemination and contamination are not only related to gold mining activities, but are very probably a combination of soil erosion, gold mining, and forest fires. The first evidences of such affirmation resulted from high, non-anthropic, mercury concentrations found in superficial mineral horizons of

[1] Possui graduação em Geologia pela Universidade de Viena, doutorado em Hidrogeologia - Ciências Ambientais pela Universidade de Viena e pós-doutorado pela Universidade Técnica de Viena. Atualmente é pesquisador e Professor Titular da Universidade Federal do Pará, Núcleo de Meio Ambiente (NUMA). Colaborador cientifico da Organização do Tratado de Cooperação Amazônica (OTCA) na área de Gestão Integrada Recursos Hídricos da Bacia Amazônica, Consultor do CORDIS (Community Research Development Information Service) da UE. norbert@ufpa.br

[2] phD, researcher at the Federal University of Oueste Pará UFOPA, Brazil

forested soils. For example Roulet et al. (1999) sustain that more than 97% of the Hg accumulated in soils of the Tapajos basin are due to natural sources. This explains the exceptionally high mercury levels (44 - 212 ng/g), detected in soils of the Rio Negro basin with little gold-mining activity (Silva-Forsberg et al. 1999).

Actually it seems to be consensus, that two main sources are responsible for Hg dissemination in the Amazonian basin: historical atmospheric inputs from natural processes (for example volcanism), described especially in the Madeira river basin, and anthropogenic inputs from colonial (1550-1880) and modern gold-mining activities.

1. THE ORIGIN OF MERCURY CONTAMINATION IN THE AMAZON BASIN

1.1 Mercury contamination in the Amazon Environment

Methyl-mercury (Me-Hg), the toxic organic compound of Mercury, is responsible for harmful human intoxication and environmental contamination. Knowledge originated by scientific research and monitoring will better assist in the development of prevention strategies and government actions targeting the mercury contamination of Amazonian environment.

So far, the process of Hg dissemination is closely related to the transformation from inorganic to organic mercury (mostly Me-Hg) and its bioaccumulation in the aquatic food chain, where fish seems to be the main source of human contamination (IPCS, 1990). Methyl-mercury is formed from inorganic mercury by the action of anaerobic organisms that live in aquatic systems including lakes, rivers, wetlands, sediments, soils and the open ocean. (Ullrich, S., Tanton, T., Abdrashitova, S. (2001).

This process converts inorganic mercury to methyl-mercury (H_3C-Hg^+) in the natural environment. Since fish is a basic diet of a lot of Amazonian communities, the relationship between fish consumption and Hg exposure has been demonstrated in a great number of publications.

Hair is the most useful indicator for Me-Hg concentration in humans, because hair binds Me-Hg proportionally to its concentration in blood and its concentration remains constant. So far, Me-Hg measurement in hair is also useful to get information about the history of Me-Hg exposure over the recent past,

Clinical symptoms of intoxication generally can be noticed only above a certain critical Me-Hg concentration in hair and the intensity of such symptoms is different for adult and prenatal life. Children with highly intoxicated mothers may present different types of neurological disorders like cerebral palsy, including microcephaly, hyper-reflexia, and gross motor and mental impairments. Serious symptoms of Me-Hg intoxication like troubles of speech and hearing and even death were observed at hair Hg concentrations in the range of 200 to 1,500 ppm (Clarkson, 1997).

The following Figure 1 - Behavior of Mercury in the environment – illustrates the Hg cycle in an aquatic environment.

(Figure 1)

1.2 Mercury emission from Gold Mining

In the Amazon rainforest gold is found basically in alluvial gold deposits. Great industrial and informal, small-scale miners are mining in these deposits using generally hydraulic mining techniques, clearing river banks, floodplain to expose sediments and gravel. Gold is usually extracted from this gravel using a sluice box to separate heavier sediment and mercury for amalgamating the precious metal (Rhett Butler, 2012). While

most of the mercury is removed for reuse or burned off, some end up in the rivers. Studies have found that small-scale miners are less efficient with their use of mercury than industrial miners, releasing an estimated 2.91 pounds (1.32 kg) of mercury into waterways for every 2.2 pounds (1 kg) of gold produced.
Actually nearly 1 million of miners are working in Artisanal Small Gold Mines in the Amazon Basin producing probably more than 160 tons of gold each year

(Tab 1)

The production of these amounts of gold causes severe emission of inorganic and organic mercury into the environment. The following Table 2 shows the different sources of Mercury emission the in Brazilian Amazon Basin.

(Table 2)

The losses of Mercury during the different gold processing procedures are high. The next Table 3 shows the losses in the Brazilian Amazon Basin according to the different activities of gold mining and commercialization processes.

(Table 3)

The impacts of industrial and artisanal small Gold Mining are is not only limited to the emission of Mercury and other toxic substances, but also due to heavy destruction of ecosystems and the surrounding landscapes, disintegration of social-economic structures and extreme dangerous and unhealthy working conditions. The following picture (Figure 2) gives an idea of the working environment of a small gold mining site in the Amazon.

(Figure 2)

1.3 Mercury emission from deforestation
Originally, high mercury levels in the blood of fish-eating people in the Amazon have been attributed to gold mining activities conducted by informal miners and the high deforestation rate in the region has not been recognized as contributing to this environmental problem. Actually we know that about 90 tons of organic mercury from the biomass are estimated to be emitted annually into the Amazonian atmosphere and precipitated in the aquatic systems for rapid transformation into methylated forms. This is a conservative assessment and may be more than 6 times this rate.
Prof. Anne H. Fostier coordinating the project "Impact of deforestation on mercury emissions in tropical forest from the Amazonian region" stated with regard to this process:

> *In forest ecosystems, intact soils and tree cover buffer the movement of mercury (Hg) in the forest, and thus mediate its impact on the human food chain. In the Amazonian region, deforestation by biomass burning can lead to the remobilization of this element at local and regional scale, thus increasing the concentrations of mercury to which local populations are exposed. Hg can be remobilized to the atmosphere and aquatic system through various processes: 1)*

volatilization of large amounts of mercury in biomass that is almost completely emitted into the atmosphere during biomass burning, 2) atmospheric emission by thermal desorption of mercury from soil, 3) atmospheric emission of Hg following the burn event, as emissions from exposed soils, 4) direct transfer of Hg from soil to aquatic system by lixiviation.

2. MERCURY RESEARCH

2.1 Mercury Exposure and Fish consumption

Several studies in the Amazonian Basin have shown that riverine populations are exposed to methyl-mercury through fish consumption. Dolbec, J., Mergler D., Larribe F., Roulet M., Lebel J., Lucotte, M. (2001) investigated the relationship between fish-eating practices and seasonal variation in mercury exposure of 36 women from a village located on the banks of the Tapajos River, a major tributary of the Amazon. The results showed a clear Me-Hg contamination of the investigated population with higher hair mercury levels in the dry season compared to the rainy season. So, the research proved the relationship between mercury exposure of riverine population and the type of consumed fish species.

2.2 Methyl Mercury concentrations in sediments and soils

Roulet M., Guimarães J.R.D., Lucotte M. (2001) investigated the spatial and seasonal variations of Methyl Hg concentrations of different sediments and soils of the Tapajos river floodplain a typical Amazonian floodplain ecosystem. The results confirmed previous observations, in the same study area, of net 203 Hg methylation potentials and the fact that fresh and labile organic matter in the litter of these floodplains are the most important factor leading to significant enrichment of Me-Hg in these particular environments.

2.3 Mercury in the Tapajos and Amazon Rivers, Brazil

Roulet M. et al. (2001) investigated the mercury concentrations in the surface waters from the Tapajos River, the Arapiuns River, its principal tributary, and the Amazon River at its confluence with the Tapajos. Normally Hg concentrations in Amazonian rivers are governed by the concentration of suspended particles. Hg concentrations in the filtered water showed to be lower than 2.8 ng/L in all samples. On the other hand, concentrations of fine particulate Hg reached values up to 29.7 ng/L. The study shows that the dominant stock of Hg in the aquatic ecosystems of this region is derived from erosion of natural soils in the catchments rather than from anthropogenic pollution. The authors sustain that, the input of natural Hg coming from soils into the aquatic ecosystems may have increased over historical levels in the region and could be responsible for high methyl mercury levels recently reported in fish and humans.

2.4 Mercury contamination in the Upper Bolivian Madeira River Basin.

Investigations of mercury concentrations (in river water, suspended particles, fish and local population) were realized in the upper Madeira River Basin by Maurice Bourgoin L., Quiroga I., Chincherros J., and Courau P., (2000).

The total mercury concentrations measured in surface waters of the upper Beni basin varied during the dry season, from 2.24 - 2.57 ng/L (Zongo river) to 7.00 ng/L (Madeira River, Porto Velho) and 9.49-10.86 ng /L at its confluence with the Amazon.

The results obtained from fish indicated surprisingly high Hg concentrations in 86%

of the piscivorous fishes collected in the Beni River, exceeding almost four times the WHO (1976) safety limit. Beni River omnivorous and mud-feeding fish samples showed Hg concentrations from 0.02 to 0.19 µg/g (wet wt.); while piscivorous fish Hg concentrations reached values up to 2.30 µg/g (wet wt.).

The results of human mercury exposure were based on samples form 80 individuals spread over the entire region. Indigenous people living on the banks of the Beni River, showed high average levels of mercury (9.81 µg/g) and increasing contamination in young breast-fed children, confirming that hair mercury concentration in babies was significantly affected by maternal mercury contamination during pregnancy. These results show that the major health impacts caused by mercury are basically due to a regular fish diet, instead of gold mining activity.

2.5 Human contamination along the Upper Brazilian Madeira Basin

Mercury exposure of riverine people living in the Upper Madeira Basin of the Brazilian Amazon, considered as heavy fish eaters, has been investigated by Boischio, Cernichiari and Henshel (2000). Ten members of a single family with a similar diet showed a very wide range of Hg hair concentrations (from 8 to 339 ppm), but the interesting result was, that even the same person showed a wide range of 136 to 274 ppm Hg hair concentration over time. The research confirms other investigations that Hg exposure is directly related to the type of fish and the period of consumption.

2.6 Scientific articles published by Amazonian research institutions 1990-2005

Despite the fact that a great part of scientific papers concerning Mercury related issues have been published by non-Amazonian institutions, an increasing participation of regional research institutions can be noted. The following Figure 2 shows the number and type of scientific papers published between 1990 and 2005 by Amazonian research institutions.

(Figure 3)

3. CONTROL POLICIES

What kind of international regional and national control policies and regulations are in place to mitigate the problems of uncontrolled Mercury use in the world and as a consequence in the Amazonian countries? Analyzing the different activities during the last decades with respect to this issue, we notice a relatively great number of international meetings and efforts to reach an international binding agreement on Mercury, but there are clearly difficulties to implement them on national levels.

For example Nordic countries have the world's toughest restrictions on mercury, but other developed countries, such as Canada and the US, are inexcusably lax about mercury. On the other hand the strong connection between mercury and coal links the debate to one of the most conflictive areas of energy supply and to a certain resistance of the emerging countries against strongly binding agreements.

3.1 International activities for control policies

3.1.1 Global Mercury Treaty

The UNEP leads the efforts to reach an effective globally binding agreement on the use of Mercury, organizing a sequence of meetings of an International Negotiating

Committee (INC) focusing on week-long exchanges of views on issues such as, supply; storage; use of Hg in products and processes; artisanal small scale gold mining; trade; atmospheric emissions; waste and contaminated sites;. These meetings took place through 2010 to 2012 and should accomplish its objectives at a Diplomatic Conference to be held in Minamata, Japan, in October 2013.

A brief history of these meetings shows the difficulties of these negotiations to reach a globally binding agreement, which can be implemented at national levels.

The following meetings already took place:

► INC-1 (7-11 June 2010). The First Session of the Intergovernmental Negotiating Committee to prepare a global legally binding instrument on Mercury took place in Stockholm, Sweden.

► INC-2 (24-28 January 2011). The Second Session of the Intergovernmental Negotiating Committee was organized in Chiba, Japan.

► INC-3 (30 October to 4 November 2011). The third session of the Intergovernmental Negotiating was held in Nairobi, Kenya.

► Finally, INC-4 took place from 27 June-2 July 2012, in Punta del Este, Uruguay, where delegates discussed a draft text reflecting the works of all prior meetings and prepared the INC-5 meeting and for the 27th session of the UN Environment Program's Governing Council/Global Ministerial Environment Forum (UNEP GC/GMEF) in February 2013. All these efforts should conclude with the adoption of a binding treaty at a Diplomatic Conference to be held in Minamata, Japan, in October 2013.

Tuesday, January 22, 2013 The News Agency Interpress Service wrote:

The Minamata Convention on Mercury, which sets out to control and reduce products and processes using the metal, was approved on Saturday Jan. 19 by representatives of over 140 governments. It will be signed in Japan in September and will enter into force once 50 countries or more have ratified it.

The UNEP hopes that following the discussions in Geneva, the mercury treaty will be finally adopted at the international conference to be held in October in Japan. One of the focal points of INC-5 is the introduction of rules to regulate mercury emissions into the atmosphere.

The proposed treaty may also call for limiting the use of mercury for certain products and at chemical plants. Particularly under study is a ban on the production of items using mercury exceeding certain levels, possibly including fluorescent lamps, batteries, and medical devices for measuring blood pressure and temperature. A specific list of banned items and when the production ban should start will be decided in these coming talks.

3.1.2 Global Mercury Project

The Global Mercury Project (GEF, UNDP, UNIDO) began in 2002 to address issues of mercury contamination from artisanal and small-scale gold mining. According to the official website of the project (http://www.globalmercuryproject.org/), the goals of the project are:

- to reduce mercury pollution of international waters by emissions emanating from small-scale gold mining,
- to introduce cleaner technologies for gold extraction and to train people in their application,
- to develop capacity and regulatory mechanisms that will enable the sector to

minimize mercury pollution,

- to introduce environmental and health monitoring programs,
- to build capacity of local laboratories to assess the extent and impact of mercury pollution.
- International guidelines on mercury management in artisanal and small scale mining
- Institutional strengthening of multi-sector cooperation with government agencies and other organizations in support of capacity-building, training, technology, education, and mobilization of resources to facilitate and assist in fulfilling the aims of the GMP
- Policies on Mercury use and Artisanal and Small-Scale Gold Mining
- Global partnerships for development strengthening and expansion of global partnerships for development - joint activities.

3.1.3 UNEP Global Mercury Partnership

The overall goal of the partnership is to protect human health and the global environment from the release of mercury and its compounds by minimizing and, where feasible, ultimately eliminating, anthropogenic mercury releases to air, water and land.

The Partnership currently has seven identified Priorities for Action (or partnership areas) that are reflective of the major source categories.

To become a partner, interested entities or individuals should submit a letter to UNEP signifying their support for the UNEP Global Mercury Partnership and their commitment to achieving its goal, and specifying how they will contribute to meeting the goal of the UNEP Global Mercury Partnership.

3.1.4 Legal disposition for the use of Mercury in Amazonian Countries

First of all it is important to mention that all Amazonian countries ratified the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal

The convention entered into force on 5 May 1992 to address the management, disposal and transboundary movements of hazardous wastes. The guidelines of the Convention are: *transboundary movements of hazardous wastes should be reduced to a minimum consistent with their environmentally sound management; hazardous wastes should be treated and disposed of as close as possible to their source of generation; and hazardous waste generation should be reduced and minimized at source.*

The ratification of the Basel Convention constitutes an important step towards more specific regulations concerning the use of Mercury. But, at national levels legal regulations are generally much more complex and difficult to implement.

Actually the basic regulations in place to control Mercury use in Amazonian countries are:

- **Bolivia.**

The Law RAAM - Environment Regulation on Mining Activities (31/07/1997) states that the use of mercury in mineral concentration process is only allowed when installing mercury recovery equipment to process the output.

- **Columbia**.

4. CONCLUSION

Worldwide recognized danger of widespread Mercury pollution of Amazon Rivers, and an important scientific production concerning Mercury related issues, did not lead to consistent and effective control policies. The main reasons for the difficulties to apply regulations are basically geographical (the immensity of the region) and socioeconomic, due to massive unemployment, high immigration rates to the region and the high international gold prices.

Despite the great difficulties to apply effective regulations there is a significant improvement of international efforts to control de impacts on public health of Mercury contamination in the amazon region.

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Table and figures

Figure 1 Behavior of Mercury in the environment Source: http://www.usgs.gov/themes/factsheet/146-00

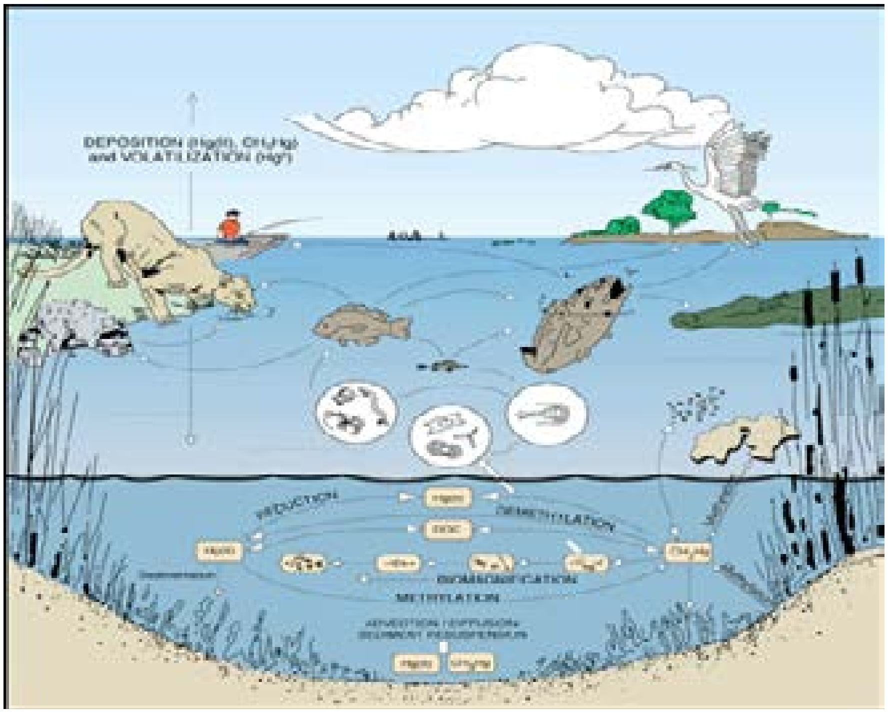

Table 1 Number of miners working in Artisanal Small Gold Mines in the Amazon Basin and corresponding gold production per year, Source: Marcello M. Veiga (1997)

Country	Gold (tons)	Number of Miners
Brazil	30 - 50	200,000 - 400,000
Colombia	20 - 30	100,000 - 200,000
Peru	20 - 30	100,000 - 200,000
Ecuador	10 - 20	50,000 - 80,000
Venezuela	10 - 15	30,000 - 40,000
Suriname	5 - 10	15,000 - 30,000
Bolivia	5 - 7	10,000 - 20,000
Guyana	3 - 4	6,000 - 10,000
Total Amazonian Countries	103 - 166	511.00 – 980.000

Table 2 The different sources of Mercury emission the in Brazilian Amazon Basin.
Source: CETEM - Centro de Tecnologia Mineral, 1989. Poconé Project
Table 3 Hg Losses during the different gold mining procedures

Source of Hg	Emission (Ton of Hg)	Concentration (µg/m³)	Author
Amalgam burning	30 -70		Pfeiffer et al. (1993)
Gold dealer shops		5.50 to 292	Pfeiffer et al. (1993)
Deforestation	8-80		Veiga et al. (1994)
Different Sources Brazilian Amazon allone	50-80		Veiga et al. (1999)

Source: CETEM - Centro de Tecnologia Mineral, 1989. Poconé Project
Figure 2 Working conditions in a small scale artisanal gold mining site in the Brazilian

Activity	Losses (% of Hg)
Volatilization during amalgam distillation	70
Dragged with the amalgamation tailings	20
Volatilization in the gold shops when gold is melted	10

Amazon. Source: Alberto Cesar Araujo, Folha Imagem, 2007

Figure 3 Number and type of publications per year 1990-2005,
Source: http://dx.doi.org/10.1590/S0102-311X2008000700003