EPM

For the provision of transparent information on mining

Source The Guardian

Source Global Witness

Enhanced Pollution Monitoring – Overview

Artisanal and Small-scale Mining (ASM), Abandoned Mines and Repositories (AMR), whether legal or illegal, are associated with negative environmental and social impacts. Despite regulations, bans, complaints, encouraging cooperatives and associations, in many locations ASMs are continuously and rapidly expanding out of control. At the same time, AMRs – contaminating water, soil, and infrastructures with dissolved metals and acidity – are often disregarded.

Enhanced Pollution Monitoring (EPM) is a customized remote sensing based service:

- To map ASMs, monitor their expansions and assess environmental impacts;
- To map and monitor AMRs, particularly infrastructures and terrain stability.

Moreover, since regulators – within the national legal framework – are also responsible for ensuring compliance of Large-scale Mining (LSM), the service comprises products verifying the conformity of mining operations *in primis* analysing mine and infrastructures stability.

Six stakeholder segments have been identified:

- Regulators responsible for ensuring compliance of ASMs and LSMs with national legal frameworks;
- Non-Governmental Organizations working on national and international levels and including watchdog organizations that critically monitor mining activities;
- Consulting companies in the domain of treatment of mine wastes and remediation;
- Multi-disciplinary consulting companies offering services in the fields of applied environmental sciences;
- ASM certification bodies developing standards to transform ASMs into a sustainable and responsible activity;
- Not-for-profit and membership organizations developing standards within the mining industry.

Overall, key and common needs is to gather objective, independent, accurate, updated information of the location, extent, and stability of mines and repositories, to monitor on-going activities, assess environmental impacts, and, as far as possible, to backtrack the history of mines and/or repositories.

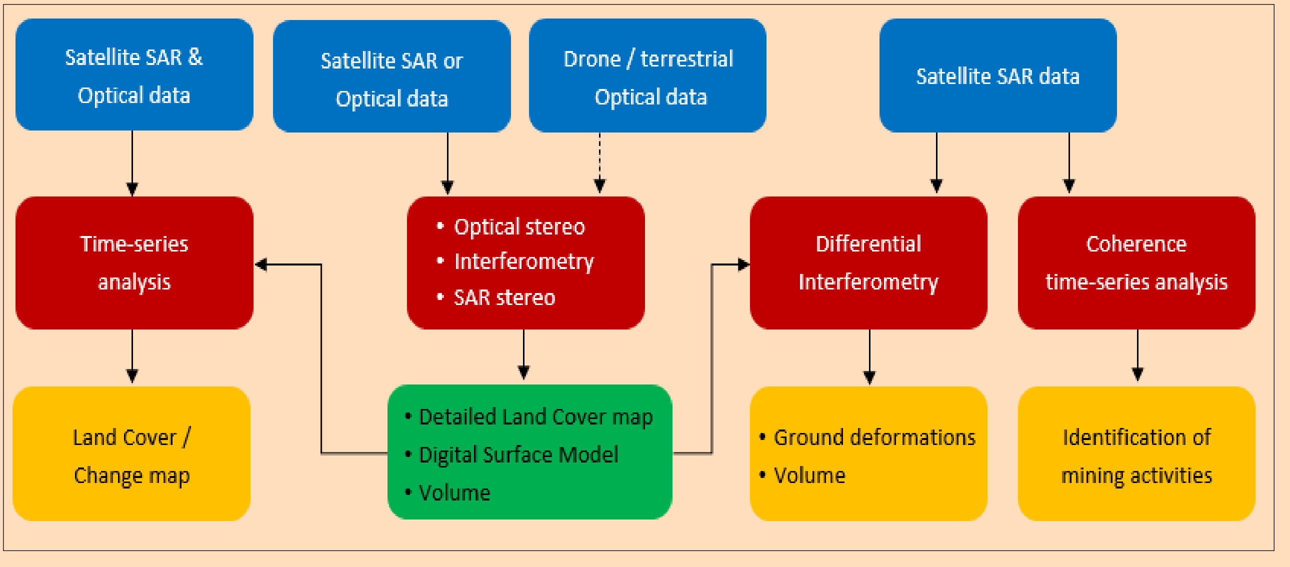
In the following, eleven pilot demonstrations – carried out within a project co-financed by the European Space Agency (ESA) and in collaboration with stakeholders representing the various sectors – are presented. They include:

- Artisanal and Small-scale Mining in Ghana, Liberia, Afghanistan;
- Abandoned Mines and Repositories in Kyrgyzstan;
- Large-scale Mining in Australia, Peru, Liberia, India, Brazil;
- Dam stability in Uzbekistan.

Enhanced Pollution Monitoring – How it works

The flow chart illustrates the service in its generic form. It includes the remote sensing data (blue boxes), the various applied data processing techniques (red boxes), and the products (orange and green boxes) providing two independent and interlinked information:

- **Monitoring information** (orange boxes):
  - is generated from free of charge data, i.e. Sentinel-1, Sentinel-2, Landsat-5/-8, all acquiring data at regular way, i.e. 12, 10 and 16 days;
  - has a spatial resolution ranging from 10 to 30 meters;
  - is based on time-series;
  - is generated using different sensors combinations and techniques.
- **Mapping information** (green box):
  - is produced from commercial satellite, drone or terrestrial stereo data over specific areas;
  - has a spatial resolution ranging from few meters to few centimeters;
  - is mainly based on a single date acquisition;
  - is generated using different techniques.



EPM makes use of all existing satellite remote sensing sensors, both Synthetic Aperture Radar (SAR) and optical data. The first, being an active sensor, has the peculiarity to penetrate the cloud coverage, a key requirement for monitoring purposes, particularly if a routine update of rapid evolution must be assessed. Moreover, radar sensors are measuring the distance from the sensor to objects on the ground with millimeter precision. Differential interferometry allows to generate precise ground deformation maps which may be used to assess ground and infrastructure instabilities.

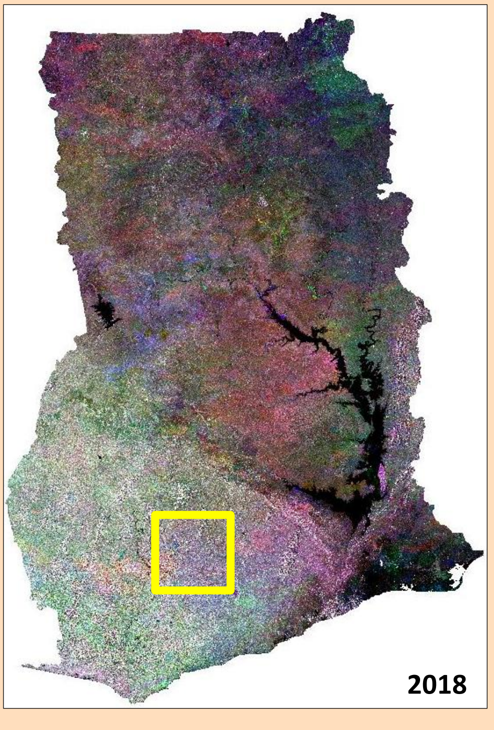
The choice to consider different data and techniques is dictated by:

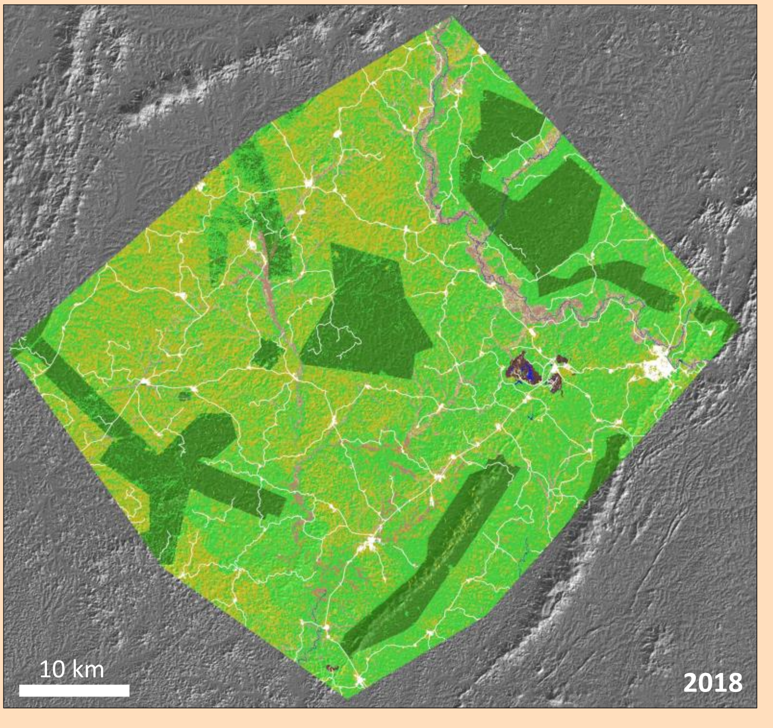
- the different needs;
- the requested level of detail;
- the temporal sampling;
- the remoteness of the area;
- the accessibility of the area;
- the available budget.

Artisanal Small-scale Mining – Ghana

Galamsey – the local Ghanaian term which means illegal small-scale gold mining **–** is not a new phenomenon in Ghana, as an estimated 200,000 Ghanaians – in turn supporting some three million people – are believed to make their living from ASM. Whereas Ghanaian law allows land owners to mine their own property, as well as sublet to artisanal miners, many small scale miners also operate outside the law, working on public lands or in remote regions. Successive Ghanaian governments have tried to find these miners jobs in the formal mining sector, yet Galamsey has stubbornly remained an important element in Ghana's economic makeup.

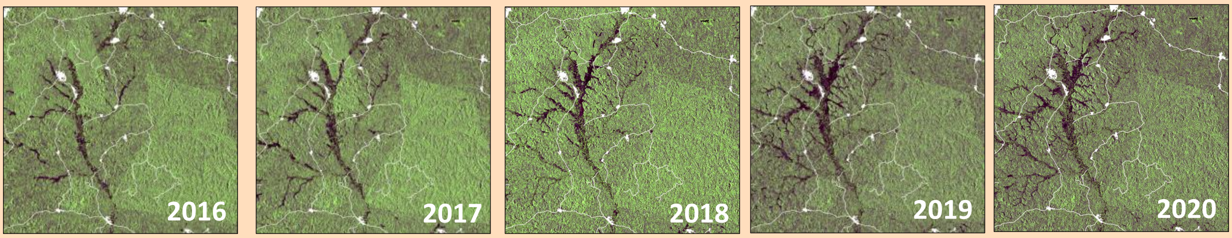
GalamWatch is an operational customized satellite based service designed to map and monitor ASMs as well as abnormal land cover changes – *in primis* associated with deforestation – often connected to incipient illegal mining activities. In tropical and large regions, the use of Synthetic Aperture Radar systems, such as Sentinel-1, is crucial, particularly if a routine update of the rapid evolution of land cover must be assessed. Given the high temporal acquisition rate – i.e. 6 days – of Sentinel-1 data in this geography, a monthly monitoring is doable, hence enabling the regular quantification of ASM evolution, to assess if mines are still active or abandoned, and, finally, to identify doubtful land transformations. This latter information, primarily related to deforestation, permits timely intervention in order to stop the establishment of ASMs. The two figures illustrate a Sentinel-1 temporal composite (left) covering the whole Ghana (238,540 sqkm) at 20 meter resolution and a baseline map (right) showing in brown the extent of the ASMs in 2018 for this area.

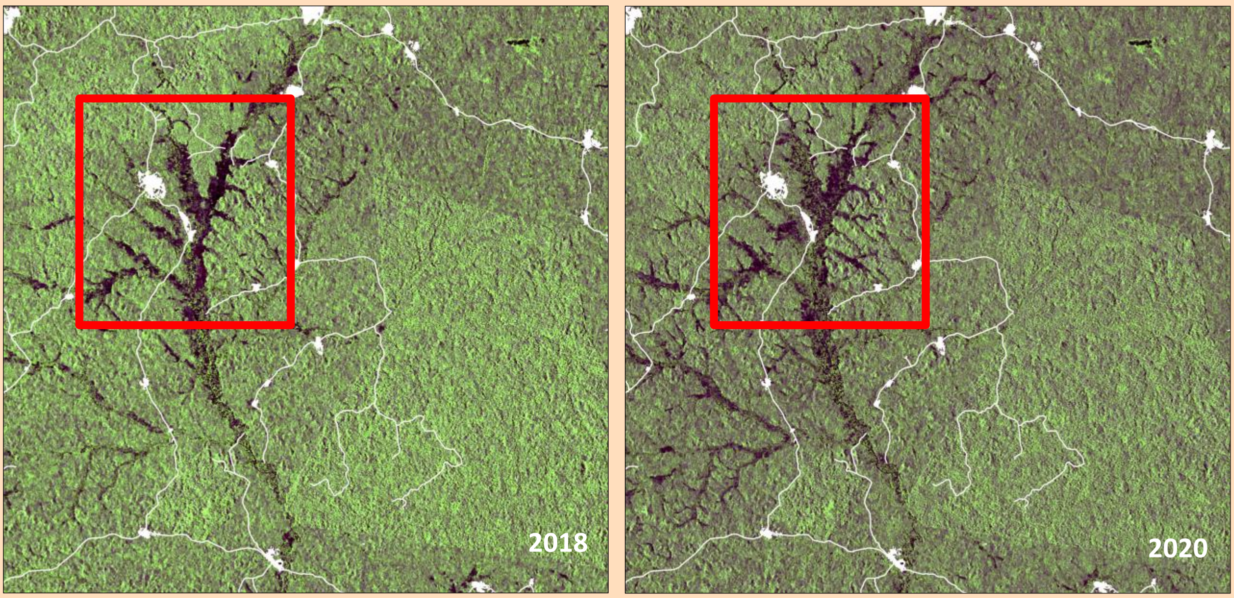




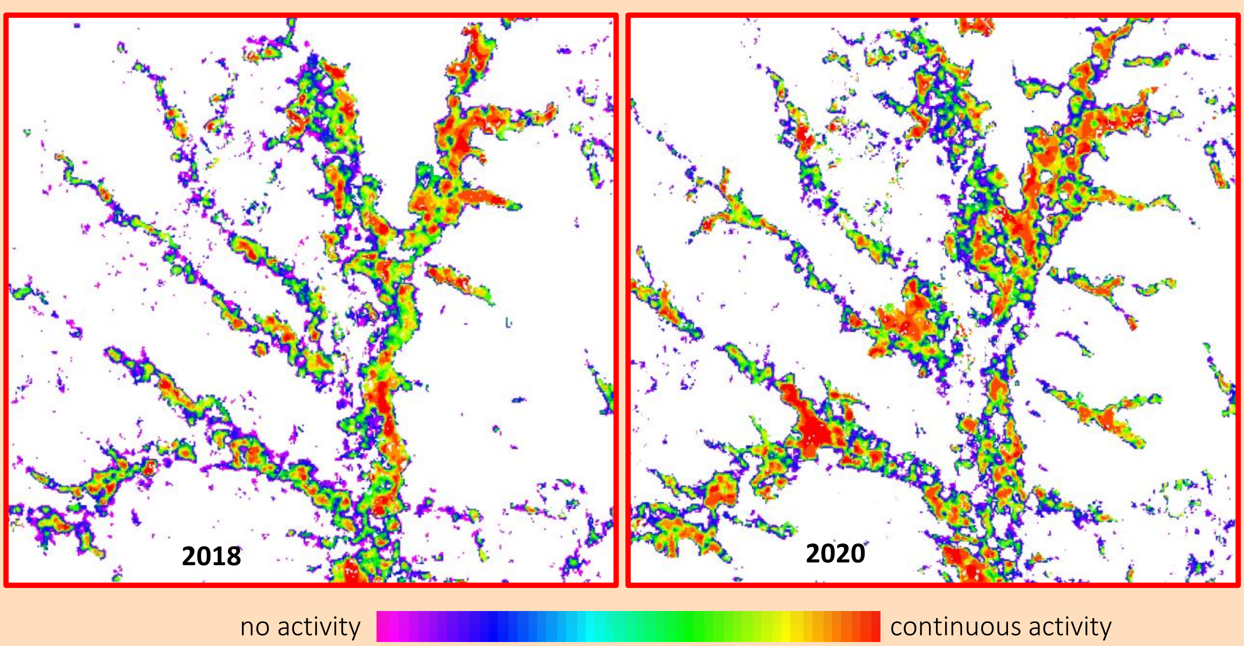
As part of measures by the Inter-Ministerial Committee on Illegal Mining (IMCIM) to regularise and reform the activities of small-scale miners, a know-how transfer to the IMCIM team on GalamWatch is currently on-going.

Sentinel-1 is operationally delivering data since 2015. This allows, for the first time ever, to retrospectively quantify annual ASM evolution rate, as shown as example in the figures below.

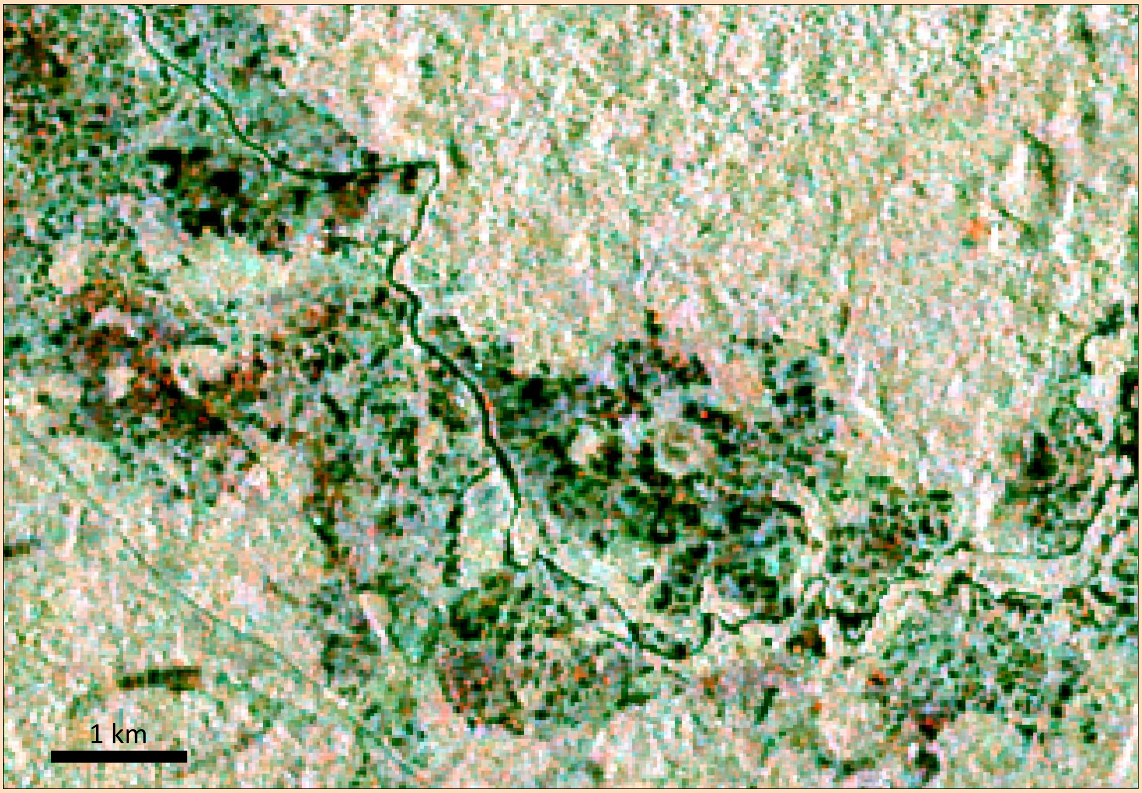


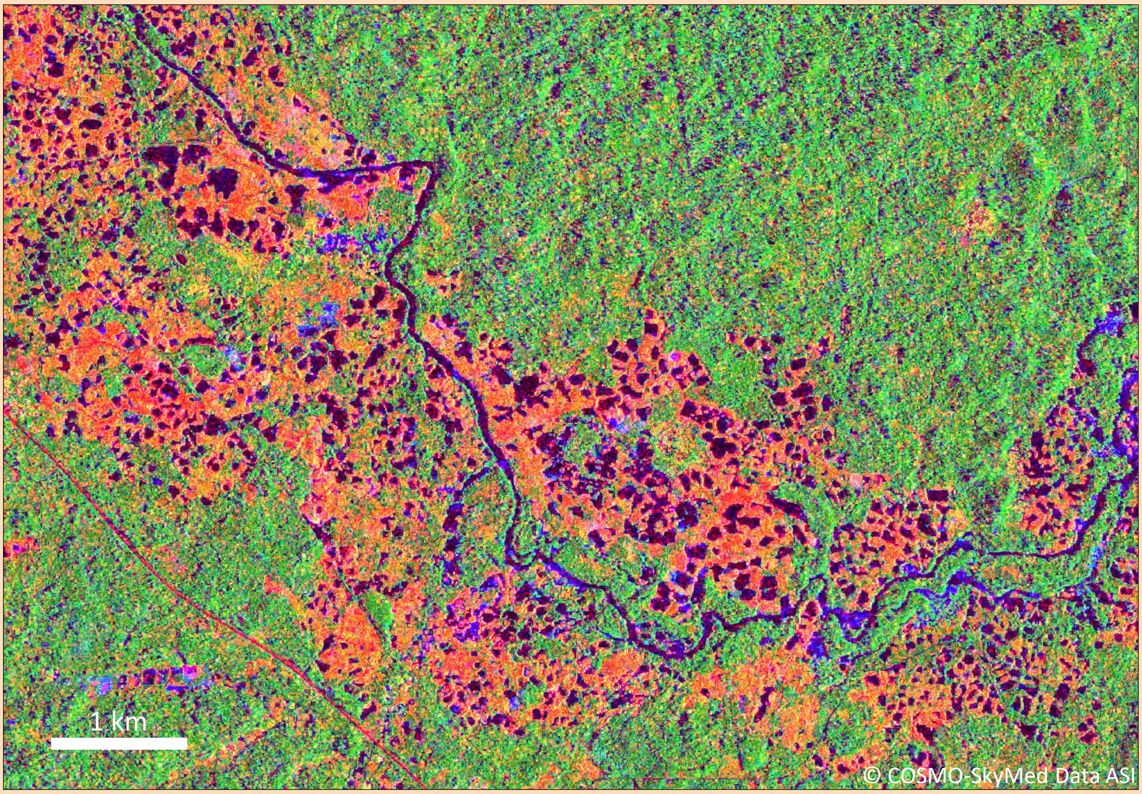


Moreover, given the short repeat cycle of the two Sentinel-1 satellites, the ASMs status – i.e. if mines are active or abandoned – can be assessed. The two figures below show as example the on-going activities in 2018 (left) and 2020 (right) during the period begin December to end February. While blue areas represent no activities during this period, red areas correspond to a continuous activity, i.e. where gold is extracted. This type of information, particularly if analyzed over years, allows a better understanding of the dynamic of ASMs expansion, but also to efficiently target either terrain or drone based inspections.

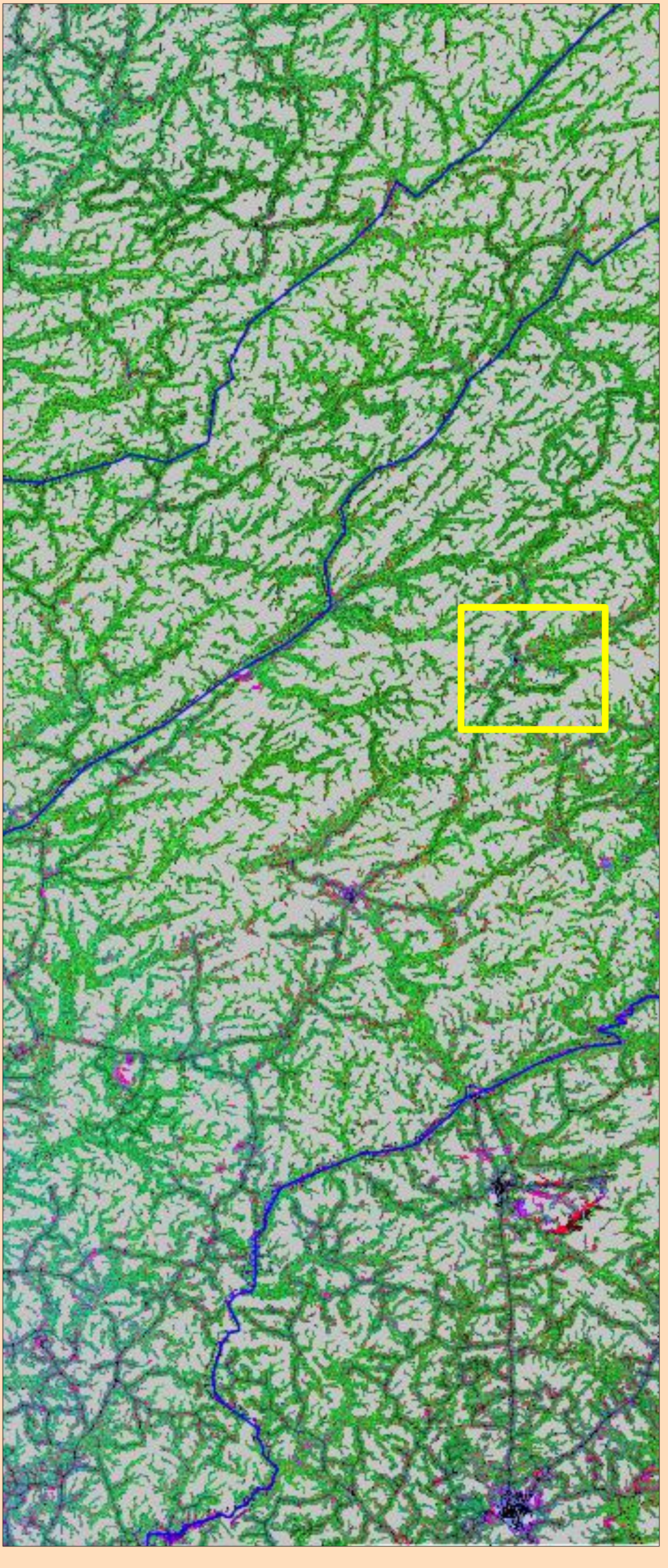


To monitor mining activities at national level, systematic acquisitions are requested. This can be exclusively achieved with sensors having a spatial resolution ranging from 10 to 30 meter. The better the spatial resolution, the higher is the level of detail, but also the amount of data (a factor 9, between 10 and 30 meter). Do have Sentinel-1 20 meter images a suitable level of detail to monitor small-scale mining in Ghana? By comparing the two figures – Sentinel-1 (top) and Cosmo-SkyMed (bottom) at 3 meter resolution acquired in the same period – it is unquestionable that 20 meter is adequate. Nevertheless, if the purpose is to accurately map each single small-scale mine, devices having a resolution better than 5 meter are needed.





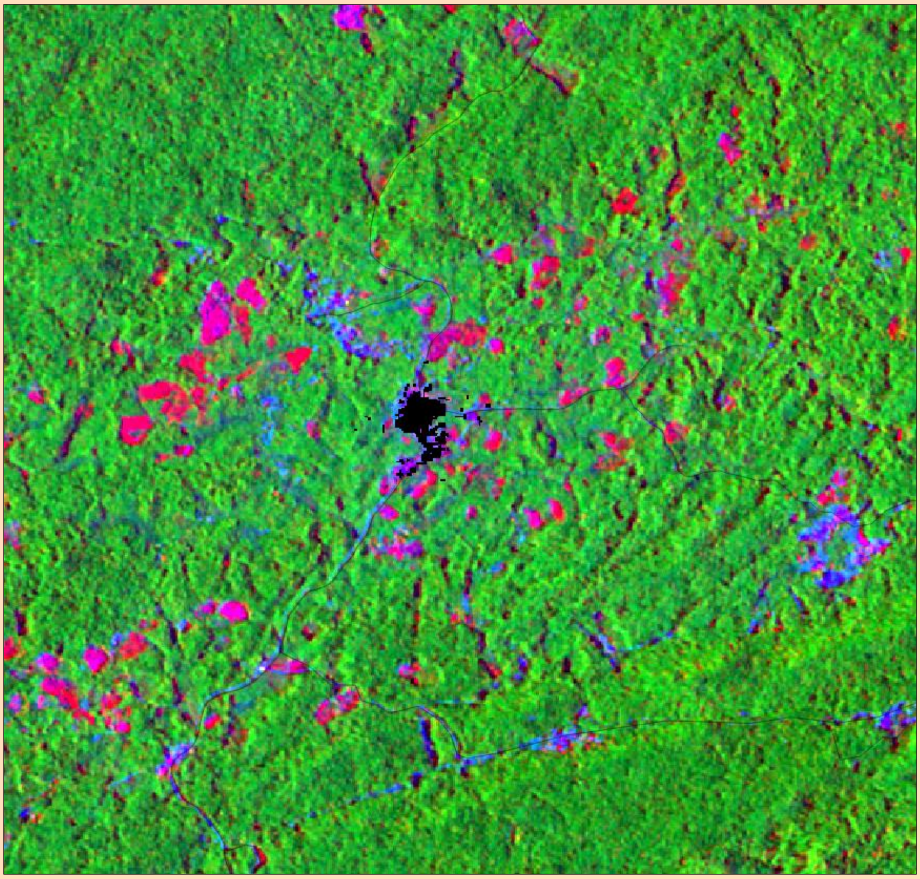
Artisanal Small-scale Mining – Liberia



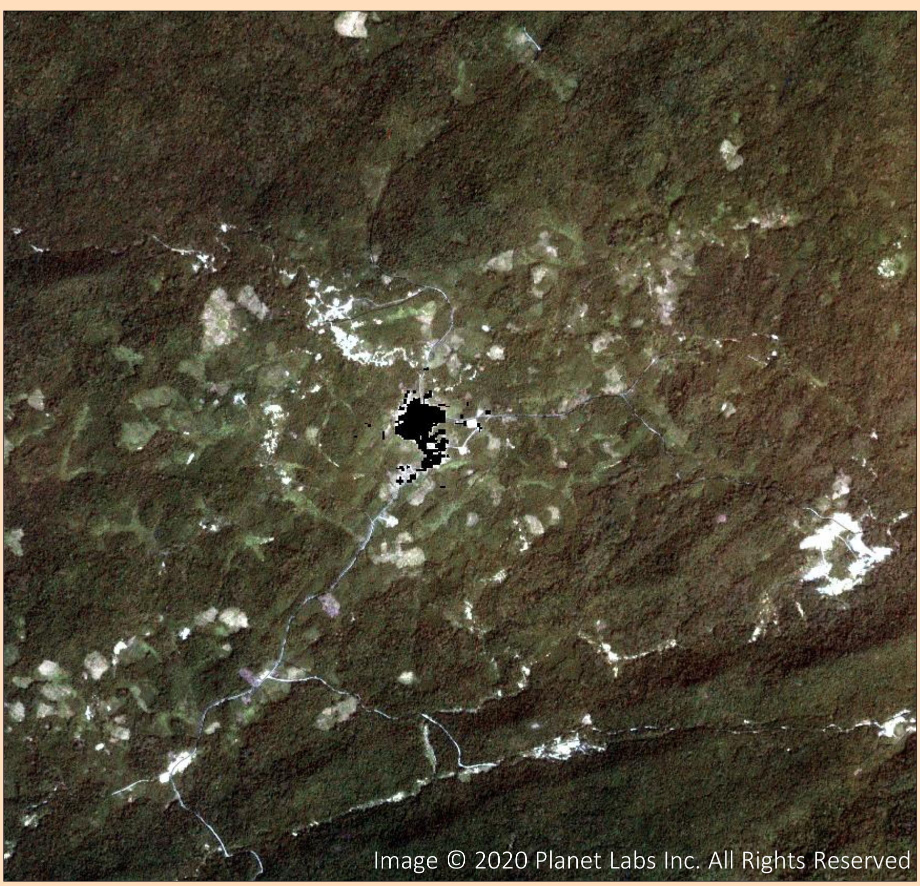
Artisanal mining in Liberia is predominantly of gold and diamonds and it is carried out primarily by illegal miners. Nonetheless, in 2016, the Ministry of Lands, Mines and Energy began an initiative aimed at formalizing the artisanal and small scale mining sector with a primary objective to encourage artisanal miners to organize their mining activities through cooperatives that would attract foreign investors into the sector and contributing to the country's economy through royalties and taxes paid by licensed dealers. However, some of the most lucrative mines are located in remote areas deep in the forest and the government often lacks the necessary resources or capacity to monitor those activities.

The Gbarpolu county, an area of around 10,000 sqkm, consists primarily of forest, subsistence farming and is probably the area of most gold and diamond artisanal mining in Liberia. Sentinel-1 data acquired from April to August – the crop season period – in 2017, 2018, and 2019 is used to differentiate small plot agriculture from bare soil, a typical indicator of artisanal mining activity. To enhance the identification of small plot artisanal mining, Landsat-8 panchromatic data is integrated into the three years Sentinel-1 time-series. Moreover, to exclude potential areas which could be wrongly interpreted as artisanal mining, only the zones surrounding the channel network based on the 30 meter SRTM Digital Elevation Model are kept. The resulting map, shown on the left, covers an area of 62 by 150 km, most of the Gbarpolu county.

Artisanal Small-scale Mining – Liberia



The figure on the left shows the land cover of the area around Henry Town (yellow box, around 120 sqkm, of the Gbarpolu county map). The town is identifiable in black, forest in green, agriculture in red, and artisanal mining in dark blue. The Sentinel-1 20 meter resolution is, to some extent, a limitation given the overall small plot nature of artisanal mining. Nevertheless, compared to the 3 meter resolution Planet Scope image acquired on January 2020, the patterns look very similar.

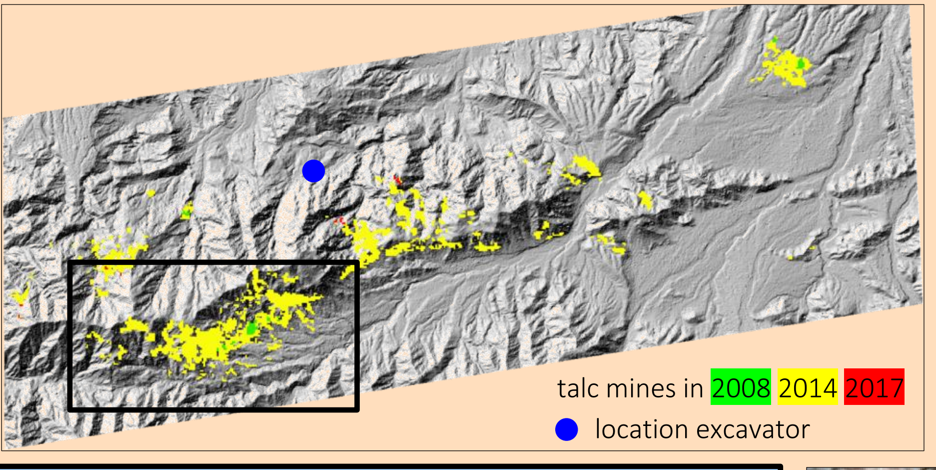


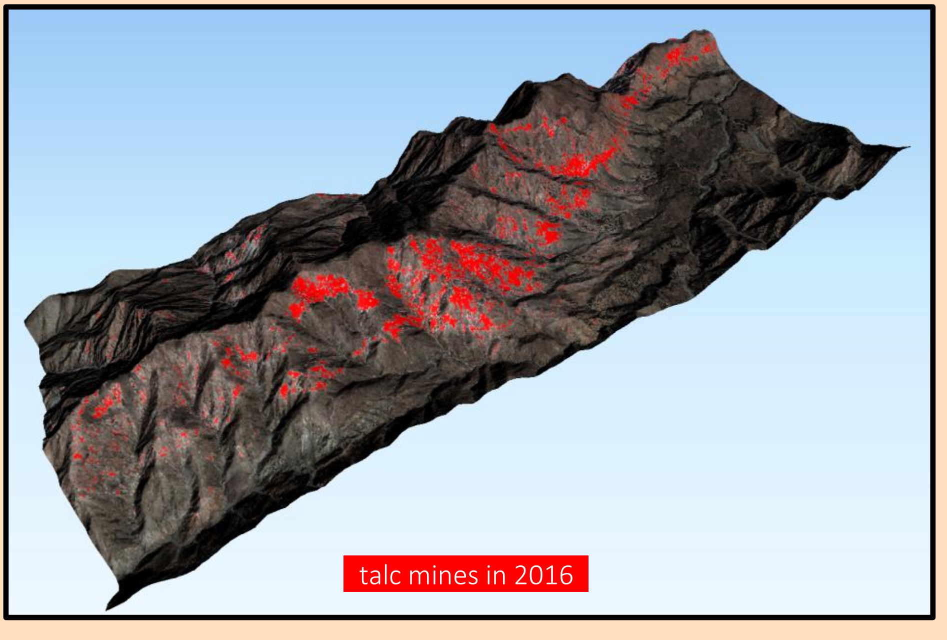
To monitor the evolution of mining activities at country level, due to the severe cloud conditions, the use of Sentinel-1 time-series is a pre-requisite, as long as they are in open areas, i.e. not under the forest cover. During the dry season (January-February) and depending on cloud free data availability, Landsat-8 and Sentinel-2 data are combined with Sentinel-1 time-series in order to enhance the identification of small plot mines. Nonetheless, a precise assessment of small plot mining is only possible by means of very high resolution images, as offered by Planet Scope data, where almost cloud free acquisitions during the dry season are ensured given the considerable number of satellites.

Artisanal Small-scale Mining – Afghanistan

The mines of the rugged North-Eastern provinces in Afghanistan are ones of the richest assets of the Afghan people, an extraordinary national treasure that should be a powerful resource for development. Instead, they are a major source of conflict and grievance, supply millions of dollars of funding to armed groups, insurgents, and strongmen, and provide a tiny fraction of the benefit they should to the Afghan people. According to the Global Witness report *At any price we will take the mines**, a number of sources testified that an armed group was particularly present around mining areas in the Nangahar province. Nevertheless, there was mixed evidence on the extent to which this group was able to exploit them. Satellite data are therefore exploited to obtain evidence of an on-going mining activities.

Given the rugged nature of the terrain and the small mining plots in Nangahar province, a detailed Digital Elevation Model (DEM) is essential to provide an accurate map. For this reason, a DEM at 3 meter resolution is produced from SPOT-6 stereo images. Subsequently, based on 30 meter Landsat-5/8 data, the evolution of the talc mining extent for 2008, 2014, and 2017 is mapped and overlaid on the DEM. As shown in the upper figure, there is clear evidence that the most significant growth occurred between 2008 and 2014, while from 2015 the mining extent remained practically stable. To assess the effective exploited area, a 0.5 meter Pleiades image acquired in 2016 is used, the talc mining area mapped (bottom figure) and calculated, resulting in around 85 hectares. Moreover, this very high resolution image permits to identify an excavator (blue circle), indicating a probable relevant talc production.



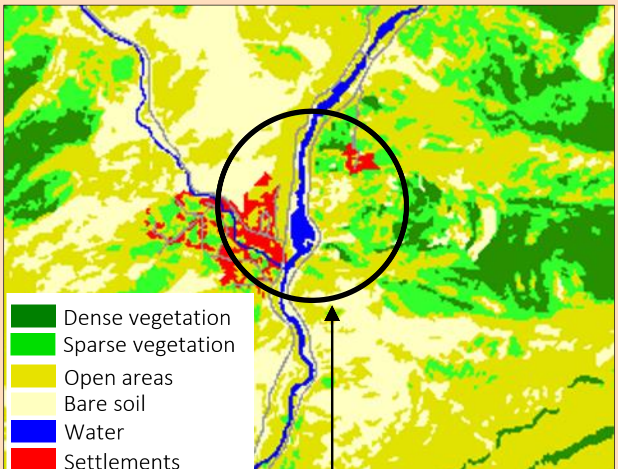


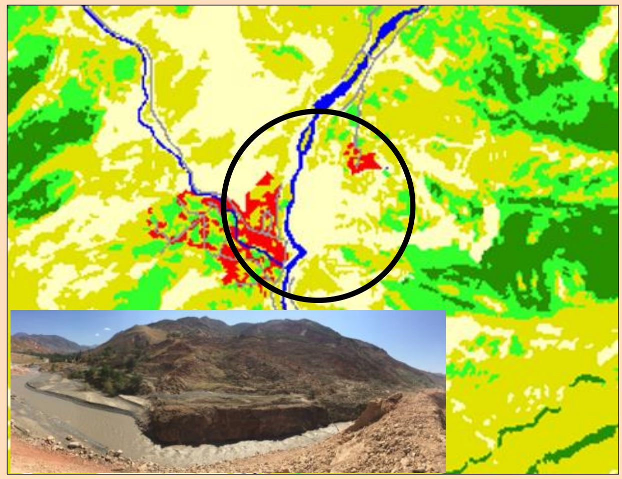
* https://www.globalwitness.org/en/campaigns/afghanistan/talc-everyday-mineral-funding-afghan-insurgents/

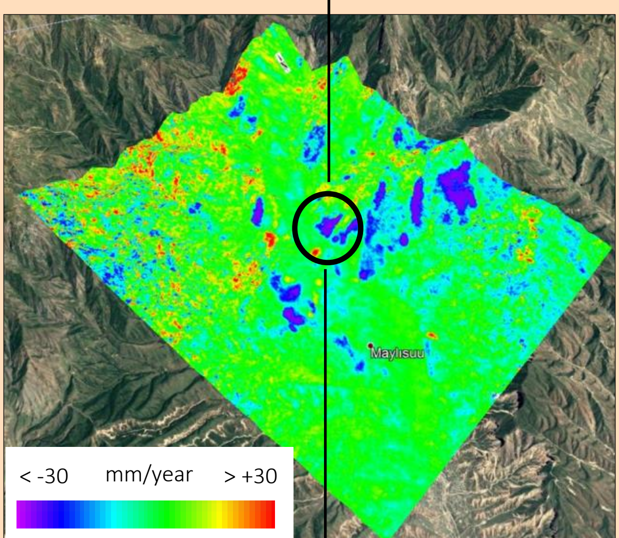
Abandoned Mines and Repositories – Kyrgyzstan, Mailuu Suu

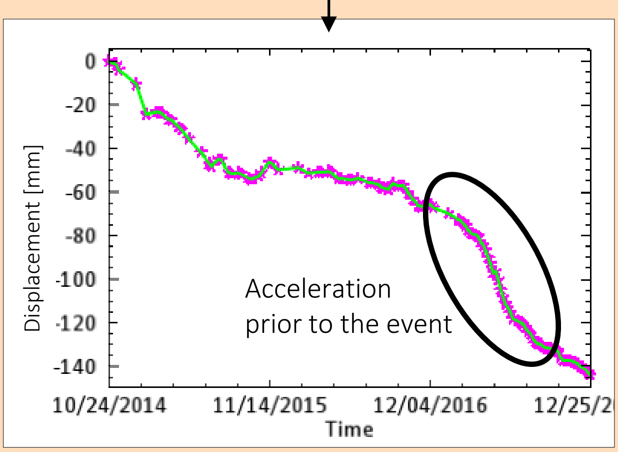
Located in Kyrgyzstan, the Mailuu Suu mine shifted from mining to processing, and imported ore from other Central Asian countries. As the amount of radioactive waste grew over time, planners decided to distribute the estimated 2 million m^3 over ten of radioactive waste rock dumps and tailings storage facilities disseminated along the valley in an area highly prone to landslide.

During the last week of April 2017 a landslide occurred right next to a small village located around 5 km North of Mailuu Suu. As shown in the two land cover maps derived from Sentinel-2 images (10 m resolution) from April (left) and June 2017 (right), the slope came down all the way into the river, whose riverbanks are clearly encroached by the landslide.









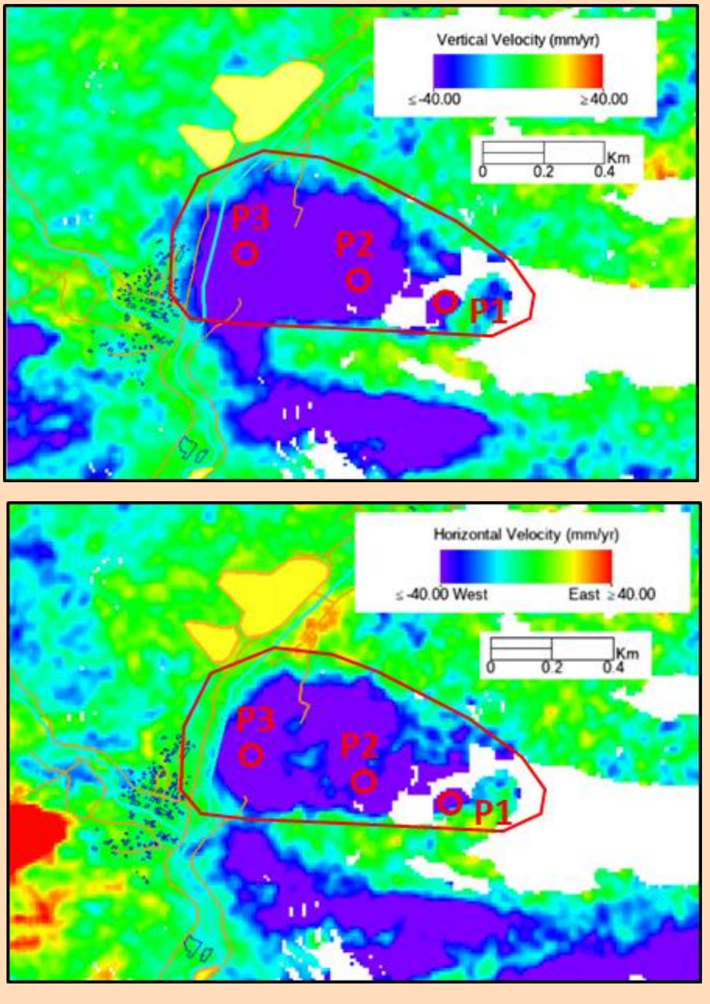
Could this landslide have been predicted? Yes.

The figure on the left – derived from the vertical component (corresponding to subsidence/compaction and uplifting) and the horizontal one (resulting from westward and eastward movements) from Sentinel-1 time-series – represents the average displacement velocity per year distinguishable in blue (displacements larger than -3 cm/year) and red (larger than +3 cm/year). The analysis of the subsiding terrain movement during the period October 2014 to December 2017 over the Koitash landslide reveals, as illustrated in the graph bottom left, non-linear deformations, particularly evident prior to the event, where the derived displacement velocities were in the order of 1 cm/month.

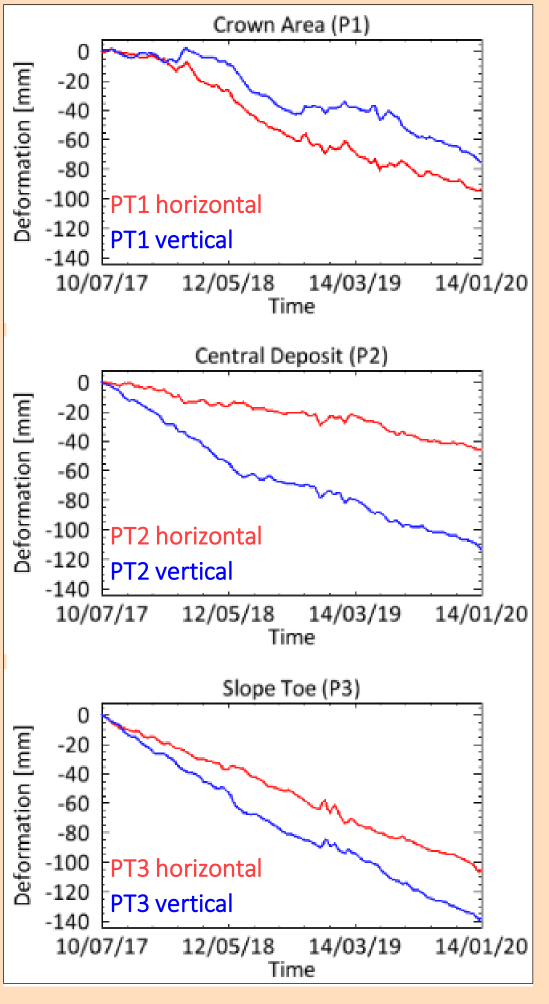
This information is not only useful to geo-technicians for landslides modelling purposes, but also to identify the location of past and on-going displacements and to regularly assess their rates, particularly in large and remote areas, as in Mailuu Suu, where waste rock dumps are scattered across the valley.

On-going deformations affecting the slope after the landslide event are derived from Sentinel-1 time-series over the period October 2017 and January 2020. Mean rate of deformation maps projected along the vertical and east-west directions are illustrated in the two figures on the left. The deformation color scale ranges from blue to red, corresponding to subsidence/compaction and uplifting in case of vertical displacements, while in the horizontal deformation map, blue areas are moving westward, while red areas are moving eastwards, depending on slope aspect. These maps show how the slope is clearly affected by vertical deformation as well as an ongoing horizontal displacement in a westerly direction, both with a rate of over 4 cm/year. It is noticeable that the area affected by ongoing deformation extends close to the tailings storage facilities (yellow polygons) located at approximately 200 m far from the collapsed slope identified.

Vertical and east-west time-series of deformations are plotted in the graphs on the right. It is evident how the crown area is more affected by horizontal than vertical deformation, while both the central part and the toe of the slope are showing a higher vertical component. In addition, P2 and P3 are characterized by an almost constant linear trend of deformations, whereas P1 is showing an initial stability followed by an acceleration, more evident in the vertical component. This describes a re-activation of the deformation some months after the landslide.



Vertical (above) and East-West (below) mean velocity maps. The red polygons identify the Koitash landslide. Yellow polygons correspond to the radioactive tailing store facilities.



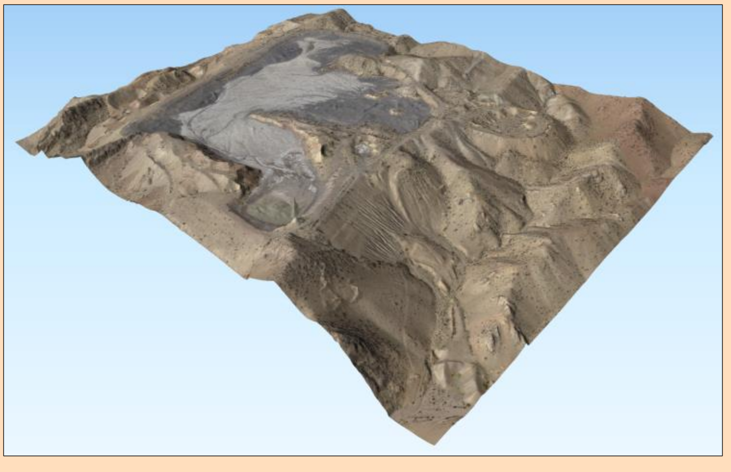
Horizontal (red) and Vertical (blue) time series of deformations plotted in P1, P2 and P3, located at the crown area, the central portion and the toe of the slope.

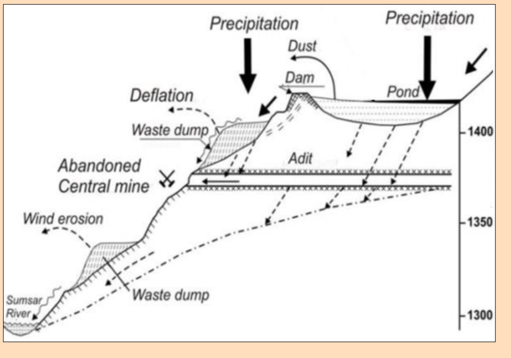
Tessari et al., Analyses of Koitash landslide, affecting Mailuu Suu valley, Kyrgyzstan, through integrated remote sensing techniques, Fifth World Landslide Forum, Kyoto, 2020.

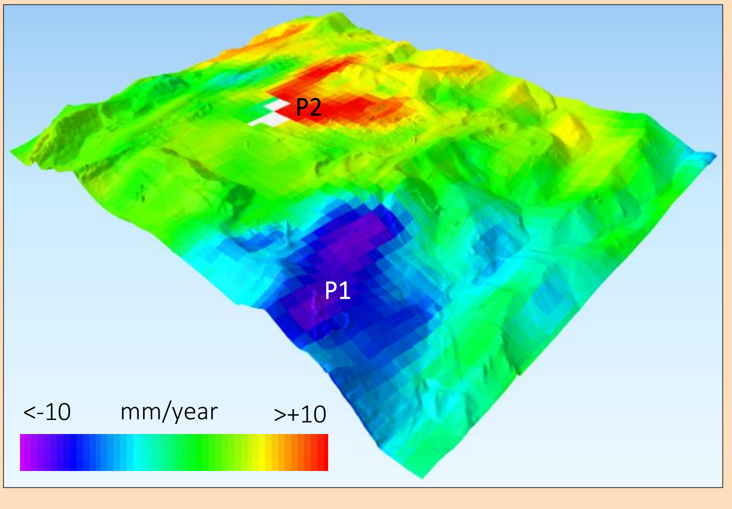
Abandoned Mines and Repositories – Kyrgyzstan, Sumsar

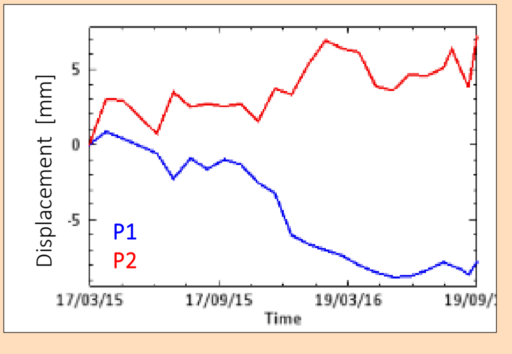
Sumsar is a village located in Kyrgyzstan with a population of around 6,000 people. The main source of pollution are three legacy tailings storage facilities located within the living environment of the valley. Large amounts of hydrometallurgical wastes deposited at three tailing sites with total amount of 2.65 million m^3 waste containing high concentrations of toxic heavy metals lead, zinc, cadmium, and arsenic. The legacy sites are approximately 10 km upstream from the northern fringes of the Fergana valley which comprises to the most important agricultural areas of former Soviet Central Asia. On the East and 100 m above of the Sumsar village is located an open surface not remediated area of 142,000 m^2 with 1,8 mio m^3 of deposited waste materials. This tailing storage facility is a potential risk of a gradual or sudden tailing dam collapse into hollow underground spaces of the former mine shafts and chemical elements from the tailings materials migrating into the ground and some of them into surface water (refer to the figure top right).

A Digital Surface Model (DSM) at a resolution of 20 cm is generated from around 200 stereo images acquired by drone. As illustrated in the figure top left, the former Sumsar lead and zinc mining and ore processing area and the waste dump are clearly visible in the 3D representation, where the mosaiced images is overlaid on the highly detailed DSM. The DSM is, in turn, used for the generation of the displacement map based on Sentinel-1 data over the period March 2015 to September 2016 – as shown in the figure bottom left – where a downward displacement of the waste dump of around 1 cm/year is estimated (blue colour) and a slight uplift is identifiable in the region coloured by red. The most critical part – even though no acceleration is noticeable in the graph bottom right – is recognizable in the steepest part of the waste dump (P1), indicating a slow but continuous sliding of the surface. It cannot be excluded that in case of heavy precipitations an acceleration would occur, resulting in a collapse.





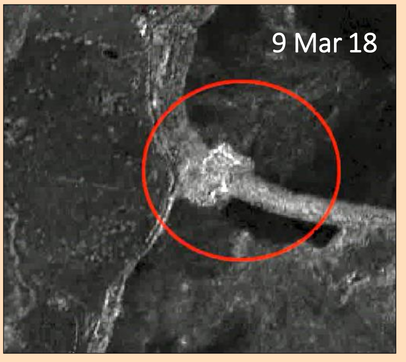


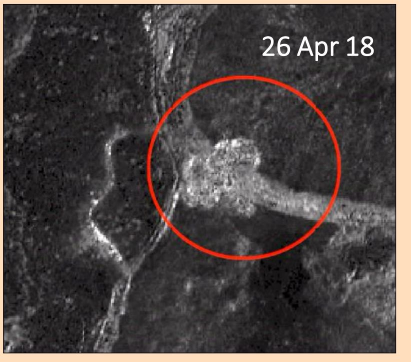


Large-scale Mining – Australia

Operations at one of Australia's largest gold mines had to be temporarily suspended on March 9th, 2018 after a partial wall collapse at one of the mine's tailings dams. The wall collapse at the mine occurred just a few days after two earthquakes hit the area (AGU Blogosphere, 12 March 2018).

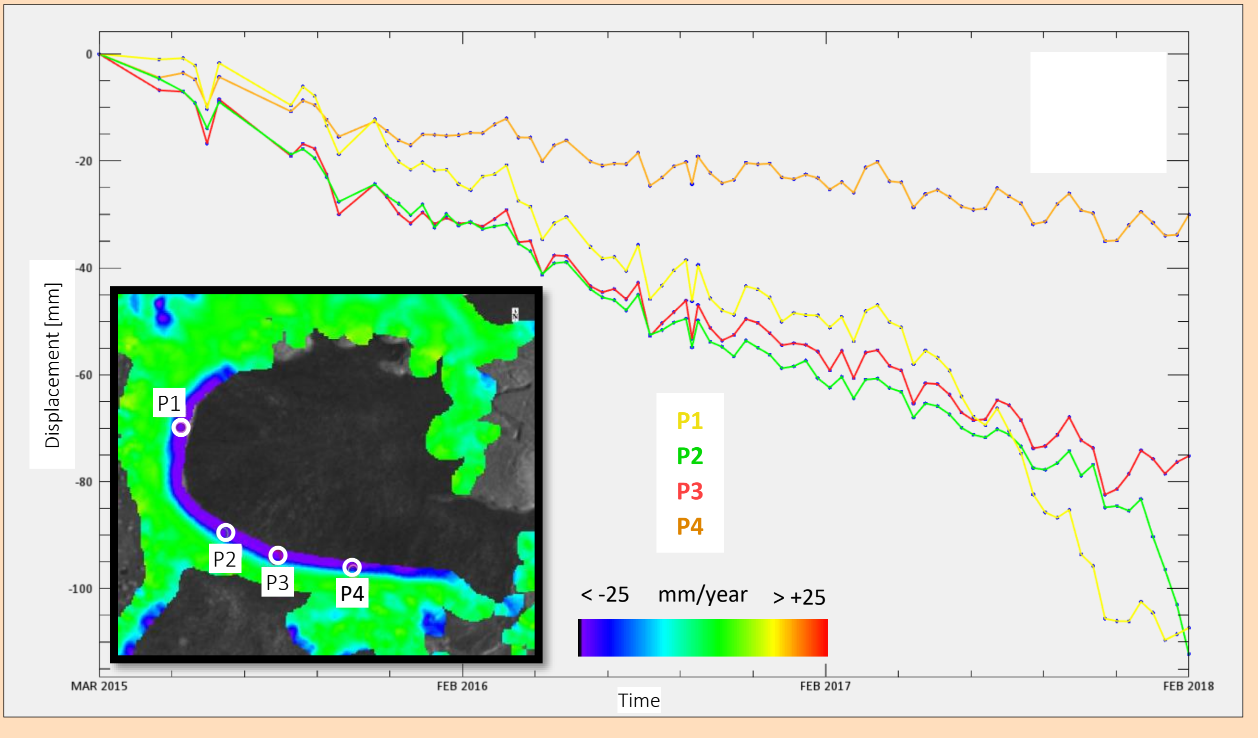
The three selected Sentinel-1 images show the dam status prior to the wall collapse (January 8th), at day of collapse (March 9th) and around one and half month later (April 26th), where it may be seen that the leakage is still on-going.





Could this wall collapse have been predicted? Yes.

Sentinel-1 data acquired over the period March 2015 to March 2018 and processed in an interferometric way allows the analysis and quantitative assessment of ground deformations. The figure within the graph represents the average displacement velocity per year distinguishable in blue (deformations larger than -2.5 cm/year) and red (larger than +2.5 cm/year). A temporal analysis of the movements for four selected points on the tailing dam reveals non-uniform displacements. While P3 and P4 time-series indicate a linear movement, the time-series on P2 (collapsed wall) and P1 show that a significant displacement increase was already on-going since January 2018 and April 2017, respectively.

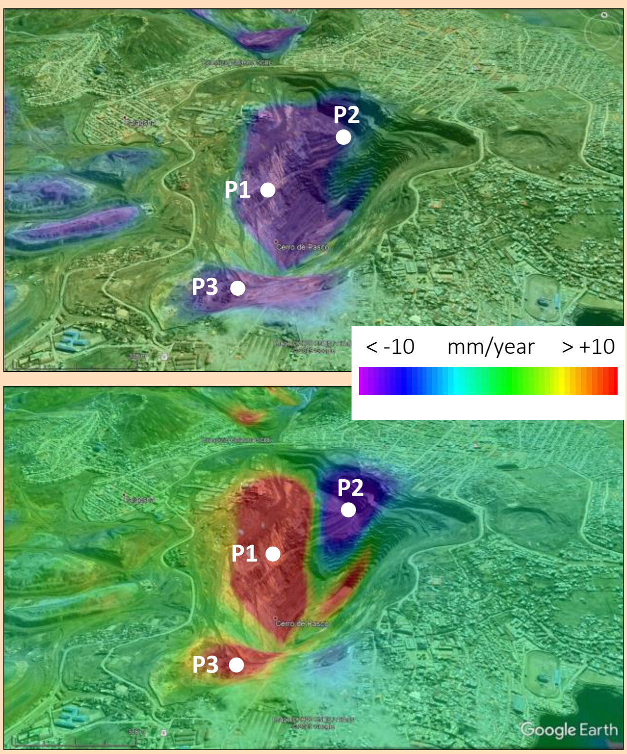


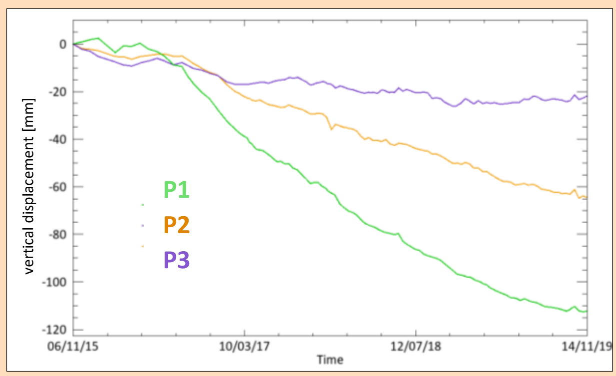
This analysis does not pretend to provide an interpretation of these phenomena, since the risk management needs to be investigated by structural engineers. However, since the deformation process has been active over the whole observation period, it appears unlikely that the earthquake could be identified as the only or major cause of the collapse.

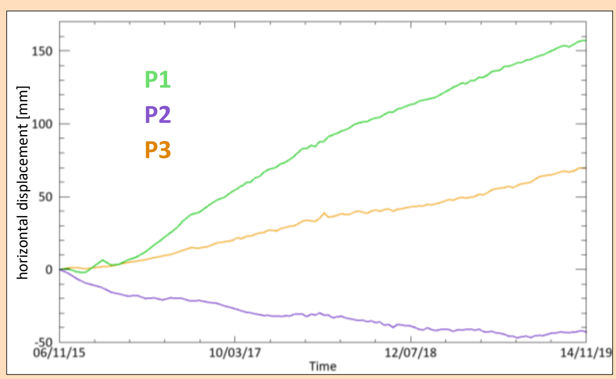
Large-scale Mining – Peru

Cerro de Pasco is a mining town located on the high plateau of Central Peru. The Peruvian governmental authorities, NGOs, and international organizations have reported that Cerro de Pasco is exposed to extreme levels of environmental pollution caused by mining which impacts on the health of the town's inhabitants. A report* published by the Centre of Climate Crime Analysis (CCCA) concluded that *the mining company contributes to, and is responsible for, systematic human rights violations and severe environmental damage in Cerro de Pasco.* The extensive analysis reported by CCCA provides evidence on – and the causes of – contaminated soil, water, food, dust and air. The document does not address the problem of mine and infrastructure stability, a crucial aspect to ensure the safety of the miners and the town's inhabitants. In order to assess possible mine, infrastructure and ground instabilities, an analysis covering a period of 5 years using Sentinel-1 is carried out.

The displacements analysis is based on Sentinel-1 data acquired over the period 2015 to 2019. As illustrated in the two graphs on the right, linear movements ranging from around 2 cm (P3 vertical) to 15 cm (P1 horizontal) are noticeable. The two figures on the left show the vertical (top) and horizontal (bottom) component of the displacements: average annual displacement velocities larger than 1 cm/year, distinguishable in blue and red colours, are identifiable. The most critical area of the mine – even though starting from end of 2016 no acceleration is noticeable in the two graphs – is detected in the steepest part of the mine (P1), where the derived annual displacement velocities in the horizontal and vertical direction are around 3.5 and 2.5 cm/year respectively.







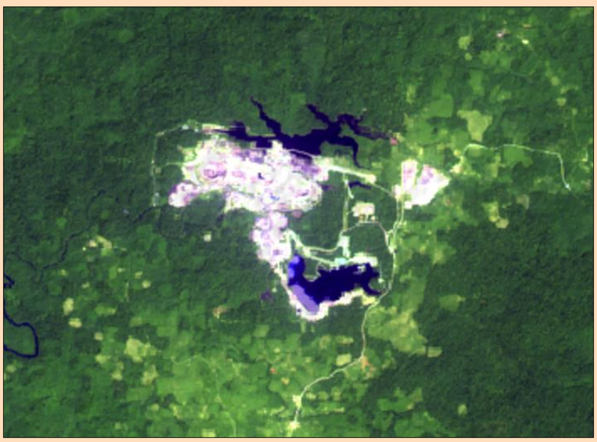
This information is not only useful to the mine industry to complement its own measurements, but also to regulators and NGOs, particularly if the mine is located in remote areas or not easily accessible regions, in order to ensure compliance of the mine activities with the national legal frameworks and cross-check information reported by mining companies.

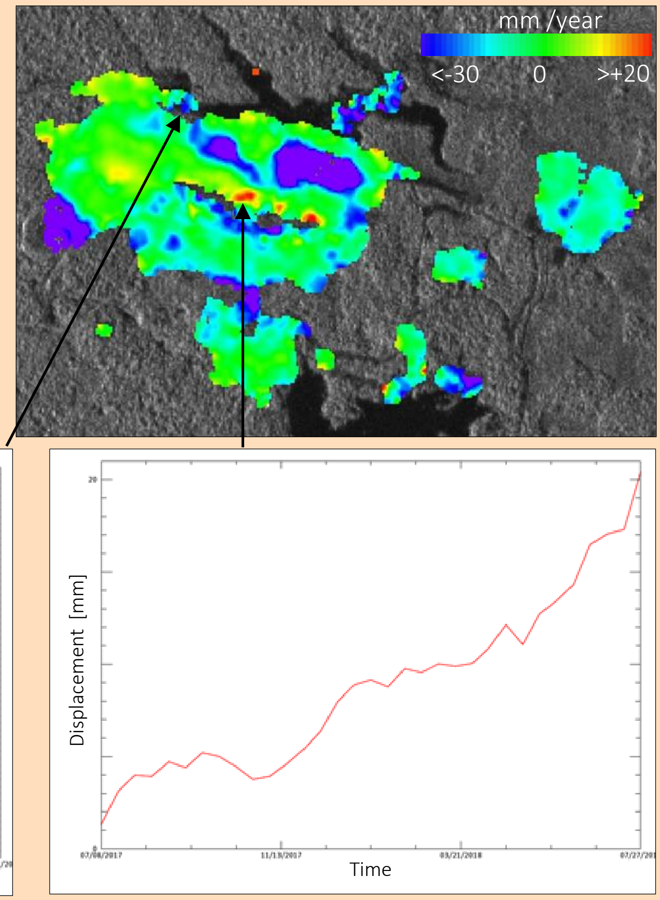
- CCCA, Report to the Council on Ethics of the Norwegian Government Pension Fund Global on the situation in Cerro de Pasco, 2019.

Large-scale Mining – Liberia

Industrial mining in Liberia includes gold and iron ore. The mining of these minerals is associated with huge environmental impacts ranging from land form degradation, pollution of air quality, loss of biodiversity, and watercourse contamination. Liberty Gold Mine is Liberia's first and largest commercial gold mine. The construction at New Liberty commenced in April 2014, with first gold poured from the process plant in May 2015 and gold sales commencing in August 2015. The commercial production was declared at New Liberty on March 2016. The New Liberty Gold mining operations require 1.2 million m^3 of water annually and its tailings storage facility is expected to discharge 9.4 million m^3 of water annually into surface water streams (Wilson et al., 2017*). Therefore, there are significant potential impacts on water quality, human health, and ecosystem from these activities.

The displacements analysis is based on Sentinel-1 data acquired over the period March 2017 to October 2018. As illustrated in the two graphs, the two selected points show subsiding movements of around 5 cm (left) and uplift movements in the order of 2 cm (right). The figure on the right displays the displacements for the entire mine: average annual displacement velocities larger than 3 cm/year, in blue, and larger than 2 cm/year, in red, are identifiable. Overall, in this period no accelerations are noticeable – the trend of the displacements is linear – and, in general, the mine is stable.





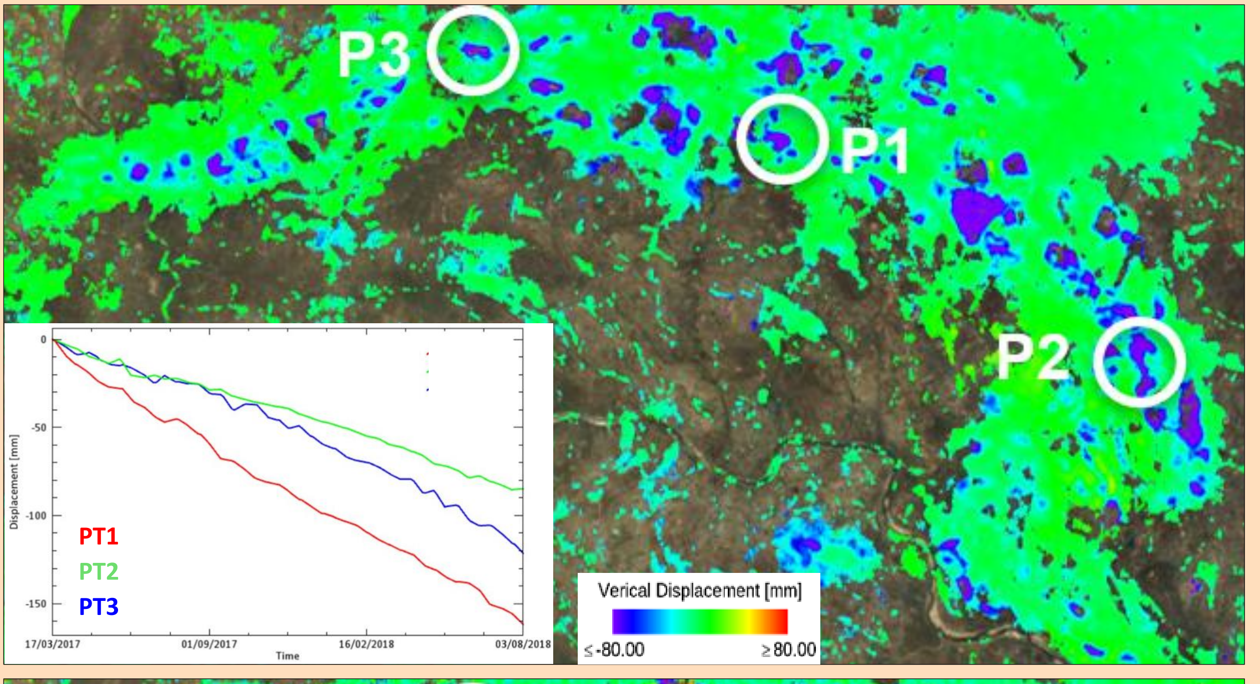
Given the recent growth in the mining sector in Liberia, the exploitation of mineral resources has significant environmental impacts that often go unnoticed. A regular monitoring of the mine stability is therefore essential to the industry, but also to regulators to ensure the compliance of the mine activities.

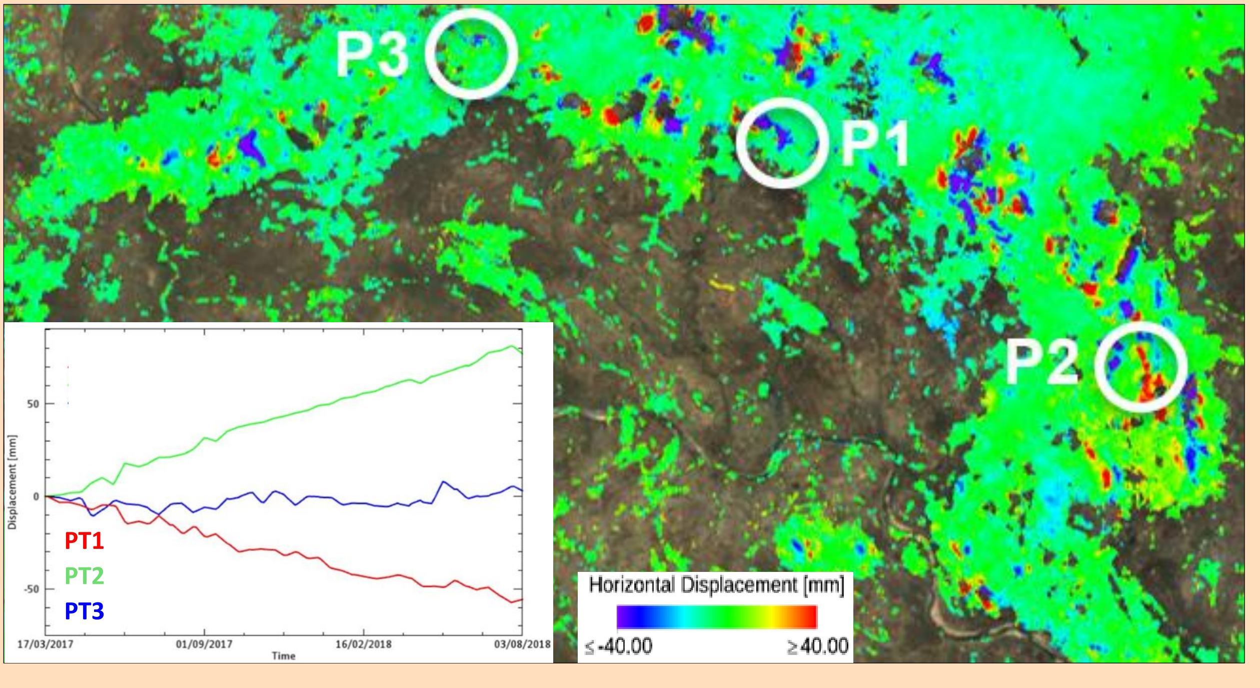
- Wilson et al., The mining sector of Liberia: current practices and environmental challenges, Environmental Science and Pollution Research, Vol 24, 2017.

Large-scale Mining – India

Jharia coalfield, located in Dhanbad district of Jharkhand state, is the largest coal reserve in India and one of the most extended in the world. It is well known not only for prime coke coal production but also for the numerous coal fires which frequently affect this area. Both the mining activity and active coal fires in open-pit and underground mines are causing dangerous collapses.

Sentinel-1 data acquired over an area of approximately 600 km^2 from October 2016 to August 2018 and processed in an interferometric way permits to distinguish between active and non-active open mines and to determine, as illustrated in the two figures, surface deformation rates larger than 8 cm/year for the vertical component (top) and larger than 4 cm/year for the horizonal one (bottom). Despite the significant displacements, noticeable in the two graphs, the linear tendency of these movements – probably associated with material compaction – does not indicate imminent risks of collapses.

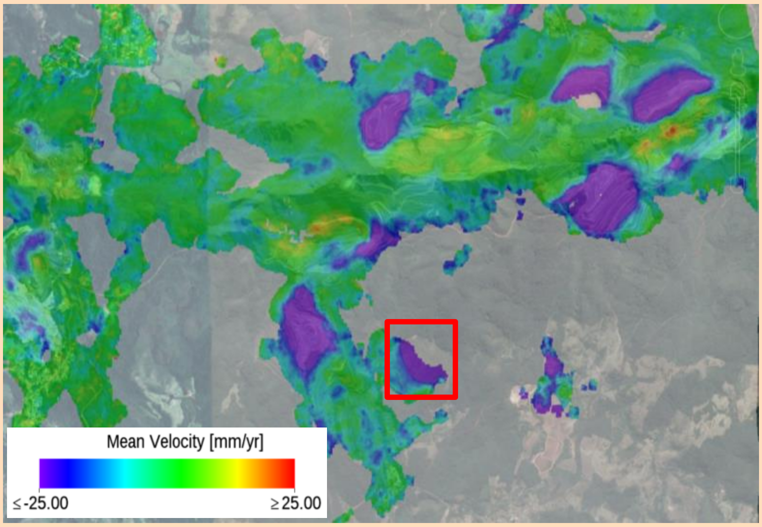


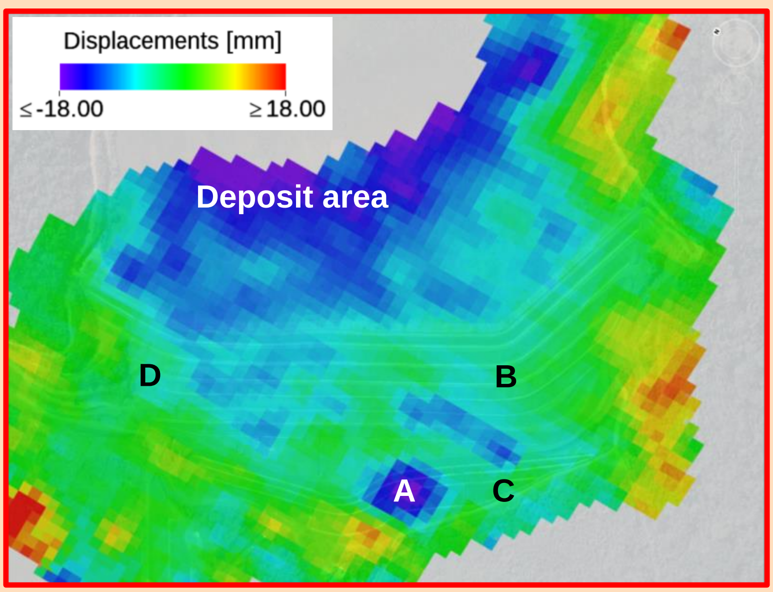


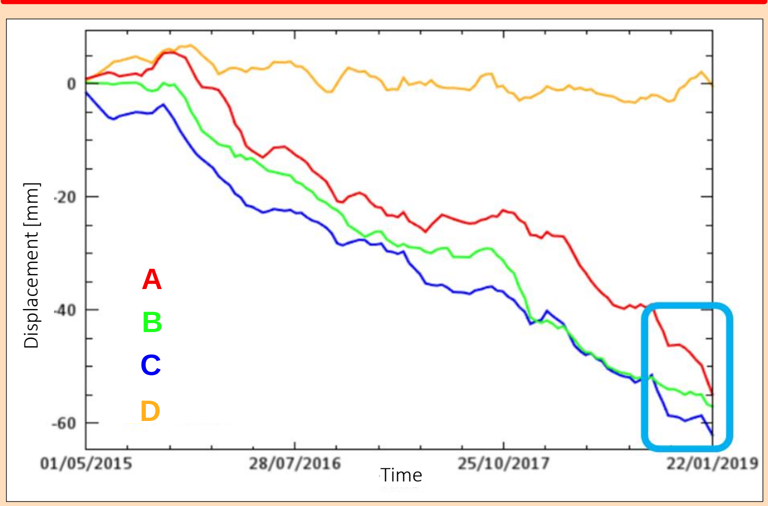
Large-scale Mining – Brazil

The Brumadinho dam disaster occurred on January 25th, 2019 when a tailing dam at the Córrego do Feijão iron ore mine collapsed causing nearly 300 fatalities. It is said that the stability of the dam had been certified shortly before the collapse.

Would have been possible to detect any precursor signs of instability by means of satellite SAR data analysis? Yes.







A first analysis based on the annual average velocity displacements inferred from Sentinel-1 data acquired from May 2015 to January 2019 – as illustrated in the figure on the top – reveals significant movements not only for the collapsed dam – marked with the red square – but for most of the other tailing dams within an area of around 120 km^2.

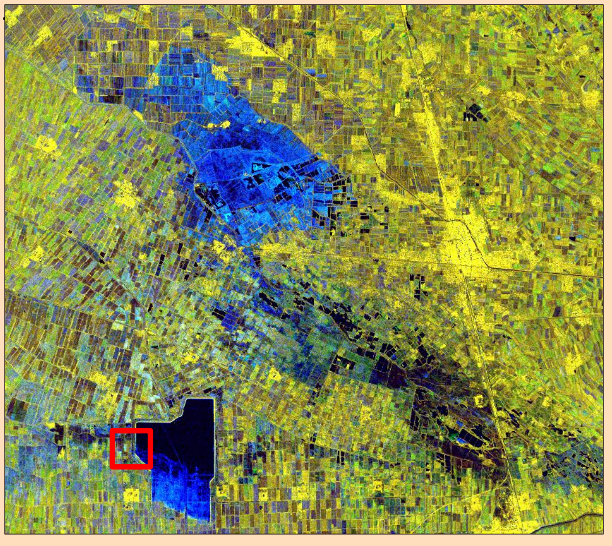
By calculating cumulative deformations of the collapsed dam from 24 September 2018 to 22 January 2019 – as illustrated in the figure on the center – the increase of the deformation rate in the last 4 months before the collapse is evident. While the average displacement rate is large in the deposit area, but consistent with a compaction curve, a large localized deformation rate in the body of the tailing dam (point A) – well matching the locations where the collapse started – is distinctly identifiable.

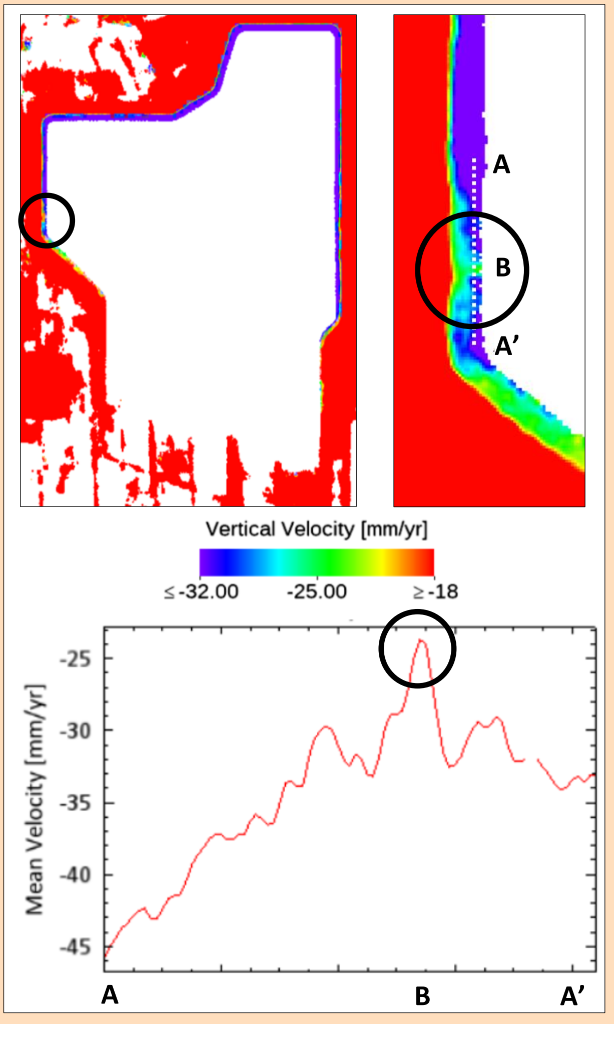
Finally, the plots data analyses – illustrated in the graph representing the cumulative deformations from 24 September 2018 to 22 January 2019 – shows for points A, B, and C a continuous and significant displacement of the tailing dam. Particularly evident is the acceleration during the last four months of point A (light blue square), confirming that these areas were already noticeable well before the collapse.

Dam stability – Uzbekistan

On May 1st, 2020 after a long rainy week a section of the earthen wall forming the Sardoba reservoir gave way. The reservoir, completed in 2017, was designed to hold 922 million cubic meters of water for irrigation of the surrounding agricultural lands (The Diplomat, 4 May 2020).

The temporal color image (left) composed from a combination of Sentinel-1 data acquired before and after (May 5th) the event, make it easy to see the flood water appearing blue. The box in the color composite image precisely indicates the location and the size of the dam failure, perfectly visible in Planet's PlanetScope 3 meter image (right) captured on May 3rd, 2020.





Could this dam collapse have been predicted? Yes.

The analysis of the vertical velocity derived from Sentinel-1 data acquired from January 2018 to April 2020 – as illustrated in the figure on the left – shows, in the upper part, a significant (larger than 3.2 cm/year) but homogeneous dam displacement rate (violet). Notwithstanding, at the dam collapse location (B) – as observable along the transect A-A’ – an important local gradient is clearly identifiable.

A quantitative assessment of the mean velocity – as noticeable in the graph – reveals a variation of around 1 cm/year from the dam break segment (B) to the surrounding wall, and around 2 cm/year to point A, 400 meter far away. This leads to the hypothesis of a possible water infiltration along the segment (B) where the dam collapsed.

This analysis does not pretend to provide the reasons of the failure, but doubtless will facilitate structural engineers in their investigations.

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