The Source and Distribution of Mercury in the Tapajós River Basin – The Importance of Suspended Sediments from Alluvial Gold Mining, Pará, Brazilian Amazon

Kevin Telmer[1], Maycira Costa[2], Eric S. Araujo[3], Rômulo Simões Angélica[4] and Yvon Maurice[5]
[1]School of Earth and Ocean Sciences (SEOS), University of Victoria, Victoria, BC, Canada
[2]Instituto Nacional de Pesquisa Espacial (INPE) – Brazilian Institute for Space Research, São Jose dos Campos, SP, Brasil
[3]Companhia de Pesquisas e Recursos Minerais (CPRM) – Geological Survey of Brazil, Goiánia, Goias, Brasil
[4]Departmento de Geochimica e Petrologia, Centro de Geociências - Universidade Federal do Pará (UFPA), Belém, Pará, Brasil
[5]Geological Survey of Canada (GSC), 601 Booth St., Ottawa, Ontario, K1A 0E8, Canada

Abstract

Dissolved mercury concentrations in waters draining mining operations in the Reserva Garimpeira do Tapajós are elevated when compared to concentrations in pristine rivers and the Tapajós River. However, essentially all dissolved mercury concentrations fall below 0.1 ppb. Mercury bound to suspended sediment is roughly 600 and 200 times the concentration of dissolved mercury per litre of water in impacted areas and pristine areas, respectively, and thus represents the major pathway of river-borne mercury. Median concentrations of Hg in suspended load from both impacted and pristine waters are 145 ppb and 80% of samples are below 300ppb - in the range of naturally occurring surficial materials world-wide. Aqueous Hg fluxes are proportional to the concentration of total suspended solids suggesting that the source of mercury is the sediment itself and not mercury discharge from garimpos. The calculated annual export of mercury from the Crepori River is 4 tonnes. This mass is difficult to account for by garimpo discharge alone suggesting that the regional riverine mercury problem (levels hundreds of times background) is dominantly caused by the enhanced physical erosion of garimpo sluicing and dredging operations and not by direct mercury discharge. This has major implications for remediation and prevention. Simply halting the use of mercury is surely a step in the right direction but regional mercury pollution will only be reduced when the dredging is stopped or contained. Mining induced sediment plumes have been contaminating the Tapajós River system for 20 years and therefore in-basin storage of historical mining emissions of fine sediment must also be considered in any Hg source apportioning theories.

Hg and Gold Mining in Brazil

Apart from being one of the most prominent of the Amazon's tributaries, the Tapajós River Basin (Figure 1) is perhaps better known for being the focal point for Brazil's modern goldrush. Since the 1950s, the Tapajós River Basin has been mined for placer (river sediment) gold. Through the 1960s, gold mining activity increased with the discovery of the rich ores in the tributary Marupa. A combination of events in the 1970s then led to the modern gold rush. First, the federal government attempted to tame the Amazon with an ambitious infrastructure program which built the 3000 km long Transamazonica. This provided transportation routes for heavy equipment and access to previously remote regions of the Amazon. Next, the price of gold skyrocketed to over $800 U.S. an ounce. At the same time, drought struck Brazil's most impoverished region - the Northeast - driving thousands of poor farmers into the Amazon in search of a basic livelihood. These farmers turned gold miners, are known as *garimpeiros*. After the price of gold skyrocketed, 100,000 garimpeiros were working the Marupa and Crepori Rivers. The boom town of Creporizão arose at the junction of these two rivers while Itaituba on the banks of the Tapajós River became the gold shop capital of the Amazon. During these high times, rumours abounded of extraction rates by single workers of up to 2 kg gold per day.

When the price of gold peaked at $800 an ounce in 1978, so too did mining activity. During this era, 90 tonnes of gold were extracted from the infamous Sera Pelada deposit. Exploited by 80,000 garimpeiros, it had the appearance of a human ant hill. Social turmoil and tax evasion prompted the government to attempt to establish a system of regulation, but this failed primarily because garimpos - the small scale gold mines - were still constitutionally illegal.

The antiquated constitution gave farmers ownership of the land surface, but the subsurface remained the exclusive property of the government. Realizing these conditions were futile, in 1988 the government implemented constitutional changes that allowed garimpeiros to legally operate garimpos for the first time. Consequently, the Reserva Garimpeira in the Tapajós basin and nine other regions in the legal Amazon were established in order to protect garimpeiros' land holdings from claim-staking by mining companies. This stabilized the relationship between the garimpeiros and the government, an essential first step in fostering collaboration on addressing environmental and social problems associated with garimpo style mining, namely river siltation and toxic mercury pollution.

Mercury (Hg) based extraction techniques are very commonly used by garimpeiros to extract the very fine gold particles found in the paleo-river sediments and consequently, the potential of toxic Hg pollution and accumulation in the food chain has become a serious concern.

Study Area

The Tapajós River Basin (Figure 1) resides entirely within the southern Amazon Basin in Brazil. With a mean discharge of 7,200 m^3/s (Gleick, 1993) and a drainage area of 520,000 km^2 (determined by GIS) it is one of the larger tributaries of the Amazon River. The Crepori River is a medium sized tributary of the Tapajós River with a drainage area of roughly 50,000 km^2 (determined by GIS) and a mean discharge of 700 m^3/s (minimal estimate using the area/discharge relationship for the Tapajós Basin). The Crepori River begins in pristine uplands in the central Tapajós basin, flows north bisecting the area of garimpo activity known as Creporizão and then continues on to conflue with the Tapajós River some 250 km south of Itaituba, the largest town on the Tapajós River and the centre for the Amazon's gold economy.

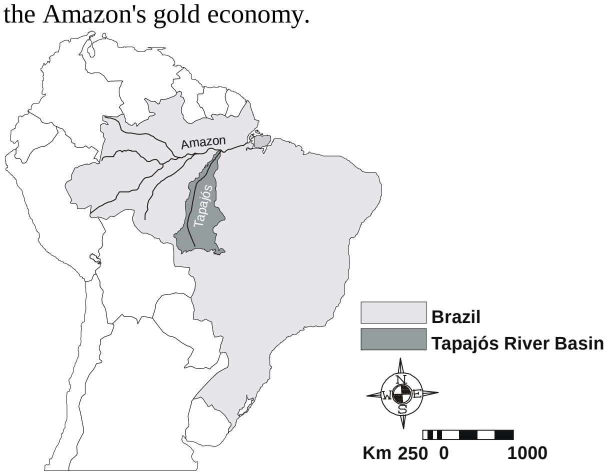

Figure 1: The Tapajós River Basin.

Method

Water samples from the Reserva Garimpeira do Tapajós, the Tapajós River and Pristine Streams were taken along the length of rivers and from the mouths of their major tributaries at as close to one instant in time as possible - in this case 2 weeks - twice, once during low water stand in October 1997 and during high water stand in May of 1998. 51 samples were collected per campaign, not including duplicates, 29 from a 1:50,000 area surrounding the garimpeiro community of Creporizão and 21 from a larger 1:250,000 scale area also centred around Creporizão. This strategy was adotpted to capture both detailed (impacted) and regional scale (background) geochemistry.

All samples are filtered to separate the dissolved from suspended load and are then treated and stored at 4°C (in iced coolers in the field) for chemical analyses. Water for the determination of Hg is processed immediately to avoid any Hg loss by volatolization. Water is filtered by syringe pressure and preserved with BrCl to stabilize and oxidize all Hg species to Hg^{2+}. The cellulose membranes from the cation aliquots and the residues are retained and collected in small polyethylene vials for the determination of total suspended solids. Further details on sampling methodology can be found in Telmer and Veizer (1999) and Telmer (1997).

Disolved Hg is subsequently analysed by hydride generation and ICP-MS or by Cold Vapor Atomic Fluorescence Spectrophotometry for very low concentration samples. For the suspended load, a fixed volume of sample is pushed through 47mm pre-ignited glass fibre membrane. The membrane and its load are then analysed for Hg directly by ignition on a Milestone AMA 254 Mercury Analyser. An evaluation of Hg analyses capability using the Milestone AMA 254 can be found in Hall and Pelchat (1997).

Discussion

Dissolved mercury concentrations are elevated in waters affected by mining operations when compared to concentrations in pristine rivers (Figure 2). However, essentially all dissolved mercury concentrations fall below the commonly used aquatic life limit of 0.1 ppb. Mercury bound to suspended sediment tells another story. Particulate Hg fluxes average 600 and 200 times the those of dissolved mercury in impacted and pristine waters, respectively, and thus, particulate bound Hg represents the major pathway of river-borne mercury (Figure 2). Total Hg fluxes in impacted waters average 15 times greater than those of pristine waters (Figure 2) but can be up to 100 times greater indicating that mining has a profound impact on transport rates of riverine Hg. However, Hg fluxes are proportional to the concentration of total suspended solids, and the histogram of Hg concentration in total suspended solids (Figure 3) shows that the majority of samples, regardless of source, either impacted or pristine, have a consistent concentration of Hg suggesting that the source of mercury is the sediment itself and not mercury discharge from Garimpos. This observation is further supported by observed Hg concentrations of 50 to 300 ppb in regional laterite profiles - this is not unusual and falls within the normal range of surficial materials world-wide.

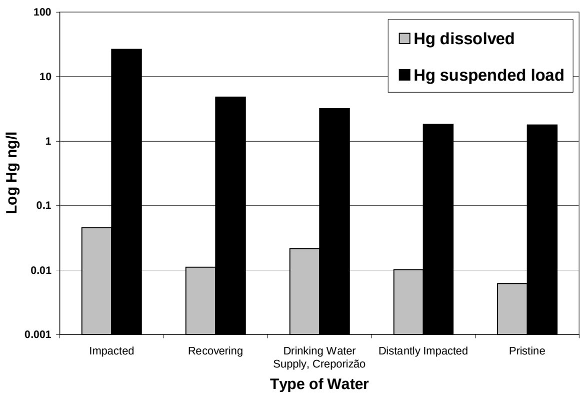

Figure 2: Burdens of Hg per litre of water in the dissolved and suspended load of water (a) directly impacted by gold mining operations; (b) recovering from direct impact; (c) for drinking in Creporizão; (d) distantly impacted by upstream tributaries (e) not impacted – pristine.

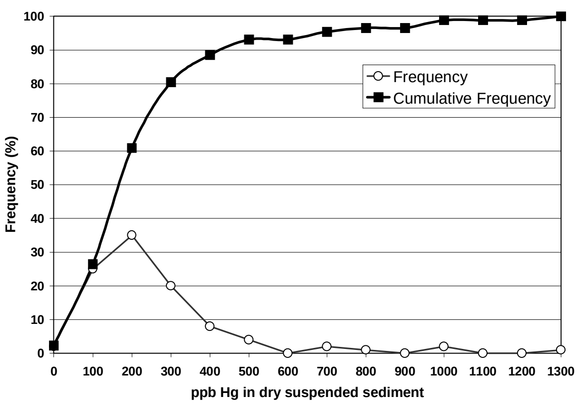

Figure 3: Frequency diagram (histogram) of the concentration of Hg in dry suspended sediment of all waters sampled in this study - 87 samples.

Roulet et al. (1998) have correctly identified burdens of riverine Hg to be controlled dominantly by particulate matter but they are incorrect in their assertion that the Hg content of Tapajós waters is independent from upstream gold mining activities. On the contrary, gold mining activities are the greatest source of particulate matter to the Tapajós system. Landuse changes such as deforestation may be an important secondary source of particulate matter to the Tapajós river, particularly during the wet season, but as illustrated by satellite imagery (Figure 4), the suspended sediment emitting from the Rio Creporí into the Tapajós River (TSS concentrations of 400-600 mg/l) is the dominant source. Background TSS concentrations in the Tapajós waters upstream of the Creporí plume are ~7 mg/l. This scenario exists for other smaller tributaries and also on a large scale in the Alta Floresta area in the upper Tapajós basin. Further these mining induced sediment plumes have been contaminating the Tapajós system for 20 years and so in basin storage of historical mining emissions of fine sediment must also be considered in any Hg source apportioning theories.

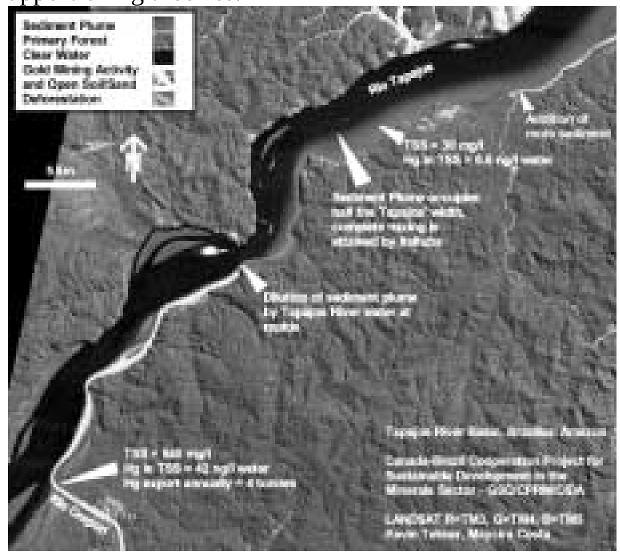

Figure 4: Landsat TM image enhanced to show the Creporí river discharging its enormous mining-induced sediment load into the Tapajós River.

Presently, Hg released by garimpeiros is almost exclusively atmospheric as mercury is no longer used directly in sluice boxes. Although a portion of the Hg released to the atmosphere may find its way back into the river, the calculated annual export of mercury from the Creporí River, 4 tonnes, is difficult to account for by Garimpo discharge alone. This is not to say that direct discharge of mercury is insignificant. Analyses of river sediments shows localized hot spots of contamination. But the regional problem - riverine mercury at 100 times background levels is dominantly caused by the enhanced physical erosion of garimpo sluicing and dredging operations than by direct mercury discharge. This has major implications for remediation and prevention. Simply halting the use of mercury is surely a step in the right direction but regional mercury pollution will only be reduced when the dredging is stopped or contained.

As desirable as it may seem, Garimpo operations cannot simply be stopped. They directly employ almost half a million people in the Amazon and countless others indirectly. The large majority of garimpeiros are subsistence workers, just scraping by from pay-day to pay-day. They have no savings and they have no other skill. Brazil has no social safety net and the capacity of retraining programs are insufficient. Many who do quit end up in the favelas of the large Amazonian cities of Manaus or Belém, where it is difficult to escape social marginalization.

Farming is a viable option for some garimpeiros as many came from farms in northeast Brazil. But the same land ownership and unfair profit sharing problems exist in Amazonia as those they initially escaped from. Rich landowners, poor labourers. As well, the fruits of labour on the farm are slow and predictable. The attraction of getting rich quick, even if it never happens on the garimpo, does not exist at all on the farm. For many, farming is resigning oneself to a life of poverty and labour.

Better technology and improved use of existing technology could reduce the ecological impact of garimpos. Presently, garimpos lose roughly 50% of their gold due to poor sluicing practices and because fine gold is trapped inside other minerals. Gravity concentrators, sluice operation education, and milling of the ore can increase the yield but unfortunately do not reduce river siltation nor necessarily the use of mercury. Some of these technologies are in practice in Brazil but due to investment costs, field logistics and ignorance, their use is not widespread. Containment ponds could hugely reduce river siltation and therefore mercury contamination at the same time. Plankton would flourish in clear flowing rivers which could again feed a thriving fishery. However, containment represents a lot of additional labour and planning but produces no additional gold. Given the cost/benefit analyses of simple containment it is doubtful such an approach would be embraced.

If containment were combined with technologies which yielded more gold, such as cyanide heap leaching, it might sound attractive but it may not be viewed as practical as it requires much greater initial investment, a higher level of expertise to operate, and a more organized labour pool; rarities in garimpeiro culture. Distrust of authority, rugged individualism, frontiersmanship and ignorance work against the implementation of more organized labour and more sophisticated technology. As well, use of cyanide has its own serious environmental hazards and although its impacts are more observable and localized than those of Hg, they are still unacceptably risky in remote and unregulated areas.

And so without practical intervention from government, it is likely that garimpeiros will continue to practice inefficient and very destructive but simple and attainable mercury amalgamation methods. Perhaps basic education and health care are good first steps in changing the legacy of the gold rush from one of ignorance and destruction into something more sustainable.

References

Gleick P.H. (1993) Water in Crisis, A Guide to the World's Fresh Water Resources. New York, Oxford University Press.

Hall, G.E.M. and Pelchat, P. (1997) Evaluation of a direct solid sampling atomic absorption spectrometer for the trace determination of mercury in geological samples. *The Analyst*, **122**, 921-924.

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., De Jesus da Silva, E., Mergler, D., and Amorim, M. (1998) Distribution and partition of total mercury in waters of the Tapajós River Basin, Brazilian Amazon. *The Science of the Total Environment*, **213**, 203-211.

Telmer K. and Veizer J. (in press, accepted Sept. 2, 1999) Isotopic constraints on the transpiration, evaporation, energy and GPP budgets of a large boreal watershed: Ottawa River basin, Canada. *Global Biogeochemical Cycles*.

Telmer, K. and Veizer, J. (1999) Carbon fluxes, pCO_2 and substrate weathering in a large northern river basin, Canada: carbon isotope perspectives, *Chemical Geology*, **159**, 61-86.

Telmer K., Taylor C., Maurice Y. (1999) Gold Mining in the Amazon, Investigating the Mercury Problem. *Video Documentary*, 33 minutes, GSC open file (# pending).