Introduction of mercury-free gold extraction for small-scale miners in the Cabo Delgado region in Mozambique

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Introduction

Mercury is commonly used in small-scale gold mining to separate gold from other minerals due to its ability to bind to gold and form amalgam. Small-scale gold mining releases large amounts of mercury to the environment and is estimated to contribute with 37% of the mercury emission on global scale (AMAP, 2013). The emission of mercury has strong negative effects on local environments, the health of the miners, the people living near the mines and the pollution affects the environment and health on global scale. In order to reduce the global mercury pollution and the health hazards related to mercury emission the use of mercury in small-scale mining should be stopped (Perez E et al., 2007). Methods for gold extraction without the use of mercury are available. One method has proven to be implementable and safe (Køster-Rasmussen et al., 2016). The method is called the *mercury-free gold extraction method* and involves smelting with borax. The method has been used among small-scale gold miners in Benguet in the northern Phillippines for more than 30 years (Leoncio, 2018). This method was implemented in a mining community that was formerly using the amalgamation method and the area remained mercury-free for at least 2 years (Køster-Rasmussen et al., 2016). In February 2018 members of the Danish NGO Diálogos and the Spanish NGO MM (funded by the European Union) carried out a project introducing the mercury-free gold extraction method by training a group of miners from the Cabo Delgado region in northern Mozambique. The teaching and training was carried out in the two mining communities Waqueia and Nanlia.

The objective of the present study was to compare the local gold extraction method and the mercury-free gold extraction method in terms of gold recovery and mercury consumption. The hypothesis was that the gold recovery would be higher with the mercury-free method compared with the locally used amalgamation method.

Gold extraction

The default method for extraction of gold among small-scale mines in Mozambique is the amalgamation method (ref?). The process of the amalgamation method in the visited mines briefly summarized goes as follows: the hard rock ore bodies are accessed from sinking shafts. The gold-bearing quartz veins are crushed into very coarse gravel size and then ground into dry powder in a ball mill without adding water. The milled ore is subsequently washed down a chute covered with a piece of cloth. The cloth captures the grains of gold and other heavy minerals. The lighter minerals end up in the tailings (mine dumps). The concentrate of heavy minerals from the cloth is mixed with

mercury in a washing pan, where the gold amalgamates with mercury. The amalgam is recovered and then heated over a bonfire in an iron cup. During the heating mercury evaporates and the gold is left, still containing some mercury. The amount of gold recovered with the amalgamation method is strongly depending on techniques of processing such as sluicing. The advantage of the amalgamation method is that it is easy and fast to operate. The main disadvantage is the use of mercury and the fact that much gold is lost to the environment (Appel & Jønsson, 2010).

The mercury-free gold extraction method uses borax in the process of smelting the gold. Borax is used in the smelting process because it lowers the melting point of gold and other metals. The Borax is used to smelt the gold, as the miners with the simple conditions and technologies used in the small-scale mines cannot reach sufficient temperatures to smelt gold without the use of borax.
In the mercury-free gold extraction method the mining of gold-bearing ore, the grinding of the mined material and the concentrating from sluicing are the same as in the amalgamation method. The concentrate of heavy minerals obtained from sluicing must contain a high concentration of gold for the borax to work as a flux to purify and smelt the gold concentrate (Appel & Jønsson, 2010). Such concentrate is obtained through panning, where lighter minerals are discarded from the washing pan to the tailings due to gravity, see picture 2. The concentrate of heavy minerals contains magnetite, which is removed with a magnet. Gold is often trapped as fine grains within larger grains of heavy minerals (ref?). To liberate the fine grained gold, the heavy mineral concentrate is ground in the washing pan with a rock. The concentrate with a high proportion of gold is then mixed with borax in a small plastic bag. The amount of borax should not be less than 30% of the estimated gold dust weight (Leoncio, 2018). To smelt the gold, the mix is placed in a clay bowl with a few grams of borax and charcoal. The charcoal is fired up and high temperatures are obtained by using a manual or electrical blower. Depending on the intensity of the blowing the smelting of the gold takes 10-20 min, see picture 3 (Leoncio, 2018).

Picture 1: Waqueia. The processing station used for the amalgamation method in the foreground and the processing station for used for the mercury-free gold extraction method in the background.

Picture 2: Local miner from Waqueia panning a heavy mineral concentrate.

Picture 3: Smelting of the gold with borax.

Methods

This is an experimental study comparing the gold yield from the amalgamation method and mercury-free gold extraction method. The study was carried out from the 11th to the 19th of February 2018 at the mining sites of Waqueia and Nanlia in the Cabo Delgado province in the northern Mozambique. The comparison was carried out so that the local miners processed gold-bearing ore with their standard procedure using the amalgamation method and the Diálogos team processed an equivalent amount of gold-bearing ore with the mercury-free gold extraction method. To make an accurate comparison of the methods, the total amount of gold-bearing ore was divided in two portions, spade by spade, to ensure homogeneity in the two portions. The two portions were weighted to ensure that the amount of the lots was equal.

Comparison of the two methods
To compare the processing with the two methods and the quantitative outcome two experiments were carried out; one in Nanlia and one in Waqueia.

The first experiment was carried out in Waqueia on the 14th of February 2018. In Waqueia 88 kg of milled ore was processed with each method. To divide the ore it was placed in a large tub, mixed and divided little by little into two lots that were weighed, see picture 5.
The local processing set up was constituted of chute made out of bamboo covered with old sacks and a sluicebox (Foreground in picture 1.) with holes of approximately 1 cm in diameter. The local miners filled up the sluicebox with the milled ore and washed it down the chute by adding water from buckets in the sluicebox, which resulted in an uneven flow of water down the chute. Subsequently, the heavy mineral concentration caught by the sacks was washed into a tub, drained and placed in a washing pan, where mercury was added. The mercury was kneaded into the material and an amalgam formed. The amalgam was then put into an iron cup and heated over a bonfire.
The processing set up used for the mercury-free gold extraction method also consisted of a chute and a sluicebox (Background in picture 1). To process the ore the milled ore was placed in the backend of the sluicebox. The chute was covered with cloth of felt. The milled ore was washed slowly down the chute with the use of a hose that was connected to a large barrel of water. The heavy mineral concentrate collected by the cloth was subsequently washed into a tub. The heavy mineral concentrate was then panned, the magnetite was collected with a magnet and the concentrate was ground with a rock to liberate the fine gold. The mineral concentrate was then mixed with borax and burned as described in the methods chapter.

The second experiment was carried out in Nanlia on the 17th of February. In Nanlia 150 kg milled ore was processed with each method. The ore was divided spade by spade into two equal lots. The local processing set up in Nanlia was similar to the one in Waqeuia, except that the chute in Nanlia was covered with 3 layers: in the bottom a layer of plastic, then a layer of fabric and on top with a layer of cloth. The milled ore was placed in the sluicebox and washed down the chute. The local miners of Nanlia used running water from a hose to create an even flow of water down the chute. A heavy mineral concentrate was collected from the layers of fabric and panned to further concentrate the ore. The mineral concentrate was then mixed with mercury to form an amalgam. The amalgam was heated in an iron cup. The Diálogos team used the same setup as in Waqueia as described above.

The gold produced with the amalgamation method still contain some mercury after the heating. In order to make a more accurate comparison the gold produced with the amalgamation method was therefore burned with borax to purify it and make the gold yield from the two methods comparable.

Results

In Waqueia the local miners recovered 0.9 g gold with the amalgamation method and the team from Diálogos recovered 1.6 g gold with the mercury-free gold extraction method. The mercury-free gold extraction method thus recovered 78% more gold than the amalgamation method. Extrapolating this result with information from the local miners regarding the yearly amount processed, the miners of Waqueia may lose approximately 2 kg of gold every year plus substantial amounts of mercury.

In Nanlia the methods recovered an equal amounts of gold: 3.6 g.

Picture 5: In order to make the comparative study the milled ore was divided in two lots of equal amount and quality.

Discussion

The comparison showed that the mercury-free gold extraction method in one case yielded 78% more gold than amalgamation method and in the other case the same amount of gold. Thus, the mercury-free method was equally good or better than the local methods. A possible explanation for why the miners in Nanlia were able to get the same amount of gold from the milled ore as the Diálogos team is that the local miners used a very efficient sluicing technique and that the ore contains none or very little fine gold and therefore not much gold was liberated from the gold concentrate when it was ground with a rock. Unlike the miners in Waqueia, the miners in Nanlia used a sluicing technique, where they were able to create an even flow of water, which makes less gold grains escape the fabric on the ramp. Furthermore, the miners in Nanlia used a finer woven cloth for their chute, which also may cause less gold to escape. The gold-bearing ore processed in Waqueia, on the other hand, contained some fine grained gold that was liberated from the larger grains of heavy minerals.

Strenght
It is a strength that the study was carried out in a real setting. It is a strength that the local miners used their well-known method in their own setting. This may

have biased the results in favor of the amalgamation method. With more iterations the Diálogos miner, may have further improved the gold yield with the mercury-free method.

Weaknesses
In the present study the comparison was only carried out two times. More iterations would have given a more valid result. However, preparing experiments takes time from both researchers and gold miners and as the project is mainly an aid and technology transfer project, it was not possible to allocate more time for more iterations.

The gold produced with the amalgamation method does, even after the burning with borax, contain small amounts of mercury, which is a bias in favor of the amalgamation method. Thus, the mercury-free method likely yielded a bit more gold even in Nanlia, where the methods at a first glance performed equally.

Potential for implementation
Adapting the mercury-free gold extraction method requires time and practice, as the smelting procedure is more complex than burning amalgam. In order to convince the miners to change to the mercury-free method they were introduced to both economical and health advantages of the method. The strengths of the mercury-free gold extraction method is the higher gold yield and the use of a cheap, benign, legal and most places readily available chemical compared with the amalgamation method. However, the mercury-free method may be more time consuming than the amalgamation method, especially for starters. Borax is typically accessible in developed urban areas, as it is commonly used in welding industry and by jewelers, but can be hard to access in remote villages. As access to borax is essential for implementation of the mercury-free gold extraction method establishment of borax distribution or information on distributors in the remote villages may be a necessity.

Conclusion
Under even circumstances in a controlled but realistic setting the gold recovery with the mercury-free method was equal to or up to 78 % higher than with the locally used amalgamation method.

Further work
The goal of the project is that the miners will adapt the mercury-free gold extraction method and that the new method will spread to other small-scale mining communities in the area. In order to facilitate this the group of Diálogos members gathered with the miners from Nanlia and Waqueia for discussions about how they can disseminate the mercury-free gold extraction method to other groups in the Cabo Delgado region. The focus of the discussion was primarily on how single miners or associations have little ability to convince other miners or associations to go mercury-free. It was suggested that the associations team-up and establish an umbrella federation. Such umbrella federation could potentially represent thousands of miners and enhance the access to the political system in order to improve working conditions for small scale miners in Mozambique.

During the training the best skilled local miners were selected as possible future trainers. In both mining areas we talked about the option of changing to wet milling, where water is added to the ball mill when grinding the mined ore, in order to protect their lungs from dust.

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