GLOBAL MERCURY EMISSIONS FROM GOLD AND SILVER MINING

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Abstract. Mercury has been used in gold and silver mining since Roman times. With the invention of the "patio" process in Spanish colonial America, silver and gold were produced in large scale, mostly in the Americas but also in Australia, Southeast Asia and even in England. Mercury released to the biosphere due to this activity may have reached over 260,000 t from 1550 to 1930, when silver reserves in Spanish colonial America were nearly exhausted and Hg-amalgamation was replaced by the more efficient cyanidation process. Exceptional increases in gold prices and the worsening of social-economic conditions in the third world in the 1970's, resulted in a new gold rush in the southern hemisphere, involving over 10 million people in all continents. Presently, Hg amalgamation is used as a major technique for gold production in the South America especially the Amazon, China, Southeast Asia and in some African countries. Mercury inputs to the environment from this activity may reach up to 460 t.yr⁻¹. Compared with other anthropogenic Hg sources, gold mining is presently responsible for approximately 10% of the global anthropogenic Hg emissions, but has never been included in global models of Hg cycling in the biosphere. Further, most of the Hg released to the biosphere through gold and silver mining during the last 500 years, roughly 300,000 t, may still participate in the global Hg cycle through remobilization from abandoned tailings and other contaminated areas.

Key words: gold and silver mining, amalgamation, mercury emissions

1. Introduction

Mercury contamination is considered one of the worst hazards among anthropogenic impacts upon the global environment. Mercury is one of the few metal pollutants which has caused human death due to ingestion of contaminated food. It is estimated that worldwide more than 1,400 humans have died and over 20,000 have been afflicted by Hg poisoning over the last 40 years, an illness with mortality rates ranging from 7% to 11% (D'Itri, 1992).

Mercury is easily transformed into stable and highly toxic Me-Hg by numerous microorganisms. This Hg species accumulates strongly in aquatic biota, resulting in contamination of fish in many regions leading to serious economic problems for populations depending on fisheries and other aquatic resources. Anthropogenic emissions of Hg originate mostly from coal and oil burning and refuse incineration to the atmosphere; and from solid and urban wastes disposal and agriculture and forestry practices to soils and waters (Nriagu, 1990). Global anthropogenic emission reaches about 4,000 t.yr⁻¹ (Porcela et al., 1996), while mobilization from natural weathering is less than one fourth of the anthropogenic sources (c.a. 900 t.yr⁻¹) (Nriagu, 1989).
The seriousness of Hg contamination has led to more intense control of emissions from industrial sources in most countries, resulting in a significant decrease in global Hg inputs to the environment. For instance, in the early 1970's estimates of anthropogenic Hg emissions to the biosphere ranged from 10,000 to 30,000 t yr\(^{-1}\). In the late 1980's however, emissions estimates decreased to 6,000 to 13,500 t yr\(^{-1}\) (SCOPE, 1985; Nriagu, 1990), clearly showing the effectiveness of Hg control policies. The decrease was primarily achieved by banning Hg fungicides and Hg-cell chlor-alkali plants and through recycling of Hg from solid wastes. Today, most Hg mines have decreased their production or even closed operations, and a significant decrease in Hg content in components of previously contaminated ecosystems is occurring throughout the world (Nuorteva et al., 1979; Ogilvie, 1981; Lodenius, 1991). It is reasonable to expect a future scenario of stronger industrial control policies and more reduction of environmental Hg levels in previously contaminated sites. Recently, the utilization of Hg in gold mining and the mobilization of significantly amounts of Hg from old mine tailings, have become a significant source of this pollutant to the environment. This traditional practice had been nearly forgotten by 1960. Presently, it is rapidly spreading throughout the tropics, particularly in Latin America and Asia, involving over 10 million people worldwide (Lacerda et al., 1995). If this growth in the use of Hg continues, its impact on human and environmental health will reach alarming proportions in the 21\(^{st}\) century.

2. Historical use of mercury amalgamation in gold and silver mining

Mercury "wets" and adheres to metallic gold and silver, forming pasty amalgams. This property has been optimized into a reliable technique for concentrating and extracting gold and silver from low-grade ores. Used worldwide up to the beginning of the present century, this "technology" faced a decline to near cessation due to exhaustion of silver reserves in Colonial South and Central America and later to the invention of cyanidation (Rose, 1915). Recently however, a confluence of economic and social situations, mostly in developing countries located in the tropics, has resulted in a new rush for gold by individual miners, for whom Hg amalgamation is a cheap, reliable and portable operation.

The use of Hg in the mining industry to amalgamate and concentrate precious metals probably dates back to the phoenicians and carthaginians, who commercialized Hg from Almadén mines in Spain as early as 2,700 BC. Pliny, in his Natural History, provided the first detailed description of the amalgamation process as a common gold and silver mining technique near the beginning of the present era. This technology however, entered into widespread use first by the Romans around the year 50 AD (Mellor, 1952). These descriptions, dating back nearly 2,100 yr, show extreme similarities with the procedures presently being in use in many gold mining areas in the world.

Prospecting for cinnabar deposits was strongly supported in the New World by the Spanish Colonial government. With the development of the "Patio" amalgamation process by Bartolomeu de Medina in 1554 in Spanish Mexico, and its later introduction in the silver mines of Peru and Bolivia, Hg amalgamation reached its apogee (Nriagu, 1993; 1994). In 1870 over 70% of Mexican silver was produced through this technology. In the Potosi mines
between 1545 and 1803, over 25,000 t of silver were produced through Hg amalgamation. At the peak of the mining operations the town had over 6,000 small silver smelting furnaces and Hg intoxication was common (Brüseke, 1993; Galeano, 1981). The "Patio" process consisted of spreading silver and gold powdered ore over large, paved flat surfaces and mixing it with salt brine and a mixture of Cu and Fe pyrites and elemental Hg. Workmen blended the mixture with hoes and rakes and let it react for days to weeks, depending on the weather, for amalgamation. After removing the amalgam, Au, Ag and Hg were recovered through roasting (Rose, 1915; Mellor, 1952; Brading and Cross, 1972; Fisher, 1977; Nriagu, 1994).

Estimates of the Hg release to the environment during this period is possible due to the similarity of the mining process used in Colonial America with the present day procedures in use in many countries. Therefore, emission factors can be calculated. Fisher (1977) calculated emission factors for the Spanish "Patio" process as \( \text{circa} \ 1.0 \ \text{kg of Hg.kg}^{-1} \) of metal produced. The production was carefully noted by Spanish mine captains. Therefore fairly reliable estimates can be derived. These estimates of Hg utilization and consequent release into the environment for the extraction of silver and gold in Central and Northern South America during colonial times were calculated by Nriagu (1993) and reach 196,000 t of Hg released into the environment between 1570 and 1900. This is in accordance with Hg production figures from the Almadén and Huancavelica mines, two major sources of Hg for silver production in Spanish America (Brading and Cross, 1972).

During the late 1800's, North America and Australia each experienced a "gold rush" and the Hg problems associated with it. Large amounts of Hg were used in California, Nevada and South Dakota and later in Canada. Estimated total Hg emissions to the environment from the America gold rush reached nearly 60,000 tons. (Nriagu, 1994; Bloom & Porcella, 1994). Much of this Hg remains in mine tailings today. Tailings built in as early as 1840, with up to 500 mg.g\(^{-1}\) of Hg are still present in Nova Scotia, Canada (Lane et al., 1988). In the Carson River area over 100,000 t of tailings containing Hg with concentrations up to 4,900 μg.g\(^{-1}\) are being continuously reworked along the Carson River Valley, Nevada, potentially mobilizing over 7,000 t of Hg (Lechler, 1993). In the South Mountains gold fields, North Carolina, fluvial sediments downstream of an old Au refinery built in 1830, and closed 30 yr after, still have anomalous high, up to 7.4 μg.g\(^{-1}\), Hg concentrations, even after 100 yr. High Hg concentrations (up to 4.9 μg.g\(^{-1}\)) in moss samples collected in that area, suggest that the old tailings in that drainage are still a significant source of Hg to the local environment (Callaham et al., 1994). At the Bendigo field, one of the largest in Victoria, Australia, up to 900 t of Hg are estimated to have been lost to the environment between 1850 and 1930, while in another site along the Lerderderg River, nearly 5 t.yr\(^{-1}\) of Hg were lost during this period (Bycroft et al., 1982).

After this first "gold rush" which ended by the early 1900's, Hg was still used in gold and silver mining in North America (8 t.yr\(^{-1}\)) up to the 1950's (USGS, 1968) as well as in Nova Scotia, Canada (Lane et al., 1978) and in Walles, UK up to 1916 (Fuge et al., 1992). An Environmental Protection Agency sampling carried out in 1970, of a mining company which has operated since 1880 at South Dakota, showed that it was still discharging from 5.5 to 18.0 kg of Hg daily into the Whitewood Creek and Cheyenne River system (EPA, 1971). In North
Carolina, "weekend panners" are still a significant source of Hg used in gold mining (Callaham *et al.*, 1994).

**TABLE I**

Estimates of past mercury annual (t. yr\(^{-1}\)) and total emissions to the environment through gold and silver production. Estimates are amounts of Hg cited in original papers or calculated using an emission factor of 1.5 when only gold or silver production figures were given.

<table>
<thead>
<tr>
<th>Site</th>
<th>Period</th>
<th>Annual input</th>
<th>Total</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roman Empire</td>
<td>since 50 AD</td>
<td>?</td>
<td>?</td>
<td>Mellor (1952)</td>
</tr>
<tr>
<td>Spanish America</td>
<td>1554-1880</td>
<td>292-1.085</td>
<td>196,000</td>
<td>Nriagu (1993)</td>
</tr>
<tr>
<td>Carson River, USA</td>
<td>1850-1900</td>
<td>200</td>
<td>7,000</td>
<td>Leder (1993)</td>
</tr>
<tr>
<td>California, USA</td>
<td>1840-1900</td>
<td>17</td>
<td>1,000</td>
<td>D’Itri and D’Itri (1977)</td>
</tr>
<tr>
<td>California, USA</td>
<td>1900-1950</td>
<td>8</td>
<td>400</td>
<td>USGS (1968)</td>
</tr>
<tr>
<td>South Dakota, USA</td>
<td>1880-1970</td>
<td>2-7</td>
<td>380</td>
<td>Walter <em>et al.</em> (1973)</td>
</tr>
<tr>
<td>All North America</td>
<td>1840-1900</td>
<td>1,000</td>
<td>60,000</td>
<td>Nriagu (1994)</td>
</tr>
<tr>
<td>Bendigo, Australia</td>
<td>1850-1930</td>
<td>11</td>
<td>900</td>
<td>Bycroft <em>et al.</em> (1982)</td>
</tr>
<tr>
<td>Colonial Brazil</td>
<td>1800-1960</td>
<td>5</td>
<td>400</td>
<td>Lacerda (1996)</td>
</tr>
<tr>
<td>Wales, UK</td>
<td>1860-1916</td>
<td>0.1</td>
<td>6</td>
<td>Fuge <em>et al.</em>, (1992)</td>
</tr>
<tr>
<td>Vitoria Australia</td>
<td>1855-1930</td>
<td>5</td>
<td>400</td>
<td>Bycroft <em>et al.</em> (1982)</td>
</tr>
</tbody>
</table>
A tentative estimate of past Hg emissions to the environment (Table 1) may reach an astonishing amount of over 260,000 t over the last 400 yr. If the present figures from industrial Hg emissions are taken as an average for the last 50 years, which is probably an over-estimate, gold and silver mining had mobilized more than half of this amount to the biosphere.

The effects upon the environment of the release of such a large amount of Hg however, will be a function not only of the total discharge, but mostly on Hg dispersal mechanisms and patterns, its speciation in the different environments and on specific ecological conditions of the affected ecosystems. Since most of the past and present emissions took and take place in tropical environments, the complexity of their natural ecosystems render it difficult to evaluate its effects, but serious ecotoxicological damages are expected, as well as an increase in the global background of Hg concentrations, since most of the Hg emitted still resides in old gold mining fields were it can be remobilized (Bloom and Porcella, 1994).

3. Present day utilization of Hg amalgamation in mining

After the development of cyanidization for mining gold from low grade ore deposits, Hg amalgamation virtually disappeared as a significant mining technology until the 1970's. An impressive increase of gold prices, from U.S. $58.16 oz.tr in 1972 to U.S. $446.56 oz.tr in 1987, has triggered a second gold rush in many tropical countries, in particular in Latin America, Asia and more recently in Africa. In Brazil Hg amalgamation was responsible for the production of 5.9 t of gold in 1973. In 1988 this "technology" was responsible for the production of over 100 t of gold, mostly from the Amazon region and Central Brazil (Lacerda and Salomons, 1991). This gold rush has rapidly spread through other Amazonian countries including Venezuela, where many rivers of the northern portion of the Guyana Shield have been deforested by miners since 1980 (Nico and Taphorn, 1994). Other important but less studied sites are located at the Pando River Department, Bolivia (Zapata, 1994), French Guyana (Lucotte, 1994) and along the Puyango River at the Peru-Ecuador border, and in the gold fields of Nariño and Choco Provinces in Colombia (Lacerda et al., 1995; Priester, 1992).

In the Philippines, where gold prospecting operations similar to those of the Amazon region occur, Hg amalgamation is believed to have produced over 10 t of gold annually since 1985, employing over 800,000 people mostly in the Mindanao Island (Cramer, 1990; Torres, 1992). Smaller scale mines are also present in Indonesia, Thailand and Vietnam and still in Canada, Australia and USA.

After granting permission to form individual enterprises in China, over 200 small mines were opened in Dixing Province since 1992, increasing gold production by 10% per year (Yshuan pers. comm.). At least one large mine has been using Hg for gold production since 1938, in the Jia Pi Valley, Ji Lin Province, using the same techniques used in California in the 1800's (Ming, 1994). The same phenomenon has occurred in
Tanzania, where since 1991 over 150,000 people are prospecting gold in the Lake Victoria fields (Ikingura pers. comm.). At the peak of these activities in 1989, over 1 million people were believed to participate in gold prospecting in the Amazon region alone and probably over 10 million throughout the world (Lacerda et al., 1995). Mercury poisoning due to gold mining has been reported at least for three major areas, the Brazilian Amazon, the Dixing region in China, and the Philippines. Figure 1 provides a preliminary distribution map of past and present sites of Hg use in mining of gold and silver. Note that in certain areas, such as Russia, Hg amalgamation is probably in use but no data could be found on these operations.

4. Amalgamation mining techniques

Mercury is used to separate fine gold particles through amalgamation following a gravimetric pre-concentration step of the heavy fraction of river sediments, soil or crushed rock ore. After separating it from the ore the amalgam is roasted, generally in the open air, emitting Hg vapor to the atmosphere. During the amalgamation process a variable amount of metallic Hg is lost to rivers and soils through handling in rough field conditions and to the atmosphere through vaporization. Additionally, Hg-rich tailings are left in most mining sites. Details of procedures, instruments and processes used in gold and silver mining through Hg-amalgamation can be found in many publications (Priester, 1992; Lacerda and Salomons, 1991; Mallas and Benedicto, 1986; Rose, 1915; Wise, 1966; Mellor, 1952).

The mining techniques presently in use can be grouped in two categories occurring in different regions, although variations of such operations may take place in specific locations. The first involves the recovery of gold and silver from soils and rocks, with precious metals content ranging from 4.0 to 20.0 g.t\(^{-1}\). This consists of digging large amounts of metal-rich material, generally soils containing quartz, veins or sulfides, passing it through mills and centrifuges to produce a metal-rich gravidic concentrate. The concentrate is moved to small amalgamation ponds, a few square meters in area or to amalgamation drums, where it is mixed with liquid Hg and latter separated in round pans. Alternatively, the powdered ore is floated with water as pulp in a thin stream over slightly inclined Cu plates amalgamated with Hg. These amalgamation tables were firstly introduced in California in the 1850's and are still in use in many regions, such as in Colombia and northern Brazil (Priester, 1992).

Any residue of the concentrate is returned to the amalgamation pond and reworked till exhaustion of the gold. A significant amount of Hg is lost to the atmosphere during this process through vaporization (Pfeiffer and Lacerda, 1988; Farid et al., 1991). After an area is exhausted, tailings are left with spots of high Hg concentrations in the previous amalgamation ponds. In such spots, Hg concentrations can reach 30 to 80 \(\mu g.g^{-1}\) of dry tailing material (Bycroft et al., 1982; Lacerda et al., 1991), but frequently range from 1 to 5 \(\mu g.g^{-1}\). Extreme values ranging from 500 to 4,500 \(\mu g.g^{-1}\) have been
reported for old mine tailings in Canada and USA respectively (Lane et al. 1988; Lechler, 1993).

The second type of process is carried on in most Amazonian rivers. Gold is extracted from bottom sediments by dredging. The gold-bearing material passes through iron nets of different mesh sizes to remove large stones. Crushing mills are not used in the operation. The material is then passed through carpeted riffles which retain heavier particles. This operation lasts for 20 to 30 hours, then the dredging stops and the heavy fraction is collected in barrels for amalgamation, which is done by hand or by using mechanical stirrers. The amalgam is then separated in the same way described above. However, residues of the procedure are released into rivers. Vaporization of Hg and losses due to bad handling also occur (Lacerda et al., 1989). The amalgam is generally roasted in pans in the open air, thus releasing Hg directly to the atmosphere, and inhalation of significant amounts of Hg vapor may occur.

Regardless of the extraction process used, the resultant gold and silver still have a variable amount of Hg as an impurity - up to 7% in weight (Farid et al., 1991). Therefore, wherever gold is sold, re-burning is a common practice. The process is performed without or with very precarious exhaustion or filtering of air, resulting in serious contamination of workplaces and significant atmospheric input of Hg (Marins et al., 1991; Malm et al., 1990).

5. Mercury input to the environment from gold and silver mining

The release of Hg from amalgamation during gold and silver mining is of environmental significance, since this process is not efficient (Nriagu, 1993; Mallas and Benedicto, 1986). Estimates of the total amount of Hg released to the environment from these mining processes are difficult to obtain. Gold and silver on the other hand, are very precious metals and their quantities produced have been carefully noted even at Roman times. Therefore, if one knows the steps of the production and the Hg losses in each step, Emission Factors (EF’s) (the amount of Hg emitted to produce one kg of gold), one could estimate more accurately the amount of Hg released into the environment using production figures.

Estimates of EF’s have been published for many historical gold mining sites. Fisher (1977) has estimated EF’s of approximately 1.5 for silver production in Spanish mines in colonial America. These EF’s could have ranged from 0.85, for silver-poor ores, to 4.1 for very rich ones (Nriagu, 1993). Wise (1966) reported similar values for XIX century mines in Victoria, Australia and Mellor (1952) assumed emission factors higher than 2.0 for this technique.

The first EF’s published on the new gold rush were based on observations done by Mallas and Benedicto (1986) in Pará State, NE Amazon, where gold is extracted from soil. They reported EF’s ranging from 2.0 to 4.0 kg of Hg for 1.0 kg of Au produced. However these first estimates were based only on interviews with miners and field observations. Pfeiffer and Lacerda (1988), studying mining sites in the Madeira River.
ESTIMATES OF PRESENT DAY ANNUAL (t yr\(^{-1}\)) AND TOTAL (t) EMISSIONS OF Hg TO THE ENVIRONMENT FROM GOLD MINING SITES. Emissions are amounts of Hg cited in original references or calculated using an emission factor of 1.5, when only the gold production was given.

<table>
<thead>
<tr>
<th>Site</th>
<th>Period</th>
<th>Input t yr(^{-1})</th>
<th>Total</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amazon, Brazil</td>
<td>since 1979</td>
<td>180</td>
<td>3,000</td>
<td>Pfeiffer and Lacerda (1988)</td>
</tr>
<tr>
<td>Southern, Brazil</td>
<td>since 1985</td>
<td>1</td>
<td>10</td>
<td>Lacerda and Salomons (1991)</td>
</tr>
<tr>
<td>Puyango River, Peru</td>
<td>since 1987</td>
<td>3</td>
<td>24</td>
<td>Lacerda and Salomons (1991)</td>
</tr>
<tr>
<td>North Sulavesi, Indonesia</td>
<td>since 1988</td>
<td>15</td>
<td>120</td>
<td>James (1994)</td>
</tr>
<tr>
<td>USA</td>
<td>since 1969</td>
<td>6</td>
<td>150</td>
<td>USGS (1970)</td>
</tr>
<tr>
<td>Canada</td>
<td>since 1976</td>
<td>1</td>
<td>14</td>
<td>Hocking (1979)</td>
</tr>
<tr>
<td>Choco region, Colombia</td>
<td>since 1987</td>
<td>30</td>
<td>240</td>
<td>CODECHOCO (1991)</td>
</tr>
<tr>
<td>Narino, Colombia</td>
<td>since 1987</td>
<td>1</td>
<td>8</td>
<td>Priester (1992)</td>
</tr>
<tr>
<td>Victoria Fields, Tanzania</td>
<td>since 1991</td>
<td>6</td>
<td>24</td>
<td>Ikingura (1994)</td>
</tr>
<tr>
<td>Pando Department, Bolivia</td>
<td>since 1979</td>
<td>20</td>
<td>300</td>
<td>Zapata (1994)</td>
</tr>
<tr>
<td>Jia pi Valley, China</td>
<td>since 1938</td>
<td>2</td>
<td>116</td>
<td>Ming (1994)</td>
</tr>
<tr>
<td>Dixing region, China</td>
<td>since 1992</td>
<td>120</td>
<td>480</td>
<td>Yshuan (1994)</td>
</tr>
<tr>
<td>Guayana Shield, Venezuela</td>
<td>since 1989</td>
<td>45</td>
<td>360</td>
<td>Nico and Taphorn (1994)</td>
</tr>
</tbody>
</table>
Rondonia, the largest tributary of the Amazon River, where gold is mined from active river sediments, found an average EF of 1.3. In a large survey of 800 mining sites in central Brazil, an EF of 1.7 was calculated by actually determining the Hg balance throughout the entire gold production process (Lacerda and Salomons, 1991). Farid et al. (1991) measured Hg EF's in six mining sites in Northern Mato Grosso State, Central Brazil. They found EF's ranging from 0.1, where closed amalgamation systems that use retorts for roasting amalgam recovers most of the Hg used, to 1.1, where such devices were not in use. Other EF's were calculated for Philippines mines (1.5), Peru (2.0) and Colombia (1.7) (Lacerda and Salomons, 1991). Notwithstanding the variability of the reported EF's, they mostly fall between 1.0 and 2.0. In addition, all studies agree that Hg EF's to the atmosphere are much higher than those to rivers and soils, accounting for 65 to 87% of total emissions (Pfeiffer and Lacerda, 1988; Farid et al., 1991).

Estimates of the present day emissions of Hg from amalgamation mining are listed in Table II. Major impacts are from the Brazilian Amazon, followed by China, where over 200 small gold mining operations were settled and 120 t yr\(^{\text{1}}\) of Hg are being released into the environment (Ming, 1994; Yshuam, 1994). Also of importance are the Guayana Shield region, Venezuela (40-50 t yr\(^{\text{1}}\)) (Nico and Taphorn, 1994), the Pando Department, Bolivia (up to 30 t yr\(^{\text{1}}\)) (Zapata, 1994), the Mindanao region in the Philippines with roughly 26 t yr\(^{\text{1}}\) (Torres, 1992; Cramer, 1990), and the Choco Department, Colombia, where 47 semi-industrial mines emit nearly 30 t yr\(^{\text{1}}\) of Hg into the environment.

Many other small mines in USA and Canada are still emitting Hg to the environment. Also, in Africa and Southeast Asia, this environmental problem is very poorly documented, and the data from these areas in Table II are probably an underestimation. Finally, small-scale gold mining activity tends to be mobile, occupying certain areas only when gold extraction through this technique is economically feasible. This mobility also makes the estimation of Hg emissions a difficult task.

The annual input of Hg through gold mining may reach up to 460 t, calculated from the data in Table II. From this total approximately 300 t go to the atmosphere. Another 160 t go to soils and and waters, in particular left as contaminated tailings, from where Hg can be eventually remobilized.

The total Hg emission from gold mining reaches nearly 50% of the total Hg input into the biosphere mobilized by natural weathering and over twice as high as the inputs from Hg mining itself. Also, these figures are equal to 10% of the total Hg inputs from all other anthropogenic sources to the biosphere, using the most recent figures from Porcella et al., (1996). Since industrial inputs of Hg are being more effectively controlled and gold mining using Hg amalgamation is probably going to spread throughout the world in the near future, this percentage is likely to increase. Assuming these annual emissions relatively constant throughout the last decade, gold mining may have resulted in a total release of c.a. 5,000 t of Hg into the environment. Again, the lack of detailed documentation on gold mining through Hg amalgamation in many parts of the developing world, suggest that this total amount may be underestimated (Lacerda et al., 1995).
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