RECOVERING THE LOST GOLD OF THE DEVELOPING WORLD: CASE STUDY IN MIGORI COUNTY, KENYA

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Abstract

Artisanal & Small-scale Gold Mining (ASGM) is a subsistence level livelihood for many rural communities across the world. In Kenya it provides work for an estimated 40,000 people and produces 5 Tonnes of gold per year. The impact of ASGM is double-edged with the economic benefits offset by damage to the environment and the health of the mining communities due to the widespread use of mercury to recover gold. As a signatory to the Minamata Convention on Mercury (2017), Kenya has agreed to eliminate the use of mercury, formalise the ASGM sector, introduce good practice and protect the health of mining communities.

Migori County is a major ASGM centre in southwest Kenya where gold is produced from quartz–carbonate reefs in the Migori greenstone belt. Recovery of gold involves extraction of the ore by mining and processing. The deep mine shafts are unstable and there are regular reports of fatalities due to mine collapse. The gold is recovered by manual crushing, ball milling, sluice box concentration and mercury amalgamation. Residual gold is recovered by cyanidation of the tailings. The local ASGM communities are concerned about the safety of the mining, the environmental impact of mercury and poor gold recovery.

The British Geological Survey (BGS) worked with the University of Nairobi and the Migori County Artisanal Miners Co-operative (MICA) to promote good ASGM practice, reduce mercury use and improve gold recovery using appropriate technology. On average hard rock gold is finer than 100 microns. This makes the use of a sluice box a very inefficient recovery method with expected recoveries as low as 20% for gold of 100 microns or finer.

This paper outlines preliminary good practice guidance for ASGM in Migori, Kenya. The guidance includes advice on sluice box design including the use of longer sluice channels (at least 3 metres or preferably more) and appropriate sluice box gradients; closed circuit milling; size classification and conditioning of the sluice box feed material; and alternative gravity processing methods to enhance gold recovery; and mercury recovery using retorts.

This BGS research was part of the BGS Official Development Assistance (ODA) research project “From source to sink: Quantifying the local and downstream environmental impacts of ASGM”.

Mitchell, C.J., Bide, T. and Odhiambo, C. 2022. Recovering the lost gold of the developing world:
Case study in Migori County, Kenya.
Pp. 98-104 in Wardrop, D. (Ed.) Proceedings of the 22nd Extractive Industry Geology Conference 2022
and technical meeting 2023, EIG Conferences Ltd, 105pp.
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Introduction

Artisanal and Small-scale Gold Mining (ASGM) is widespread in many Archaean greenstone belt terranes across the world, particularly in Africa, Asia and South America. It is a major employer and provides a significant source of income for many rural communities (Intergovernmental Forum on Mining Minerals Metals and Sustainable Development, 2017). Improvement to ASGM practices has the potential to provide a significant boost to local economies by securing livelihoods and enhancing the quality of life. However, ASGM can also have significant negative environmental consequences. This can be through the release of harmful chemicals used in processing (including mercury and cyanide) into soil and water, destruction of natural forest for timber used in shaft construction and maintenance, poor water management practices and the incorrect storage and management of waste.

Gold recovery in ASGM areas involves simple gravity processing methods that rely on the relative density of gold, such as panning and sluice boxes. These are ideal for the recovery of the alluvial gold found in river sediments, as it is relatively coarse-grained (typically 300 to 1500 microns). Gold that occurs in greenstone belts, often referred to as ‘hard rock’ gold, is very fine-grained (typically less than 100 microns, with a significant proportion finer than 10 microns). The recovery efficiency of a sluice box is as low as 20% for gold finer than 100 microns (Mitchell *et al.*,1997). This results in a high proportion of the gold in greenstone belt ASGM areas being lost when gold recovery methods such as panning or sluice boxes are used. This represents a poor financial return for the hard work and risks taken by the rural farming or migrant labourers that typically make up ASGM communities. It may also result in higher throughput of material and associated detrimental environmental impacts that are associated with ASGM.

The British Geological Survey (BGS) worked with the University of Nairobi and the Migori County Artisanal Miners Co-operative (MICA) in Migori County, Kenya on ASGM good practice with a focus on the reduction of mercury use and the efficient recovery of gold (Mitchell & Bide, 2020). In Kenya, ASGM is a subsistence level livelihood that provides work for an estimated 40,000 people, mainly in rural communities and produces an estimated 5 Tonnes of unofficially produced gold per year (Barreto *et al.*, 2018). The recommendations in this paper focus on changes to mining practice to help improve gold recovery rates, increase the income for ASGM communities and reduce the environmental impacts of mining. This aligns with the Kenyan National Action Plan commitment to the Minamata Convention on Mercury. (https://www.epa.gov/international-cooperation/minamata-convention-mercury).

RECOVERY OF GOLD USING A SLUICE BOX

The use of a sluice box is one of the oldest known processes to recover gold. The mythical tale of Jason and the Argonauts, set around 1300 BC, describes the quest to find the Golden Fleece. This is a reference to sheep fleeces that were used to line streams as a rudimentary sluice to capture gold from the stream sediment. This technique is still in use in the mountainous region of Svaneti in northwest Georgia and is likely to be the original inspiration for the legend (Okrostsvaridze *et al.*, 2014). Gold in the stream sediment was caught in the fleece that was then hung in a tree to dry and later brushed to remove the gold.

Today, sluice boxes are in common use for the recovery of gold by commercial mining operations for example in Alaska and Yukon in North America as well as the much smaller ASGM sites in the developing world. They are comparatively cheap to build and operate and can be used to process ore with gold grades from as low as 0.1 g/m3 (which is equivalent to 0.05 to 0.16 grams per Tonne).

It might be useful to show working and assumptions here:

Taking a bulk density of gold ore at 1.6t per m^3 then:-

Grade at 0.1g/m^3 = 0.1 x1.6 = 0.16g per Tonne. At todays price 1g = $65.

The ratio of gangue (non-gold) to gold particles can be as high as 10,000 to 1 meaning that a huge effort is required to make a meagre return.

A commercial sluice box consists of an open channel that is inclined at 5 to 10° below the horizontal. Matting, such as a heavy traffic office building floor matting, is used to line the bed of the sluice and acts as a trap for the gold particles. This is overlain with riffles, typically angle iron or expanded metal mesh. The feed slurry typically has a concentration of 9% (weight/volume) of solids in water. The slurry flows down the sluice and stratifies into three layers (Clarkson, 1994) as shown in Figure 1.

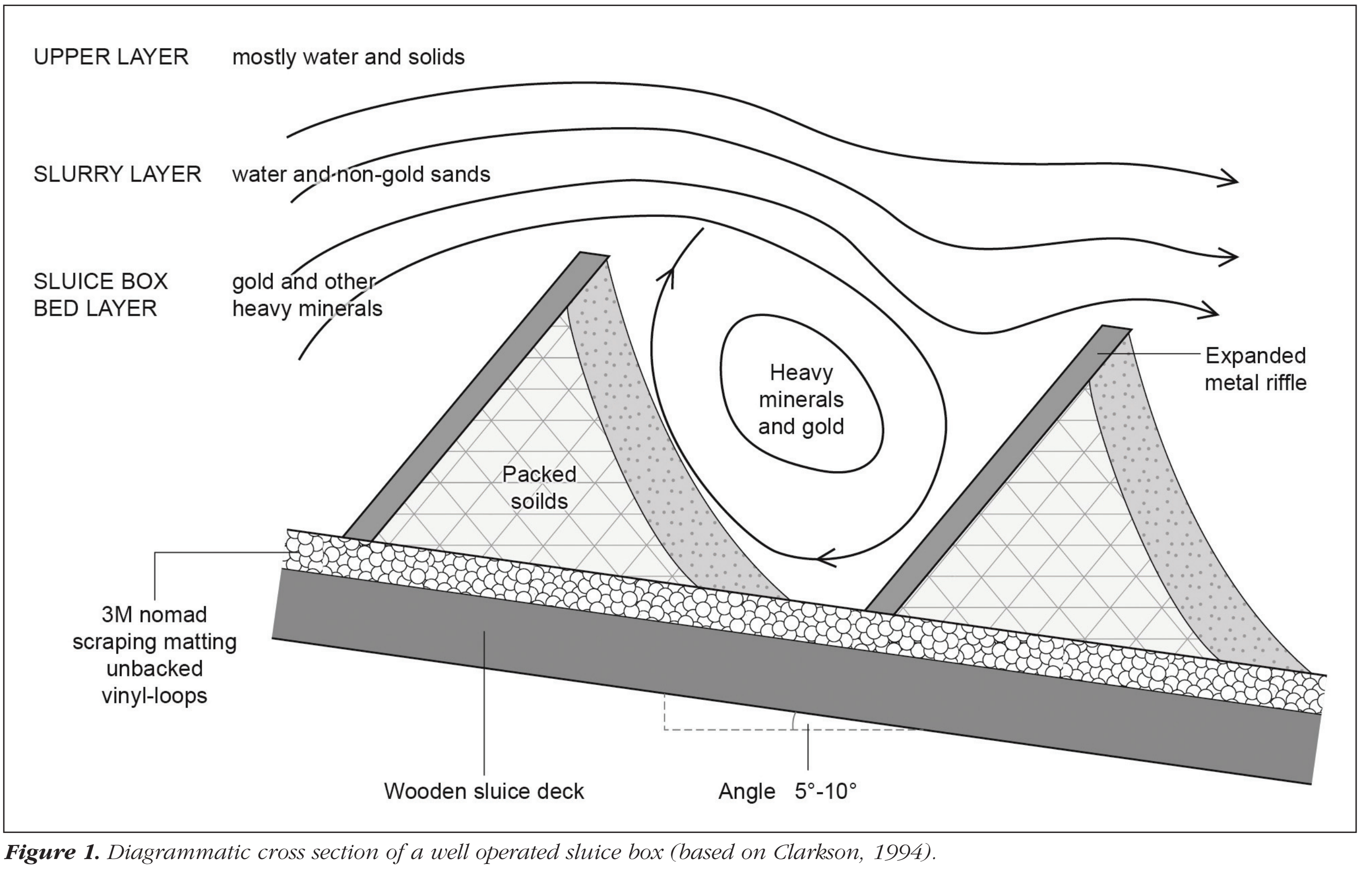

Figure 1. *Diagrammatic cross section of a well operated sluice box (based on Clarkson, 1994).*

Sluice box bed layer: This is the bottom layer which travels directly over the bed of the sluice box. As gold is a very dense mineral (19.32 g/cm^3) compared to typical gangue minerals such as quartz (2.65 g/cm^3) it sinks very quickly to this bottom layer of the slurry. The bottom layer contains most of the gold.

Slurry layer: This is the main solids transport layer where the gangue minerals are washed down the sluice. There may be some very fine gold that is entrained within the non-gold minerals in this layer. There is a continuous transfer of solids between this and the lower sluice box layer.

Upper layer: This layer consists mostly of water with some fine-grained minerals such as clay. It may also contain very fine-grained flake gold that is carried down the sluice as it is supported by the surface tension of the water.

The riffles cause a vortex-like disruption of the sluice box bed layer of the slurry that acts as a form of centrifugal separator. This captures the gold particles in between the riffles and eventually drives them into the matting where they remain. A well operated sluice box can recover over 95% of 1mm sized gold particles. This however reduces to less than 20% of gold particles finer than 0.1mm (100 microns) (Mitchell *et al*., 1997).

OBSERVATIONS ON GOLD RECOVERY IN MIGORI, KENYA

Migori County is a major ASGM centre located in southwest Kenya. Gold is produced from quartz–carbonate reefs in the basalt and banded iron formation of the Precambrian Migori greenstone belt. Deep unstable mine shafts propped with wood, use of explosives in cramped tunnels, poor ventilation and inadequate mine dewatering make the gold mines a difficult and dangerous place to work. Ore is hauled out manually, crushed using hammers and milled in Tanzanian-designed ball mills. The mills are deafeningly noisy and are the shrill hallmark of ASGM in Kenya.

The milled ore is processed using poorly built sluice boxes (Plate 1) and the concentrates are then panned with mercury. The tailings from the sluice box are reprocessed multiple times. This is a recognition by the miners that a significant amount of gold remains in the tailings after sluice box processing. The gold combines with the mercury to form a putty-like amalgam which is heated over an open fire to drive off the mercury as a vapour and leave behind a small porous ball of 'sponge gold'. Residual gold in the tailings is recovered by cyanidation (Mitchell *et al*., 2020).

Observation of the artisanal gold mining operations in Migori identified multiple technical issues that are likely to

Plate 1. *Sluice box in artisanal gold mining site, Kehancha, Migori County, Kenya.*

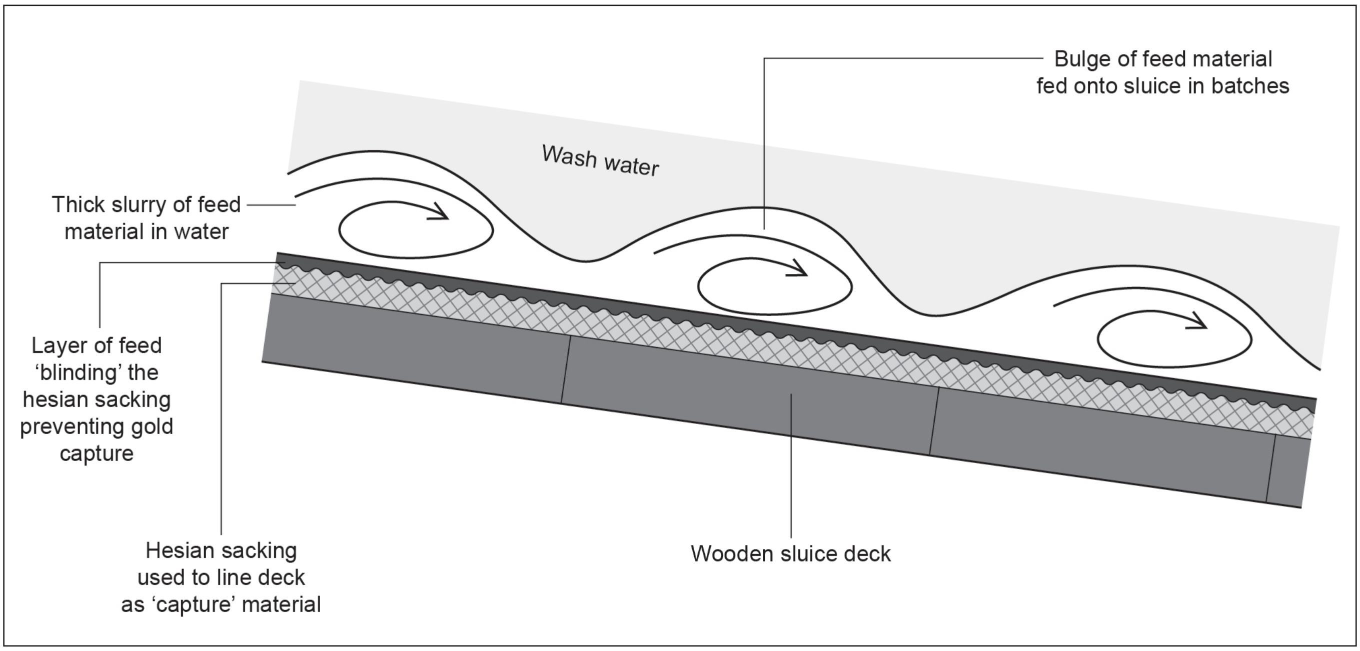

Figure 2. *Poorly operated sluice box as seen in Migori, Kenya.* *Not to scale*

result in poor gold recovery. These are summarised below and various aspects are illustrated in Figure 2.

Poor sluice box design: The sluice boxes are randomly inclined at angles between 5 and 15° from the horizontal. The length of the sluice box is often too short, typically less than the optimum 3 to 5 metres length (Clarkson, 1994). Short pieces of hessian sacking material of different pore sizes are used to line the sluice deck to trap the gold. The sluice bed is often irregular with breaks in slope (Figure 2). These latter two issues cause interruptions in the flow and lead to poor gold recovery.

Fine particle-size of the feed material: The gold ore is milled to a very fine particle size (65 to 90% finer than 100 microns in diameter). At this particle size it is likely that much of the gold is washed over the sluice into the tailings. Material finer than 75 microns, otherwise known as 'slimes', interferes with efficient separation (Teschner et al, 2017).

Blinding of the trapping media: The hessian sacking used as the trapping media is often 'blinded' i.e. the spaces where gold is meant to be trapped are filled with feed material so there is no space left for gold to be captured. Consequently gold particles are washed over the surface of the sluice box and are lost to the tailings.

Poor feed delivery: The gold ore is fed onto the sluice box manually in batches with insufficient wash water. This results in an irregular and inconsistent flow across the sluice box. The flow dynamics of the feed slurry are not established sufficiently to enable efficient trapping of gold particles into the trapping media.

RECOMMENDATIONS FOR IMPROVED GOLD RECOVERY

Implementation of the following good practice recommendations would help to improve the gold recovery of the existing ASGM operations in Migori (illustrated in Figure 3):

Recommendation 1: Sluice box design

Longer sluice box channels of at least 3 metres to increase the gold capture area. Consistent sluice deck slope appropriate for the particle size of the ore. Use of more effective trapping medium such as 3M^{tm} Nomad matting and expanded metal riffles or wooden bars across sluice deck. Regular cleaning of the matting to recover the gold (Figure 4).

Recommendation 2: Closed circuit milling

Ball milling of gold ore tends to over-grind a proportion of the feed material. Reducing the residence time of the feed material in the mill and introducing a screen to remove ground material would help to reduce over-grinding.

Recommendation 3: Coarse and fine sluice box feed

Screening to separate the milled ore into fine-grained and coarse-grained material to enable more efficient gravity processing. The separation of particles based on difference in their density is more efficient with closely sized feed material. Separate sluices boxes for fine-grained and coarse-grained feed material would be necessary. These would have different operating conditions such as a faster wash water flow rate and steeper sluice box inclination for coarser material.

Recommendation 4: Conditioning of sluice feed

Thorough mixing of feed material with water by the operatives is recommended before introducing it into the sluice feed box. This enables a more consistent, steady flow across the sluice box with no interruptions. In addition, use of a surfactant such as soap in the wash water will reduce surface tension and minimise the amount of floating gold lost to the tailings.

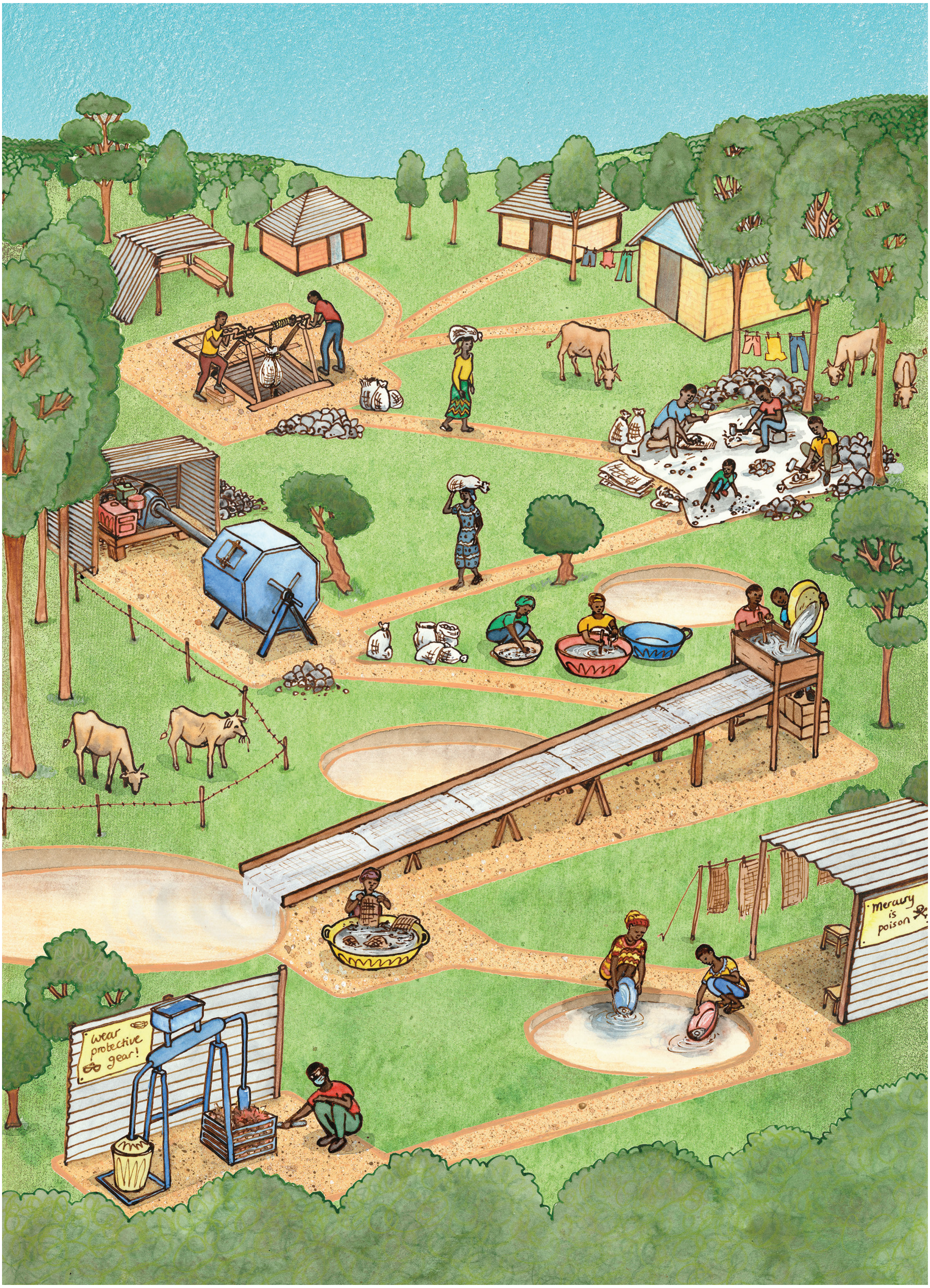

Figure 3. *Diagrammatic representation of gold recovery in Migori, Kenya following good practice recommendations (Illustration © Sarah Hannis Illustration).*

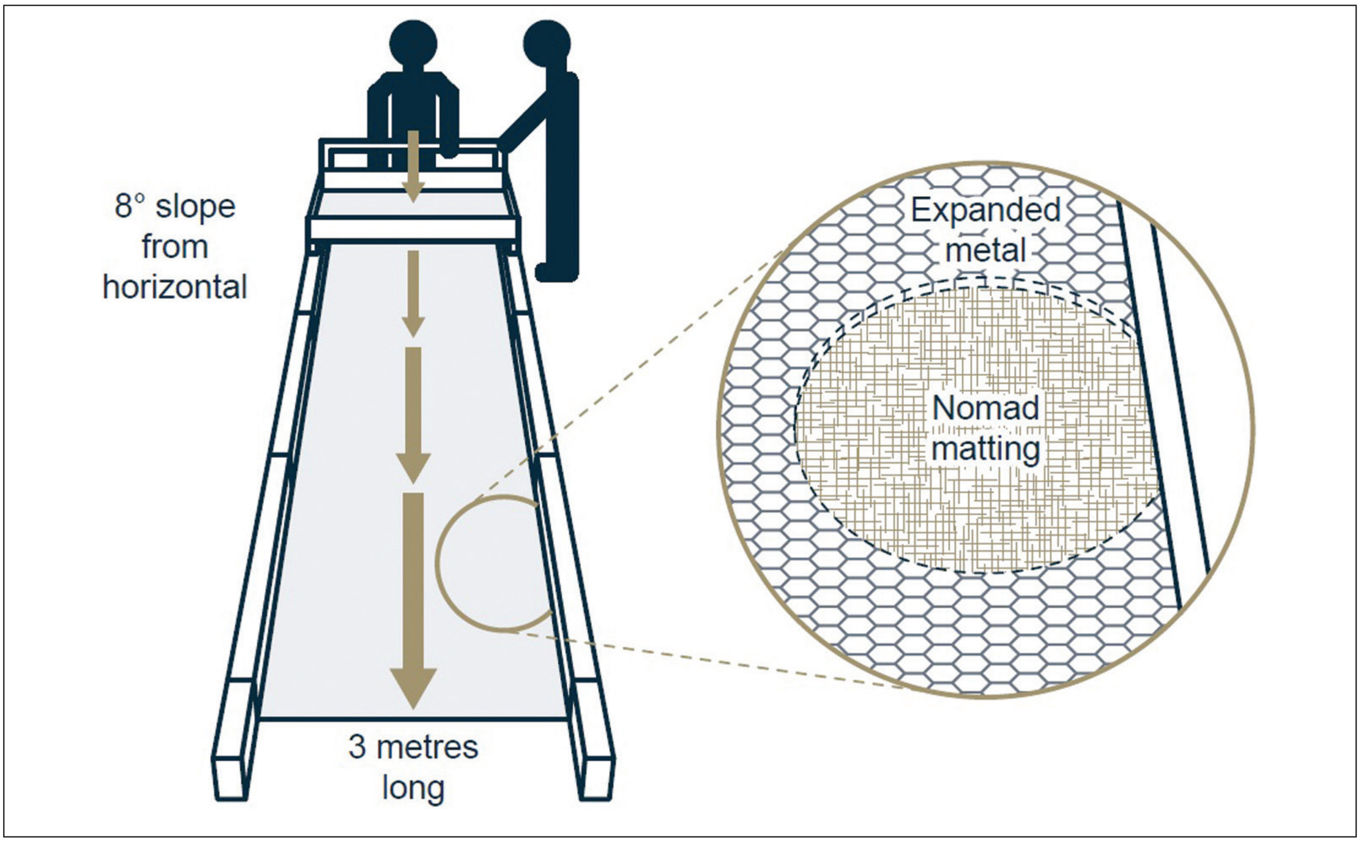

Figure 4. *Optimised sluice box for gold recovery (with a cut away showing the matting layer).*

Recommendation 5: Alternative gravity processing

The lower particle size limit of gold recovered by a well operated sluice box is around 100 microns, although recovery efficiency is low below 200 microns. An alternative gravity recovery method, more appropriate for fine-grained hard rock gold, is a shaking table which can recover gold as fine as 15 microns.

Recommendation 6: Mercury recovery

Mercury-gold amalgam is typically cooked over an open fire. The mercury evaporates leaving behind a small ball of 'sponge' gold. This process is responsible for releasing a significant amount of mercury into the environment. The use of a mercury retort is recommended instead. In this retort amalgam is heated in a sealed container so that the mercury vapour condenses and is captured in a container without being released into the environment (Figure 5).

Figure 5. *Mercury retort (Illustration © Sarah Hannis).*

Small-scale mining cooperatives

The Migori County Artisanal Miners Co-operative (MICA) have established a small-scale gold processing facility to demonstrate good practice for gold recovery. The MICA gold processing plant includes a jaw crusher, hammer mill and shaking table. This shaking table has the capacity to recover gold down to a much smaller particle size than the sluice boxes used by the artisanal miners. MICA also has a centrifugal (bowl) separator and a ball mill which members plan to deploy in a second demonstration gold processing circuit. A mercury retort has been produced by MICA for use by the artisanal miners to safely recover mercury from the amalgam. This is based on a retort from Zimbabwe and is manufactured locally in Migori town. Use of this retort would lead to a significant reduction in the amount of mercury being released into the environment. It would also save money by reducing the amount of mercury required.

The uptake of mercury reduction solutions will rely on the success of small-scale mining cooperatives such as MICA in promoting good practice for gold recovery and building on the success of past technology transfer. The Tanzanian ball mill, which was introduced by MICA and is now ubiquitous across Migori, despite its limitations, is an example of successful good practice implementation. Future good practice implementation by MICA will focus on the use of shaking tables for fine gold recovery and retorts for mercury recovery.

CONCLUSIONS

Fine grained gold can be recovered efficiently and with minimal use of mercury. The recovery of gold in ASGM areas such as Migori in Kenya could be improved by using consistent feed delivery, consistent wash water flow, increasing the sluice box length and an appropriate inclination of the sluice box. Switching from a sluice box to a shaking table would increase the amount of gold recovered and reduce loss of gold to the tailings. Use of a mercury retort would reduce the amount of mercury released into the environment and reduce the money spent on mercury.

Implementation of good mining practice would improve the amount of gold recovered and reduce the amount of mercury consumed by the existing artisanal gold mining operations. However, a more fundamental shift away from sluice boxes to shaking tables would be needed to achieve a greater increase in the amount of gold recovered.

The good mining practices demonstrated by the mining cooperative MICA, such as shaking tables and retorts to recover mercury, are likely to be the most effective means of successfully improving gold recovery and reducing mercury consumption in the artisanal gold mining district of Migori. This would be an important change which in the medium to longer term would have great benefits to the environment and health of mining communities of western Kenya.

ACKNOWLEDGEMENTS

The authors of this report would like to thank the following for their assistance and support:

- Professor Eric Odada, Professor Daniel Ichang'i, Dr Lydia Olaka and Jemimah Mulu from the Department of Geology, University of Nairobi
- John Asembo and James Asembo, Migori County Artisanal Miners Associatio7n (MICA)
- Dr Joseph Mankelow, Dr Michael Watts, Dr Andrew Marriott, Ellie Evans, Alessandro Novellino and Claire Fleming from the BGS
- Evance Juma (private driver) and Sammy & James (drivers, University of Nairobi)
- Terry Garde and Joshua Read (Mining Engineers) for their advice and support.
- Illustrations in Figures 1 and 2 by Henry Holbrook, BGS; Figure 4 by Craig Woodward, BGS
- Illustration in Figures 3 and 5 by Sarah Hannis www.sarahhannis.com

This work was supported by the British Geological Survey via NERC national capability (BGS NC-ODA grant NE/R000069/1 entitled Geoscience for Sustainable Futures). It was delivered via the BGS Eastern Africa Official Development Assistance (ODA) Research Platform.

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REFERENCES

Barreto, M, Schein, P, Hinton, J, and Hruschka, F. 2018. Economic contributions of artisanal and small-scale mining in Kenya: Gold and gemstones. *East Africa Research Fund* https://assets.publishing.service.gov.uk/media/5a392bb8e5274a79051c9d7c/Kenya_case_study.pdf

Clarkson, R.1994. The use of nuclear tracers to evaluate the gold recovery efficiency of sluiceboxes. *CIM Bulletin,* 87, No. 979, p.29-37.

Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development. 2017. Global Trends in Artisanal and Small-Scale Mining (ASM): A review of key numbers and issues.

Mitchell, C.J., Evans, E.J. and Styles, MT. 1997. A review of gold particle-size and recovery methods. *British Geological Survey Technical Report WG/97/14.* http://nora.nerc.ac.uk/id/eprint/9014/

Mitchell, C.J. and Bide, T. 2020. Artisanal and Small-scale Gold Mining in Western Kenya. Blog: http://britgeopeople.blogspot.com/2020/02/artisanal-and-small-scale-gold-mining.html

Mitchell, C.J., Palumbo-Roe, B. & Bide, T. 2020. Artisanal & small-scale gold mining research field work, Migori County, Kenya. *British Geological Survey Open Report OR/20/010.* http://nora.nerc.ac.uk/id/eprint/528810/

Okrostsvaridze, A., Gagnidze, N and Akimidze, K. 2014. A modern field investigation of the mythical "gold sands" of the ancient Colchis Kingdom and "Golden Fleece" phenomena, *Quaternary International*, 409, pp 61-69 http://dx.doi.org/10.1016/j.quaint.2014.07.064

Teschner, B, Smith, N.M., Borrilo-Hutter, T, John, ZQ is this correct Z. Q. ? Wong, TE again is this correct ? T. E.. 2017. How efficient are they really? A simple testing method of small-scale gold miners' gravity separation systems. *Minerals Engineering* 105, pp 44–51.