Footprint of mining sites along the Migori River using Earth Observation

BGS Global - Eastern Africa ODA Platform

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Foreword

This report summarises the Earth Observation work carried out by the Geodesy and Earth Observation capability of the British Geological Survey (BGS) as part of the Integrated Research Project: Small-scale Artisanal Gold Mining and Water Quality in Kenya. This work forms part of the BGS Official Development Assistance (ODA) programme *Geoscience for Sustainable Futures*, RP1: Integrated Natural Resource Management in eastern Africa, as part of NERC Grant ODA-NC NE/R000069/1. Eastern Africa faces severe natural resource challenges due to exponential population growth, rapid urbanisation and economic development. Our current activities build on BGS' strong and diverse research experience in this region, contributing to welfare and future economic growth through the responsible use of natural resources.

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The authors would like to thank Airbus for providing us with the SPOT-5 and Pleiades data (contract numbers: SDS/20-014/SW, SDS/20-015/SW and SDS/20-064/PB) which have been bought through the NERC grant NE/R000069/1 awarded to the British Geological Survey. Some of the background maps throughout this report were created using ArcGIS® software by Esri. ArcGIS® and ArcMap™ are the intellectual property of Esri and are used herein under license. The authors would like to thank K. Mills and J. Mankelow (British Geological Survey) for their insightful comments and suggestions. The authors of this report would like to thank the following contributors for their assistance and support in preparation for and revision of this document: professor Eric Odada, Dr Lydia Olaka and Cavince Odhiambo from the University of Nairobi and Martin Nyakinye from the Ministry of Petroleum and Mining of Kenya.

Contents

Summary

This report describes the findings from the Earth Observation (EO) work undertaken along the Migori River (Kenya). The purpose of this work was to identify potential mining sites and assess any changes though time (e.g., distribution and/or size). We present a new dataset of mining extents derived by visual interpretation of high-resolution satellite images. A total of c.30GB of satellite data from Sentinel-2, Pleiades and SPOT-5 covering c. 26,000 km^2 has been analysed for the years 2005-2020 (inclusive). A total of 67 mining sites concentrated over an area of 140 km^2 have been mapped: 57 of which from satellite and 10 from a field survey. The results have been used to inform our work on the environmental impacts of mining and measures that can be taken to mitigate against these.

1 Introduction

Artisanal Small-scale Gold Mining (ASGM) is a critical source of income supporting livelihoods for large areas in lower middle-income countries. In Kenya, ASGM contributed to c. 1% of the GDP in 2015 and is estimated to involve at least 40,000 miners (East Africa Research Fund - EARF, 2018). ASGM is also related to many social and environmental issues (Fritz et al., 2017). For example, the excavation of ground for mining causes widespread deforestation and leaves dangerous unstable pits that fill with standing water, creating breeding grounds for malarial mosquitos (Bansah et al., 2018). The unregulated mineral processing also results in heavy metal pollution, especially increased mercury levels (Telmer and Stapper, 2007).

The Government of Kenya (GoK) has recognized the economic potential of ASGM and is now aiming to increase the mining sector's share of the national GDP to 10% by 2030 (EARF, 2018). Therefore, the GoK has directed efforts to improve mineral exploitation, and in the last 5 years they have implemented the Mining and Minerals Policy (GoK, 2016). As part of this, the Ministry of Petroleum and Mining (MoM) has the mandate to develop and implement policies that will allow the country to benefit from its mineral wealth and ensure that mineral exploration and extraction take place safely and cleanly. One of the top priorities for MoM is the appropriate management of ASGM activities whose benefits directly addresses UN Sustainable Development Goals such as: #1 (no poverty), #8 (decent work and economic growth), #11 (sustainable cities and communities) and #12 (responsible consumption and production) (https://sdgs.un.org/goals).

Effective ASGM management is, however, inhibited by factors such as the informal and undocumented nature of the sector, legacy of inappropriate policies, limited government resources and the remote location of many mine sites. Detailed, accurate and inexpensive geoinformation about ASGM activities could aid legislative pathways by providing rapid mapping resources to support small scale licensing claims, one of the major barriers to effective legislation (McQuilken and Garvin, 2016). These datasets could also support the timely interventions when addressing environmental problems by focusing enforcement and remediation efforts where they are most needed. Earth Observation (EO) data from satellites could generate this geoinformation, especially given the increase in mapping capabilities as a result of the recent launch of advanced satellite imaging systems with increased temporal and spatial resolution. Geoinformation derived using these advanced imaging systems enables the collection of much needed baseline data on the location and scale of mining operations, without the need for costly and time intensive field-based surveys that local regulators often do not have the required resources to conduct.

By using EO, we propose the development of an inventory of ASGM activities at an unprecedented level of accuracy and detail for minimal cost. This will assist effective ASGM monitoring along the portion of the Migori River within the Migori County where data products on mines location and extension are absent to date despite being the main income-generating activity of the area (EARF, 2018).

The objectives of this report are (i): to present an inventory of the mining sites which could be used to analyse the future impact of ASGM policies and (ii) support BGS fieldwork activities performed for quantifying the local and downstream environmental impacts of ASGM.

2 Study Area

The Migori County in Kenya encompasses a c. 2,586 km^2 area including the last c. 90 km of the Migori River before it enters the Lake Victoria (Figure 1). The central and southern sector of the Migori County is geologically part of the Archean Migori greenstone belt, an area known to contain gold in quartz veins within metabasalts, banded ironstones, shales and andesites (Ogola, 1987; Ogola et al., 2001).

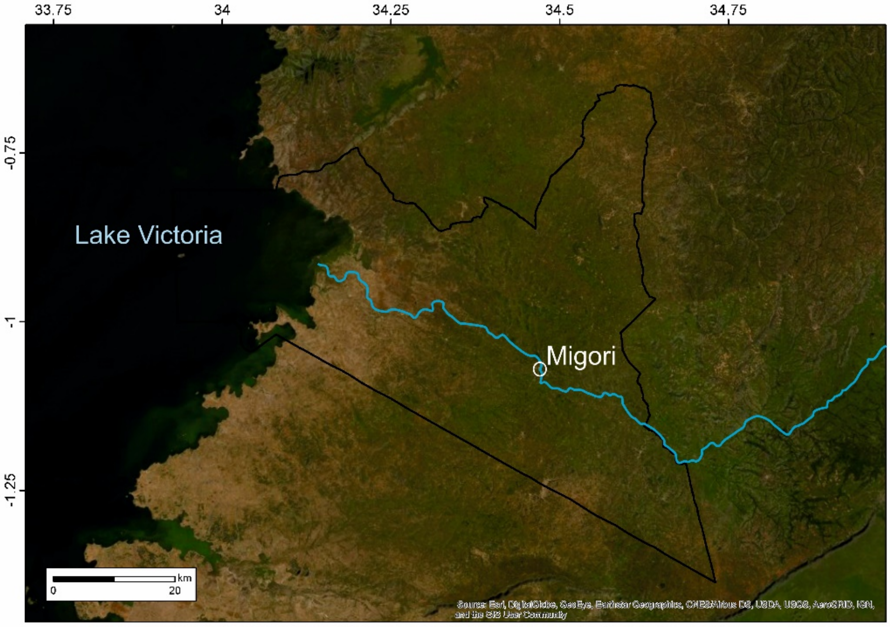


Figure 1 - The Migori River path within the Migori County (black line). Grid reference system: WGS84. Sources of the background image: Esri, DigitalGlobe, GeoEye, i-cubed, USDA FSA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

Gold was discovered in the Migori Gold belt in the 1920s and it was the focus of large-scale mining operations that came to a halt shortly after Kenya's independence in 1963. Since then ASGM has been the sole producer of gold in the belt (Ogola et al., 2001), aside from the Macalder Mine. The Macalder deposit was discovered in the mid-1930s and mined for copper and gold, though operations are thought to have ceased in 2017 (https://www.mindat.org/loc-298164.html). The tailings produced during that period have been shown to contain potentially economic levels of residual gold mineralisation, amenable to cyanide leach extraction (https://www.rrrplc.com/projects-and-investments/gold/migori-gold-project/). Observations from the region demonstrate that ASGM operations involve unstable shafts at extraction sites whose entrances are usually located under rudimentary corrugated metal roofs (Mitchell et al., 2020). This characteristic makes it near impossible to distinguish the mine entrance from standard residential or commercial buildings using EO. The manual extraction and crushing of the gold ore is followed by milling, using Tanzanian-designed ball mills. The gold is then concentrated using sluice boxes and recovered from the concentrates using mercury. The mine tailings are sent to a cyanidation plant to remove the remaining gold (Mitchell et al., 2020). As a consequence of gold extraction, the Migori County ecosystem is highly polluted by harmful metals, with arsenic concentrations in topsoil being amongst the highest reported worldwide (Odumo et al., 2017).

3 Dataset and Methodology

For this study, the EO work included a reconnaissance survey at regional scale using land cover maps derived from medium resolution satellite imagery. We then narrowed down the study area from thousands of km^2 to hundreds of km^2. The refined study area was inspected for a visual interpretation of the mining sites from high-resolution satellite imagery. This approach is precise and also cost and time-effective if kept at local scale (< thousands of km^2).

The reconnaissance survey was based on Sentinel-2 imagery, freely available through the Copernicus programme of the European Space Agency (https://www.esa.int/Applications/Observing_the_Earth/Copernicus). Sentinel-2 imagery has a footprint of 100 km × 100 km at 10 m resolution and covers the whole of Migori County. A land cover classification was carried out based on the Classification and Regression Trees (CART) classifier in the Google Earth Engine platform following the method detailed in Novellino et al. (2021). The classification included the definition of 4 landcover classes over the Migori County: “artificial surfaces”, “agricultural areas”, “forests and semi-natural areas” and “water bodies”. We then limited our investigation only to the “artificial surfaces” class as this includes the following subclasses: (i) urban fabric, (ii) industrial, commercial and transport units, (iii) artificial, non-agricultural vegetated areas and (iv) mine, dump and construction sites. However, to distinguish these subclasses, and therefore enable the mapping of the location and extent of potential mining sites, we required data at higher spatial resolution. This detailed analysis was performed using high-resolution SPOT-5 and Pleiades satellite imagery (≤2.5 m resolution) purchased from Airbus (Figure 2), covering a time period of 15 years (Table 1). Google Earth also provided a complementary source of information for the years 2014 and 2016 through its archive of high-resolution satellite data available from the National Centre for Space Studies of France (CNES) and Airbus.

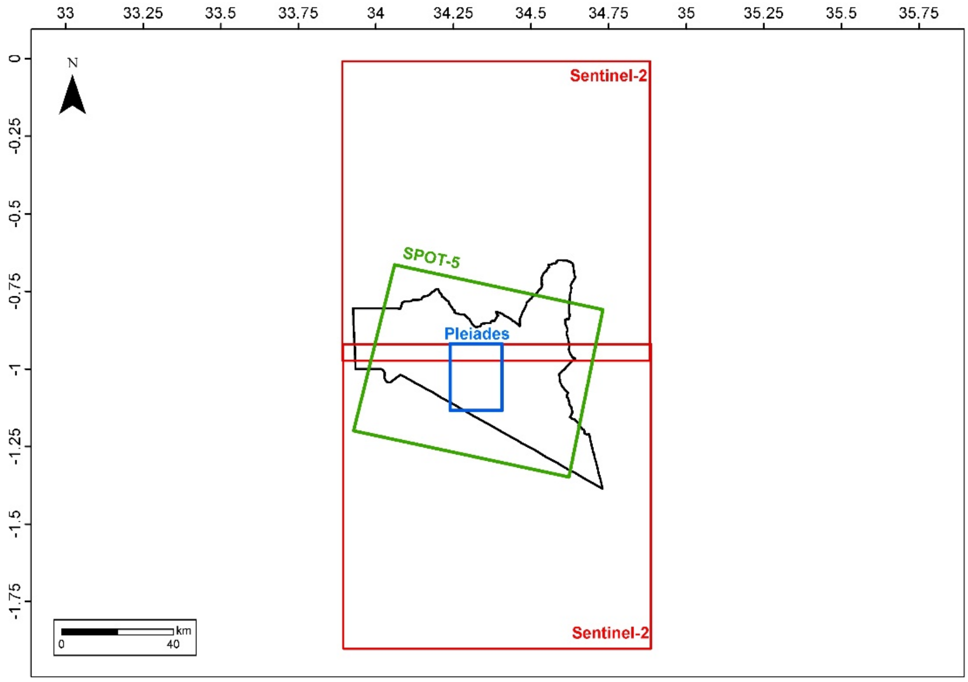


Figure 2 - Area covered by each of the satellite datasets used in this work. Grid reference system: WGS84. The black outline is Migori County, Kenya.

Table 1 - Main characteristics of the satellite imagery used in this work.

sensor	source	acquisition date	resolution [m]
SPOT-5	Airbus	10/12/2005	2.5
Sentinel-2	European Space Agency	22/05/2017	10
Pleiades	Airbus	07/08/2017	0.5
Pleiades	Airbus	12/08/2019	0.5
Sentinel-2	European Space Agency	19/09/2019	10
Sentinel-2	European Space Agency	29/09/2019	10
Pleiades	Airbus	02/04/2020	0.5

We consider a mine site or mine unit as an area covering all mining ground features, from open cuts to tailings dams, waste rock piles, water ponds and processing infrastructure. The delineated polygons do not distinguish the different ground features within the mines, i.e., each polygon can cover several mining features (open cuts, tailings dams, waste rock dumps, etc). As a final product from the delineation we obtained a set of polygons covering the total land occupied by mining.

4 Results

Land cover maps confirm that c. 3% of Migori County is covered by artificial surfaces in both 2017 and 2019 (Figure 3). Agricultural areas, and forest and seminatural areas, consistently represent >95% of the land cover. Almost all mining activities occur NW of Migori town, equally sparse alongside the north and south bank of the Migori River.

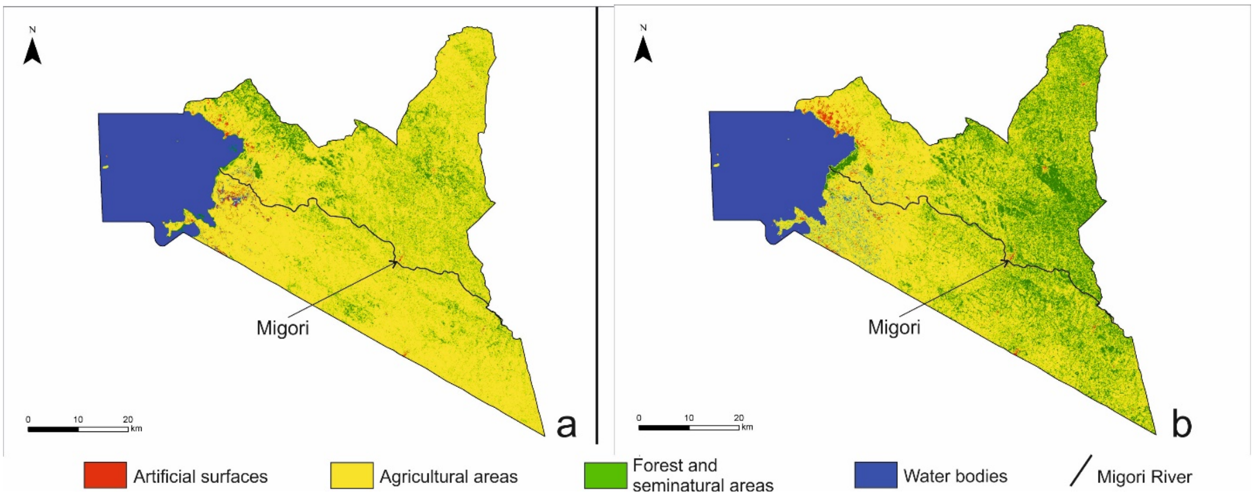
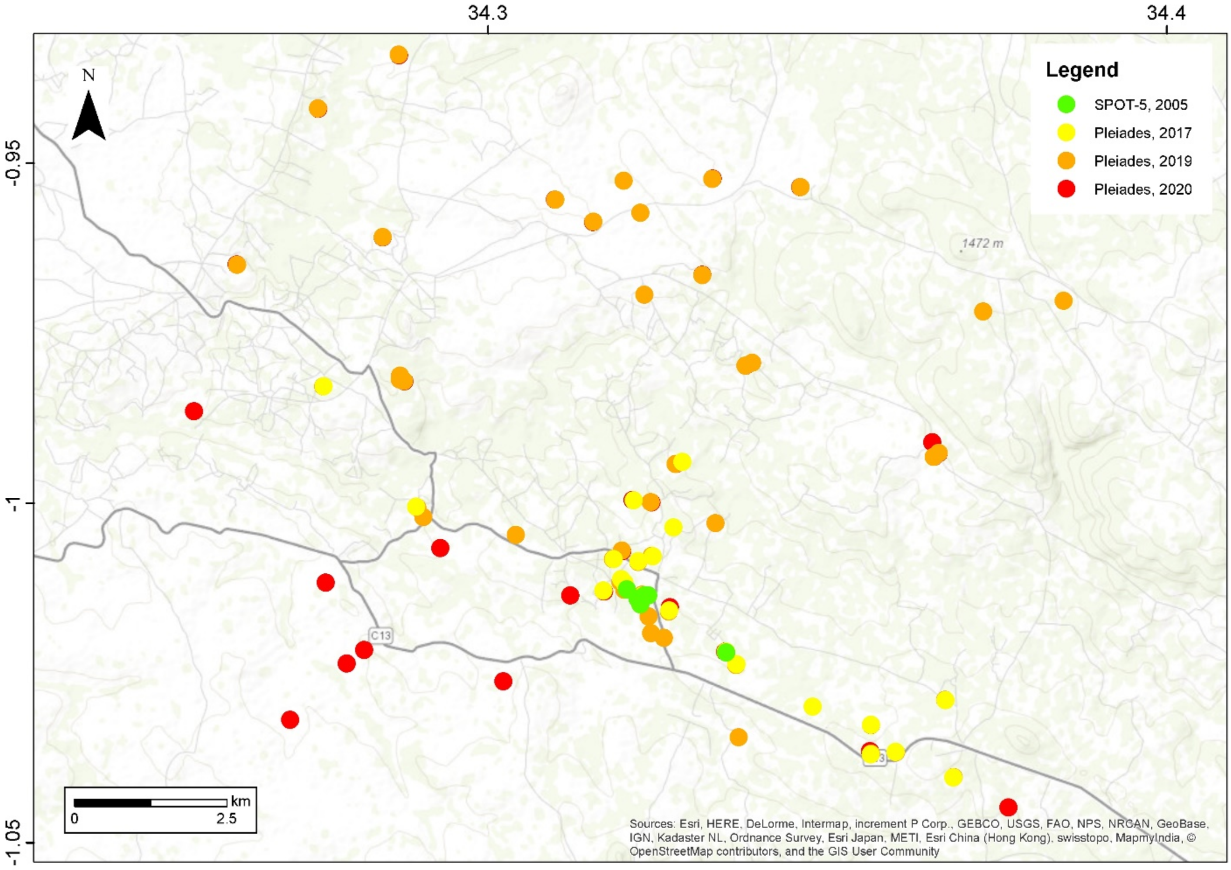


Figure 3 - Land cover maps for the Migori Country in (a) 2017 with overall accuracy of 99% and (b) 2019 with overall accuracy of 99%.

For 2020, a total of 57 mining sites (Appendix) have been mapped along the Migori River, all within the proximity of the local road network (Figure 4). Mining sites develop mainly as a conversion of pre-existing agricultural areas or, to a lesser extent, of previous artificial surfaces areas.



Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Figure 4 - Inventory map of the mining activities in the Migori County from the date of first identification in the high-resolution satellite imagery. The road network is represented by grey solid lines. Grid reference system: WGS84. Sources of the background maps: Esri, DeLorme, HERE, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, and the GIS User Community.

The number of mines has increased almost 10-fold since 2005 (from 6 to 57) and their cumulative area has increased from <0.01 km^2 to 0.92 km^2 (Table 2). The most rapid period of expansion occurred between 2015 and 2017 and, whilst mining area is increasing overall, there has been a marked decrease in the growth rate since 2017. Sites identified in the 2005 imagery are still active in 2020.

Table 2. Summary of the mine catalogue for the Migori County.

sensor	year	no of mines	cumulative size [km2]	area change [%]
SPOT-5	2005	6	0.007	-
Pleiades	2017	21	0.141	+1,914
Pleiades	2019	49	0.846	+500
Pleiades	2020	57	0.923	+9.1

The frequency distribution of the size of the mining sites is a further evidence of the fact that they are ASGM; c 84% of the sites have a size <0.013 km^2 (Figure 5).

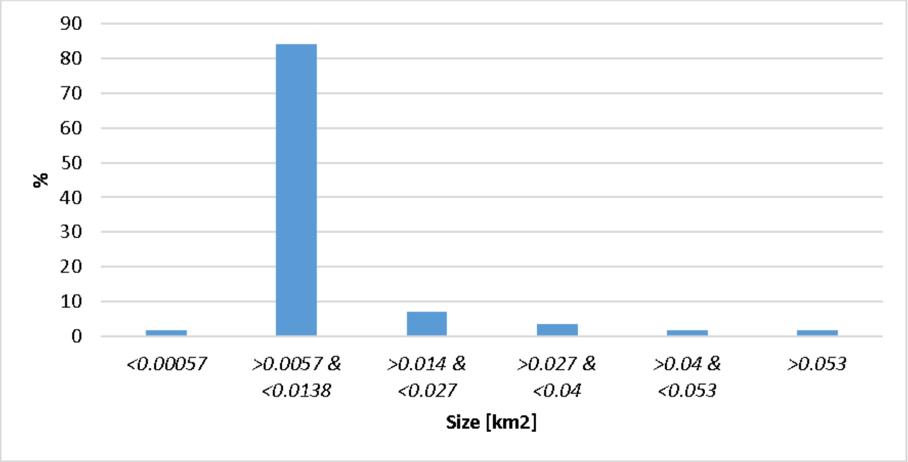


Figure 5 – Histogram of the size of the mining sites retrieved from the high-resolution satellite imagery.

For most of the mapped mines, high-resolution satellite data enabled identification of areas corresponding to different stages of mining activity: cyanidation tanks (Figure 6a,d), mine waste material or bare/worked ground (Figure 6b) and tailing ponds (Figure 6c). The latter tend to be circular in shape with a diameter in the range of c. 3 to 5 m.

Figure 6 – Different sectors of the mining activity identifiable from the 2/04/2020 Pleiades imagery: (a) worked ground with initial constructions of cyanidation tanks, (b) mine waste, (c) tailing ponds and (d) worked ground with fully developed cyanidation tanks. Contains ©CNES 2020 data, distribution Airbus DS/Spot Image.

It was also possible to map different stages of mine development: before mining begins, when the area was covered by agricultural land (Figure 7a), its initial development (Figure 7b) and its expansion with more cyanidation tanks, bare/worked ground and mine waste material (Figure 7c-d). Overall the size of the mine reported in the example of Figure 7 has increased from 0.002 km^2 in 2017 to 0.018 km^2 in 2019 (an 800% increase).

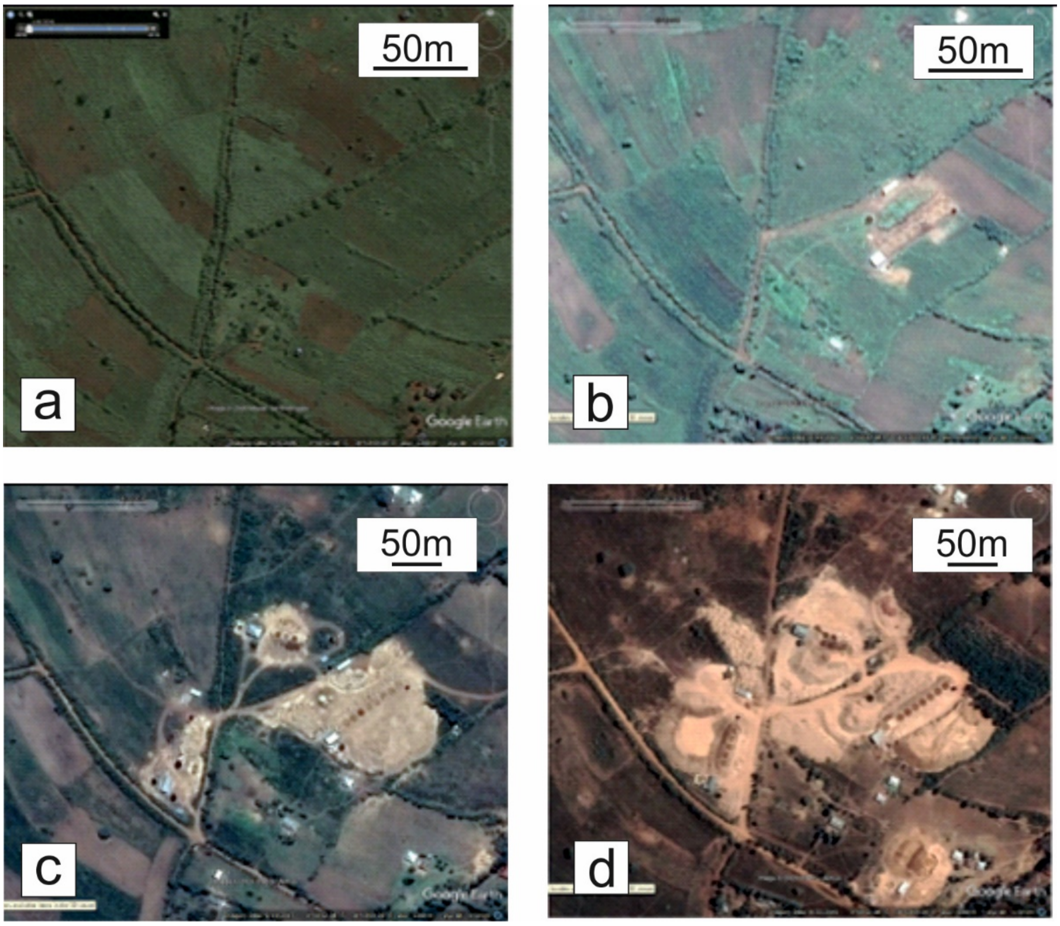


Figure 7 - Evolution of mining activity over time: (a) agricultural land is present before mining starts in 2016, (b) activity begins with a small number of cyanidation tanks in 2017, (c) expansion of the mining with more cyanidation tanks, bare/worked ground and mine waste material in 2018, and (d) further expansion with additional cyanidation tanks and mounds of mine waste material in 2019. Maps Data: Google, ©CNES 2017, 2018 and 2019 data.

Of the 57 mines delimited from the EO inventory, 17 of these have been visited and validated during a fieldwork campaign conducted in November 2019 (Figure 8), details of which are reported in Mitchell et al. (2020). Additionally, 10 other sites were added to the EO inventory from field investigations which were either too small or undistinguishable from residential and industrial buildings (Figure 8, Appendix).

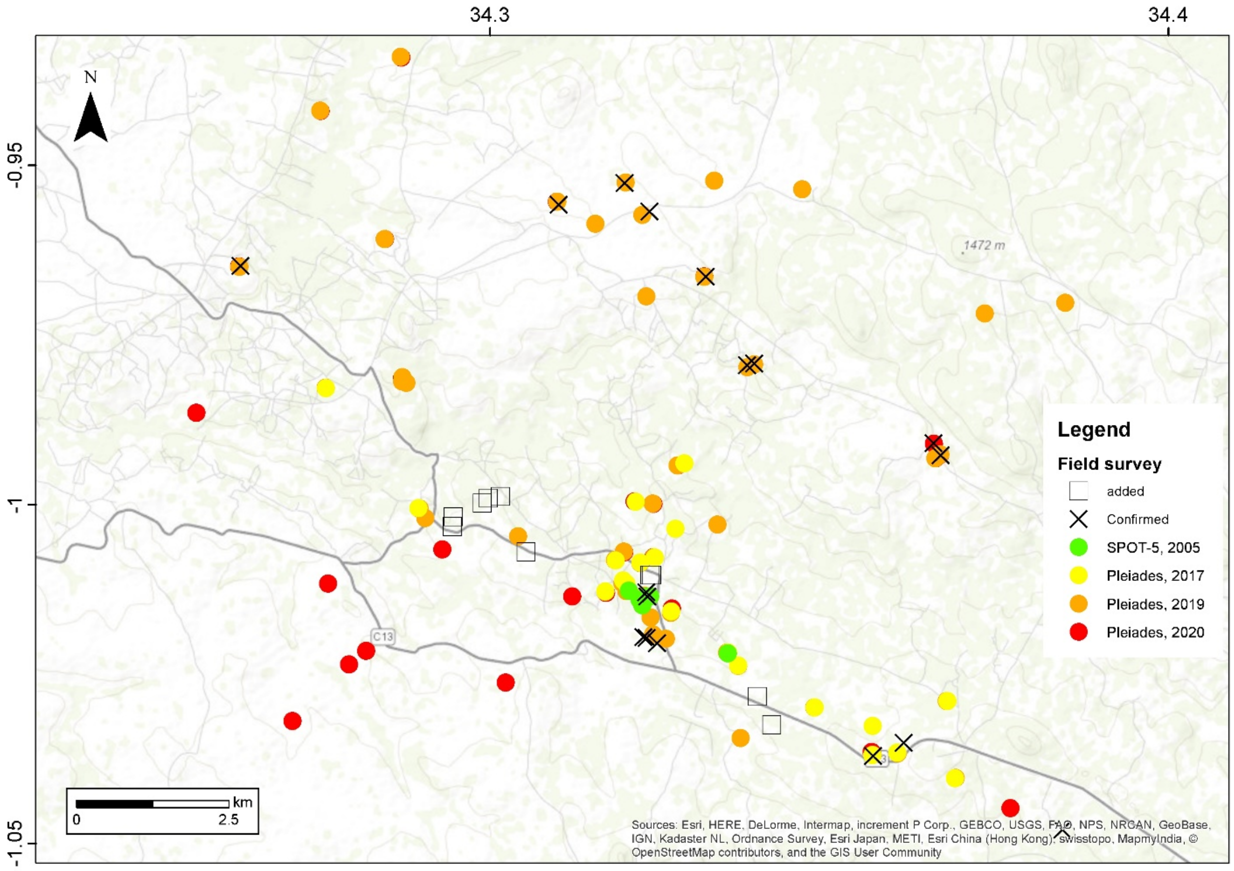


Figure 8 - Final inventory map with the mines added from the field survey and mines identified from EO (see Figure 4) and validated from the field survey. Grid reference system: WGS84. Sources of the background maps: Esri, DeLorme, HERE, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, and the GIS User Community.

5 Discussion and Conclusions

This report has provided detail regarding the mapping of mining sites connected to ASGM using satellite data for the 2005-2020 period with the support of a field survey. Visual interpretation of satellite images has been an effective and precise approach for such a study. Our methodology has been shown to provide accessible, accurate and inexpensive data on ASGM at county level, which can be used to create more sustainable mining practices but the same approach can be costly and time-intensive when upscaled at larger scales.

Despite the different resolution and coverage of the EO datasets we can confirm that the footprint of ASGM has extended as a result of the increasing number of sites and/or their extension with agricultural areas being more vulnerable to being converted into extraction or processing sites. We do not have sufficient data to determine how many mining operations occur in this county. Satellite images have also been an important source of information for planning field campaigns, directing the team towards the area with the highest density of ASGM sites. The work undertaken as part of the field campaign has been used to draw preliminary observations and develop guidelines on improving practice for the artisanal gold miners. We envisage that the datasets produced in this study could provide government agencies with baseline material required to develop a detailed knowledge of ASGM changes within their jurisdictions. An improved understanding of the spatiotemporal patterns of ASGMs could be used to:

- assess the environmental hazards (e.g., deforestation, land and water degradation, waste disposal) associated with the mining activity, for example over residential and public key infrastructure in the Migori County, and subsequently support policy / regulation on the mining sector.
- Track the effectiveness of a range of mitigation strategies to reduce the environmental impact of mining and supporting environmentally friendly ASGM, by identifying sites with good practices and earmarking them for support.

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Appendix

Table of mine sites with latitude and longitude of the centroid of the polygon delimiting the site. Details on the source used to map the site are given (EO = Earth Observation, FS = Field Survey).

Mine ID	latitude	longitude	source
1	-0.942016	34.274975	EO
2	-0.934162	34.286901	EO
3	-0.955377	34.309861	EO, FS
4	-0.960933	34.284476	EO
5	-0.964950	34.262994	EO, FS
6	-0.986547	34.256671	EO
7	-0.981382	34.287020	EO
8	-0.982109	34.287650	EO
9	-1.000712	34.289583	EO
10	-1.006704	34.292949	EO
11	-1.011747	34.276086	EO
12	-1.021652	34.281732	EO
13	-1.023648	34.279193	EO
14	-1.031980	34.270846	EO
15	-1.026307	34.302266	EO
16	-1.013642	34.312095	EO
17	-1.013072	34.317089	EO
18	-1.011671	34.319494	EO
19	-1.012754	34.320287	EO
20	-1.013530	34.322707	EO, FS
21	-1.015386	34.326799	EO
22	-1.016723	34.323636	EO
23	-1.019234	34.324013	EO, FS
24	-1.019892	34.325911	EO, FS
25	-1.021921	34.334950	EO
26	-1.023871	34.336547	EO
27	-1.034520	34.336915	EO
28	-1.036565	34.356262	EO, FS
29	-1.029036	34.367348	EO
30	-0.970301	34.384802	EO
31	-0.971877	34.372935	EO
32	-0.999582	34.321304	EO
33	-0.999958	34.324065	EO
	-1.003024	34.333505	EO
35	-1.007850	34.324101	EO
36	-1.008694	34.322117	EO
37	-1.008280	34.318391	EO
38	-1.004730	34.304104	EO
39	-1.007136	34.319756	EO
40	-1.040413	34.368617	EO
41	-1.036746	34.360098	EO, FS
42	-1.032727	34.356420	EO
43	-1.044879	34.376703	EO
44	-0.966440	34.331583	EO, FS
45	-0.969387	34.323044	EO
46	-0.957333	34.322450	EO, FS
47	-0.958664	34.315497	EO
48	-0.952578	34.319989	EO, FS
49	-0.979813	34.337946	EO, FS
50	-0.979401	34.338913	EO, FS
51	-0.952306	34.333068	EO
52	-0.953548	34.346020	EO
53	-1.030006	34.347823	EO
54	-0.994300	34.327676	EO
55	-0.992705	34.366395	EO, FS
56	-0.993233	34.365701	EO, FS
57	-0.991126	34.365431	EO, FS
58	-1.010400	34.323800	FS
59	-1.028300	34.339400	FS
60	-1.001800	34.294500	FS
61	-1.003300	34.294400	FS
62	-0.998800	34.301500	FS
63	-0.999100	34.299700	FS
64	-0.999800	34.298800	FS
65	-1.007000	34.305300	FS
66	-1.032500	34.341500	FS
67	-1.010400	34.323500	FS