# IMPLEMENTING PROGRAMS TO IMPROVE GOLD RECOVERY AND REDUCE ENVIRONMENTAL IMPACTS BY ARTISANAL GOLD MINING IN BRAZIL

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## ABSTRACT

Artisanal and small-scale gold mining (ASM) is the largest source of mercury release into the environment from intentional use sources. One of the largest sites is located in the Tapajos River Basin region, in the Brazilian Amazon.

In 2002 GEF/UNDP/UNIDO (United Nations Industrial Development Organization) implemented the GMP (Global Mercury Project) in Brazil, aiming at the reduction of mercury emissions through the introduction of simple technologies, as well as the implementation of health and environmental awareness.

The program trained 4,200 miners in 115 mining sites in Brazil. The main highlights are the improvement of gold concentration by the use of "zig-zag" sluice boxes with better carpets, demonstration of closed-circuit amalgamation conducted in excavated lined pools, introduction of an electrolytic mercury activation process, introduction home-made retorts, refilling of old pits with tailings as a step to reclaim degraded areas. The original survey has shown 64.6% of miners in selected areas refilling old pits, 58.3% retaining sediments, 12.5% recycling mercury, 35.4% conducting amalgamation in lined pools, 43.8% using latrines, 20.8% drinking filtered water and 43.8% collecting their garbage. These numbers escalated to 100.0, 91.7, 91.7, 75.0, 100.0, 81.3 and 100.0% respectively, 90 days after the GMP training program and awareness campaign.

## INTRODUCTION

Artisanal small scale gold mining (ASM) releases into the environment over 1,000 tonnes of Hg/a. This is the largest anthropogenic source of mercury release in the world. According to UNIDO (United Nations for the Industrial Development Organization) about 100 million people are directly or indirectly involved in the ASM worldwide and 10% of this population live the Amazon. In Brazil ASM is locally known as "garimpo", and produces 30 tonnes of gold a year (DNPM, 2006), 8 tonnes in the Tapajos river basin region (DNPM, 2006). This process consumes around 40 tonnes of mercury, and part of it is lost to the environment. ASM also causes siltation of the rivers (sediments in suspension) and flora and fauna destruction.

In 2002 Brazil was chosen for the implementation of an UNIDO initiative titled GMP (Global Mercury Project). This project aims at the reduction of mercury emission through the introduction of simple technologies, education campaigns and environmental awareness. The selected location in Brazil was the Tapajos river basin, where 40,000 miners work in the extraction of alluvial and primary gold.

The implementation of the GMP (Global Mercury Project) in 2002 represented a significant contribution to mitigate the impacts resulting in uncontrolled small scale gold mining. Since then, GMP has demonstrated ways of overcoming barriers to the adoption of consistent cleaner mining practices, which include correct garbage disposal practices, measures to prevent mercury pollution, protection of water streams, protection of miners' health, and introduction of techniques to increase gold recovery rates consequently increasing miners' revenue. The results reached in Brazil are significant, and the partnership between GMP and local government agencies has been proven to be a solid mechanism to implement such programs.

Site location: Tapajos river basin – Itaituba – Brazil

It is known that the Tapajos region in Brazil is the largest artisanal gold mining region in the world. There are more than 2,000 mine sites and 432 landing strips in the 98,000 $km^2$ (SEMMA - Itaituba Environmental Agency) of the Tapajos basin and its sub-basins. The GMP has selected and evaluated pilot sites of artisanal gold mining in the Tapajos region (including Creporizão, Creporizinho and São Chico) to implement the activities of environmental and health assessment and technology demonstration to gold miners.

Objectives of GMP

Overall, the ultimate goals of the GMP are (1) to reduce mercury pollution caused by artisanal miners, thereby protecting human health and local water bodies; (2) to introduce cleaner technologies for gold extraction and develop mechanisms to allow this technology to be supplied locally; and (3) to train local miners and develop community awareness about all environmental impacts derived from artisanal mining. Besides the environmental issues, this program also aims to train miners in procedures related to the formalization / legalization of their activities and "good practices" to improve their health and quality of life.

The use of mercury in the artisanal small-scale gold mining sector (ASM)

Around 70% of the mercury used by ASM is lost in the aquatic system, and one of the main reasons for this loss is the use of the copper plates for amalgamation of the whole ore. Around 20 to 30% of the mercury is lost to the atmosphere and measurements made in the local area have proved the contamination of miners, their families and the neighboring communities (Veiga & Baker, 2004)

The amalgamation of the whole ore using copper plates is responsible for the largest mercury loss in the mines. Around 2 to 3 times more mercury is lost when the whole ore is amalgamated, compared to only a small portion of concentrate that is amalgamated in the sluice boxes or centrifuges (Veiga et al., 2006). The contaminated tailings with 50 to 200 ppm Hg that leave the cooper plates go into the water streams and are subject to the oxidation and methylation of mercury, which can be transformed in a more poisonous form, methylmercury. This is why in addition to developing environmental awareness it is crucial to work towards the elimination of practices such as the amalgamation of the whole ore, instead of

only the concentrate. Simple and effective orientations aiming at these goals are part of the GMP training programs.

Some miners use mercury contaminated tailings to remove part of the residual gold by cyanidation. The sodium cyanide dissolves not only gold but also mercury, forming mercury cyanide, which is either more bio-available to be methylated than metallic mercury. This fact has been identified in different locations worldwide including Brazil, where GMP has already found in Tapajos levels of Hg in fish as high as 22 ppm, whereas the permissible maximum level for human consumption is 0.5 ppm total Hg (UNIDO, 2006).

The roasting of amalgam in open air pots is another critical health problem faced by the miners, their families and community around the mines. Mercury vapors are inhaled by the miners and accumulate in their kidneys and brains. Several miners and community members of Tapajos showed neurological symptoms of mercury intoxication from exposure to vapor. The use of retorts can substantially reduce the emission of Hg to the atmosphere as well as occupational exposure. It is unknown how far the mercury vapor can travel, however the use of low-cost retorts can reduce more than 95% of mercury vapor.

## METHOD AND RESULTS

Diagnostical phase – Environmental and health assessment

In order to address the problems and solutions for mercury pollution, a series of studies were implemented to evaluate the seriousness of mercury contamination as well to establish the magnitude of the problems. A social economic study was conducted in July 2003 to analyze the history, the characteristics and dynamics of the selected mining communities. A legal study was also conducted aiming to identify the existing legal framework, mining regulation and other related activities. The environmental and health assessment provided a baseline to evaluate the degree of the mercury impact on the targeted communities.

The GMP team collected 658 samples from soils, sediments and water, and found out that in Sao Chico over 50,000m$^2$ of the area is covered with contaminated tailings averaging 5 m in depth. Samples 30cm deep in the mining sites have shown levels of Hg of 0.15b ppm, while surface background levels reached 0.8ppm, demonstrating the heavier use of Hg in the past 20 years. The mercury level in the tailings ranged from 4 to 300 ppm Hg, while the river sediments ranged from 7 to 14 ppm. About 234 fish samples were collected from 16 species, revealing levels of contamination in carnivorous fishes averaging 4.16+/-5.42ppm Hg, reaching a maximum of 21.9 ppm Hg in Sao Chico. In Creporizinho these numbers averaged 1.33+/-1.38 ppm Hg. Non-carnivorous fishes showed lower levels of contamination, averaged 0.50+/-0.41 Hg in Sao Chico and 0.32+/-0.30ppm Hg in Creporizinho. Mercury levels in the urine showed average of 9.3ppm and maximum of 78.5ppm in São Chico and average of 6.0 and maximum of 62.0ppm in Creporizinho (Rodrigues et al., 2004). This study showed the extremely high mercury levels in soils, sediments and fish, and this problem is exacerbated by the use of cyanidation of Hg-contaminated tailing. Considering that in the Tapajos river basin most mining communities employ the same technology for extracting gold as the villages used in the study, it can be assumed that equivalent levels of mercury

contamination can be found in different locations, thus justifying the choice of Tapajos river basin for the implementation of training programs and awareness campaigns.

The general working and living conditions at both mining sites Sao Chico and Creporizinho are very basic, and the incidence of malaria, parasitosis and other diseases are very high. The main source of contamination was mercury vapour inhalation during the amalgam burning process and the ingestion of contaminated fish. The results indicated the bioaccumulation in both miners and non-miners and linked this to the consumption of contaminated fish, and the high urine levels indicate exposure to Hg vapour.

Training program and awareness campaign

Concepts of ISO - Quality Management Systems (Tricker, 2000) were employed with the purpose to train miners and evaluate effectiveness. The strategic plan involved the capacity building and preparation of a team of trainers. These actions resulted in significant success in the mining community of Creporizão (base village for the artisanal mining activities in the region), where 60 people were trained and 13 trainers were selected for the first multiplication phase. The training was extended to 4,200 miners in 141 different mining locations in Tapajos river basin.

The training program included the following topics: how to increase the recovery of gold, how to recycle mercury, how to use retorts, impacts of the mercury on the health and environment, mercury in the gold shops, how to protect water, how to diversify the miners' economy, how to legalize a mining site (Mining permit and environmental license), tailings management, old pits refilling, pools for mercury amalgamation, use of latrines and mosquito nets, how to filter water, garbage disposal, and reforestation of degraded areas. Special booklets were developed with language tailored to the miners.

Besides the training program, awareness campaign and evaluation of sites, the program also involved the development of a pilot plant with hammer mill, ball mill and centrifuge which is used primarily to reprocess tailing for gold extraction.

Evaluation of effectiveness

The concept of Balanced Scorecard (Kaplan & Norton, 1996) was employed with the purpose to evaluate effectiveness. The success of the project cannot be measured simply by the number of miners attending the training program, but by how each trained individual incorporates the new practices in the daily mining activities. To evaluate this change of behavior a record of evaluation of each mine was developed to be used before the training and 90 days after the training. The overall improvement shown through successive evaluations is one of the best indicators of the results of the training program. However, several others indicators were established, such as: number of multipliers qualified, grades of the training evaluation, change of behavior shown through improvement of the grades between successive evaluations[1], number of miners trained, number of mines and communities involved, number of mines

[1] Evaluation form as per Table 1

raised to the condition of the model mine (overall grade above 70%), number of good practices[2] incorporated to the mine[3], number of promotional material materials[4] distributed, hours of awareness campaign in the local media, total of resources (including those "in kind") added to the budget by the other partners, and research of the miners' satisfaction with the actions of the program.

In order to have a successful case the GMP identified a mining site called "Garimpo Canaan", which was already adopting good environmental procedures. Having obtained the highest grade in the GMP evaluation criteria, this mining site (garimpo) has been used as a role model for others.

Indicators of results

Overall the training program has aimed at improving the main aspects regarding the following themes:

- Legalization of mining sites ("garimpos")
- Techniques and processes to increase gold recovery
- Protection of water and forest
- Minimization of the use of Hg
- Improve the miners' overall health and quality of life.

These indicators show the number of good practices implemented by the miners, as presented in Table 1.

[2] Equipments and processes
[3] For example: confinement of mercury in pool of amalgamation, use of retorts, etc
[4] T-shirts, caps, bags, booklets, posters

**Table 1: Degree of conformity per evaluated item, before and after the training**

| Theme of evaluation | N | Evaluated Item | % garimpos attaining requisites | | | |
|---|---|---|---|---|---|---|
| | | | Before training (total sites) | Before training (selected sites) | After training (selected sites) | Absolute improvement |
| Legalization of garimpo | 1 | Environmental License available | 0.7 | 2.1 | 2.1 | 0.0 |
| | 2 | Mining License available | 1.4 | 2.1 | 2.1 | 0.0 |
| | 3 | Receipt issued for gold sale | 13.4 | 18.8 | 33.3 | 14.6 |
| Gold Production | 4 | Use scientific method to find gold | 44.2 | 47.9 | 50.0 | 2.1 |
| | 5 | Right equipment and process available | 46.0 | 41.7 | 50.0 | 8.3 |
| | 6 | Equipment and process to recover fine gold | 46.7 | 47.9 | 50.0 | 2.1 |
| | 7 | Equipment maintenance and stock of supplies | 51.4 | 64.6 | 66.7 | 2.1 |
| Protection of water and forest | 8 | Refilling old pits | 40.6 | 64.6 | 100.0 | 35.4 |
| | 9 | Reforestation of degraded areas | 1.5 | 8.3 | 37.5 | 29.2 |
| | 10 | Quality of water / sediment containment | 35.1 | 58.3 | 91.7 | 33.3 |
| Use of Mercury | 11 | Mercury reactivation and recycling | 4.3 | 12.5 | 91.7 | 79.2 |
| | 12 | Mercury confinement (pool for amalgamation) | 10.9 | 35.4 | 75.0 | 39.6 |
| | 13 | Use retorts during burning process | 20.3 | 41.7 | 41.7 | 0.0 |
| | 14 | First steps towards mercury-free technology | 0.0 | 0.0 | 0.0 | 0.0 |
| Quality of life | 15 | Use of latrines | 26.8 | 43.8 | 100.0 | 56.3 |
| | 16 | Use of filtered drinking water | 17.0 | 20.8 | 81.3 | 60.4 |
| | 17 | Use of methods for prevention of malaria | 62.0 | 70.8 | 81.3 | 10.4 |
| | 18 | Exposure to risks / safety | 4.3 | 2.1 | 4.2 | 2.1 |
| | 19 | Garbage disposal | 16.3 | 43.8 | 100.0 | 56.3 |
| | 20 | Practices of awareness of miners | 0.7 | 8.0 | 10.4 | 2.4 |
| | | Mean | **22.2** | **31.8** | **53.4** | **21.7** |

**Note:** degree of conformity express the percentage of garimpos (mining sites) that comply with the requisites of the evaluation criteria

These results show that at least 7 good practices have had high impact in the field: refilling old pits / sluice boxes removed from the river (8), sediment containment (10), reactivation and recycling of mercury (11), mercury confinement / pool for amalgamation (12), construction and use of latrines (15), use of filtered water (16), garbage disposal (19).

Although the item reforestation of degraded areas (9) has showed substantial improvement, at this point it should not be considered yet as the scale is still not significant, e.g., although 29.2% of areas evaluated had initiated reforestation, they had planted a symbolic number of trees.

**Table 2: Degree of conformity per theme of evaluation, before and after the training**

| | Theme of evaluation | Degree of conformity (% garimpos) | | | |
|---|---|---|---|---|---|
| | | Before training (total sites) | Before training (selected sites) | After training (selected sites) | Absolute improvement |
| 1 | Legalization of garimpo | 5.2 | 7.6 | 12.5 | 4.9 |
| 2 | Gold Production | 47.1 | 50.5 | 54.2 | 3.6 |
| 3 | Protection of water and forest | 25.7 | 43.8 | 76.4 | 32.6 |
| 4 | Use of Mercury | 8.9 | 22.4 | 52.1 | 29.7 |
| 5 | Quality of life | 21.2 | 31.5 | 62.8 | 31.3 |
| | | **22.2** | **31.8** | **53.4** | **21.7** |

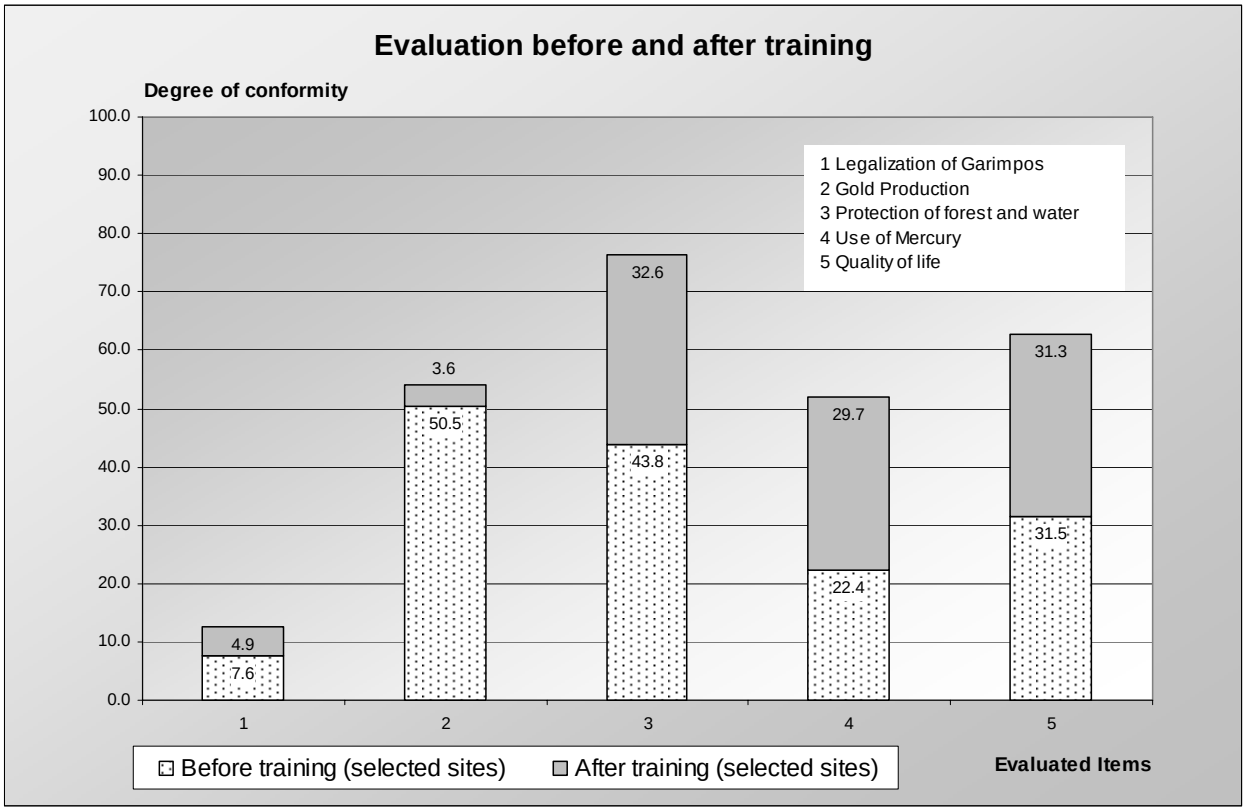


**Figure 1: Degree of conformity per theme of evaluation, before and after the training**

Based on the results showed on Table 2, the most successful themes were "protection of water and forest", "use of mercury" and "quality of life". The detailed items on Table 1 explain the major contributions for this success.

The themes "legalization of garimpos" and "gold production" were not as successful as others. Changes in behavior regarding the legalization of the areas are more difficult to be reached as the government presence in the region is not strong enough to provide mechanisms of registration and control. Thus, even when the miners take the initiative to legalize their mining sites, obtaining all necessary documents, the government bureaucracy and lack of resources do not facilitate field access for inspectors, and the licenses are not issued. It is difficult to encourage miners to step forward with their legal requirements when they

are aware that there is no real consequence for being illegal. The GMP has been working with the government, in order to propose methods to simplify the legalization process. Regarding gold production, it also requires some time and effort to disseminate good practices, and the results obtained by reprocessing tailings is the best argument to convince miners of the opportunities of using new techniques.

The achievements of GMP in Brazil were evaluated according to practical indicators of results in distinct phases:

Phase I: Diagnostical analyses and studies

- Socio-economic, health & environmental study in "São Chico" and "Creporizinho" communities. Main point: Mercury vapor exposure represents greater risk than fish consumption
- Micro-credit alternatives study: program not implemented due to the high level of informality. Main point: Necessary to work in partnership with Ministry of Mines in order to formalize the "garimpos"
- Study of environmental legislation for use of mercury. Main point: prohibition of Hg in garimpo has proven to be inefficient and must be combined with awareness and training of good practices for reactivation, recycling and replacement of mercury with alternative technologies.
- Mercury trade and routes. Main point: majority of mercury enters the country illegally or legally for other uses (such as dental)
- Study of environmental impacts versus environmental legislation in the Tapajós river basin. Main point: a strict environmental legislation was created in 1965 (Forest Code, law 4771); however, low effectiveness low due to the lack of awareness, education, coercion, and economic alternatives.

Phase II: Training of trainers

- Number of trainers prepared: 13 trainers, 60 participants
- Training evaluation (express the acceptability of the training): 93.5% (graded by participants)

Phase III: Multiplication of training

- Improvement of evaluations (change in attitude/ implemented actions): 21.7% general improvement (grades evolve from 31.8% to 53.4% between 1st and 2nd evaluation).
- Number of miners ("garimpeiros" ) trained and sometimes retrained: 4,200 (10% of the whole population: 40,000 miners)
- Mining sites ("Garimpos") and communities involved: 141 (7% of total existent: 2,000)
- Number of "garimpos" leaving the bottom line (evaluation below 20% conformity with the evaluation criteria): 100% (Originally 35% of garimpos were classified below 20% conformity)
- Number of "best practices" strongly incorporated to "garimpos": 7 (mercury confinement / pool for amalgamation, reactivation and recycling of mercury, sluice boxes removed from rivers, refilling old pits, construction and use of latrines, garbage disposal)
- Equipment for training: pilot plant including hammer mill, ball mill and centrifuge
- Number of biosand filters implemented to be tested: 10

- Number of retorts donated: 60 (donation occurred after the 2nd evaluation was done, so the impact of donation was not measured by the evaluation)

Phase IV – Promotion of the program

- Workshops, meetings and approximation of stakeholders in all Federal, State and Municipal levels. At least 3 workshops were conducted with substantial participation of local miners and authorities.
- Number/hours of promotional campaigns (local TV station, radio, outdoors, posters, T-Shirts, kits, booklets, flyers, etc). Campaign aired on TV/radio for 3 months, at least 5 outdoor billboards, 1,000 posters, 10,000 brochures, 10,000 flyers, 300 kits and T-shirts.
- Number of scientific papers produced and published: around 10 papers directly related to GMP in Brazil

## LESSONS LEARNED AND CONCLUSIONS

- Overall the results are solid and highly positive.
- Four studies (socio-economic, environmental, legal, microcredit) were conducted, around 10 technical papers were published, 4,200 garimpeiros trained (sometimes retrained), 141 garimpos evaluated, 20 "good practices" were promoted.
- At least 7 good environmental/health practices had substantial impact: reactivation and recycling of mercury, pool for amalgamation, old pits refilling, sediment containment, garbage disposal, use of latrines, filtered water.
- Practices not widely incorporated yet but with high potential to be accomplished: use of retorts (distribution of retorts occurred only after 2nd evaluation was done), awareness to mining accident and development of internal awareness campaign.
- The improvement of grades from 31.8 to 53.4% is the best evidence that miners respond to training and education better than they respond to the strict legislation only. Improvement of grades corresponds to changes in behaviour.
- Studies and monitoring are important but actions in the field should have greater priority and be allocated most of the resources. The continuous presence in the field in crucial for the success of the objectives.
- Monitoring and intervention can be simultaneous.
- Involvement of other partners at the operating level should be increased. As an example, USEPA (The U.S. Environmental Protection Agency) implemented fume hoods in gold shops in the same project site.
- Gold production: new tests for increasing gold recovery and reprocessing of tailings should be highlighted in an eventual project second phase. (Pilot Plant includes hammer mill, ball mill and concentrator). Studies of cyanidation should be implemented.
- Legal aspects: it is not enough to train miners to comply with legal requirements. Stakeholders (miners and government representatives) should discuss alternative solutions to simplify processes and make formalization a viable action. GMP can support and initiate this relationship.
- The Federal, State and Municipal government are willing to participate and support a project second phase.

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