Artisanal & Small-scale Gold Mining research field work, Migori County, Kenya

BGS Global Geoscience Programme

Open Report OR/20/010

BRITISH GEOLOGICAL SURVEY

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Keywords

Gold; Artisanal & Small-scale Gold Mining; ASGM; Migori; Kenya; Mercury; Sluice box.

Front cover

Sluice box at small-scale gold mine, Masara, Migori County, Kenya.

Bibliographical reference

CJ MITCHELL, B PALUMBO-ROE & T BIDE 2020. Artisanal & Small-scale Gold Mining research field work, Migori County, Kenya. *British Geological Survey Open Report*, OR/20/010. 39pp.

Keyworth, Nottingham British Geological Survey 2019

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Foreword

This report summarises field work carried out by the British Geological Survey (BGS) as part of an Artisanal and Small-scale Gold Mining (ASGM) research project based in Kenya.

The ASGM research forms part of the UK Government Official Development Assistance (ODA) research programme of the BGS. The ASGM research is a component of the Western Kenya Integrated Project (Research project 1, RP1) "From source to sink: Quantifying the local and downstream environmental impacts of ASGM". This project aims to combine a science-based enquiry with a community action learning approach addressing environmental issues related to ASGM and human health; the latter both directly (mining practice), and indirectly (contamination of food sources).

This research was supported by 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.

Acknowledgements

The authors of this report would like to thank the following for their assistance and support in preparation for and during the scoping and field trips carried out for this ASGM project:

- Professor Eric Odada, Professor Daniel Ichang'i, Dr Lydia Olaka and Jemimah Mulu from the Department of Geology, University of Nairobi
- Cavince Odhiambo, graduate geologist, University of Nairobi
- John & James Asembo, Migori County Artisanal Miners Association (MICA)
- Dr Joseph Mankelow, Dr Andrew Marriott, Alessandro Novellino and Claire Fleming from the BGS
- Evance Juma (private driver, scoping trip) and Sammy & James (field trip drivers, University of Nairobi)
- Terry Garde (Mining Engineer) for his encouragement, advice and support.

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Summary

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, particularly due to the widespread use of mercury to recover gold. As a signatory to the Minamata Convention on Mercury, 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 the quartz–carbonate reefs in the Migori greenstone belt. Recovery of gold involves extraction of the ore by mining. The deep mine shafts are unstable and dangerous places to work. 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 in the tailings is recovered by cyanidation. The local ASGM communities are primarily concerned about the safety of the mining, the environmental impact of mercury and poor gold recovery. The extent to which pollution from the mining activities leaches into groundwater and impacts water resources is also unknown.

The British Geological Survey (BGS) is working 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, alongside assessing the potential pressures ASGM poses on water resources.

Samples of gold ore, crushed and milled ore, concentrates and tailings were collected from ASGM operations. 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. Characterisation of the ore will provide the particle-size distribution of the gold and enable the liberation size to be determined. Size analysis of the milled material is expected to show that the ore has been 'over-milled' with a large proportion finer than 50 microns. It is likely that some of the gold has been reduced in size to the point where simple gravity processing methods such as sluice boxes will not work.

A total of 30 waters were sampled from shallow wells, boreholes, springs and mine shafts, to represent the different sources from which water is obtained by the public, during the period from the 15th to 20th November 2019, while assessment of surface water quality was carried out in a previous survey in January 2019. Mine processing waters and spoil runoff were also sampled.

This work will develop good practice guidance for ASGM. It will include advice from a mining engineer to improve mine safety; the use of retorts to reduce mercury consumption; and the use of longer sluice channels (at least 3 metres), appropriate sluice box gradients, consistent sluice box feed supply, alternatives to manual crushing, modification to the milling and alternative processing methods to improve gold recovery. The analysis of the inorganic chemical status of groundwater in the ASGM areas around Migori will assess the potential pressures posed by ASGM on water resources.

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

1 Introduction

Artisanal and Small-scale Gold Mining (ASGM) is a subsistence level livelihood that provides work for an estimated 40,000 people, mainly in rural communities, in Kenya. ASGM produces an estimated 5 tonnes of unofficially produced gold per year in Kenya (Barreto *et al*, 2018).

Migori County is a major ASGM centre located in the former Nyanza Province of 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 up with wood, the 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. These mills are deafeningly noisy and are the hallmark of ASGM in Kenya. The milled ore is processed using poorly built sluice boxes and the concentrates panned with mercury. Typically, the processing is done by women to sort the good ore from bad when it comes out of the mine and sluicing and panning to concentrate the gold from the ore. The gold-mercury amalgam is heated to drive off the mercury and a small ball of 'sponge gold' is the final product. Residual gold in the tailings is recovered by cyanidation. The local ASGM communities are primarily concerned about the safety of the mining, the environmental impact of mercury and poor gold recovery.

In response to these concerns, the British Geological Survey (BGS) is working with the University of Nairobi and the Migori County Artisanal Miners Co-operative (MICA) to promote ASGM good practice, reduce mercury use and improve gold recovery using appropriate technology.

This report outlines the field work conducted by the BGS in 2019. Samples of gold ore, crushed and milled ore, concentrates and tailings were collected from ASGM operations. Characterisation of the ore will provide the particle-size distribution of the gold and enable the liberation size to be determined. The aim of this work is to provide good practice guidance for ASGM that aims to align with the Kenyan Minamata Convention on Mercury National Action Plan.

2 Scoping visit

2.1 SCOPING VISIT INTRODUCTION

A scoping visit was carried out by the BGS and the University of Nairobi to the Artisanal and Small-scale Gold Mining areas of Migori County, Kenya. This scoping visit was part of the planning for the field work carried out in November 2019.

The scoping visit took place from Sunday 18th to Tuesday 20th August 2019. Participants were:

- Clive Mitchell (BGS)
- Cavince Odhiambo (on behalf of the university of Nairobi)
- Evance Juma (private driver; the vehicle (Nissan twin-cab 4x4) used was hired)

The objectives of the scoping visit to Migori County were as follows:

- Establish the practicalities of travelling to and around Migori County
- Identify suitable accommodation in Migori town
- Make contact with significant stakeholders and identify other stakeholders for the planned community engagement/ project sensitisation
- Visit mining areas to have a better understanding of ASGM operations
- Use the findings to draft a detailed plan for the community engagement (planned for the end of September/ early October) and the main fieldwork (planned for November 2019)

2.2 SCOPING VISIT ITINERARY

The scoping visit itinerary was as follows:

Sunday 18th August 2019

- 10am Set off from Nairobi to Migori
- 6pm Arrive Migori town

Monday 19th August 2019

- 9am Migori County Geologist Office and Commissioners Office
- 10am Travel from Migori town to Masara
- 11am Meeting with MICMA (Migori County Mining Association)
  Meeting with MICRODEPRO (Migori County Development Group)
  Visit to Masara ASGM sites
- 12.30 Travel from Masara to Macalder
- 1.10pm Meeting with MICA
- 1.45pm Travel from Macalder to Migori town
- 3.30pm Migori
- 4.40pm Contact with Tai Saf (gold miner)

Tuesday 20th August 2019

- 7.45am Migori County Ministry of Water
- 8am Travel from Migori town to Masara
- 8.30am Meeting with MICA. Visit MICA gold processing and leaching plants
- 10am Travel from Masara back to Nairobi
- 6.30pm Arrive back in Nairobi

2.3 SCOPING VISIT DAY 1

The drive from Nairobi to Migori town took 8 hours with 355 kilometres travelled. The route has good tarmac roads for most of the journey. There is an appropriate mid-way point at Narok town for lunch and refuelling at Kisii town. The stretch of road between Kisii and Migori towns is currently being resurfaced with large stretches of gravel roads and tortuous diversions. This added a considerable amount of time to the journey over this part of the journey. It seems unlikely that this work will be completed by November 2019.

Figure 1. Evance Juma (Driver) & Cavince Odhiambo (Geologist)

2.4 SCOPING VISIT DAY 2

First meeting of the day was with the Migori County Geologist office. The county geologist, Joseph Kuria, was out. We discussed the ASGM project with Siringi Danstan (Mining officer/ Geologist) and Amelemba Mourice (Mining Officer/ Inspector of Mines). In their experience the major environmental problem with ASGM is the leaching associated with the cyanidation of tailings; animal deaths have been reported locally.

Figure 2. Clive Mitchell at Migori County Geologist Office (left) and MICRODEPRO mine shaft (right)

They recommended that we contact the Migori County Commissioners office and MICMA (Migori County Mining Association). The chairman of MICMA is Kephas Ojoka; we contacted Kephas and he put us in touch with Bismarck Onyando (the coordinator of MICMA). They escorted us over to the office of the Migori County Commissioner. We discussed the ASGM project with the Deputy Commissioner, Denis Mutiso.

Mid-morning we travelled from Migori town to Masara. The road condition was good. We met Bismarck Onyando who is the coordinator of MICMA and the chairman of MICRODEPRO (Migori Community Development Group). MICMA is an umbrella organisation that represents the various mining groups in Migori County at an administrative and political level. MICRODEPRO operates a Fairtrade accredited gold mining operation at Kolongo in Masara. Bismarck asked MICRODEPRO treasurer, Johanes Ojuwi, to show us around the MICRODEPRO operation and the surrounding small scale mining area.

The MICRODEPRO operation was inactive and looked like it had been that way for some time. The surrounding ASGM operations were very active with multiple mine shafts, manual crushing, milling using Tanzanian-designed ball mills, gravity recovery of gold using sluice boxes and mercury amalgamation of the gold from the concentrates. Tailings were piled high everywhere and are sold to the operators of the leaching operations.

Figure 3. Gold ore (left) and manual crushing of gold ore (right)

Figure 4. Tanzanian-designed ball mill (left) and gravity recovery of gold using a sluice box (right)

Early afternoon we travelled to Macalder for a brief meeting with John Asembo, General Secretary of the Migori County Artisanal Miners Co-operative (MICA). He agreed to show us the MICA operation the next morning. Later that afternoon, we had contact with Tai Saf who is establishing a gold mine in Masara. He arranged for one of the company directors to show us his operation the next morning.

Figure 5. Mercury amalgamation of sluice box concentrate (left) and gold-mercury amalgam (right)

2.5 SCOPING VISIT DAY 3

As much of the scoping visit objectives had been met it has decided that the trip would be cut from its original 4-day duration to 3-days. We visited the Migori County Ministry of Water to collect data on water borehole location. The Ministry require a letter, which we recommended would best come from the University of Nairobi.

Next stop was Masara where we met up with John Asembo (MICA) who showed us their gold processing plant. This was very impressive with a processing circuit that included a jaw crusher, hammer mill and shaking table. They also have a bowl concentrator that they plan to use in a second circuit alongside a ball mill designed and built by Jomo Kenyatta University of Science and Technology. Currently, gold production is around 100 grams per day, their target is 500 grams per day. Tailings are sent to the MICA leaching plant which was just across the road; the gold content of the tailings is from 0.3 to 0.8 grams per tonne.

Figure 6. Migori County Artisanal Miners Co-operative (MICA) jaw crusher (left) and hammer mill (right)

The MICA leaching plant is surrounded by tailings waiting to be treated and spent tailings. The tailings are shovelled into large cylindrical concrete lined tanks and a solution of sodium cyanide added. Gold forms a complex with the cyanide (‘aurocyanide’) which is water soluble. The gold enriched leachate from these tanks is then passed over a separate series of smaller concrete tanks which contain activated charcoal. The gold cyanide complex is adsorbed onto the surface of the activated charcoal. The gold cyanide complex is removed from the charcoal by washing (typically with a caustic soda solution). The gold is produced from the washing solution by electrowinning, further washing and smelting. This process is known as Carbon-in-Pulp (CIP). Gold production is approximately 1.2 to 1.5 kilogrammes per month.

Figure 7. MICA ball mill (left) and shaking table (right)

Figure 8. MICA tailings leaching plant (left) and cyanidation tanks (right)

Figure 9. MICA Carbon-in-Pulp (CIP) tanks (left) and activated charcoal (right)

We left Masara at 10.30am and arrived back in Nairobi at 6.30pm.

2.6 SCOPING VISIT CONCLUSIONS

The scoping visit to the ASGM operations in Migori County was a success with the objectives fully met. The practicalities of conducting a 10-day field sampling exercise in Migori were explored, access around the area is possible albeit a little slow going in some places and the hotel accommodation is adequate. This will be a fairly hard going 10-day field programme and I recommend a break midway through.

The key ASGM stakeholders were identified and contacted, either directly or by phone. The process of building up a contact list of the wider group of ASGM stakeholders will be part of the planning and will also be informed by the community engagement planned for late September/ early October. This will be conducted by Cavince Odhiambo. Appendix 1 gives a list of stakeholders. Appendix 2 shows the route from Nairobi to Migori.

The visits to the ASGM areas were highly informative and confirmed that the initial sampling programme envisioned is appropriate. The MICA processing plant was a revelation. It is very likely that this will form the template for future gold mining in Migori County. MICA were responsible for introducing the Tanzanian-designed ball mill to the ASGM community in Migori County about 5 years ago, there are now approximately 3000 mills being used in Migori County. The influence of MICA in this regards does make it seem likely that the ASGM community will take notice of the success of the MICA gold processing plant.

The uptake of the process used by MICA is probably, in the medium to longer term, the solution to the use of mercury in Migori County. This begs the question what is the value of the work we are proposing on the ASGM operations? The answer is simple, it is important to demonstrate that gold can be recovered with the minimal use of mercury. The research should demonstrate how effective the MICA process is in comparison to the ASGM operations. It is important that the sampling includes the MICA plant. This way we can effectively contribute to an important change which in the medium to longer term will have great benefits to the environment of western Kenya.

3 Field work

3.1 FIELD WORK INTRODUCTION

The field trip carried out by a joint BGS and the University of Nairobi (UoN) team as part of the ASGM research project took place from 12th to 21st November 2019. Participants were as follows:

- Gold Team: Clive Mitchell & Tom Bide (BGS), and Cavince Odhiambo (UoN)
- Water Team: Barbara Palumbo-Roe (BGS) and Dr Lydia Olaka & Jemimah Muluu (UoN)
- Two drivers: Sammy Otieno & James (two UoN 4x4 vehicles were used)

The objectives of the field visit to Migori County were as follows:

- Gold Team to collect samples of ore, crushed and milled ore, and sluice box concentrates and tailings, and shaking table concentrates, middling products and tailings.
- Water team to collect samples of water from boreholes and other sources of drinking water.

3.2 FIELD WORK ITINERARY

The field trip visit itinerary was as follows:

Tuesday 12th November

- Travel from Nairobi (set off 7.30am) to Migori (arrived 4.45pm).

Wednesday 13th November

- Meetings with Migori County Government Departments (Education, Health, Water & Energy) and National Environment Management Authority (NEMA).

Thursday 14th November

- Visited Migori County Artisanal Miners Cooperative Association (MICA) and artisanal gold mining sites in Masara (Nyatike Sub-County).

Friday 15th November

- Meetings with Migori County Commissioners office, Migori County Geologist (Joseph Kuria) and Migori County Governor's office.
- Ground truthing artisanal mine sites identified by satellite imagery.
- Water team starts the groundwater sampling.

Saturday 16th November

- Gold team split with Cavince sent to purchase samples; Clive & Tom visited the sites after samples collected.
- Full day of water sampling.

Sunday 17th November

- Rest day. Gold team joined by Professor Daniel Ichang'i (UoN) for remainder of field trip.

Monday18th November

- Day spent at MICA plant – two samples processed using shaking table.
- Full day of water sampling.

Tuesday 19th November

- Visit to ASGM sites in the Kehancha area in the SE part of Migori County.
- Full day of water sampling.

Wednesday 20th November

- Morning spent sorting out the samples (all unique IDs checked, samples weighed and a list created for the Export Permit).
- Afternoon spent in Migori town collecting official letters and sorting out admin for the Export Permit.
- Full day of water sampling and sample sorting/packing for travel.

Thursday 21st November

- Travel from Migori (set off 8.30am) to Nairobi (arrived 6pm)

Figure 10. ASGM field party: LH photo: Tom Bide, Barbara Palumbo-Roe & Clive Mitchell; RH photo: Jemimah Muluu, Cavince Odhiambo & Lydia Olaka

3.3 NACOSTI RESEARCH LICENCE AND MINERAL EXPORT PERMIT

Research in Kenya requires a licence from the National Commission for Science, Technology & Innovation (NACOSTI) https://www.nacosti.go.ke/. The application is made through the NACOSTI Research Information Management System (RIMS) https://research-portal.nacosti.go.ke/ and requires an ORCID identifier https://orcid.org/. Payment is required upfront before the application is submitted; in our case it was US$500 per international researcher (one for Clive Mitchell and one for Barbara Palumbo-Roe).

The application requires a proposal document, an affiliation with a Kenyan research organisation and proof of payment for the NACOSTI fee. The process took 3 weeks from submission of the application online to the NACOSTI licence being granted. The research licence is valid for research in Migori County, Kenya for one year. It requires relevant County Government departments to be informed. Also, a hard copy and digital copy of the final report must be deposited with NACOSTI on completion of the research.

A Mineral Export Permit was required for taking the samples collected back to the UK. The Mineral Export Permit application process required submission of a completed form (S.171). This application was supported by a letter from the University of Nairobi confirming that the samples were for research and of no commercial value. A fee was paid for each permit (one for the gold team samples and one for the water team samples). The application forms were signed on behalf of the Cabinet Secretary (Mining). Two copies were issued for each permit..

3.4 MIGORI COUNTY GOVERNMENT AND NATIONAL AGENCIES

As per the requirement of the NACOSTI research licence, the County Director of Education, County Commissioner and County Governor were informed of the research. In addition, other departments and agencies were informed. Official letters were issued by some of these departments as approval of the research in Migori County. The contact list from the scoping trip in August 2019 has been updated with the new contacts made (Appendix 1).

3.5 GOLD TEAM FIELD WORK

3.5.1 Geology of the Migori Greenstone belt

The Migori Greenstone Belt lies at the north eastern end of the Archean Tanzanian Craton and is bounded by younger Archean granites and Proterozoic rocks. The Greenstone Belt itself has been dated at around 2.7-2.3Ga and consists of a mix of metasediments, predominately pelitic greywackes and shales, as well igneous rocks including tuffs, dolerites and andesites with varying degrees of associated metamorphism. The belt has been formed from a complex sedimentary basin consisting of several volcanic centres forming a pattern of subaerial andesites and associated volcano-sedimentary rocks, subaqueous basalts, dacites and rhyolites and turbiditic sediments.

Banded iron formations also occur associated with turbiditic rocks. Also of note are VMS deposits around the Macalder area, possible of Kuroko style, which have been worked for copper zinc and silver, and is currently worked for gold by small scale operations.

Gold mineralisation occurs within banded iron formations, tuffaceous rocks and most commonly in steeply dipping, strike parallel, quartz veins often associated with steeply dipping strike slip faults. The majority of current gold workings seem to be in close proximity to the granite contact. All samples taken during this trip were all from either quartz veins within turbidites (with varying levels of tuffaceous material) or andesites.

3.5.2 ASGM sampling

The sample collection was not straightforward. We were fortunate to have the assistance of John Assembo from MICA who provided invaluable advice and guidance throughout the field trip. In addition, the Gold Team was joined by Professor Daniel Ichang'i for the last 3 days.

The team could not arrive at ASGM sites and expect to collect samples without some degree of negotiation and payment. Therefore the team was split with Cavince Odhiambo accompanying John Assembo to the ASGM sites to negotiate the price for the samples. The price was agreed for the full set of samples from each site (ore, crushed and milled ore, and sluice box concentrates and tailings). The remaining team members Clive Mitchell and Tom Bide visited the ASGM sites the day after.

Figure 11. Left to Right: John Asembo, Professor Daniel Ichang'i, James Asembo, Tom Bide, Cavince Odhiambo & Clive Mitchell

In addition to the standard ASGM sites (manual crushing, ball milling and sluice box processing) we spent some time at the MICA processing site under the supervision of James Asembo (MICA). We collected two set of samples which were processed using an MBMM (Mount Baker Mining & Metals) shaking table. These sample sets included ore, crushed and milled ore, shaking table concentrates, middling products and tailings. These samples were also purchased. This will provide an interesting comparison with the ASGM sites; it should, in theory, show a greater degree of gold concentration with gold recovered at a much finer particle size.

Figure 12. ASGM operation photos: Top: mining & milling; Middle: sluice box processing & tailings pond; Bottom: panning with mercury & sponge gold

The full sample list is given in Appendix 3, the location of the sample sites in Appendix 4, the location of the sample sites overlain on the geology map of Migori in Appendix 5 and photographs of the ore samples collected in Appendix 6.

3.6 FIELD OBSERVATIONS ON CURRENT AND GOOD PRACTICE FOR ASGM IN MIGORI COUNTY

3.6.1 Mining

The mining of gold ore using poorly supported shafts and tunnels is of great concern. The tunnels are cramped, poorly ventilated and require pumping to keep dry. Explosives are used to extract the ore which is then hauled out manually. There are relatively frequent mine collapses often leading to the death of miners.

Advice on mining is outside the expertise of the project team and requires experienced mining engineers. In Migori County this advice is being provided on an occasional basis by Terry Garde who is an experienced mining engineer originally from Zimbabwe but now based in the UK.

3.6.2 Crushing and milling of ore

Ore is currently crushed manually. This is a laborious and slow process. The MICA plant uses a jaw crusher which is an efficient and rapid means of crushing ore.

Crushed ore is then milled using a Tanzanian-designed ball mill. This is an efficient means of milling. The question that remains is whether or not the ore is being over-ground i.e. is it being ground down to a particle-size that is far smaller than that required for liberation of the gold. Ideally this question will be answered by particle-size analysis of the gold in the ore sample and particle-size analysis of the milled ore.

The MICA plant currently uses a hammer mill. This is not an ideal mill to use for hard material such as the quartz-rich gold ore in Migori. There are frequent problems due to high wear of the mill hammers. MICA have plans to switch to a ball mill designed by Jomo Kenyatta University of Agriculture and Technology (JKUAT).

3.6.3 Sluice box operation

Milled ore is then processed using a simple wooden sluice box lined with sacking as the gold trapping medium. From observation of the sluice box processing it appears to be highly inefficient. There are multiple technical issues with the processing that probably result in poor gold recoveries as follows:

- Particle-size of the feed material: the milled ore is much finer than is usually processed with a sluice box and it is likely that much of the gold is simply washed over the sluice into the tailings.
- Blinding of the trapping media: the 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. Therefore there is no space left for gold to be captured and this then leads to its loss into the tailings.
- Poor feed delivery: the milled material is fed onto the sluice box in batches by hand meaning that there is an irregular flow across the sluice box. This means that the flow dynamics of the feed slurry are not established sufficiently to enable efficient trapping of gold particles into the trapping media.
- Insufficient wash water: the feed slurry does not have sufficient wash water to enable it to flow across the sluice in a steady and consistent stream. This means that the flow dynamics of the feed slurry are not established sufficiently to enable efficient trapping of gold particles into the trapping media.

- Poor sluice box design: the inclination angle is randomly set anywhere between 5 and 15^{o}; the length of the sluice box is often too short, typically less than the optimum 3 metres in length; and the sluice bed is often irregular with breaks in slope between sluice sections.

The tailings from the sluice box are reprocessed multiple times. This is a recognition by the miners that a significant amount of gold remains after the initial stages of sluice box processing.

MICA are working on an improved sluice box design (Figure 13).

3.6.4 Alternative gravity processing options

The MICA plant is currently operating with an MBMM shaking table. This has the capacity to recover gold down to a much smaller particle size than the slice boxes used by the artisanal miners. MICA also owns a centrifugal ('bowl') separator, although this has yet to be deployed.

The lower particle size limit of gold recovered by a well operated sluice box is around 100 microns, although recovery efficiency drops significantly below 200 microns. For a shaking table the lower limit is around 15 microns, although the efficiency drops significantly below 40 microns. A centrifugal separator has a lower limit of 1 micron, although recovery is really only effective down to 30 microns. Centrifugal separators are notoriously difficult to set up and operate effectively. Therefore, the better option for small scale gold processing is a shaking table.

Figure 13. Left hand photo: Shaking table at MICA plant; Right hand photo: metal sluice box at MICA plant

Figure 14. Left hand photo: Visible gold on shaking table; Right hand photo: Visible gold on sluice box

3.6.5 Panning, mercury amalgamation and use of mercury retorts

The sluice box concentrates are panned to concentrate the gold. Mercury is added to the pan to amalgamate with the gold. Excess mercury is removed by squeezing the amalgam in a cloth. The resulting amalgam is the consistency of putty and is 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.

A mercury retort has been produced by MICA for use by the artisanal miners. 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.

Figure 15. Mercury retort at MICA plant

3.7 INITIAL PLANS FOR ANALYSIS OF THE GOLD TEAM ASGM SAMPLES

Initial plans for analysis of samples collected from the ASGM sites in Migori County is as follows:

Ore samples

- Polished thin sections, possibly several per sample.
- Petrographic analysis by Optical Microscopy and SEM (Scanning Electron Microscopy) to determine the particle-size distribution of the gold and its mineral associations.
- Photomicrographs of the gold.

Crushed ore

- Particle size analysis.
- Gold assay.

Milled Ore

- Particle size analysis.
- Gold assay, possibly of multiple sub-samples and the size fractions.
- Heavy Media Separation.
- Resin mounted polished blocks.

- Petrographic analysis by SEM to determine the amount, size and liberation of gold.
- Quantitative mineralogy by XRD (X-Ray Diffraction) analysis?

Concentrates

- Gold assay (if enough material).
- Heavy Media Separation & concentration of the gold particles.
- Photomicrographs of the gold grains.

Tailings

- Gold assay.

3.8 WATER TEAM FIELD WORK

3.8.1 Field work purpose

The objective of the field work was to assess the inorganic chemical status of groundwater in the ASGM areas around Migori. This was identified as one of the knowledge gaps in order to assess the potential pressures posed by ASGM on water resources. Assessment of surface water quality was carried out in a previous survey in January 2019.

3.8.2 Study area and sampling strategy

Initial reconnaissance visit and study of the google aerial photos indicate both potential point and diffuse sources of contamination represented by the numerous shafts and clustered surface mining operations, as well as heaps of tailings scattered in the rural landscape. To what extent pollution from such widespread activities leaches into groundwater is unknown. Hence, the study area was selected to cover known present and past mining areas, in the sub-counties of Nyatike and Kehancha. Figure 16 shows the sampling locations.

Existing boreholes in the study area largely defined the potential sites for groundwater sampling. Logistical issues that defined borehole accessibility, such as for example inaccessible wells in school premises during school exam periods, influenced the sampling locations.

Water resources used in the area are potentially diversified, including river water, shallow wells, deep boreholes, mine water, springs and rainwater collection systems. Sampling points were then selected to be representative of the different sources from which water is obtained by the public.

A total of 30 waters were sampled from 7 shallow wells, 12 boreholes, 3 springs, 4 mine shafts, 4 mine processing waters and spoil runoff (Figure 17 to Figure 21). Water sampling was carried out during the period from the 15^{th} to 20^{th} November 2019.

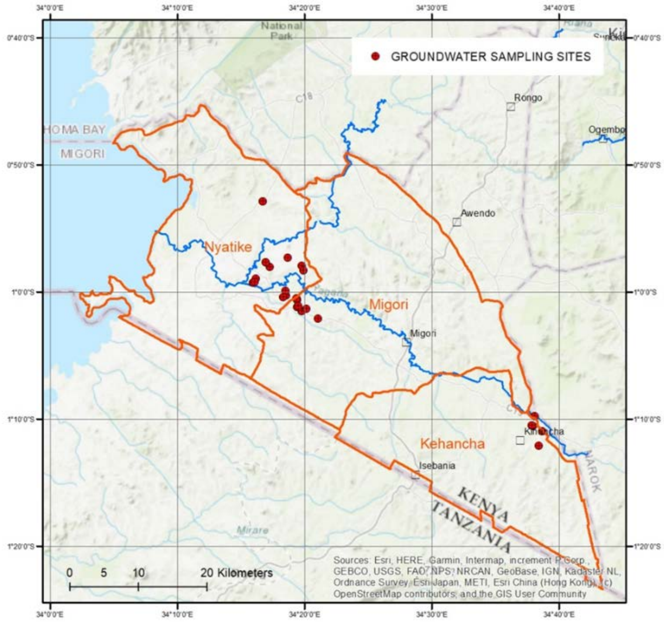


Figure 16 Location of water sampling sites

Figure 17 Private shallow well with tailings leaching plant using cyanidation visible in the background

Figure 18 Borehole with solar powered pump (left) and with hand pump (right)

Figure 19 Mine shaft used by the community

Figure 20 Mine water pumped directly into mining village culvert

Figure 21 Spring used for domestic use, recreational use and livestock

3.8.3 Field sampling procedure

Groundwater was sampled from hand-dug wells and boreholes, using existing hand- or solar powered-pumps, rope and bucket, or water taps, into Teflon sampling jugs, rinsed 3 times with the sample water and then filled; natural springs and mine effluents were sampled using a Teflon jug. The sample locations were recorded using Global Positioning System (GPS). No purging was carried out of the boreholes or wells; however, they were in constant use, thus ensuring fresh samples. Measurements of electrical conductivity (EC), pH, redox potential (Eh), dissolved oxygen and temperature were carried out immediately on site using a separate beaker. Dissolved oxygen measurement were obtained in air tight sample tubes filled immediately to prevent air contamination. Field alkalinity was determined by titration in the field using 50 ml sample and 1.6 N sulphuric acid.

Water was sampled from the sampling jug and filtered using a plastic syringe and 0.2 µm cellulose nitrate filter with the Swinnex filter holder into plastic bottles, rinsed three times with the sample water. The un-acidified sampling bottles were carefully filled just to overflowing to ensure no air bubble was trapped inside the sample container. The samples were labelled, and stored in ice boxes until the return to the base camp and then at 4 °C to avoid any major chemical alteration prior to analysis. Samples for cation analysis were acidified (1% v/v Aristar nitric acid) on return to the UK prior to analysis.

A sample Information Sheet was created for each sample recording: sample ID, date of sampling, time of sampling, location and name of sampling site (include GPS coordinates if available), borehole details and sampling method, weather conditions, field measurements, container pre-treatment and preservations added, colour, odour, sediment and any other observation that may affect the results of the analysis.

3.8.4 Analytical quality assurance and quality control

Blank samples, consisting of deionised Millipore water in place of the sample, and duplicate samples were obtained to monitor potential contamination and reproducibility, respectively, during sampling and analysis.

3.8.5 Health and Safety

The team carried out the activity safely, taking into account the issues identified in the risk assessment and complying with the BGS Guidance note: A safe system of fieldwork. Version 1.2 May 2019. IR/02/095.

4 Field work conclusions regarding ASGM in Migori County

The field visit to the ASGM operations in the Masara area of Migori County was a success with the objective of the Gold Team fully met. A full suite of samples was collected including ore, crushed and milled ore, processing concentrates and tailings. The evaluation of these samples will include petrographic analysis (by optical microscopy and SEM), assay of the gold content, particle-size analysis, heavy media separation and mineralogical analysis by XRD.

From observation of the artisanal mining during the field visit, these are some initial thoughts on good practice for the artisanal scale gold mining:

- <u>Mining</u>: Advice from experienced mining engineers is sorely needed to help make mining safer and conditions in the mines more bearable for the miners.
- <u>Crushing and milling</u>: Manual crushing of ore is laborious and slow; the use of mechanised jaw crushers should be considered. The current use of ball mills is good practice for the scale of the operations.
- <u>Sluice box processing</u>: The current processing 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.
- <u>Shaking tables</u>: switching from a sluice box to a shaking table would increase the amount of gold recovered and reduce the loss of gold to the tailings.
- <u>Mercury retort</u>: use of the mercury retort produced by MICA would reduce the amount of mercury released into the environment and reduce the amount spent on mercury.

It seems likely that the approach used by the MICA will form the template for future gold mining in Migori County. The influence of MICA makes it likely that the ASGM community will take notice if the gold processing plant proves to be successful. Whereas this will not in itself remove the use of the mercury, combined with the use of the mercury retort they have manufactured, it will significantly reduce the amount of mercury being used and lost into the environment.

This ASGM research is an important means of demonstrating that fine grained gold can be recovered efficiently and with the minimal use of mercury. Ideally the findings of the analysis we carry out on the samples collected will demonstrate how effective the MICA process is in comparison to the ASGM operations. In this way we can effectively contribute to an important change which in the medium to longer term will have great benefits to the environment of western Kenya.

As part of the groundwater survey we have collected water samples from hand-dug wells, springs and boreholes as well as mine water from mine shaft. A stream water survey was carried out in a previous field trip. The community depends on all these sources for various uses. The analysis of the inorganic chemical status of groundwater in the ASGM areas around Migori will contribute to the assessment of the potential pressures posed by ASGM on water resources and water quality.

To communicate the findings of the research, it is recommended that a workshop is held in Migori in the autumn of 2020.

References

British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: https://envirolib.apps.nerc.ac.uk/olibcgi.

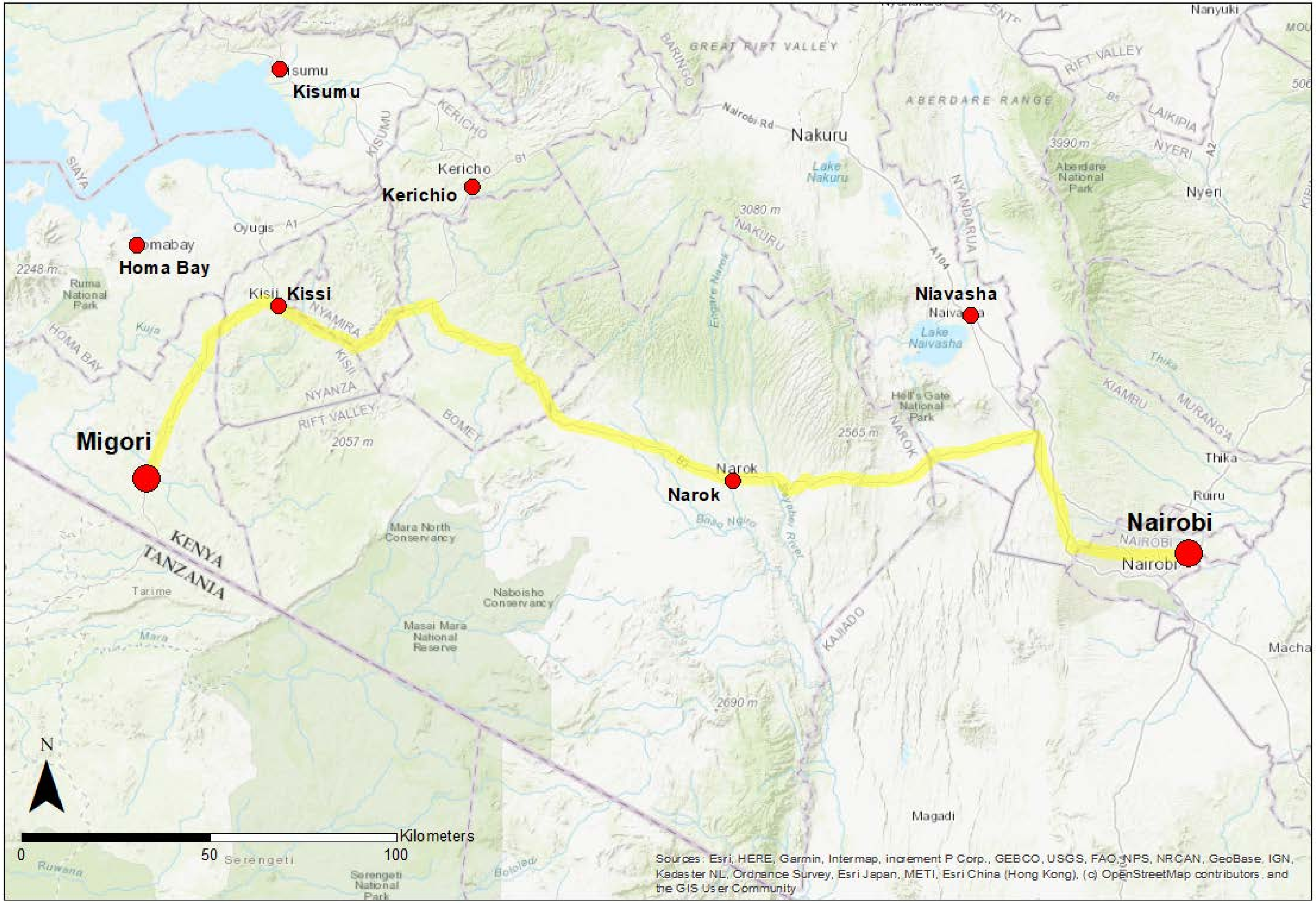
Barreto, ML, Schein, P, Hinton, J & Hruschka, F. 2018. Economic contributions of artisanal and small-scale mining in Kenya: Gold and gemstones. East Africa Research Fund, Department for International Development. https://assets.publishing.service.gov.uk/media/5a392bb8e5274a79051c9d7c/Kenya_case_study.pdf

Appendix 1 Stakeholder list

Name	Organisation
John Asembo	General Secretary, Migori County Artisanal Miners Co-operative (MICA)
Siringi Danstan	Geologist, Migori County Geologist office
Terry Garde	PhD student/ Mining Engineer
Prof Daniel Ichang'i	Chairman, Dept of Geology, UoN
Evance Juma	Driver
Edward Kabaka	Chief Officer, Dept of Water & Energy, Migori County Government
Joseph Kuria	Migori County Geologist
Mr Maina	Mineral Export Permits, Cadastre Office (3rd floor), Old Madini House, Nairobi
Mary Midida	County Chief Officer
Hon. Rebecca Ghati Maroa	County Executive Committee Member, Dept of Water and Energy
Amelemba Mourice	Inspector of Mines, Migori County Geologist office
Jemimah Muluu	Dept of Geology, UoN
Martin Nyakinye	Head of Geo Data Centre
Professor Eric Odada	University of Nairobi (UoN)
Cavince Odhiambo	University of Nairobi (UoN)

Name	Organisation
Kephas Ojoka	Chairman, Migori County Mining Association (MICMA)
Jonanes Ojuwi	Treasurer, MICRODEPRO
Dan Okwiri	Lodge owner
Dr Lydia Olaka	University of Nairobi (UoN)
Iscar Oluoch - Owino	County Executive Committee Member, Health Services
David Ombetu	County Water Office
Bismarck Onyando	Coordinator, MICMA & Chairman, MICRODEPRO
Julius Opiyo	Chairman of MICA
George Otieno	Training Coordinator, MICA
Moses Ouma	Head of Protocol, Office of the Governor, Migori County Government
Tai Saf	Gold mine owner
James Siaji	County Environmental Officer, National Environment Management Agency (NEMA)
Ian Visiagie	General Manager, Kilimapesa Gold Mine

Appendix 2 Route taken from Nairobi to Migori and back (highlighted yellow)

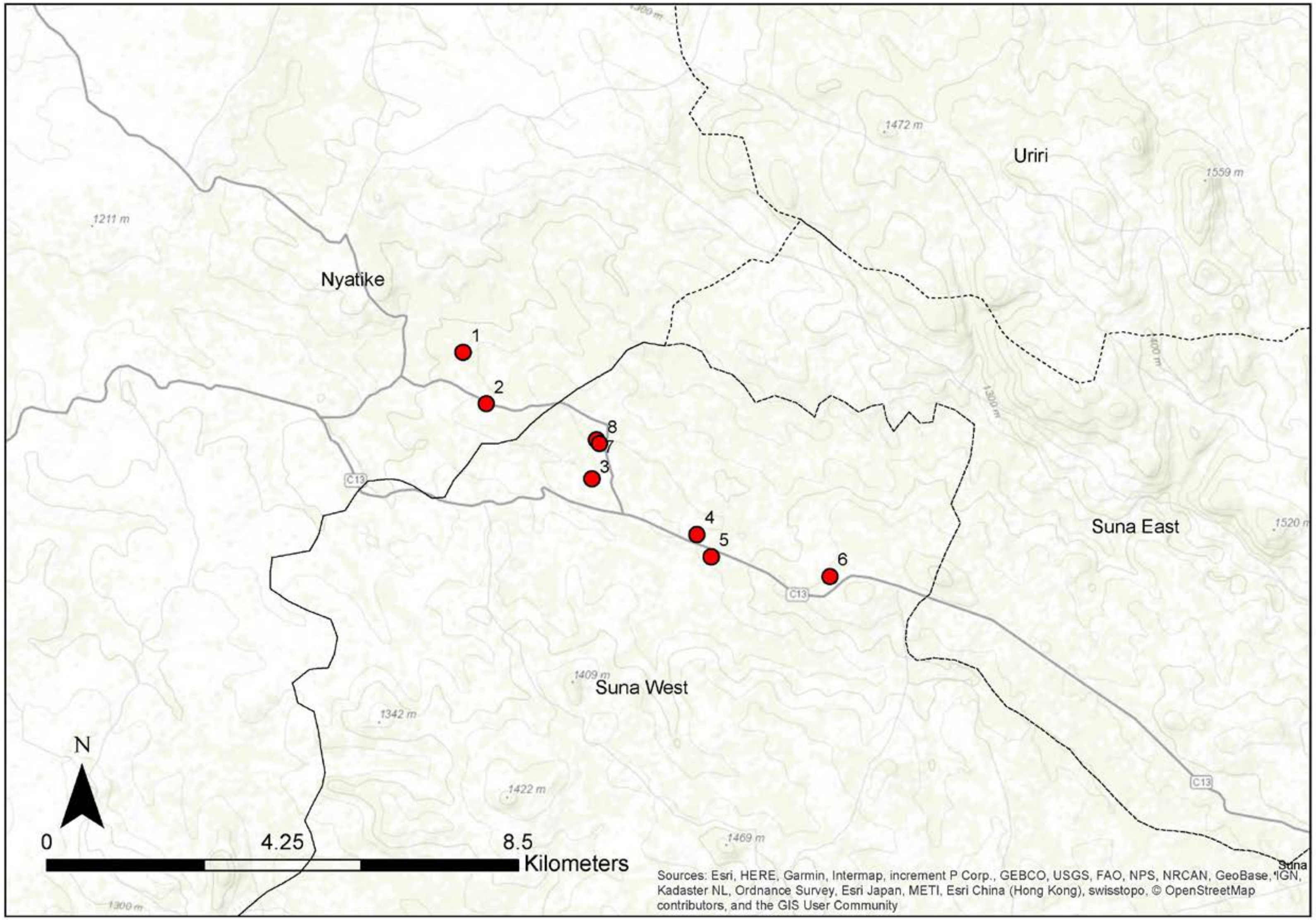


Appendix 3 Sample list

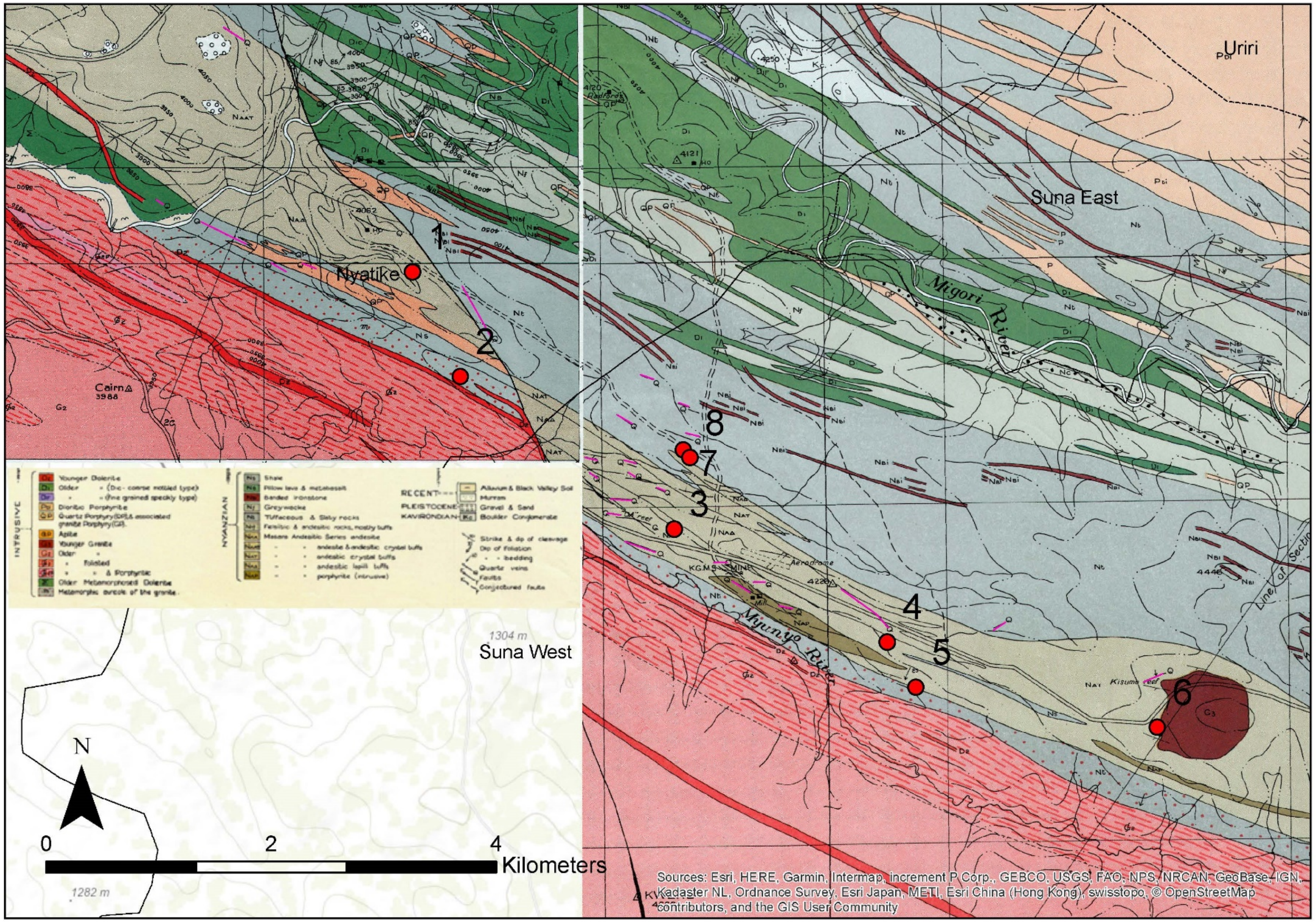
Sample ID	Site number	Location name	Sample type	Latitude	Longitude	Geology	Dry weight (grams)
01	1	Mikeyi	Crushed ore	-0.99876	34.30145	Masara Andesitic Series - Andesitic crystal tuffs	317.4
02	1	Mikeyi	Milled ore	-0.99876	34.30145	Masara Andesitic Series - Andesitic crystal tuffs	391.49
03	1	Mikeyi	Tailings	-0.99876	34.30145	Masara Andesitic Series - Andesitic crystal tuffs	257.8
04	1	Mikeyi	Concentrate	-0.99876	34.30145	Masara Andesitic Series - Andesitic crystal tuffs	38.5
05	1	Mikeyi	Ore	-0.99876	34.30145	Masara Andesitic Series - Andesitic crystal tuffs	1714.9
06	2	Kakula, Mikei	Concentrate	-1.00712	34.30526	Nyanzian Shale in Metamorphic Aureole of Granite	148
07	2	Kakula, Mikei	Crushed ore	-1.00712	34.30526	Nyanzian Shale in Metamorphic Aureole of Granite	366.6
08	2	Kakula, Mikei	Milled ore	-1.00712	34.30526	Nyanzian Shale in Metamorphic Aureole of Granite	181.8
09	2	Kakula, Mikei	Ore	-1.00712	34.30526	Nyanzian Shale in Metamorphic Aureole of Granite	1000.4
10	2	Kakula, Mikei	Tailings	-1.00712	34.30526	Nyanzian Shale in Metamorphic Aureole of Granite	207.5
11	3	Kolongo, Masara	Crushed ore	-1.0193	34.32235	Masara Andesitic Series - Andesitic crystal tuffs	345.8
12	3	Kolongo, Masara	Milled ore	-1.0193	34.32235	Masara Andesitic Series - Andesitic crystal tuffs	297
13	3	Kolongo, Masara	Ore	-1.0193	34.32235	Masara Andesitic Series - Andesitic crystal tuffs	1019.9
14	3	Kolongo, Masara	Concentrate	-1.0193	34.32235	Masara Andesitic Series - Andesitic crystal tuffs	103.4
15	3	Kolongo, Masara	Tailings	-1.0193	34.32235	Masara Andesitic Series - Andesitic crystal tuffs	287.5
16	4	Masara	Crushed ore	-1.0283	34.33938	Masara Andesitic Series - Andesitic crystal tuffs	330.2
17	4	Masara	Ore	-1.0283	34.33938	Masara Andesitic Series - Andesitic crystal tuffs	566.2
18	4	Masara	Milled ore	-1.0283	34.33938	Masara Andesitic Series - Andesitic crystal tuffs	334.2
19	4	Masara	Tailings	-1.0283	34.33938	Masara Andesitic Series - Andesitic crystal tuffs	362.6
20	4	Masara	Concentrate	-1.0283	34.33938	Masara Andesitic Series - Andesitic crystal tuffs	17.2
21	5	Masara	Concentrate	-1.03192	34.34169	Tuffaceous and slaty rocks	108.7
22	5	Masara	Tailings	-1.03192	34.34169	Tuffaceous and slaty rocks	332.7
23	5	Masara	Milled ore	-1.03192	34.34169	Tuffaceous and slaty rocks	167.9
24	5	Masara	Ore	-1.03192	34.34169	Tuffaceous and slaty rocks	443.9

Sample ID	Site number	Location name	Sample type	Latitude	Longitude	Geology	Dry weight (grams)
25	5	Masara	Crushed ore	-1.03192	34.34169	Tuffaceous and slaty rocks	371.4
26	6	Mukuru	Tailings	-1.03512	34.36098	Masara Andesitic Series - Andesitic crystal tuffs	354.8
27	6	Mukuru	Ore	-1.03512	34.36098	Masara Andesitic Series - Andesitic crystal tuffs	539.3
28	6	Mukuru	Crushed ore	-1.03512	34.36098	Masara Andesitic Series - Andesitic crystal tuffs	320.9
29	6	Mukuru	No sample (missing concentrate)	-1.03512	34.36098	Masara Andesitic Series - Andesitic crystal tuffs	0
30	6	Mukuru	Milled ore	-1.03512	34.36098	Masara Andesitic Series - Andesitic crystal tuffs	347.4
31	7	Kabobo	Crushed ore	-1.01296	34.32309	Tuffaceous and slaty rocks	618
32	7	Kabobo	Ore	-1.01296	34.32309	Tuffaceous and slaty rocks	419.9
33	7	Kabobo	Milled ore	-1.01296	34.32309	Tuffaceous and slaty rocks	329
34	7	Kabobo	Concentrate 2	-1.01296	34.32309	Tuffaceous and slaty rocks	500.7
35	7	Kabobo	Concentrate 1	-1.01296	34.32309	Tuffaceous and slaty rocks	95.4
36	8	Kabobo	Crushed ore	-1.01359	34.32361	Tuffaceous and slaty rocks	459.9
37	8	Kabobo	Ore	-1.01359	34.32361	Tuffaceous and slaty rocks	574.9
38	8	Kabobo	Milled ore	-1.01359	34.32361	Tuffaceous and slaty rocks	369
39	7	Kabobo	Middling	-1.01296	34.32309	Tuffaceous and slaty rocks	411.2
40	7	Kabobo	Tailings	-1.01296	34.32309	Tuffaceous and slaty rocks	403.1
41	8	Kabobo	Concentrate 1	-1.01359	34.32361	Tuffaceous and slaty rocks	6.7
42	8	Kabobo	Concentrate 2	-1.01359	34.32361	Tuffaceous and slaty rocks	125.6
43	8	Kabobo	Middling	-1.01359	34.32361	Tuffaceous and slaty rocks	371.5
44	8	Kabobo	Tailings	-1.01359	34.32361	Tuffaceous and slaty rocks	415
45	4	Masara	Ore (from different shaft)	-1.01359	34.32361	Masara Andesitic Series - Andesitic crystal tuffs	877.2
46	4	Masara	Crushed ore (from different shaft)	-1.0283	34.33938	Masara Andesitic Series - Andesitic crystal tuffs	325.1
						Total weight	17,577.6

Appendix 4   Map of ASGM sites sampled by the Gold Team in Migori County, Kenya



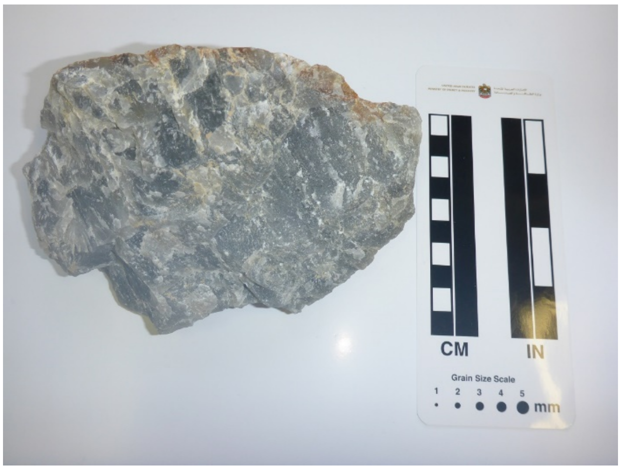
Appendix 5 Geological map showing ASGM sample sites in Migori County, Kenya



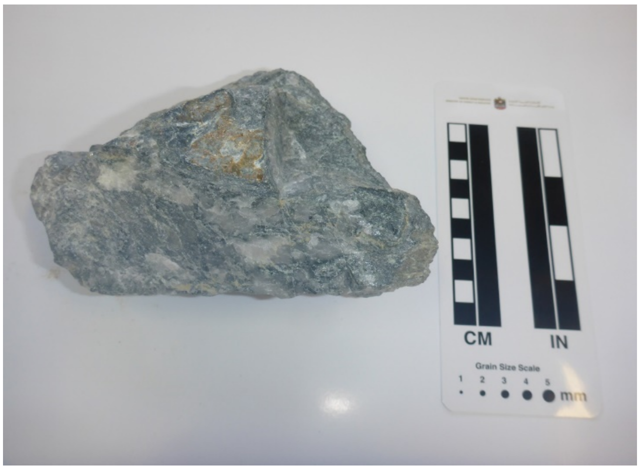
Appendix 6 Ore sample photographs

ASGM site 1 Ore sample (ID No. 05)

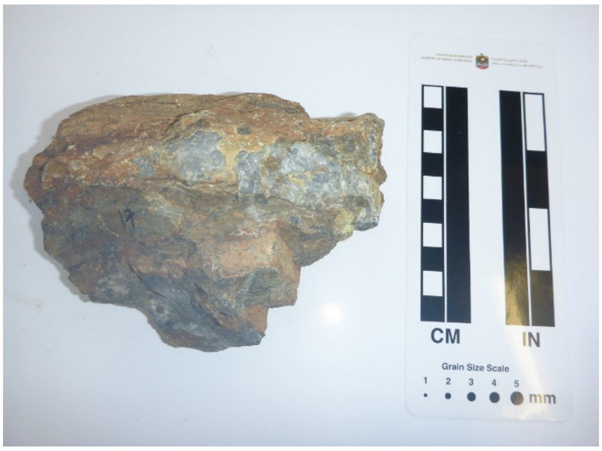
ASGM site 2 Ore sample (ID No. 09)

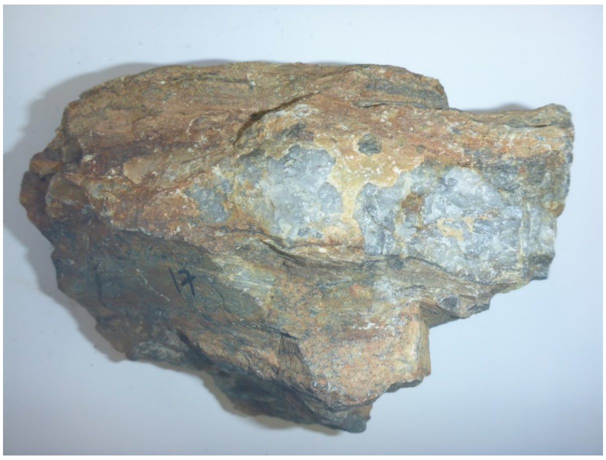


ASGM site 3 Ore sample (ID No. 13)

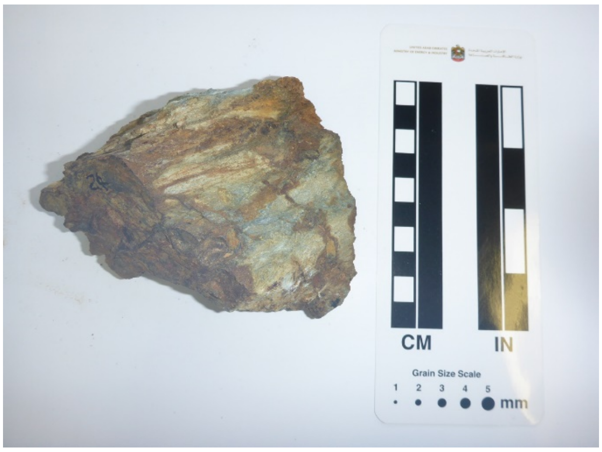


ASGM site 4 Ore sample (ID No. 17)

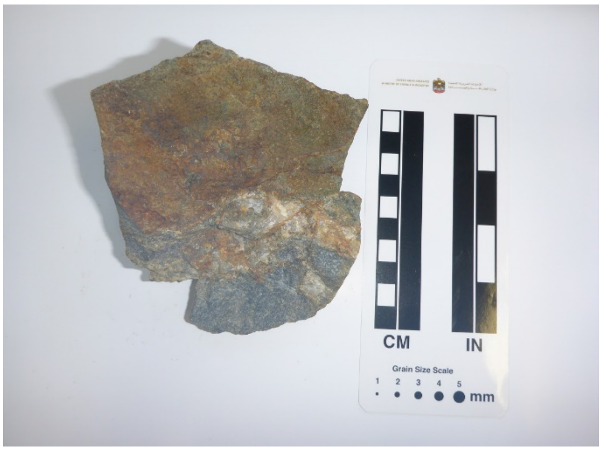




ASGM site 5 Ore sample (ID No. 24)



ASGM site 6 Ore sample (ID No. 27)



ASGM site 7 Ore sample (ID No. 32)

ASGM site 8 Ore sample (ID No. 37)

ASGM site 4 Ore sample (ID No. 45)