Pilot Project for the Reduction of Mercury Contamination Resulting From Artisanal Gold Mining Fields in the Manica District of Mozambique

FINAL REPORT

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Project Team Members

Marcello M. Veiga, Chief Technical Advisor, UNDP/GEF/UNIDO Global Mercury Project
Dennis Shoko, Assistant Country Focal Point for Zimbabwe, Global Mercury Project
Samuel J. Spiegel, Coordinator of Policy Development, Global Mercury Project
Olivier Savornin, Small-scale Mining Expert, Global Mercury Project
Pius Raphael, Director of Centre for Sustainable Development for Natural Resources Management (CDS-RN), Ministry for the Coordination of Environmental Affairs (MICOA), Mozambique
Pedro Castigo, Chief of Community-Based Natural Resources Management Sector, CDS-RN
Eduardo N'dunguru, Provincial Chief Inspector of Mineral Resources, Manica
Rodrigues Sandramo, Engineer of Provincial Direction of Environment, Manica
Piano Jantar, Technician of CDS-RN

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United Nations Industrial Development Organization (UNIDO), and the Centre for Sustainable Development for Natural Resources Management (CDS-RN) of the Ministry for the Coordination of Environmental Affairs (MICOA), Mozambique

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TABLE OF CONTENTS

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EXECUTIVE SUMMARY

The health and environmental impacts of artisanal gold mining, a source of income for many people in rural areas in developing countries, have been growing concerns in Manica District, Mozambique. Currently, more than 12,000 people in this region are directly and indirectly involved in artisanal gold mining activities. Most people extract gold using mercury, which pollutes the nearby environment and poses a severe threat to human health. With support from the Blacksmith Institute (New York), technical experts from the United Nations Industrial Development Organization (UNIDO) and the Ministry for the Coordination of Environmental Affairs (MICOA) carried out a pilot program to reduce the negative mercury-related impacts of gold mining operations in this region. The objective of this pilot project was to contribute to the reduction of occupational health hazards of artisanal gold miners by promoting a safer, healthier and more cost-effective use of mercury in their mining operations.

Field visits were made to assess mercury use and mining and milling practices in Manica, with particular emphasis on the chosen pilot areas for community training. Assessments covered health and environmental factors, geological and mineralization information, social factors such as the role of men, women and children, as well as socio-economic factors including the production and distribution of gold, access to mercury, and availability of technical equipment. The program was carried out by a team of four international experts from the GEF/UNDP/UNIDO Global Mercury Project, in collaboration with five locally-based practitioners who were selected and trained in Manica under the co-ordination of the Centre for Sustainable Development for Natural Resources Management (in Chimoio). The assessments revealed that current mining practices cause significant health and environmental hazards in this area, with mercury exposure being a severe problem due to the fact the miners burned the mercury amalgams in open-air bonfires throughout the community. Based on breath test samples, the average level of mercury in the miners in Munhena, the main training site, was 8.23 $\mu g/m^3$. Some burners had above 50 $\mu g/m^3$ (50 times higher than the WHO guideline for maximum public exposure to mercury vapour).

Pilot training programs were conducted in selected areas to introduce miners and their families to mercury retort technologies and related ways of reducing mercury emissions. Tests performed with home-made retorts (made of salad bowls) showed that mercury emissions can be reduced significantly and cheaply, thus decreasing the exposure to humans and the surrounding environment. A training curriculum was designed and implemented to suit the community's basic technical infrastructures. After the training sessions, preliminary monitoring showed that the miners were using the retorts successfully. Through discussions with community leaders, members of the miner association, and the government inspector, the team identified follow-up plans including the establishment of a Community Amalgamation Centre and other opportunities for future collaboration in the community. Further fieldwork is necessary to train more people in the community and develop their capacity to implement the solutions that were introduced in this Pilot Project. Due to the rapid increase in artisanal gold mining activities in many African countries, the success of this project suggests that this project model should be replicated on a larger scale in other communities as well.

SUMÁRIO EXECUTIVO

Os impactos ambientais e de saúde causados pelos garimpeiros de ouro no Distrito de Manica, Moçambique têm recebido cada vez mais atenção. A garimpagem de ouro é uma atividade que provê recursos financeiros à uma grande parte de indivíduos nas áreas rurais. Atualmente mais de 12.000 pessoas na região de Manica estão direta ou indiretamente envolvidas. A maior parte dos garimpeiros utilizam mercúrio para extração do ouro poluindo o ambiente e ameaçando a saúde da população. Com o suporte financeiro do Instituto Blacksmith (Nova Iorque), especialistas da Organização das Nações Unidas para o Desenvolvimento Sutentável (ONUDI) e do Ministério para a Coordenação da Acção Ambiental (MICOA) conduziram um projeto piloto na região de Manica. O objetivo foi contribuir para a redução dos problemas de saúde dos garimpeiros causados pelo mercúrio através da divulgação de processos baratos e seguros.

As visitas de campo foram estabelecidas para avaliar o uso de mercúrio e as práticas de mineração/processamento em Manica, com ênfase ao treinamento da comunidade na área piloto. A availação englobou fatores ambientais e de saúde, informações geológicas, fatores sociais tais como papel do homem, mulher e criança, assim como fatores socio-econômicos incluindo produção e distribuição de ouro, acesso ao mercúrio e disponibilidade de equipmanetos técnicos. O programa foi realizado por uma equipe de quatro peritos internacionais do Projeto Global de Mercúrio do GEF/UNDP/UNIDO, com a colaboração de cinco profissionais técnicos locais que foram selecionados e treinados em Manica sob a coordenação do Centro para o Desenvolvimento Sustentável para a Gerência de Recursos Naturais (em Chimoio). As avaliações revelaram que as práticas garimpeiras atuais nesta área causam significativos danos a saúde e ao ambiente com a exposição da população ao mercúrio. Isto é um grande problema devido ao fato que os garimpeiros queimam os amálgamas de ouro em fogueiras abertas espalhando o vapor de mercúrio por toda a comunidade. Baseados em amostras de ar expirado (Hg nos pulmões) pelos membros da comunidade, o nível médio do mercúrio nos garimpeiros em Munhena foi de 8.23 $\mu g/m^3$. Alguns queimadores de amálgamas tiveram níveis de Hg acima de 50 $\mu g/m^3$ (50 vezes maior que os níveis aceitáveis pela OMS para a exposição pública ao vapor de mercúrio).

O programa de treinamento piloto foram conduzidos em áreas selecionadas para introduzir aos garimpeiros e suas famílias a tecnologia de retortagem de mercúrio e maneiras de reduzir emissões do mercúrio. Os testes executados utilizando retortas de fabricação caseira de baixo custo (tais como uso de bacias e saladeiras; tubos de conexão de água) mostraram que as emissões do mercúrio podem ser reduzidas significativamente, diminuindo a contaminação da população e do ambiente circunvizinho. Um curriculum de treinamento foi projetado e executado adaptado à infraestrutura local. Após as sessões de treinamento, observou-se que os garimpeiros utilizavam as retortas com sucesso. Nas discussões com os líderes da comunidade, membros da associação de garimpeiros e a equipe do governo, identificou-se planos para continuação do trabalho, incluindo o estabelecimento de um Centro de Amalgamação e outras oportunidades para a comunidade. Trabalhos de campo adicionais são necessários para treinar mais indivíduos na comunidade e para desenvolver a capacidade de executar as soluções que foram introduzidas neste projeto piloto. Devido ao aumento rápido das atividades garimpeiras de ouro em muitos países africanos, o sucesso deste projeto sugere que este modelo seja reproduzido em uma escala maior em outras comunidades.

BACKGROUND

Manica is a district of Mozambique in the Manica Province with a population of 155,731 people. Manica District borders with the Republic of Zimbabwe in the west, the District of Gondola in the east, the District of Barué to the north through the Pungué River, and the District of Sussundenga in the south, which is bounded by the Revué and Zonué Rivers. In 2001, it was estimated that 10,000 people are currently directly and indirectly involved in artisanal and small scale gold mining activities in Manica District.[1] Assessments conducted during this pilot project indicate that the population has increased to above 12,000. The main sources of economic revenue in this area are mining and mineral production, agriculture (especially tobacco and corn), animal farming, and trade. Most miners and mineral processors use mercury to extract gold, which pollutes the nearby environment and poses a sever threat to human health. Very little of the mercury used by the "*garimpeiros*" (artisanal miners) to extract gold from the ore deposit is safely recovered from amalgamation processes.

Artisanal and small-scale gold mining (ASM) is a significant source of gold in the developing world, with at least a quarter of the world's total gold supply coming from ASM. As a consequence of its misuse, mercury amalgamation results in the discharge of an estimated 1000 tons of mercury per annum which represents about 30% of the world's anthropogenic mercury releases. It is estimated that between 10 and 15 million artisanal and small scale gold miners worldwide, including 4.5 million women and 600,000 children.[2] Because mercury amalgamation is simple and inexpensive, it is the gold concentration method most used by miners. Small-scale gold miners combine mercury with gold-carrying silt and the gold and mercury combine to form an amalgam, making recovery of the gold easier. The amalgam is subsequently heated with blow torches or over an open flame so that the mercury burns off and is subsequently inhaled. Acute mercury poisoning can lead to severe neurological and kidney damage. Mercury which is not inhaled or washed away during the amalgamation process settles into the surrounding environment, where it is absorbed and processed by a variety of living organisms. This process transforms elemental mercury into methylmercury. Methylmercury is one of the most toxic organic compounds and a powerful neurotoxin that works its way up the food chain through bioaccumulation.

There are a number of cleaner technology alternatives to current methods of mercury amalgamation. The use of retorts during the mercury burn-off stage is a simple and cost-effective way to decrease the occupational exposure to mercury and minimize its release into the environment. Retorts allow for the efficient capture and reuse of mercury. Assessments of previous initiatives to introduce new mining technologies and practices have shown that the

[1] Zacarias, R. and Manuel, I. (2003). Assessment of Mercury Use in Artisanal Gold Mining in the Manica District of Mozambique. In: Artisanal and Small-scale Mining in Developing Countries. *Urban Health and Development Bulletin*, v. 6, n. 4, p. 57-61.

[2] Veiga, M.M., Baker, R. (2004). *Protocols for Environmental and Health Assessment of Mercury Released by Artisanal and Small Scale Miners*, Report to the Global Mercury Project: Removal of Barriers to Introduction of Cleaner Artisanal Gold Mining and Extraction Technologies, GEF/UNDP/UNIDO, 170p.

biggest barrier to the uptake of such technology is educational. This project intended to provide artisanal gold miners with the education and technology needed to minimize the use of mercury, their exposure to mercury vapour, and its release into the environment.

PROJECT OBJECTIVES

Local partners identified a pilot area in Manica in which project activities were focussed. Successful implementation of retort technology and related educational outreach will result in replication of the project throughout Manica District and, with the support of Blacksmith Institute, other sites in Africa that are coping with the effects of mercury amalgam.

The objectives for this project were to:

- Conduct field visits to mining sites in selected areas to assess mining and milling practices and mercury amalgamation in Manica District and, specifically, the chosen pilot area
- Team up with local inspectors and MICOA to conduct short assessments of geological and mineralization factors, mercury emissions released into the surrounding environment, community health risks related to mining practices, milling activities and mercury use (using the LUMEX Mercury Analyser Equipment), and community socio-economic factors related to gold production and distribution
- Conduct pilot demonstration programs to introduce miners to mercury retort technology and related ways of reducing mercury emissions and contamination
- Train miners in effective use of retort technology and how to make retorts
- Monitor the successful uptake and ongoing use of this technology, along with favourable impacts on the surrounding environment

METHODOLOGY

To achieve the above objectives, the following methodologies were employed:

1. **Initial assessment of mercury use in Manica District mining activities:** This entailed a review of existing MICOA data and experience, focused on the environmental impact and the extent of artisanal gold mining in the area, along with affected rivers and water courses, assessment of existing artisanal gold mining techniques, interviews already conducted in the area, mining waste studies, and other information on the area. A review of artisanal mining in other developing countries and measures implemented to reduce mercury pollution was helpful as well. Activities of the Global Mercury Project (in Zimbabwe, Tanzania, Lao Peoples' Democratic Republic, Indonesia, and Sudan) were helpful in developing the project strategies and previous uses of retort technology served as models for Manica pilot project.

2. **Identification of pilot area and stakeholders:** Following the information-gathering stage, team members identified an area for project implementation along with all relevant

community and government stakeholders and pilot area details - population, geographical area, affected waterways, extent of mining activity and mercury use.

3. **Demonstration activities:** Education and training sessions were conducted on the use of retort technology along with demonstrations of how to manufacture a retort from locally accessible equipment. These activities occurred May 15-23 2005.

4. **Training:** Designated MICOA representatives conducted training seminars focused on effective retort use, along with on-site training for miners who cannot attend the seminars. Following training, retorts were left with the miners to use and information on local retort construction was provided.

5. **Monitoring/Assessment:** Immediate monitoring following the training activities, to ensure that the retorts were used successfully. Observations and measurements were recorded to keep determine the amount of mercury recovered. Further monitoring is necessary to determine the number of miners trained and the impacts on mercury releases.

RESULTS AND OBSERVATIONS FROM VIELD VISITS

Description of Pilot Area

Munhena, a region of Manica District, was selected as the focus area for the pilot project demonstration and education activities. In the Munhena area, mining and mining-related work is the chief source of income, and, for almost all the inhabitants, mining is the only revenue source. There are 3764 miners (all legal) in the Munhena area, all of whom are members of the local mining association. The number of people who are economically dependent on these mining activities is estimated to be more than 12,000.

The Munhena area includes three main topographic parts, each serving a different community function:
- valley (processing centers)
- foot of the hill (village)
- the hilltop (mines):

The *valley* serves as the processing operation center, encompassing several water tanks dug in the soil where the millers pan the ore. Some of these water tanks are connected by small flows of water. A family of five people generally uses two or three tanks. There are several small manual ball mills in the valley where miners reduce and process the ore. Throughout the valley area, mercury is used to recover gold and the amalgam is burned in open air bonfires.

The village is located at the *foot of the hill*, with houses going from the edge of the valley where there are people processing the ore up to the bottom of the waste rock dump 70 meters above.

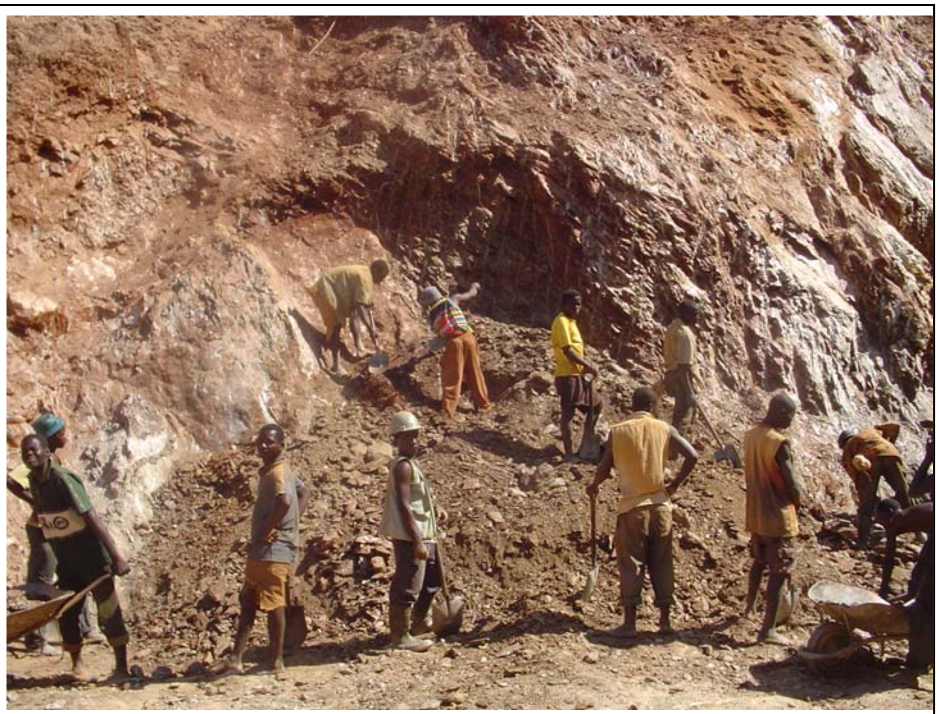
The miners and their families live in small houses made from wood and clay at the foot of the hill, surrounded by banana trees.

The mines are located on the *hill*, in large open pits that dip 20° into the hill. Midway on the hill, just under the mine sites, there are several locations where the waste rock is dumped, and this remains a giant mass of fallen rock. Tailings are transported down the hill, past the village area, and into the valley where they are processed.

Occupations of Women, Men and Children

Women represent probably 25% of the population in Munhena. The miners and millers are mostly men. Women partake in all the processing operations: crushing, milling, panning, digging the water tanks and burning. Women are not allowed in the ore extraction fronts. The organizing members of the mining association are mostly men, but some women partook in our discussion and education groups as well as breathing tests with the LUMEX.

Key informant interviews revealed that children (under 15 years old) generally do not work. During the field visits, some (~5-10) children were seen processing the ore, though children were not seen to be involved in mining extraction operations (on the hilltop). However, most young children accompany their mothers while working and are exposed to (if not also involved in) the panning and processing activities. Children in the area all attend primary school, generally beginning at age 5 or 6. A public school is located 2km from the village.



Miners excavating and transporting waste rock along the hilltop in Munhena

Women panning ore using tanks in the valley

Child operating ball mill in the valley

Current Practices of Mineral Extraction (Mining) and Processing (Milling)

Mining is done with picks and shovels, and rock waste is dumped with wheelbarrows. Ore is transported into buckets 200m down the village on a very long, steep, narrow and dangerous track. It was reported that each miner can extract as much as 50kg of ore/day. Workers said that transporting ore down the track to the processing centre is one of the greatest difficulties facing the miners.

Crushing is done manually with a metal stick in a metallic corn grinder. Milling is conducted using manually driven ball mills. These improvised ball mills are constructed using propane tanks, an idea that reportedly originated from a miner coming from South Africa years ago. The ball mills have a capacity of 7–12 kg/ore. The millers turn the ball mills for 15 to 45 minutes, and they determine the rate and time of processing according to the sound of steel balls grinding the ore: when the sound changes, they stop the milling process. Transformation of a gas tank into a ball mill costs US$20.8.[3] The balls are forged or cast steel (1-3 inches in diameter). Millers add 14 balls in each mill, ~ 10kg (a tub) of ore, and 50% water.

The millers go inside the water tanks and they concentrate gold by panning. They let the tailings fill the tank and they collect only the amalgam at the end of the panning process. They burn the amalgam in an open pan in a bonfire to recover the gold. The tailings are re-ground and re-processed afterwards (especially if the mining is not efficient - i.e. if they are not producing new ore). The local workers said that there are often periods of many weeks (even months) in which only wastes are processed.

During our field visit, the only materials being extracted were waste rocks. The miners were not mining any ore. The income of the miners was therefore very low at this time. Miners said they sometimes live for 7 months without extracting new ore. The miners were extracting, moving and dumping the wastes down the hill. The mining activity is now stopped for different reasons, mainly because the soil and ore quality is becoming too hard to mine with traditional picks and shovels. Furthermore, there are several collapsed zones of waste on the ore, making mining operations very dangerous and impractical. The miners were shovelling directly for ore by digging into the hill at a 20° angle, and they did not reinforce the roof or the edge of their hole; therefore, the risk of collapse has increased as the size of the hole has increased. Moreover, the more they advance, the more soil is above the hole. The miners explained that collapses occur frequently. So far two people have been killed from collapses.

It was indicated that the private gold buyers (who also provide the mercury) might develop plans to rent bulldozers to the miners in the future. Also, workers indicated the possibility that the private gold buyers might rent equipment for processing at some time in the future, although no plans have been developed. We mentioned the possibility of building a transport track to carry ore from the mine to the processing centre, which the local workers thought could be very

[3] 1US$ = 24,000 Meticals in the parallel market

beneficial. After this field trip, this project invited two representatives of the miner association to visit mining sites in Zimbabwe in order to learn techniques of transporting ore with cable hoists.

Sequence of Mining and Milling Activities in Munhena

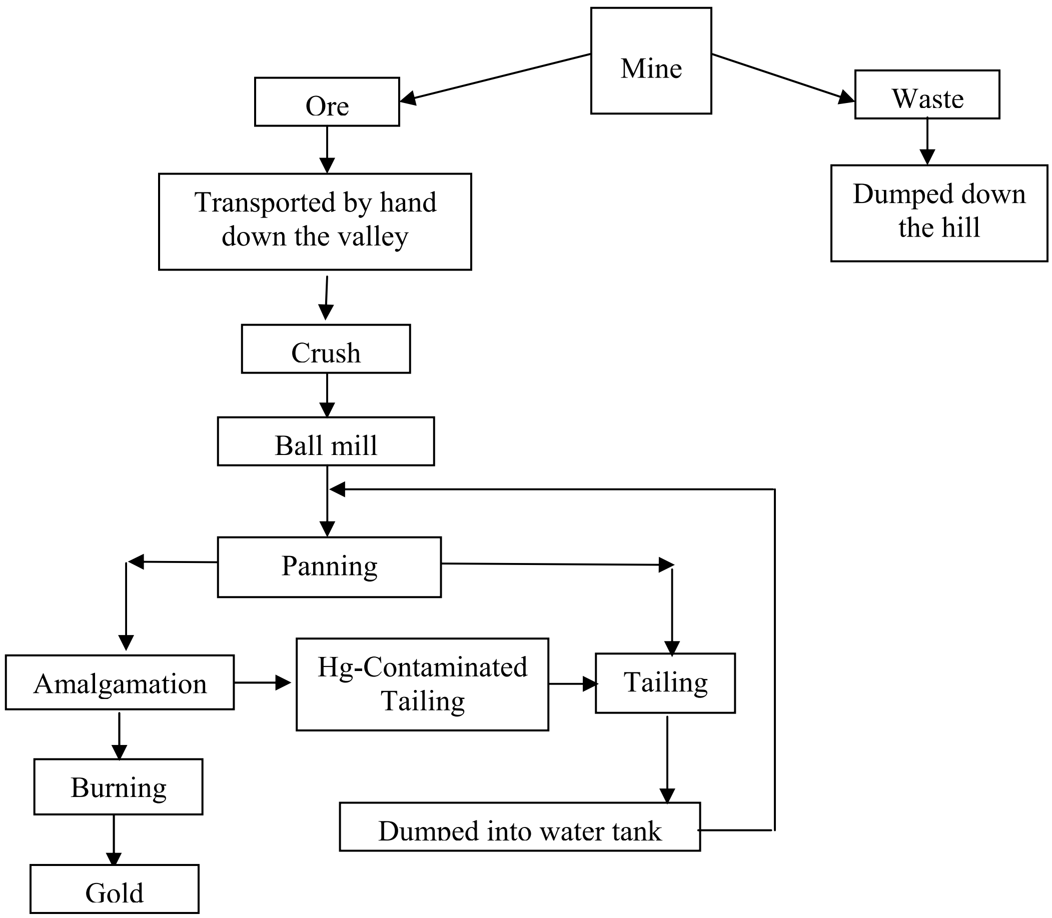


Fig. 1 – Flowchart of Mining and Milling Operations in Munhena

Note: Hg-contaminated tailing is mixed with primary concentration tailing, which increases the pollution risks. Hg-contaminated tailing should be stored separately from primary tailing.

Impact of Placer Mining (Upstream from the Village)

Visits were also made to small unlicensed mining operations in another area above the valley where miners were extracting rocks in the streams. They were moving the flow of small rivers to erode and mine the ore, placing sluice boxes downstream to recover nuggets. These miners were able to mine some ore, but because of poor mining methods, they recovered only very little. More efficient ways of recovering gold were explained, including moving the sluice box closer from the processing place. These miners often worked during the night, because they did not have legal titles to operate. It was observed that the practice of mining in the streams was causing extensive pollution in the water supply and should not be continued.

Uphill from Munhena Village, a polluted stream converges with a clear stream

Socio-Economic Assessment and Use of Mercury

On average, miners in Munhena extract 3g of gold/miner/week, with monetary revenue of ~US$22 (prices are discussed below). The total capacity of gold production in Munhena is between 40 and 50kg a month (or 1-2 kg/day). Only 1kg/month of this amount is sold to the Provincial Direction of Mineral Resources which has a system to buy gold from the miners who bring the gold to the town of Manica. Because of the low price offered by the Government most of the gold is sold to private buyers. Key informant interviews revealed that there are three (3) main private buyers in the area.

It was observed that miners in all areas visited use mercury for amalgamation. They have two options for obtaining mercury. The first option is to purchase mercury for US$2/22g (~US$1/10g or US$100/kg). The 22g correspond to the amount of Hg in a water bottle cap. According to all interviewed sources, this is extremely expensive for them. It should be noted that the international Hg price is US$12/kg. (At the same time a year before the field visit, the international Hg price had been US$4/kg.) The second option is to deal with the gold buyers; these buyers offer the miners a production agreement whereby the mercury is provided (rationed) for free by the private buyers but, in exchange, the miners have to sell the gold for US$7.5/g to the private buyers instead of selling for US$8.2/g to the government buyers. Most of the miners in the area obtain mercury from the private gold buyers (utilizing this second option) as they do not have the option to purchase mercury from alternative sources. It is noteworthy that in Manica some gold buyers buy gold at rates up to US$10.5/g. It is also noteworthy that, on May 31, 2005, the international pure gold price was US$13.38/g (or US$416.3/oz), significantly higher than the prices paid to the miners.

It was reported by Zacarias and Manuel (2003)[4] that miners use ~ 48g of Hg per 25g of Au produced. Thus, the ratio of $Hg_{used}:Au_{produced}$ is 2:1. The authors also report that 62.5kg of gold was produced in Manica District in 2001. The price of gold was as low as US$ 256/oz in April 2001. As the gold price increased over the last five years, as noted above, the total gold production in Munhena alone has increased to 40 and 50kg/month as indicated by the local miners. Based on observation during the field visit, the high price of mercury and the process used by miners (amalgamation of panned concentrates and no retorts used) it is very likely that the ratio of $Hg_{lost}:Au_{produced}$ must be around 1:1. It is important to notice that some of the mercury used in the amalgamation process is reused. Therefore it is not adequate to report the amount of mercury used; the amount lost must also be recorded.

Gold and Mercury Circulation in/to/from Manica District

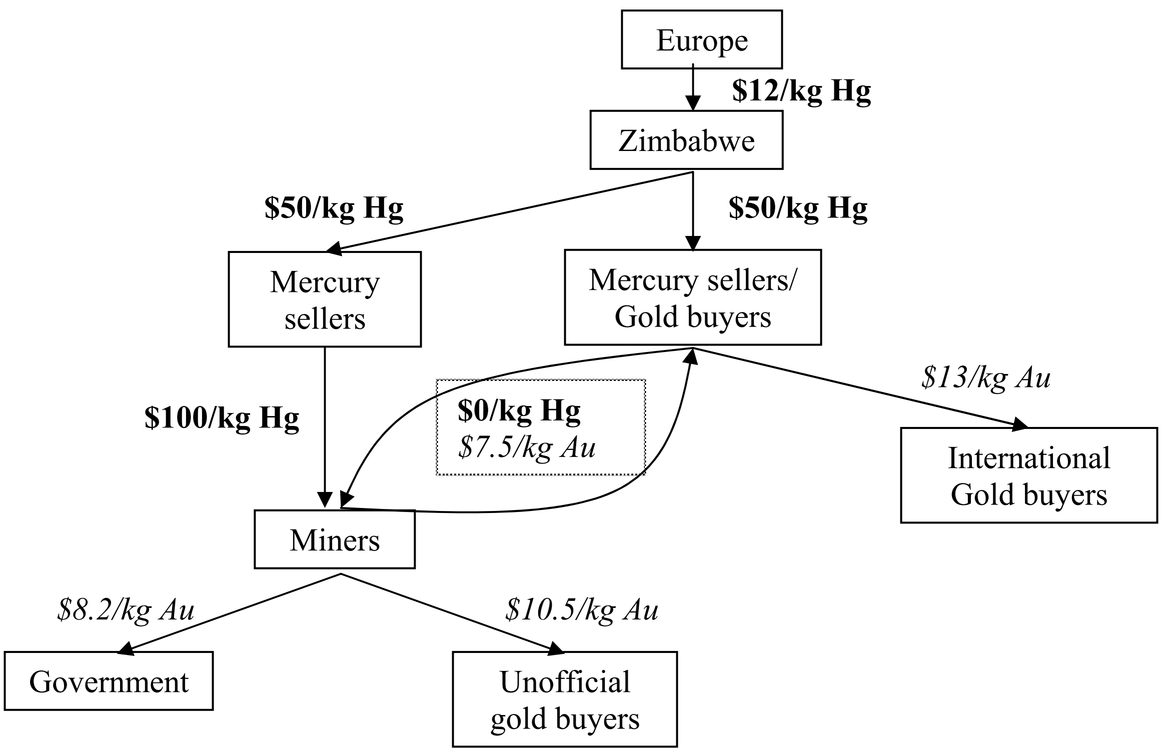


Fig. 2 – Flux of Hg and Au to Munhena Mine

[4] Zacarias, R. and Manuel, I. (2003). Assessment of Mercury Use in Artisanal Gold Mining in the Manica District of Mozambique. In: Artisanal and Small-scale Mining in Developing Countries. *Urban Health and Development Bulletin*, v. 6, n. 4, p. 57-61.

Community Health and Development

It was noted that government inspectors as well as heads of departments from the Ministry of Mineral Resources and the Ministry of Health came to visit the Munhena area in 2003. They assessed some of the mining and milling conditions and concluded that the community members needed to organize themselves into a miners association. Since that time, the miners created a well-organized miners association and raise funds from the community for the association. There is a chief in the community, and the president of the community is Mr. Majale. There are 3764 miners (all legal) who are members of the association.

Health services in the community are difficult to obtain. There is a small hospital located 3km from the village, and it was reported that the hospital is in great need of a first aid box and training. There are high levels of malaria and HIV AIDS in the community, and poor nutrition and the lack of safe drinking water are also significant problems. One worker who had been treated for malaria explained that the treatment is available at the nearby hospital for 2000 Meticals (less than US$0.10). Several serious occupational health risks were also observed, especially relating to the very labour intensive mining work and mercury exposure. Workers indicated that there had not been many health initiatives in the community, but that a program to promote condoms had been implemented in 2002. It was also indicated that there is a water well a few kilometres from the village where children often go to fetch water, but most water used comes from rivers and not the well. Sanitation was identified as a significant problem. The inhabitants do not have toilets and they use bushes. The government had planned to bring toilets for the community in 2002 but the program was cancelled.

There are some NGOs active in Manica, such as World Vision and Rotary Club, but they have not worked in Munhena area in recent years.

MICAO (with support from Finland) has built a new training facility in Chimoio and is currently developing a training curriculum in sustainable development. It may be possible to incorporate sustainable mining and mercury management in this training program.

Mercury Exposure and Contamination

The problem of mercury emissions from amalgamation burning was clearly widespread and severe, due to the many open air mercury burning sites. Mercury was being burned throughout the processing centre area as well as the village area, with winds spreading the emissions considerably. The community did not designate particular areas as “burning areas” and thus many burners used a variety of locations for burning.

It is well-known that one the best indicators of undue mercury vapour exposure is urine. However urine analysis requires more elaborate sampling process as well as creatinine analysis to eliminate the urine dilution effect. This method can be pursued in the follow-up of this initial pilot project. The level of mercury in the breath is also a strong indication of exposure to vapours, and the measurement of mercury in the breath it is rapidly executed and more appropriate for a first community visit. In this process, miners are asked to blow for 10 seconds into a plastic hose connected to the LUMEX spectrometer. The readings are provided every second and the maximum is registered. It should be noted that scientific literature is beginning to show a correlation between mercury levels found in urine analysis and in exhaled air. Pogarev et al (2002) assumed that 7% of the dose received by the subject is released during respiration, accounting for a difference between measurements based on urine and exhalation.[5] The authors found that 80% of the mercury inhaled is absorbed by the lungs and that the effect of alcohol consumption can reduce this amount 2-3 fold and can also promote the removal of mercury from the human body. More research is necessary to establish specific correlations between urine and breath in the mining sites.

Based on breath test samples from the miners and community members using the LUMEX, the average level of mercury in the miners in Munhena was 8.23µg/m³. Note that the WHO guideline for maximum public exposure to mercury vapour is 1µg/m³ and the TWA is 25µg/m³.[6] Without the three people most contaminated (who identified themselves as mercury burners), this average was 3.12µg/m³. Breath test results were shared immediately with the miners as they requested. When the three most intoxicated people took the LUMEX hose in their hand, it could be known instantly (even before they breathed into the LUMEX) that there were contaminated; as soon as they extended their hand to the LUMEX, the spectrometer has indicated levels of mercury in the air around 30µg/m³. For the air immediately surrounding the other people sampled, the LUMEX recorded mercury levels at approximately 1µg/m³. It was determined that mercury levels must have risen so quickly for some people because of high levels of contamination detected in their clothes. Air in the village contained an average mercury contamination level of 0.4µg/m³.

Due to exceptionally high levels of mercury in some places visited (especially the burning sites), the LUMEX equipment was contaminated. Repair work had to be performed to recalibrate the LUMEX and replace its hose piece.

The problem of methylmercury was not assessed. However, regionally, there are large rivers crossing the valley and fish must be analyzed. The local workers explained that the valley is flooded at least once a year in February. Thus, the tailings washed over along with the other parts of the processing centre (including the Hg), and they are spread into the surrounding grounds and rivers. This flooding process can also be responsible for mobilization of methylmercury formed on the local sediments. The main mechanism of mercury mobilization in Munhena can be the contaminated sediments that move during seasonal flooding. This should be investigated in future fieldwork. It was reported that some people eat small fish that grow in the tanks used to

[5] Pogarev, S., Ryzhov ,V., Mashyanov, N., Sholupov, S. (2002). Direct Measurement of the Mercury Content of Exhaled Air: a New Approach for Determination of the Mercury Dose Received. *Anal. Bioanal Chem*. v. 374, p. 1039-1044.

[6] World Health Organization (2003). *Elemental Mercury and Inorganic Mercury Compounds: Human Health Aspects*. Concise International Chemical Assessment Document 50. Geneva ISBN 92 4 153050 2, 61p.
TWA = Time Weighed Average means the time weighed average concentration for a normal 8 hour day and 40 hour workweek, to which nearly all workers can be repeatedly exposed without adverse effect

amalgamate the ore. These fish must show high levels of methylmercury and must be analyzed in future monitoring programs.

Table 1 – Levels of Hg in the Breath of Miners and Community Members in Munhena, Manica, Mozambique

25 Sample Breath Tests	
Hg (µg/m³.)	*Subject*
1.50	Miner (man)
1.90	Miner (woman)
4.30	Miner (man)
3.20	Miner (man)
2.80	Miner (man)
50.0	Burner (man)
5.00	Miner (man)
3.50	Miner (woman)
27.0	Burner (child)
2.70	Miner (man)
2.00	Miner (man)
3.00	Miner (man)
3.50	Miner (woman)
2.50	Miner (man)
4.00	Miner (man)
2.00	Miner (man)
2.80	Miner (man)
2.20	Miner (woman)
3.00	Miner (man)
1.00	Miner (man)
2.20	Miner (man)
3.60	Miner (child)
60.0	Burner (woman)
7.00	Miner (woman)
5.00	Miner (man)

It was observed that technicians at the Provincial Direction of Mineral Resources are exposed to high levels of mercury vapour when buying gold from artisanal miners. When the miners retort amalgams in low temperature bonfires for a short time, the retorted gold contains up to 20% mercury. When miners sell this gold to the government buyers, the air in the office becomes very contaminated. Measurements conducted with the LUMEX showed levels of 35µg Hg/m³ in the air. This is 35 times the WHO guidelines for maximum public exposure to mercury. The employees operating this buying facility must be significantly contaminated with mercury.

The government employees also take the gold from the miners and leach it with hydrochloric and nitric acid, thus removing the iron, silver, mercury and other impurities. This operation is conducted in the lab at the Provincial Direction of Mineral Resources facility under a fume hood. This practice reduces the mercury exposure significantly and the mercury level in the lab was below 10 µg/m³. In the past, they used to melt gold in a gas oven before weighing the gold to pay the miners, which was very hazardous for the people in the lab due to the high levels of mercury released. Although the current practice is safer, this leaching process is carried out without the presence of the miners, and miners have indicated that this creates a lot of suspicion that not all the gold recovered is paid back to them.

One of the solutions for the employees is to receive the gold in the lab, i.e. under the fume hood and dissolve residual mercury with nitric acid, instead of receiving the gold in the confined office space where contamination is a factor. Doing this, the employees will be able to reduce their exposure to mercury fumes. Also, this would allow miners to see the mercury being leached directly and immediately see the gold that is recovered. This will increase the credibility of the government gold buyers and will attract more miners to sell gold to them.

INTRODUCTION OF CLEANER TECHNOGOLOGIES

Training, Education and Demonstration Activities

A weeklong series of education and demonstration activities was conducted in the project area. We carried out three main types of workshops:

Workshop 1 – Education on Mercury Hazards and Exposures:
The first workshop focussed on mining and processing practices, the dangers of breathing mercury vapours, the sources of exposure, and environmental risks related to mercury use in the area. This workshop was followed by the breathing tests with the LUMEX Mercury Analyzer. Results were shared immediately so that the miners could see their level of mercury in the lungs directly. In addition a simple test of episodic memory was conducted in which three words were given to the miners to repeat after 10 minutes. Very few of the miners could repeat the three words in the test, which was repeated many times with the same people who volunteered. Miners were shown the effects of intoxication, the causes of intoxication, and preventative measures to reduce exposure.

Workshop 2 – Training in Solutions and Cleaner Techniques of Processing:
The second workshop focussed on the two types of retorts to reduce Hg emission: the kitchen bowl retort and the home made pipe retort were demonstrated. All materials for these retorts were obtained from local equipment stores. During this workshop, the miners were trained in the use of the retorts, their underlying principle, and their advantages compared to other ways of burning the amalgam.

Workshop 3 – Training to Increase Gold Recovery:
The third workshop presented another way of collecting gold through the use of magnetic sluice box. In the third workshop, emphasis was also on developing ways to increase the recovery of gold, how to obtain materials to build a retort, and how the mining association and community

members can organize in the future to increase their income and put the health and environmental solutions (above) into practice.

Success of the Train-the-Trainer Model

The UNIDO Team trained local workers in Munhena on the use of retorts to reduce Hg exposure…

…later in the day, the local workers were teaching others in the community.

Introduction of Cleaner Mining and Processing Technologies

The first innovation introduced to the miners was the magnetic sluice boxes. The magnetic sluice box made of common ferrite permitted the miners to recover fine gold from their tailings. This ferrite was purchased in Canada, costing US$10-15, and it was 1mm thick, 1.2m long and 0.4mwide. This ferrite is usually used to make fridge magnets for commercial distribution. Magnetite as a common accessory mineral in gold ores is concentrated in the sluice forming an effective surface to trap gold. As the miners in Munhena use steel balls to grind the ore, the residual steel released by abrasion during the grinding process is also concentrated by the magnetic sluice, contributing to form a mat to trap gold. It was shown that the recovered gold was very fine and mercury was not able to amalgamate it due to surface tension. The magnetic sluice box allows the miners to employ techniques that use less mercury, and therefore increases gold recovery.

Magnetic Sluice Box

Two different types of retorts were demonstrated, the kitchen bowl retort and the home-made pipe retort. In both retorts, the amalgam is heated in a closed structure, releasing mercury that condenses and can be collected and reused later. The retorts allow the miners to burn the amalgam without being intoxicated by the mercury vapours. The retorts were also shown to help the burners to recover mercury. The kitchen bowl retort consist of two salad bowls (one bottom and one top) and a small stainless steel cup where the amalgam is introduced. (It should be noted that an enamel cup or a stainless steel cup generates yellow gold after retorting. When using ordinary steel in contact with retorting amalgam, rather than stainless steel, gold always comes brown, reducing the market value of the gold). The retort was sealed with wet sand around the cover. The amalgam was heated in a bonfire and mercury is evaporated to be condensed on the surface of the cover; then mercury droplets fall on the sand. In the first test using the kitchen-bowl retort with a glass bowl as cover, the retorting process was conducted in a bonfire. Miners could inspect the result of the amalgam decomposition by visual observation of the color change. They indicated, based on this preliminary test that the time taken to burn the amalgam and cool down the retort was longer than expected (20 minutes for 2 grams of amalgam) basically because it is difficult to cool down the glass cover. Therefore, we obtained a kerosene burner (stove) for the tests to speed up the retort-burning time and used steel bowls as the cover which is rapidly cooled down with water. The whole retorting and cooling process for 6g of amalgam took 10 minutes. It was observed that the initial use of a retort cover made of transparent glass is important to show the miners how the retorting process works. After showing the miners the retort process with a glass cover, it is advantageous to use a metallic cover because it cools down faster.

Kitchen-bowl retort in a bonfire in Munhena

A home-made retort built with standard plumbing water pipes was also demonstrated and found to be useful to reduce mercury emission[7]. The retort was made with ordinary water plumbing connections. The distillation chamber was made by connecting an end plug into which the amalgam is placed. The size of the retort was 1.5" (and can vary from 1/2 to 3"). An iron tube (for ordinary plumbing purposes) of 1/2" was welded at a local metal shop to the elbow bend. The condensation tube was 50cm long and curved downwards to permit good condensation of gaseous mercury without using coolant. The tip of the tube extended into the water in the plastic bowl. The galvanized steel pipes and connections were previously burned in the kerosene stove to remove the zinc

Homemade pipe retort

[7] Veiga,M.M.; Meech,J.A.; Hypolito,R. (1995). Educational Measures to Address Hg Pollution from Gold Mining Activities in the Amazon. *Ambio*, v. 24, n.4, p.216-220.

layer on the steel and the amalgam was introduced in the retort. Using the kerosene stove, mercury was condensed and recovered afterwards.

After tests with the retorts, the mercury condensed in the sand was panned and recovered using water from the tanks. It was observed that mercury was very pulverized, and the droplets of mercury were recovered using a simple electrolytic methods developed by the Colombian Dr. Fred Pantoja. The droplets of mercury were transferred to a plastic recipient with a saline solution (salt table). The process consists of agglomerating mercury by connecting the droplets to a positive pole of a flash-light battery. The negative pole stays in the saline solution. The process removes the superficial oxidation layer of the droplets and the mercury is then agglomerated.

The miners said that they agreed that the solutions brought to them were beneficial, reasonably inexpensive, and easy to make. In total, three kitchen bowl retorts, two homemade pipe retorts and a petrol burner were assembled by the UNIDO Team for the demonstration activities. The material for the retorts was found locally in both Chimoio and Manica, and the operation for cutting the bottom of the bowls was performed in Manica. The kerosene burner was obtained in Chimoio. It was learned that welding work can be done in Manica and Chimoio. The total cost for making 1 kitchen bowl retort (metallic) was US$3.30 (incl. service for cutting the metal). Glass bowls could not be found in Manica but metallic bowls were found (a demonstration glass bowl was brought from Canada). The cost for making 1 home-made pipe retort was US$4.80.

Electrolytic Process to Agglomerate Hg Droplets

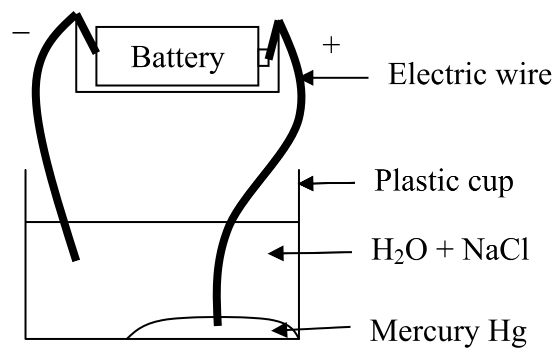


Table 2 - Local Retort Materials Used and Prices in Local Stores

Kitchen bowl	**Price in US$**
1 spoon	0.6
2 small tea cups	0.8
3 medium size bowls	2.5
3 small size bowls	1.9
Service to cut hole in the bottom of the bowls + cut of the top of the cups	4.2
Total retorts (3)	10.0
One retort	**3.3**

Home made	**Price in US$**
Plumbing bigger one	2.9
Plumbing smaller one	2.5
Pipe for both	2.1
Welding	2.1
Total retorts (2)	9.6
One retort	**4.8**
Kerosene burner	19.8

LUMEX measurements were taken during the burning with both types of retorts. Before starting the retorting process, the level of mercury in the air was measured between 0.30 and 0.60µg/m³, with an average of 0.412 µg/m³. In the air surrounding the kitchen bowl retorts, the average level of Hg measured was 40.87, 3.39, and 0.622 µg/m³ respectively for 0.1m high, 1m high, and the person's nose (~2m from retort).

Table 3 –Hg Levels (µg/m³) in Air Surrounding Kitchen-Bowl Retort

0.1m from retort	1m from retort	People's nose (~2m from retort)
37.0	1.6	0.9
44.0	1.3	1.0
25.0	2.6	0.4
18.0	3.0	0.4
78.0	4.2	0.5
33.0	7.0	
47.0	4.0	
45.0		

In the air surrounding homemade pipe retorts, the average level of Hg measured was 35.67, 2.11, 1.93 µg/m³ respectively for 0.1m high, 1m high, and the person's nose (~2m from retort).

Table 4 –Hg Levels (µg/m³) in Air Surrounding Homemade Pipe Retort

0.1m from retort	1m from retort	People's nose (~2m from retort)
12.0	2.0	1.7
51.0	1.6	2.0
18.0	1.6	2.1
44.0	3.26	
54.0		
35.0		

Natural Hg levels in air in rural areas usually range from 0.001 to 0.004 µg/m³ and in urban areas from 0.01 to 0.17 µg/m³. Typically, Hg is found in air as elemental Hg but 1 to 25% can occur in the form of Hg (II), depending on the type of emission source (USEPA, 1993)[8]. The WHO (1991)[9] recommended health-based exposure limit for metallic Hg is 25 µg/m³ for long-term exposure (TWA). The National Institute for Occupational Safety and Health (NIOSH, 1992)[10]

[8] USEPA - U.S. Environmental Protection Agency, (1993). Summary Review of Health Effects Associated with Mercuric Chloride. Office of Health and Environmental Assessment, Washington, D.C. EPA/600/R-92/1993. Sept. 1993.

[9] WHO - World Health Organization (1991). Environmental Health Criteria. 118. Inorganic Hg. Geneva, 168 p.

[10] NIOSH (1992). Recommendations for occupational safety and health: Compendium of policy documents and statements. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 92-100.

has established a recommended exposure limit (REL) for mercury vapour of 50µg/m³ as a TWA[11] for up to a 10-hour workday and a 40-hour workweek. Malm (1991)[12] measured up to 60,000 µg/m³ of Hg in air when amalgam was burned in open pans in an ASM operation. When retorts were used, this concentration dropped to as low as 10 µg Hg/m³. It is obvious that miners are exposed to unacceptably high levels of Hg when they burn amalgam in an open pan or shovel. The WHO (1991) believes that an individual exposed to Hg levels in air above 80 µg/m³ has a high probability of developing symptoms of Hg intoxication.

[11] TWA = Time Weighed Average means the time weighed average concentration for a normal 8 hour day and 40 hour workweek, to which nearly all workers can be repeatedly exposed without adverse effect

[12] Malm, O., (1991) Human and Environmental Mercury Contamination in Gold Garimpo Region of Madeira River, Amazon. Doctorate Thesis at the Federal Univ. of Rio de Janeiro - Biophysics Institute Carlos Chagas Filho. Rio de Janeiro, 106 p. (in Portuguese).

CONCLUSION

- Future fieldwork should be undertaken to assess health and environmental impacts according to the UNIDO Protocols, i.e. including urine, fish, and hair analyses as well as other health and ecosystem factors.

- The problem of methylmercury was not assessed. However, local workers explained that the valley is flooded at least once a year in February and mercury contaminated tailings are washed over along with the other parts of the processing centre, spreading into the surrounding grounds and rivers. This flooding process can also be responsible for mobilization of methylmercury formed on the local sediments. The main mechanism of mercury mobilization in Munhena can be the contaminated sediments that move during seasonal flooding. This should be investigated in future fieldwork.

- The introduction of the kitchen-bowl and water-pipe retorts was successful and well-received by the communities in Munhena, Manica District, Mozambique. Continued monitoring is necessary to ensure successful operation of the retorts left with the workers. The miners were also shown how to make their own retorts and further monitoring should ensure that they were able to do so successfully. Further fieldwork is also necessary to train more people in the community and develop their capacity to implement the solutions that were introduced in this Pilot Project.

- In the communities visited, workers did not designate particular areas as “burning areas” and thus the problem of mercury exposure was widespread and severe. The establishment of a centralized location for burning mercury is necessary to ensure that men, women and children become less exposed to mercury vapour in the future. With continued support from Blacksmith, UNIDO, and perhaps CASM as well, we plan to follow this work up by building an Amalgamation Centre in Munhena. MICAO will put together a design and a budget, and the centre will include the following specifications:
    - a cement tank to keep all amalgamation tailings
    - a small mill (as they use) made of gas tanks with a coarse chain inside or rubber balls to amalgamate their concentrates, avoiding manual amalgamation
    - a PVC filter that can be attached to a bicycle wheel to remove excess mercury from amalgams avoiding manual contact with mercury
    - a bench where the kerosene burner (such as the one we left in Munhena) can be used to retort the amalgam
    - the centre must be open at the sides but covered
    - at the back of the centre, a small meeting room can be created for miners to exchange experiences
    - 2 or 3 latrines

- The concept of amalgamation centres is expanded by providing miners with training in mining and mineral processing techniques enhancing their technical and economic skills.

With some trainers at the site (in future projects), while producing gold, miners can be exposed to concepts of geological exploration, ore reserve estimation, mining and concentration techniques, environmental impact, water reclamation, tailing pond building, revegetation, bookkeeping, etc. In addition, the Centre can improve the economic and social welfare of artisanal miners and their families providing advice on how to obtain legal mineral titles and financial support, how to plan a mining operation, how to avoid occupational exposure, how to start alternative economic activities and other family matters. Brochures, posters, videos and other communication material may be distributed. For those who insist in conducting their own amalgamation in their places, they can receive instructions on how to make their own retorts using plumbing water connections or kitchen bowls. The Centre can also be a meeting place for miners to exchange their experiences and have moments to socialize and organize themselves.[13]

- Additional capacity building efforts should focus on the organization of the miners association and integrate with their plans. In addition to the association already involved in the project, it was reported that 5 new miners associations are currently being developed in this area.

- Future efforts should be linked closely with MICOA, especially to integrate sustainable mining and mercury management modules into the new training programs on sustainable development in the town of Chimoio at the Centre for Sustainable Development for Natural Resources Management (CDS-RN).

- Future efforts should aim to build the capacity of the government mining inspector to assess environmental and health factors and promote good practices.

- It was observed that the government buys only 1kg out of 40kg of gold being produced monthly in the region. In spite of the better price being offered by the government, miners are overwhelmingly selling their gold to the private buyers in the area because: 1) the private buyers are more present than the government in the mining sites; 2) the private buyers are providing mercury for free (in exchange for a guaranteed gold sale) in an area where mercury is difficult to obtain; 3) the miners are not confident that the government scheme will pay them for all the gold they produce.

- In light of the above factors, it was observed that the government should buy gold on site. However, if the government is unable or unwilling to travel to the mining sites to buy gold, then the government should receive the gold in an appropriate place where 1) mercury exposure is limited and 2) miners can see the gold being cleaned with acid from impurities. Currently, government gold buyers are being contaminated when they buy gold with residual

[13] Veiga,M.M. and Beinhoff,C. (1997). "UNECA Centres, a Way to Reduce Mercury Emissions from Artisanal Gold Mining and Provide Badly Needed Training". UNEP (United Nations Environment Programme) - Industry and Environment, Oct-Dec. 1997, v. 20, n.4, p.49-51.

mercury in offices in the town of Manica. One of the solutions is that the government gold buyers should receive the gold in the lab, i.e. under the fume hood and dissolve residual mercury with nitric acid, instead of receiving the gold in the confined office space where contamination is a factor. Doing this, these employees will be able to reduce their exposure to mercury fumes and this would also allow miners to see the mercury being leached directly and immediately see the gold that is recovered. This will increase the credibility of the government gold buyers and will attract more miners to sell gold to them.

- Additional fieldwork should identify and work with the gold buyers (both government and private) to promote the establishment of cleaner and more efficient technologies, improved facilities and better practices.

- The actions are very timely since the price of mercury is currently very high in Munhena (US$100/kg), resulting in a heightened attention on the need to minimize mercury losses. Also, the new gold rush in the region is resulting in an increasing number of people involved in artisanal and small scale mining activities.

- This pilot project developed valuable knowledge for future capacity building efforts. Due to the rapid increase in artisanal gold mining activities in many African countries, the success of this project suggests that this project model should be replicated on a larger scale in other regions in Africa as well. Strategies for replication in other communities will be presented in future proposals. Immediate follow-up activities should include developing fund raising and partnerships with Blacksmith Institute, UNIDO, USEPA, World Bank/CASM, GEF and other international agencies as well as the private sector. The government of Netherlands has recently pledged support through UNIDO for these initiatives in Mozambique, and other governments have also made requests to participate in, and contribute to, these activities.

- The Global Mercury Project is currently working in 6 countries, Zimbabwe, Tanzania, Sudan, Indonesia, Lao PDR, and Brazil. The knowledge acquired from the activities in these countries will be shared with neighbouring countries and applied for future global efforts.

APPENDIX – PHOTOGRAPH IMAGES IN MANICA DISTRICT

Marcello Veiga showing the retort to miners in Munhena

The UNIDO Team discusses how to implement the retorts

22 grams of mercury is measured in a bottle cap and costs US$2.

Placer mining in the local streams, just above Munhena village

Woman showing the gold concentrate before being amalgamated

Testing mercury levels in breath

UNIDO Team discussing future plans with the Miners' Association

Miner showing others in the community how to use the kitchen-bowl retort

Children getting drinking water from the well, 2km from the village

Measuring the reduction of Hg emission when using the retorts

Miners learning about Hg in their lungs during the training workshops

Concentrating gold by panning in the pools

Propane tanks transformed into ball mills

Woman grinding ore using the ball mill

MICOA representative with the Vice-President of the Miners' Association

Workshop participants take a moment for a picture

Miner using the water-pipe retort

Amalgam before retorting

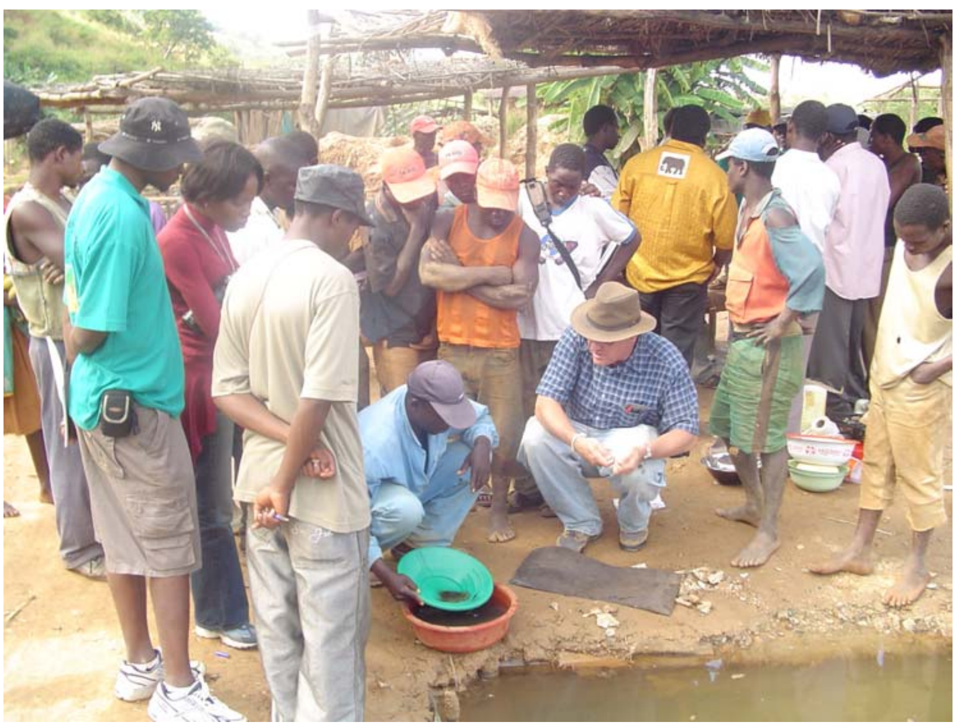
Retorted gold

Kitchen-bowl retort can also use a metallic cover

Processing area in Munhena

Foot of the hills and pools where ore is processed

Amalgamation tailings are left in the pools



UNIDO Team demonstrates how to recover Hg by panning when the kitchen-bowl retort is used

Miners reworking old tailings

Concentrating and amalgamating gold in the pools

Workshop on health effects of mercury exposure

Miners were shown a variety of options for retorting

Home-made pipe retort in operation with kerosene stove

Female miner with her baby at the mine