BELGIAN TECHNICAL COOPERATION

Enhancing Environmental Quality through Improved Gold Recovery in Artisanal and Small-Scale Gold Mines in Tanzania

FINAL DRAFT REPORT

NOVEMBER 2009

Prepared by

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List of Acronyms

BTC	: Belgian Technical Corporation
GEUS	: Geological Survey of Denmark and Greenland
NEMC	: National Environmental management Council
ToR	: Terms of Reference
TASSMAG	: Tanzania Small-Scale Mining Advancement Group
URT	: United Republic of Tanzania

Executive summary

Mining operations, gold extraction processes and environmental problems have been investigated in three small-scale mining communities. Itumbi near Chunya is a community where small-scale mining has been the main source of income for decades. Londoni near Manyoni used to be a small sleepy village with a few hundred inhabitants. A few years ago gold was found and a major gold rush with more than 10.000 small-scale miners rushing to the village. Mpambaa near Singida is an area of farmland where gold was found February 2009. This resulted in a small gold rush.

Samples of every step in gold extraction have been collected. Samples of tailing have also been collected. The samples have been analysed for gold and some of them for mercury as well. The assay results show that the techniques used by small-scale miners in not very efficient. The miners loose a lot of gold and release lots of mercury to the environment.

The results of the present project indicate that the first steps in increasing recovery of gold for the small-scale miners seems to be better milling techniques and improved sluices. The best available technique (BAT) for gold extraction in both communities is borax. This technique is able to extract as much gold as the presently used mercury technique, but without negative environmental and health impacts.

The non toxic borax gold extraction technique was tested on a number of samples of gold concentrates from the three communities. All samples proved to be amenable for using borax in gold extraction. If this method is adopted by the small-scale miners then use of mercury will stop. Alternatively mercury recycling can be introduced. This will reduce release of mercury to the environment with more than 90 percent.

Soil sampling in maize fields in and around Itumbi and Londoni showed high concentrations of mercury. Disturbing was the discovery of a soil sample collected more than 10 km from any small-scale mining site which carried high amounts of mercury. This indicates that the mercury pollution from gold extraction is distributed over vast distances. These results show that mercury from small-scale gold mining causes regional health hazards for the population of Tanzania.

The finding from the project was presented to a group of stakeholders at a workshop on 21st of October 2009. NEMC and the Consultant received a number of very valuable comments and recommendations, which can be summarize to the following:

- A genuine need of improving gold recovery and reduce mercury pollution of the environment.
- Representative of small scale miners agree that there is importance of introducing Borax method in recovering gold.
- NEMC should organize a workshop where by small scale miners from pilot areas (Itumbi and Londoni) will explain to their fellow colleagues how efficiently borax works in recovering gold. The alternative of the use of gas instead of charcoal should be considered.
- NEMC will work with stakeholders in taping in the existing funds from Minerals Development fund (under Ministry of Energy and Minerals) and others to ensure that small scale miners and artisans use best available technology such as borax.
- A cost benefit analysis should be conducted comparing the use mercury versus borax.
- Improvement of the existing processing mechanisms such as efficient use of clothes and retort for recycling of gold.
- Introduce the use of borax in selected pilot areas. The small-scale miners present at the workshop found the suggestion of bringing in a small-scale miner from the Philippines to Tanzania in order to teach them using borax as excellent. This will be done during the last two weeks of January 2010.

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Location of the investigated small-scale
mining communities

1. Foreword

This final report is the response by the GEUS team to the Terms of Reference of the project "Enhancing Environmental Quality through Improved Gold Recovery in Artisanal and Small-Scale Gold Mines in Tanzania" and the Technical Proposal by GEUS of February 2009.

The GEUS team comprised of Dr. Peter Appel (GEUS), Mr. John Tychsen (GEUS), Dr. Jesper Jonsson (GEUS), Dr. Kinabo Crispin (TASSMAG) and Mr. John Wihalla (TASSMAG) undertook two missions during the period of 13th of May 2009 to 23rd of October 2009.

The GEUS team appreciated the welcome offered by Resident Representative Mr. Nebeyu Shone and Senior Programme Officer Mr. Cranmer Chiduo, Belgian Technical Cooperation (BTC) as well as the very kind and competent assistance provided by Director Ruzika Muheto, Director Anna Maembe and Mr. Yohana Mtoni, National Environmental Management Council.

This Final Report describes the outcome of the project and the recommendations from the final workshop 21st of October.

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2. Introduction

Gold has been mined in Tanzania for a long time by large mining companies and by small-scale miners. Small-scale gold mining has gained momentum over the last decades. An estimated 300.000 people are presently depending on small-scale gold mining. It is carried out in large parts of Tanzania from Lake Victoria region through Singida and Chunya regions to Mpanda in Lake Tanganyika areas.

A small number of small-scale miners have established mining communities where gold extraction has been carried out for more than ten years. In such permanent to semi permanent small-scale mining communities mining becomes an integrated part of the livelihood. One example of such a community is Itumbi near Matundasi, Chunya, where small-scale mining has been carried out for more than a decade. Itumbi was thus chosen as one of the target communities for our investigations.

The vast majority of small-scale gold miners are migrant workers. They work at one place until a rumour spreads of a new promising gold discovery. This creates gold rushes and they occur ever so often. Londoni near Manyoni was a sleepy village with a few hundred inhabitants depending on farming and livestock. In July 2004 gold was discovered and in no time more than ten thousand people invaded the area. Some of them were small-scale miners others were workers providing food, beverages and sex. This turned the life at Londoni upside down. Londoni near Manyoni was chosen as the second small-scale mining community for our investigations. In February 2009 a gold rush started in Mpambaa near Singida. This drained Londoni for many of its small-scale miners as well as supporting businesses. Londoni did in May 2009 look almost like a ghost town. Mpambaa on the other hand is full of small-scale miners many of which came from Londoni. The rumour at Mpambaa told in May 2009 that the gold is not as abundant as believed, so many of the small-scale miners consider returning to Londoni. Mpambaa was briefly visited during our investigations.

Objectives of the project.

The present project comprises both field and laboratory investigations.

Field investigations

These investigations were carried out in two ASM areas and comprised

:

1. Geological mapping of the gold ores mined.
2. Sampling of the different types of gold ore.
3. Scrutinising crushing and grinding of the gold ore and sampling of material from each step of the preparation.
4. Evaluation of the gold extraction techniques and collection of samples from each step of the gold extraction.
5. Collection of tailings from gold extraction.
6. Collection of sediments in the general area of ASM. This part of the project aims at a first step towards evaluation of the pollution of the environment by toxic substances, in particular mercury.

Laboratory investigations

These investigations which will be carried out at GEUS and at Southern and Eastern African Mineral Centre (SEAMIC) will comprise:

1. Chemical analyses for gold of all the collected samples.
2. Chemical analyses of tailings and sediment samples for gold and mercury.
3. Microscopic investigations of samples of the gold ores and samples from each step during crushing and grinding of the gold ores. These investigations focus at discovering how the gold grains occur and how fine grained the gold grains are.

Project activities

The project was divided into 3 phases and the main field and laboratory activities carried out by the consultants included:

1. To assess the degree of environmental degradation caused by disorganized ASM activities for Matundasi and Londoni ASM areas in Tanzania.
2. To conduct geological mapping and collection of gold ores.
3. Detailed investigation of the presently used gold extraction techniques and collection of samples from all steps of gold extraction as well as the tailings (rejects).
4. To conduct laboratory investigations and analyses of gold in gold ores and in all samples from the different steps of gold extraction. The raw gold ores and other samples will be

analyzed mineralogically in order to unravel the grain size of the gold and to what extent the gold is locked up in other minerals. The laboratory analysis was carried out at Southern and Eastern African Mineral Centre (SEAMIC) in Dar es Salaam and at GEUS in Copenhagen.

5. To conduct laboratory experiments on the collected samples in order to evaluate the applicability of the borax gold extraction method.
6. To develop best available techniques (BAT) for the particular gold ores in question. When BAT of the chosen gold mining district(s) has been found, the methods will be tested in the field in close cooperation with the local ASM. The artisanal and small-scale miners in the chosen districts will then be introduced to the BAT for their particular ore body.

Participation and stakeholder involvement

The Consultant finds that direct and active stakeholder involvement is crucial in order to obtain a participatory process and subsequent sustainability of the project.

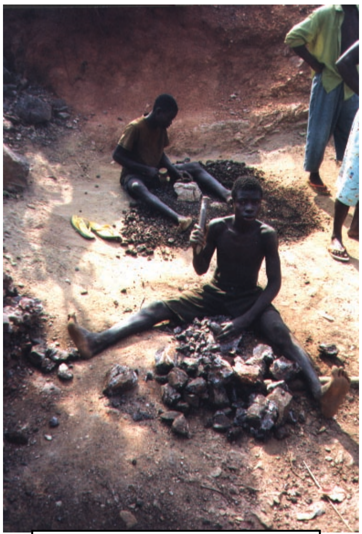
In the stakeholder workshop arranged for 21st of October the Consultant presented all the gathered data and results from the field work and the laboratory analysis as well as the findings of the project. These were discussed and the workshop provided a number of very valuable recommendations to be included in the planned NEMC action plan

3. Brief description of small-scale gold mining and processing techniques

Small-scale gold mining is carried out in alluvial or hard rock deposits. This project deals with small-scale gold mining in hard rock only.

First step in mining is sinking shafts and digging tunnels. This is mostly done with a minimum of technical equipment. Hammer and chisels are the essential tools. Sometimes dynamite is used for breaking the rocks. The shafts are sunk down to more than 60 m below surface. Tunnels are dug from the shafts in order to follow the gold reefs. The tunnels are up to many tens of metres long.

When the gold ore is broken and hoisted up to the surface, it is crushed. This is mostly done manually. However, in Itumbi a jaw crusher has recently been installed. After crushing the cm-sized bits of gold ore are ground in ball mills. This is dry milling by large homemade metal drums. The milling is done by fist sized hard steel balls. This makes an awful noise and creates lots of dust. The noise will cause tinnitus and the dust will give stone lungs (silicosis) to the labourers. After sometime of milling, the milled gold ore is removed from the mill and the gold extraction begins. First step is sluicing. The milled ore is washed down a sluice which is covered by a piece of cloth. The heavy minerals including gold are supposed to be caught in the cloth, whereas the light particles are washed down the sluice into the tailing dam.



Crushing gold ore

Milling gold ore

Washing cloth

Adding mercury

Burning amalgam

Final product

After each run through the sluice, the small-scale miners take the cloth with the heavy minerals and wash it in a bucket. The heavy minerals are then transferred to a pan, where mercury is added. The mercury is mixed thoroughly with the heavy minerals. During this process the gold amalgamates ("dissolves" in mercury), and is easy to separate from the other heavy particles. The amalgam is then heated over a fire whereby the mercury evaporates and is released to the environment and the gold remains. The small-scale miners do, however, realise that the sluicing is not one hundred percent efficient. They therefore run the tailings through the process repeatedly (up to ten times); in order to make sure that all gold has been extracted.

4. Sampling program

Sampling procedure

In order to test the efficiency of gold extraction done by the small-scale miners several sets of samples were collected. A description of the processing of gold has been presented in a previous chapter.

Milled ore was sampled before the sluicing. The samples are denoted RS-x above. The milled ore is flushed down the cloth which covers the sluice. Samples were collected from, the uppermost part of the cloth. These samples are denoted RS-x cloth. These two sets of samples were analysed for gold by Actlabs in Canada. The material which is not caught in the cloth is flushed down into a small dam. That material is called tailing. The tailings were sampled and analysed for gold at Seamic in Dar es Salaam. These samples are denoted RS- x tailing.

Sampling of tailing

Efficiency of sluicing

The first set of analyses was made in order to get an idea of the efficiency of the sluicing to catch the gold grains. Nine samples of crushed and ground gold ore were analysed together with samples of the corresponding material caught on the cloth in the sluice (see table below).

	Gold g/ton	Enrichment
RS-1 ABOVE	3.64	
RS-2A ABOVE	19.6	
RS-2B ABOVE	11	
RS-2C ABOVE	6.8	
RS-3 ABOVE	3.72	
RS-4 ABOVE	48.1	
RS-5 ABOVE	2.74	
RS-7 ABOVE	10.5	
RS-13 ABOVE	1.91	
RS-1 CLOTH	43.6	12
[illegible]	[illegible]	[illegible]

The enrichment factor of gold range from 4 to 46. The enrichment factor does obviously not depend on the amount of gold in the ore (RS-x above). RS-4 above has the highest gold content (48.1 g/t) but the lowest enrichment factor whereas sample RS-2A with a gold content of 1.96 g/t has an enrichment factor of 46.

Efficiency of extracting gold in a sluice depends on several factors e.g.:

1. Technical set-up of the sluice
2. Skills of the labourers running the sluice
3. Mineralogical characteristics of the gold ore

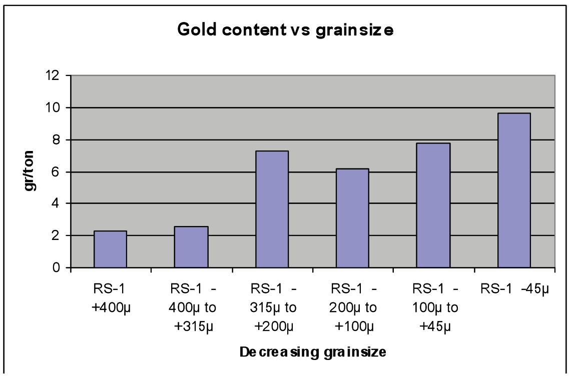
RE 1: Some of the sluices in Itumbi are more elaborately constructed than other sluices in Itumbi and the sluices in Londoni and Mpambaa e.g. the one used for processing samples RS-2 and RS-3. The water flow is maintained by a hose which assures a fairly constant water flow down the sluice. Other sluices in Itumbi and the sluices in Londoni and Mpambaa water is added in buckets which give strong water flow alternating with slow water flow. A constant water flow is crucial to high recovery of gold from the ore.

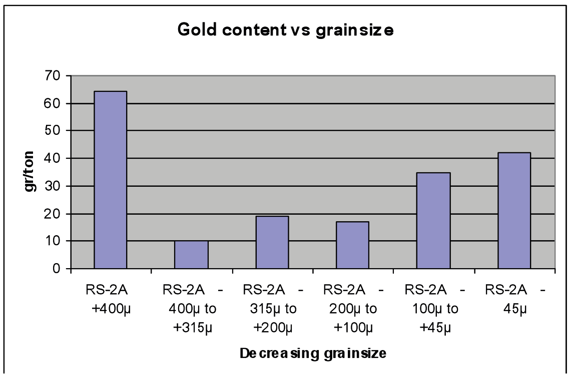
RE 2: There are vast differences in technical skills of the labourers not only from site to site but also within the same site. This is probably the explanation for the significant difference in enrichment factor shown in the table above. Samples RS-2A-C and RS-3 were treated by the same group of workers in the same sluice, whereas the other samples were processed at other sluices by other workers. RS-5, and 7 are from Londoni. RS-13 is from Mpambaa where they had problems with insufficient milling.

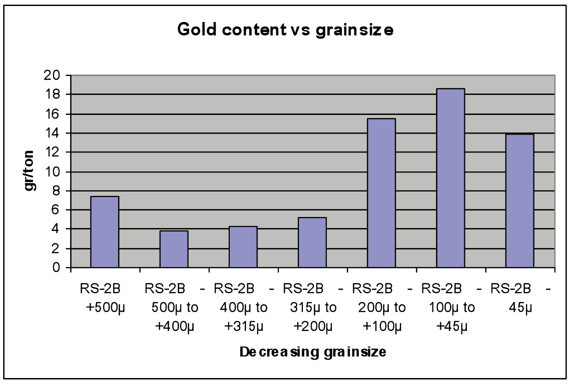
RE 3: In general the efficiency of sluicing depends on the grain size of the gold. The finer the gold grains are, the less efficient is the sluicing process. It was thus decided to split the crushed and ground ore (samples RS-x above) according to grain size and analyse each size fraction for gold. The results are shown in the table below and are plotted in the diagrams seen below. The gold contents in the different grain sizes varies within wide limits, but supports the general belief that the finer the grain size of the gold the less efficient is sluicing. This is shown by comparing samples RS-2A and RS-4. A large fraction of the gold in RS-2A is coarse grained and thus easy to capture in the cloth (enrichment factor of 386. Most of the gold in sample RS-4 is fine grained and thus more difficult to catch in the sluice. Enrichment factor of RS-4 is 7.

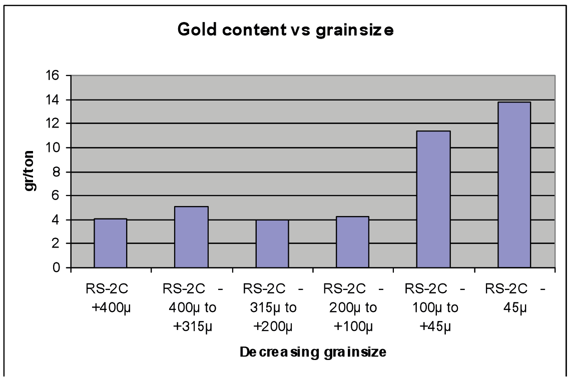
Grainsize	Gold g/ton	Grain size	Gold g/ton
RS-1 +400µ	2.26	RS-4 -500µ to +400µ	19.1
RS-1 -400µ to +315µ	2.55	RS-4 -400µ to +315µ	21.9
RS-1 -315µ to +200µ	7.26	RS-4 -315µ to +200µ	24.9
RS-1 -200µ to +100µ	6.15	RS-4 -200µ to +100µ	30.3
RS-1 -100µ to +45µ	7.76	RS-4 -100µ to +45µ	46.8
RS-1 -45µ	9.63	RS-4 -45µ	77.7
RS-2A +400µ	64.4	RS-5 -400µ to +315µ	8.33
RS-2A -400µ to +315µ	10.2	RS-5 -315µ to +200µ	60.7
RS-2A -315µ to +200µ	19.2	RS-5 -200µ to +100µ	4.55
RS-2A -200µ to +100µ	17.1	RS-5 -100µ to +45µ	6.08
RS-2A -100µ to +45µ	34.8	RS-5 -45µ	2.88
RS-2A -45µ	42	RS-6 -200µ to +100µ	80.3
RS-2B +500µ	7.39	RS-6 -100µ to +45µ	61.4
RS-2B -500µ to +400µ	3.87	RS-6 -45µ	25.8
RS-2B -400µ to +315µ	4.26	RS-7 -315µ to +200µ	6.67
RS-2B -315µ to +200µ	5.17	RS-7 -200µ to +100µ	9.78
RS-2B -200µ to +100µ	15.5	RS-7 -100µ to +45µ	14.2
RS-2B -100µ to +45µ	18.6	RS-7 -45µ	8.66
RS-2B -45µ	13.9	RS-13 -500µ to +400µ	1.67
RS-2C +400µ	4.04	RS-13 -400µ to +315µ	<0.03
RS-2C -400µ to +315µ	5.1	RS-13 -315µ to +200µ	19.8
RS-2C -315µ to +200µ	3.94	RS-13 -200µ to +100µ	4.1
RS-2C -200µ to +100µ	4.26	RS-13 -100µ to +45µ	5.38
RS-2C -100µ to +45µ	11.4	RS-13 -45µ	2.06
RS-2C -45µ	13.8		
RS-3 +400µ	1.25		
RS-3 -400µ to +315µ	2.76		
RS-3 -315µ to +200µ	12.3		
RS-3 -200µ to +100µ	3.3		
RS-3 -100µ to +45µ	7.66		
RS-3 -45µ	3.82		

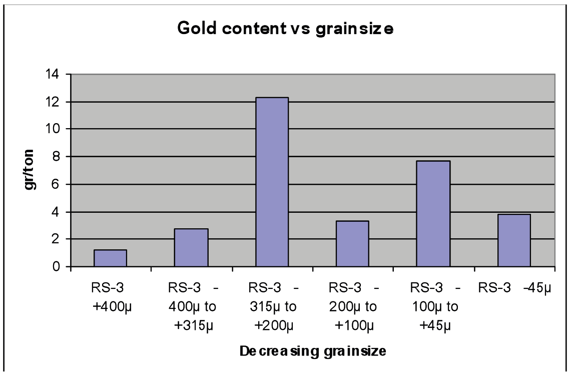
Gold content in different grain size fractions of crushed and ground gold ore

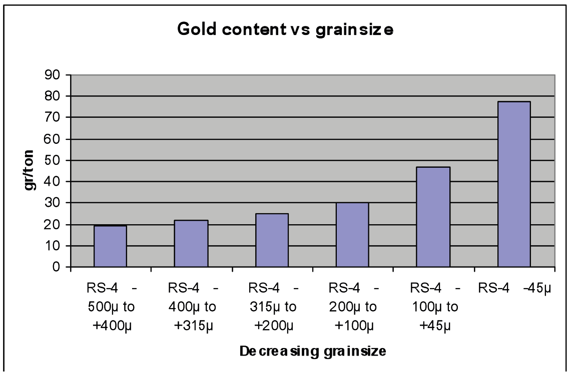

Gold content vs grainsize
gr/ton
RS-1 +400µ
RS-1 - 400µ to +315µ
RS-1 - 315µ to +200µ
RS-1 - 200µ to +100µ
RS-1 - 100µ to +45µ
RS-1 -45µ
Decreasing grainsize

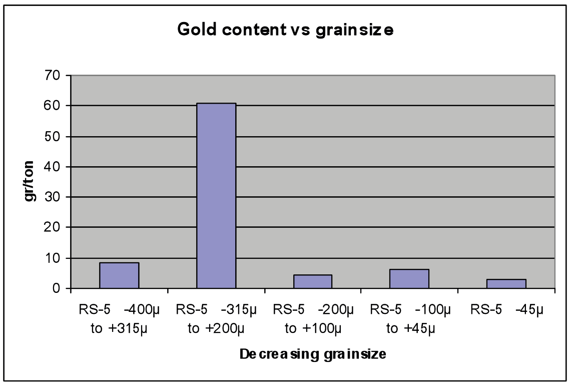

Gold content vs grainsize
gr/ton
RS-2A +400µ
RS-2A - 400µ to +315µ
RS-2A - 315µ to +200µ
RS-2A - 200µ to +100µ
RS-2A - 100µ to +45µ
RS-2A - 45µ
Decreasing grainsize

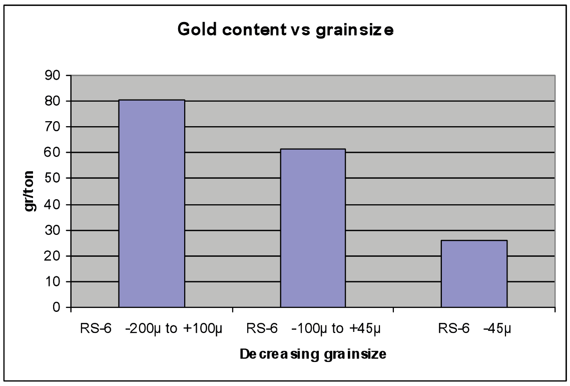

Gold content vs grainsize
gr/ton
RS-2B +500µ
RS-2B - 500µ to +400µ
RS-2B - 400µ to +315µ
RS-2B - 315µ to +200µ
RS-2B - 200µ to +100µ
RS-2B - 100µ to +45µ
RS-2B - 45µ
Decreasing grainsize

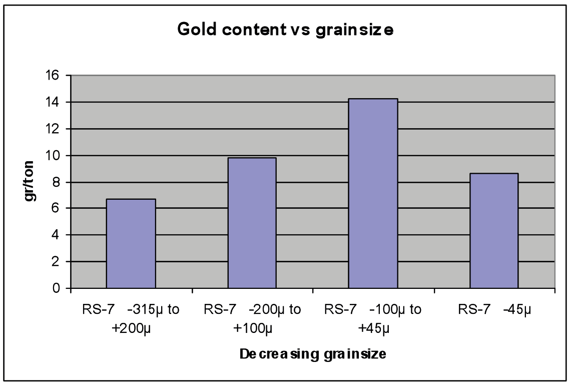

Gold content vs grainsize
gr/ton
RS-2C +400µ
RS-2C - 400µ to +315µ
RS-2C - 315µ to +200µ
RS-2C - 200µ to +100µ
RS-2C - 100µ to +45µ
RS-2C - 45µ
Decreasing grainsize

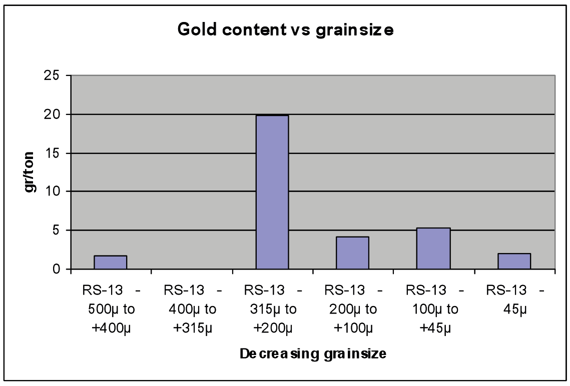

Gold content vs grainsize
gr/ton
RS-3 +400µ
RS-3 - 400µ to +315µ
RS-3 - 315µ to +200µ
RS-3 - 200µ to +100µ
RS-3 - 100µ to +45µ
RS-3 -45µ
Decreasing grainsize


Gold content vs grainsize
gr/ton
RS-4 - 500µ to +400µ
RS-4 - 400µ to +315µ
RS-4 - 315µ to +200µ
RS-4 - 200µ to +100µ
RS-4 - 100µ to +45µ
RS-4 -45µ
Decreasing grainsize


Gold content vs grainsize
gr/ton
RS-5 -400µ to +315µ
RS-5 -315µ to +200µ
RS-5 -200µ to +100µ
RS-5 -100µ to +45µ
RS-5 -45µ
Decreasing grainsize


Gold content vs grainsize
gr/ton
RS-6 -200µ to +100µ
RS-6 -100µ to +45µ
RS-6 -45µ
Decreasing grainsize


Gold content vs grainsize
gr/ton
RS-7 -315µ to +200µ
RS-7 -200µ to +100µ
RS-7 -100µ to +45µ
RS-7 -45µ
Decreasing grainsize


Gold content vs grainsize
gr/ton
RS-13 - 500µ to +400µ
RS-13 - 400µ to +315µ
RS-13 - 315µ to +200µ
RS-13 - 200µ to +100µ
RS-13 - 100µ to +45µ
RS-13 - 45µ
Decreasing grainsize

The gold ores show very different distribution of gold according to grain size. Gold ores RE-1, RS-2C and RS-4 show increasing gold contents in the fine fractions, whereas the other gold ores show very different gold grain size distributions. These results prove that the ores have to be treated differently in order to maximise recovery of gold.

Tailings

The small-scale miners in Itumbi and Londoni realise that they do not capture all their gold in the first run through the sluice. They therefore run the tailings through the process several times. They even put the tailings through the ball mills once or twice more in order to grind the coarser particles that were not milled during the first run in the mill. In Itumbi the small-scale miners claim that they extract gold from their tailings nine to ten times. In Londoni they claim to process the tailings four times. In Mpambaa small-scale mining has not been going on for a long time, thus there is no tradition as to how many times they reprocess their tailings.

Nine samples were collected of tailings which had not been processed. The samples were analysed for gold (see table below). The results clearly show that there is a considerable amount of gold left in the tailings after the first sluicing has been made. It also justifies that the small-scale miners spend time on running the tailing through the process again and again.

Sample number	Gold g/ton
RS-1 tailing	3.6
RS-2A tailing	9.6
RS-2B tailing	12.4
RS-2C tailing	4.4
RS-3 tailing	7.2
RS-4 tailing	16
RS-5 tailing	1.8
RS-7 tailing	2.2
RS-13 tailing	5.2

Gold contents in tailings after first gold extraction in the sluice

Six samples from tailings which had been through the whole process of milling, sluicing and amalgamation a couple of times, but were not regarded as exhausted, were analysed for gold and mercury see table below.

Sample no.	Gold g/ton	Mercury g/ton
OT-1A	6.67	1.94
OT-1B	6.85	2.15
OT-1C	5.20	2.21
OT-2A	7.51	0.58
OT-2B	5.05	<0.01
OT-2C	9.02	<0.01

Gold and mercury contents in reworked but not exhausted tailings

The tailings have only been reworked once or twice. The small-scale miners realise that the tailings contain more gold. What they do not realise are the high mercury contents of the tailings. Some of the mercury contents are very high and this mercury will gradually evaporate and later enter the food chain.

After having extracted gold from their tailings up to ten times the final tailings are dumped and vegetation is allowed to grow on the dumps. Nine tailing dumps covered by thick vegetation and even tall trees were sampled in order to check whether all the gold had been extracted (see table below).

Sample no.	Gold g/ton	Mercury g/ton
FW-1	12.2	<0.00
FW-2	9.84	<0.00
FW-3	12.6	<0.00
FW-4A	4.2	<0.00
FW-4B	32	<0.00
FW.5	104	<0.00
FW-6	3.24	<0.00
FW-7	1.6	<0.00
FW-8	4.83	<0.00

Gold and mercury contents in abandoned tailing dumps

These results are alarming in two aspects: High gold contents and low mercury contents. All the abandoned tailing dumps contain ore grade gold. This proves that the small-scale miners use inappropriate processing techniques. The mercury contents are very low compared with the tailings in the table above. The explanation is unfortunately straight forward. All the mercury which used to be in the old tailings has evaporated and been deposited elsewhere in the environment.

Analyses of soil

In order to get an idea of whether amalgamation of gold ores in Itumbi and Londoni causes serious mercury pollution in the surroundings, a small soil sampling program was carried out in and around the two villages. The soil samples were analysed at Seamic chemical laboratory in Dar es Salaam.

Itumbi

Sample no. and location	Mercury content g/ton
SS-.1 In Itumbi village	3.54
SS-2 In Itumbi village	0.29
SS-3 In Itumbi village	0.57
SS-4 In Itumbi village	0.76
SS-5 3.5 km from Itumbi village	1.1
SS-6 7 km from Itumbi village	0.24

Londoni

Sample no. and location	Mercury content g/ton
SS-7 1 km outside Londoni village	0.09
SS-8 1 km outside Londoni village	0,07
SS-9 In Londoni village	0.77
SS-10 In Londoni village	0.87
SS-11 In Londoni village	0.31
SS-12 In Londoni village	0.22
SS-13 In Londoni village	0.69
SS-14 In Londoni village	0.83
SS-15 10 km from Londoni village	2.9

Mercury contents in soil samples above 0.5 ppm are considered as potential health hazards to people. These results are thus alarming. Several of the samples were collected in maize fields and there is a great risk that the mercury has been taken up by the plants and then will concentrate in the people of the village when they eat the crops.

It must be emphasized that this is a mini survey and the few samples may not give a reliable picture of mercury distribution in and around the two villages. The results do, however, prove that a proper survey should be undertaken with systematic sampling of the soils in the villages and in their surroundings.

Soil sample SS-15 is puzzling. It was meant to be a blank for comparing the results from the villages, since it was taken far from any amalgamation activities. The source of the mercury in this sample is unknown. One explanation, and an alarming one, is that it may indicate a regional pollution with mercury from small-scale gold mining.

5. Environmental and health issues

Small-scale miners in general are accused of creating a number of environmental problems such as:

- Deforestation
- Siltation of the drainage system
- Land degradation
- Pollution with toxic elements

The small-scale miners in the investigated areas do not cause significant deforestation; neither do they clog up the drainage system with silt. They cause some degree of land degradation. The shafts are rarely re-filled, neither are they fenced off. They thus pose a significant threat to people and cattle of falling into the shafts. Falling into a fifty metre deep shaft causes serious injuries and death.

Land degradation

Noise and dust pollution

The mo[illegible]alth problem caused by small-scale gold mining is pollution of the environment with mercury. During amalgamation the miners inhale mercury vapour. The vapour which is not inhaled will gradually precipitate on the soil in the villages. The mercury in the soils will gradually be converted by bacteria to methylated mercury which is incorporated in the plants e.g. maize and then enters the food chain.

The present project was merely a pilot project with limited resources. However, the results obtained warrant establishing a large project with systematic sampling of soil and vegetables. A future project should also comprise investigation to what extent the population has been affected by mercury. This can be done by collecting urine or blood samples and analyse them for mercury.

6. Number of small-scale miners per productive area/mine claim

The number of small-scale miners working at each mining claim depends on a variety of factors such as:

- Time of the year. Many miners are part time farmers and in times when they do not need to work in the agriculture they seek employment in the mines.
- Prosperity. If a rich gold reef is struck in an area people flock to that area and seek employment.
- Rumours about new gold discoveries elsewhere can within days drain almost all small-scale miners from and area and the claim owner will be in a situation with no one to work for him. This can happen over night. An example of that was seen in Londoni where hundreds of small-scale miners had moved to Mpambaa.

Some of the claims we investigated had as few as four people working for the claim owner, whereas other had up to ten miners digging gold.

7. Findings from the tests with borax and other new methods

Gold extraction with borax has been used by small-scale miners in northern Philippines for more than a decade. The physical principle behind the method is that borax reduces the melting point of all minerals and metals including gold. The melting point of gold is 1063°C. Small-scale miners cannot achieve that temperature over a bonfire. If, however, they add borax to the gold concentrate then the melting temperature not only of the gold, but also of all other minerals decrease.

The method is quite simple. The sluiced ore is concentrated in a pan. The concentration has to be quite thorough, that is more than the Tanzanian small-scale miners are used to do. The gold-rich concentrate is then put in a small plastic bag, mixed with borax and a few drops of water. The bag is placed in a small clay pot and heated. After some time the minerals including the gold melts. The small gold drops coalesce and the job is done. The gold is picked out of the clay pot with the tip of a knife.

The borax method has a number of advantages:

1. Borax is virtually non toxic. Virtually indicates that compared to mercury borax is non toxic. In very large quantities borax is considered slightly toxic. However, only a few gram of borax is needed in each run.
2. Borax is cheap compared to mercury
3. Borax is readily available in most towns. It is used in many households for cleaning purposes.
4. Borax gives clean gold which will obtain a better price than gold produced by amalgamation which will contain some amount of mercury.

The borax process has the following disadvantages:

1. It is a slightly more difficult to process than amalgamation
2. It requires more training of the small-scale miners than amalgamation
3. The mineralogy of the gold ore may cause problems.

In order to make a first test of the borax method, samples of mineral concentrate were bought from small-scale miners in Itumbi, Londoni and Mpambaa. The samples were denoted RS-x borax. Prior to the test a simple mineralogical investigation was carried out. Each sample was dried and treated by a simple strong hand magnet, in order to get a qualitative estimate of the content of magnetic minerals. These minerals may obstruct the borax melting of the gold.

The samples were then brought to the Philippines and borax melting was performed in order to see how they reacted to the process. All samples were melted with borax and produced very pure gold. Similar tests were carried out at the laboratories of the Geological Survey of Denmark and

Greenland. The tests shows that the gold ores mined at the three places in Tanzania are amenable to borax gold extraction.

Gold from amalgamation with ~10% mercury

Gold from borax extraction
Pure gold

No other gold extraction methods were found suitable for implementation in the near future. On the long run it will be worth while to introduce cyanide gold extraction. This method is highly recommended in order to extract the fine grained gold. Cyanide gold extraction will also be able to extract gold from the numerous auriferous tailings from small-scale mining throughout Tanzania.

8. Summary and conclusions

Mining operations and gold extraction processes have been investigated in three small-scale mining communities. Itumbi near Chunya is a community where small-scale mining has been the main source of income for the inhabitants for a long time. Londoni near Manyoni where a major gold rush with more than 10.000 migrant small-scale miners started a few years ago. Mpambaa near Singida is an area of farmland where gold was found in early 2009. This resulted in a small gold rush.

Gold extraction methods are the same in the three communities, regardless of differences in composition and characteristics of the different gold ores. Small-scale mining in Itumbi is generally better technically developed than in the other communities. They have a jaw crusher and better sluicing facilities. This is of course to be expected since small-scale gold mining has taken place for decades in Itumbi. Londoni and Mpambaa gold fields are dominated by migrant small-scale miners who are not prepared to invest much in technical equipment.

The small-scale miners realise that the gold extraction process is not efficient. They therefore reprocess the tailings several times. In Itumbi they claim to reprocess the tailings up to ten times. In Londoni they claim to reprocess the tailings up to five times. Our sampling programme of these tailings shows that in spite of repeated re-processing they still contain high amounts of gold. In addition to high amounts of gold they contain high amounts of mercury. The latter pose serious threat to the environment.

When the tailings are believed to be exhausted for gold, they are left and will not be processed again. These abandoned tailings are gradually covered by vegetation even with metre high trees. Sampling of some abandoned tailings showed, however, that they contain considerable amounts of gold (up to 100 g/ton). They do not contain mercury. The reason is probably that all the mercury which used to be in these tailings over time has been released to the environment.

A limited soil sampling programme proved that the soil in Itumbi and Londoni is polluted with mercury. This is a serious threat to the environment and to the health of the inhabitants.

Each step of gold extraction has been investigated, from the milled ore to the tailings. One conclusion is that the milling is not efficient. The sluicing is quite efficient for coarse grained gold, whereas gold dust is difficult to capture in the sluice. The sluicing can be improved by having a constant water flow and possibly with other types of cloth. Comparing cloth types used in Tanzania and elsewhere e.g. Philippines indicate that an improved recovery might be obtained in using more appropriate types of cloth.

Mineral concentrates from the three different small-scale mining communities were tested by the borax method. These tests indicated that regardless of types of ore, the borax gold extraction can be used.

It can be concluded that the borax technique is the best available technique (BAT) for gold extraction on the level where small-scale mining is carried out in Tanzania

In conclusion:

- Gold recovery is not efficient, hence a lot of gold is not recovered
- The amalgamation process pollutes not only the villages, but also the whole region thus causing serious health hazards to the local population.
- Best Available Technique for gold extraction is the borax method

9. Recommendations

The task of *Enhancing Environmental Quality through Improved Gold Recovery in Artisanal and Small-Scale Gold Mines in Tanzania* is not an easy one. The present project has shown that there is a genuine need of improving gold recovery and reduce mercury pollution of the environment. The present project also outlines ways to solve the problems.

The question is which way to go?
Advanced equipment can do the job, but needs infra structure, funding, easy access to spare parts, access to electricity etc. There have been several well meant attempts to help the small-scale miners increase their recovery of gold. World Bank built a huge gold extraction plant for small-scale miners near Matundasi, Chunya district. The site chosen was near one of the most promising small-scale mines. That mine has unfortunately not come into production yet and all other small-scale mining communities are situated more than 5 km from the plant and transportation costs are therefore prohibitively high. The extraction plant has thus never produced one gram of gold.

UNIDO made a well documented report entitled: *Equipment specification for the demonstration units in Tanzania (Veiga, 2004)*. The report concludes that stationary crushing; milling and gold extraction units are not feasible since much gold mining is carried out by migrant small-scale miners moving from site to site. The report thus recommends mobile units which can follow the migrant workers. At a first glance the suggestion seems fine, but it has its flaws. Maintenance is always a problem if such machinery is not the responsibility of a person or an entity. Spare parts to some of the suggested equipment may be difficult to obtain. Who is responsible for moving the mobile units and who will pay the bill?

An important consideration is not to introduce highly mechanised equipment as the first step. It is the belief of the authors that improving gold recovery and reducing the environmental impacts by small-scale mining shall initially be done by simple not sophisticated equipment.

The results of the present project suggest the following road map:

- Detailed and comprehensive investigation of the milling and sluicing processes
- Test other types of inexpensive mills and sluices. Different types of cloth in the sluices may prove beneficial to increased gold recovery.
- Detailed investigation of the grain size distribution of gold in the tailings and whether the gold in the tailings is locked up in other minerals and thus not recoverable with the presently used techniques. If the gold is locked up in other minerals then experiments should be made in order to recover that gold.
- Geological, mineralogical and chemical investigation of the different types of gold ore
- Further investigate the amenability of all the different ores to gold extraction by the borax method

When those investigations have been carried out it is important to:

- Train the small-scale miners to recycle mercury by using retorts
- Teach the small-scale miners using borax
- Teach the miners to use other mill types and better sluicing techniques.

The environmental problems should be monitored through:

- Mapping the extent of mercury pollution of the soils
- Investigating the mercury contents in crops and cattle
- Measure mercury contents in small-scale miners and villagers

Health problems:

- Inform the small-scale miners and the communities of health problems such as stone lungs, tinnitus and mercury related problems.

When those investigations have been carried out it is important to:

- Inform the communities of the long term dangers of mercury poisoning
- Teach the communities on how to avoid mercury and other health problems.

One of the stumble stones in the presently used processing is the use of dry milling. It is suggested to test wet milling as used in the Philippines and elsewhere. The wet rod mills used in the

Philippines are inexpensive locally made drums which will not cost more to manufacture than the presently used mills. This method has two immediate health advantages:

1. No dust hence no risk of silicosis
2. No noise pollution hence no risk of tinnitus.

Introducing wet milling could then create a win win situation and a first step in increasing gold extraction without use of sophisticated equipment.

How to reduce gold loss to the tailings.

It is a well known fact, as also witnessed by the present study, that the vast majority of small-scale gold miners do not recover all the gold in their gold ores. The recovery rate varies from place to place, but in general in the order of 40 percent of the gold is not recovered.

The main reason is either that the gold which cannot be recovered is too fine grained, or the gold is locked up in other minerals. Are there ways to recover the fine grained gold? A widely used method to recover fine grained gold is to use cyanide. The biggest problem in suggesting cyanide is the reaction from people. Most will immediately reject the suggestion by referring to the extreme toxicity of cyanide. Cyanide is extremely toxic no doubt about that. However, the toxicity is neutralised very quickly by the atmosphere. If a cyanide spill occurs, it will be harmless within a very short time. The cyanide is thus only lethal for a short time, whereas mercury is toxic for generations.

Cyanide gold extraction does require much skill and training. A cyanide plant cannot be moved from place to place following migrant small-scale miners. However a cyanide plant can be established and operated in more permanent small-scale mining communities. It is thus recommended to investigate whether cyanide plants can be installed in places like Itumbi.

It is important to follow-up on the teaching and training. When a teaching programme has been carried out in a small-scale mining community it is vital that it is followed up. The community has to be revisited repeatedly over a long period in order to make sure that no technical problems arise and to keep informing the miners of the financial benefit for them as well as a benefit for the environment.