Contribution of Earth Observation in Environmental and Societal Impacts during the mining life cycle

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Abstract

Several national and international initiatives, both from the private or the institutional sectors, intend to address the sustainable development of the extractive industry and the reduction of its environmental footprint. The extractive industry is facing increasing environmental and societal pressures, being regulatory or not, during all phases of a project, from exploration to exploitation and closure. The social acceptability of a project is among the major key issues to be dealt with.

The EO-MINERS project (Earth Observation for Monitoring and Observing Environmental and Societal Impacts of Mineral Resources Exploration and Exploitation) is a EU funded Research and Technological Development project completed in 2013, which aims to help EC in its raw material policy and in better exploiting mineral resources from the European territory and its mineral supplying countries, as well as to improve the interaction between the mining industry and the society. To this end, the overall objective of the EO-MINERS project is to bring into play EO-based methods and tools to facilitate and improve interaction between the mineral extractive industry and society, for its sustainable development, while improving its societal acceptability.

EO-MINERS scientific and technical objectives are to: i) assess policy requirements at macro (public) and micro (mining companies) levels and define environmental, socio-economic, societal and sustainable development criteria and indicators to be possibly dealt using EO (Earth Observation); ii) use existing EO knowledge and carry out new developments on demonstration sites to further demonstrate the capabilities of integrated EO-based methods and tools in monitoring, managing and contributing to the reduction of the environmental and societal footprints of the extractive industry during all phases of a mining project, from the exploration to the exploitation and closure stages; iii) contribute making reliable and objective information about affected ecosystems, populations and societies, to serve as a basis for a sound "trialogue" between industrialists, governmental organisations and stakeholders.

The project has developed EO-based tools and methods to assess the mining footprint over three demonstration sites, i.e. the Czech Sokolov lignite open cast in western Bohemia, the South African Mpumalanga coalfield around eMalahleni and, the Makmal gold mine and processing plant in central Kyrgyzstan, near Kazarman.

Project expertise and stakeholder interviews (national and on-site) as well as site investigations, have followed an in-depth analysis of policies related to the environmental and social footprint of mineral industries, and have led to the establishment of a list of indicators to be monitored, either directly or indirectly, through parameters accessible by EO.

The EO methods deployed consisted in i) satellite imagery, conventional and/or very-high resolution, ii) airborne data acquisition surveys, including imaging spectroscopy, thermal infrared and LiDAR and, iii) in situ measurements and data acquisition (field spectroradiometry, point measurements of vegetation, soils and waters, dust collection and analyses…).

The corresponding EO datasets acquired and processed have been fused and/or integrated into products to meet the environmental indicators identified and the environment concerns documented during the stakeholder interviews. The products have been presented during on-site stakeholder workshops, gathering the industry, the regulatory bodies and the civil society, in view of getting their feedback about the developments carried and the products developed.

1 Introduction – General methodological approach

Because it significantly affects the quality of the human environment, mining nowadays is often perceived as only having negative social impacts; however, communities can benefit from mining activities and reclamation. From historical ore discovery and access, markets and capitals, worker safety, environmental issues, the scope of concern today is moving towards taking communities and equity into account (Shields and Solar, 2006)

Earth Observation offers a unique opportunity and varieties of methods to collect and process spatial information to address, either directly or indirectly, monitoring and assessment of the impacts of mining at each phase of the mining cycle. This includes: satellite borne and airborne imagery, ground and airborne geophysics, geochemistry, in situ measurements, monitoring networks, 3D models, socio-economic data …

Figure 1 summarises the general methodological approach followed during the project.

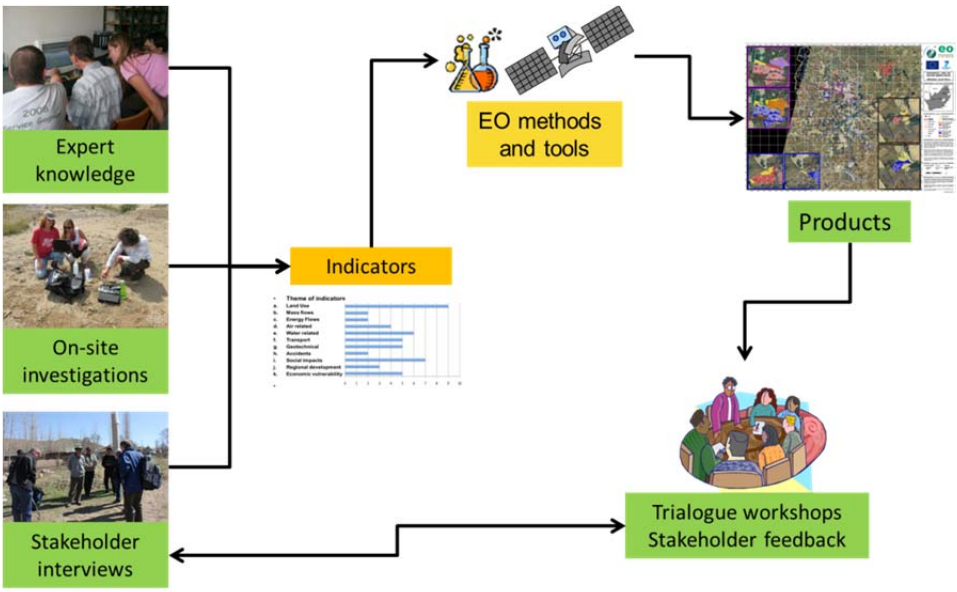

Figure 1: EO-MINERS general methodological approach

1.1 Indicator development

The need to assess policy requirements and define societal and environmental criteria and indicators to be possibly dealt with using EO methods and tools has been first addressed through an analysis of policies related to the environmental and social footprint of mineral industries.

Different types of indicators that support the analysis of environmental and societal pressures and impacts related to mineral extraction have been identified, evaluated and developed. For the selection of applicable Earth Observation techniques, the project has identified and analysed policies of private companies, public authorities and civil society related to the footprint of mining industries. In this context, selected stakeholders at the South African, Kyrgyz and Czech demonstration sites have been interviewed. The aim was to have equal input from each component of the three stakeholder groups, i.e. authorities and regulatory bodies, industry, and civil society.

The identification of operational indicators included a multi-pronged approach, consisting of i) issues determined by expert knowledge, ii) examination of site-specific conceptual models for the three demonstration sites, and iii) a semi-deliberative approach elucidating input from stakeholders outside the project team. The three processes ran in parallel, resulting in three sets of indicators that then were analysed for their respective coverage. This process went through several loops of iterations in order to consolidate the set of indicators.

1.2 Product development

EO-MINERS then contributed by developing high level EO-based data products applicable to the different stages of mining activities within the life cycle of mining operations, over the demonstration sites. These processes aimed to contribute to the development of generic EO data integration schemes, in particular in view of characterising affected ecosystems, populations and societies and prepare objective documents that intend to become an authoritative basis for a sound “trialogue” between industrialists, governmental organisations and civil society. To this end, the project continuously took care of robust and reliable standards and protocols that guarantee the repeatability of the methods deployed.

It was necessary to establish a mechanism to assess the data and to consider and decide what EO-based products would be made (Figure 2). Throughout the project, a very extensive product development matrix was generated and maintained for each of the three demonstration sites, which tabulated the stakeholder-driven indicators with the environmental parameters derived from the conceptual models along with the EO data available to the EO-MINERS project.

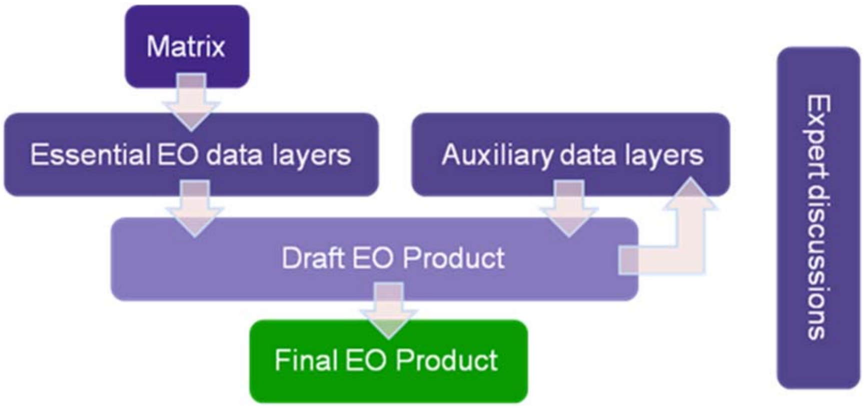

Figure 2: role of the product development matrix in the product development scheme

The matrix clarified which input layers were required to make each possible EO-based product and was used within the project as a decision-making tool to determine the range of EO-based products that were made in EO-MINERS in response to the stakeholder requirements. Furthermore, it helped to prioritise which products were made. It was a transparent method to explain which products were made, and why.

1.3 Trialogue activities

The three groups involved in the EO-MINERS trialogue are the industry, the governmental bodies and the civil society. It is meant to contribute to reconciliation of interests among the three groups involved in order to reach common agreement upon actions to deal with environmental and social impacts of mining activities. Besides, the trialogue enables to reinforce the project idea and outcomes and confirm its usefulness.

The EO-MINERS trialogue activities comprises two part (Figure 3): i) trialogue related to the European level (“European trialogue”), aiming at determining the way of presenting the project contribution to policy requirements, and, ii) trialogue related to each of the mining sites under investigation, so-called “Site-specific trialogue", describing the current situation specific for the particular site, including problem identification and the EO-MINERS product-type response.

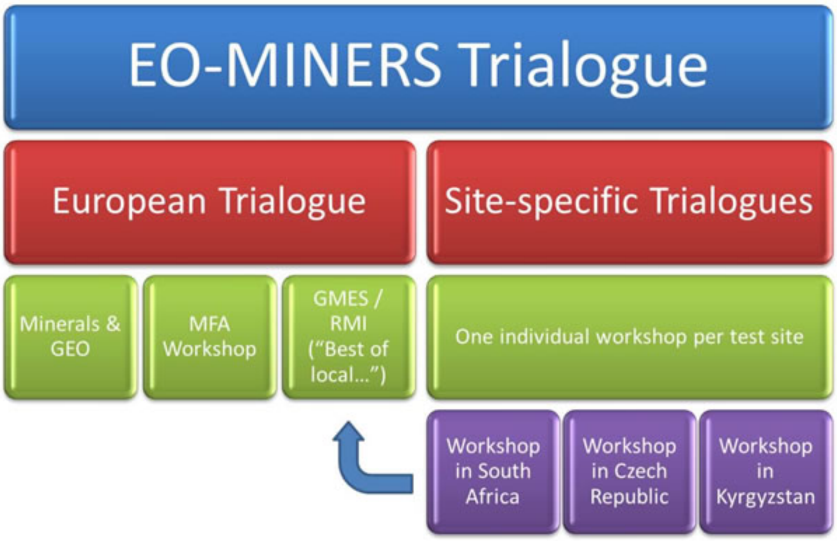

Figure 3: the EO-MINERS trialogue activities

The European trialogue has to be seen in a wider policy context (Europe 2020 Strategy, flagship initiative for a resource efficient Europe (common vision to support a long-term perspective for an efficient use of natural resources)). It provided a platform for interaction between all stakeholders at the European level that are directly and indirectly related to the minerals sector (e.g. industry, policy makers, professional associations, governments and authorities, NGOs, environment agencies, etc.). This also included groups dealing with the environmental and social effects of mining. The target groups comprised among many others the Copernicus (former GMES), GEO (Group on Earth Observation), the Raw Materials Initiative and ETP-SMR (European Technological Platform for Sustainable Mineral Resources).

2 Description of the demonstration sites

2.1 The Sokolov lignite open pit, Czech Republic

The Sokolov lignite mining area is located in the North-West of the Bohemia province, west of the town of Karlovy Vary, close to the German border. The area is largely affected by mining activities (Figure 4): open casts and dump sites.

The mining of brown coal is accompanied by several environmental problems, including:

- Local changes in morphology, landscape and drainage as well as degradation of land use due to dumping of material.
- Erosion of bare or thinly-vegetated dump slopes.
- Acid-mine drainage (AMD) and décharge of highly-mineralised water from mine dumps and contamination of surface and subsurface water.
- Vegetation stress due to contamination – air, soil, water.

The area is largely affected by AMD due to the presence of sulphur in the brown coal itself (5 to 8% pyrite in the coal) and, in the hydrothermal deposits along the faulting system that borders the basin and that is affected by the exploitation.

The oldest exploited areas are under rehabilitation: revegetation and recreation areas (golf course).

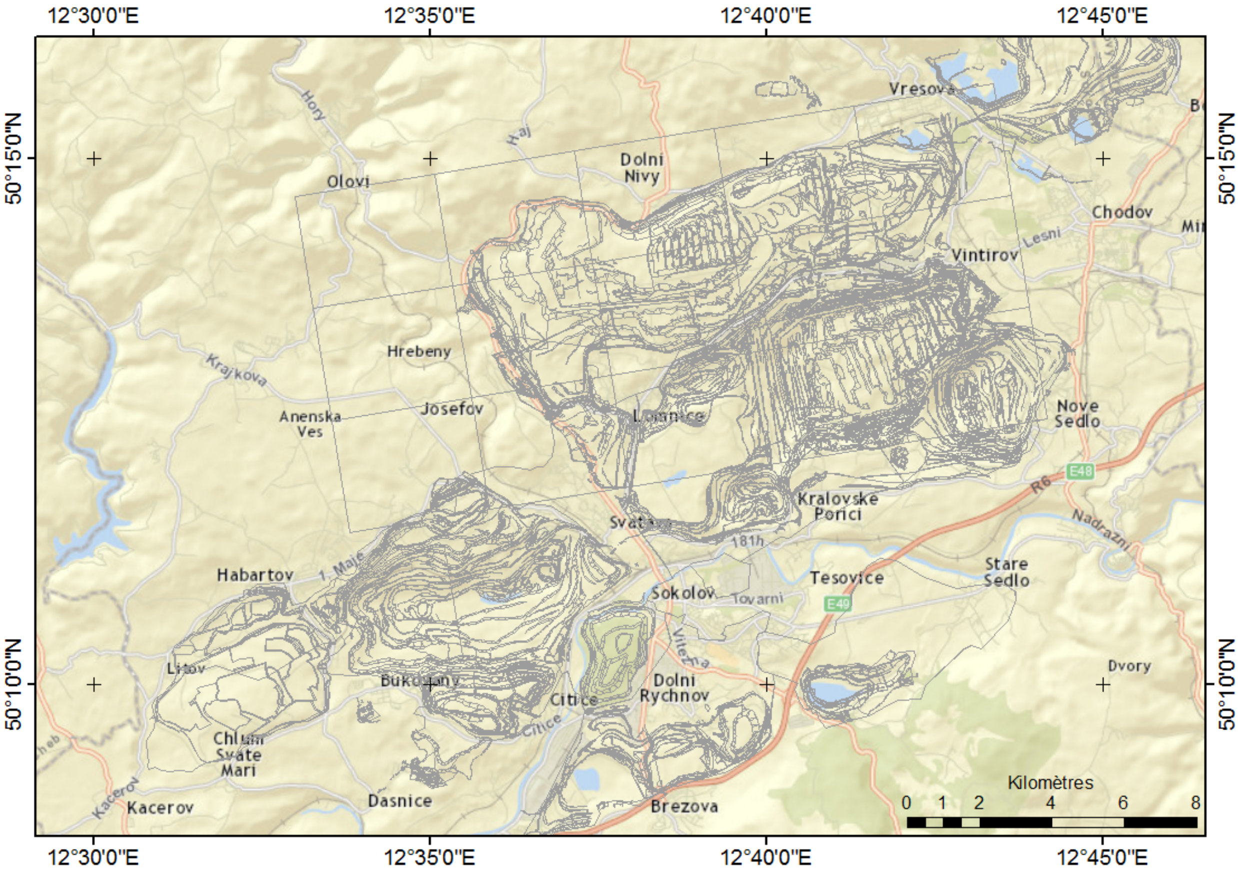

Figure 4: the Sokolov area (source World Street Map – ESRI) with mining footprint overlaid

2.2 The eMalahleni coalfield, Mpumalanga province, South Africa

Coal mines within the eMalahleni (former Witbank) Coalfield are owned and operated by a number of coal mining companies, while many mines are abandoned and may be classified as “derelict and ownerless”. This mining district covers a very large area and includes mines encompassing all stages of mining, from exploration through modern operating mines, mines undergoing closure (Figure 5). The Council for Geoscience identified a total of 209 abandoned mines in this catchment, including 118 coal mines.

Water pollution sources in the mining areas include operating, closed and abandoned mines, with acid mine drainage and related metal contamination forming the most important problems. Important sulphide bearing materials which can lead to the formation of acid mine drainage include the coal and discarded material and some of the overburden materials used in the rehabilitation of more modern open-pit operations. In addition, many wetlands and rivers are believed to be clogged with coal dust.

Other environmental issues include spontaneous coal combustion, dust dispersal, intense subsidence due to underground exploitation schemes.

Societal issues include those common to most mining areas in South Africa, where with the promise or expectation of jobs resulting in the creation of large informal settlements with high levels of poverty and unemployment. The physical and pollution hazards resulting from coal mining exacerbate many of the related societal health problems.

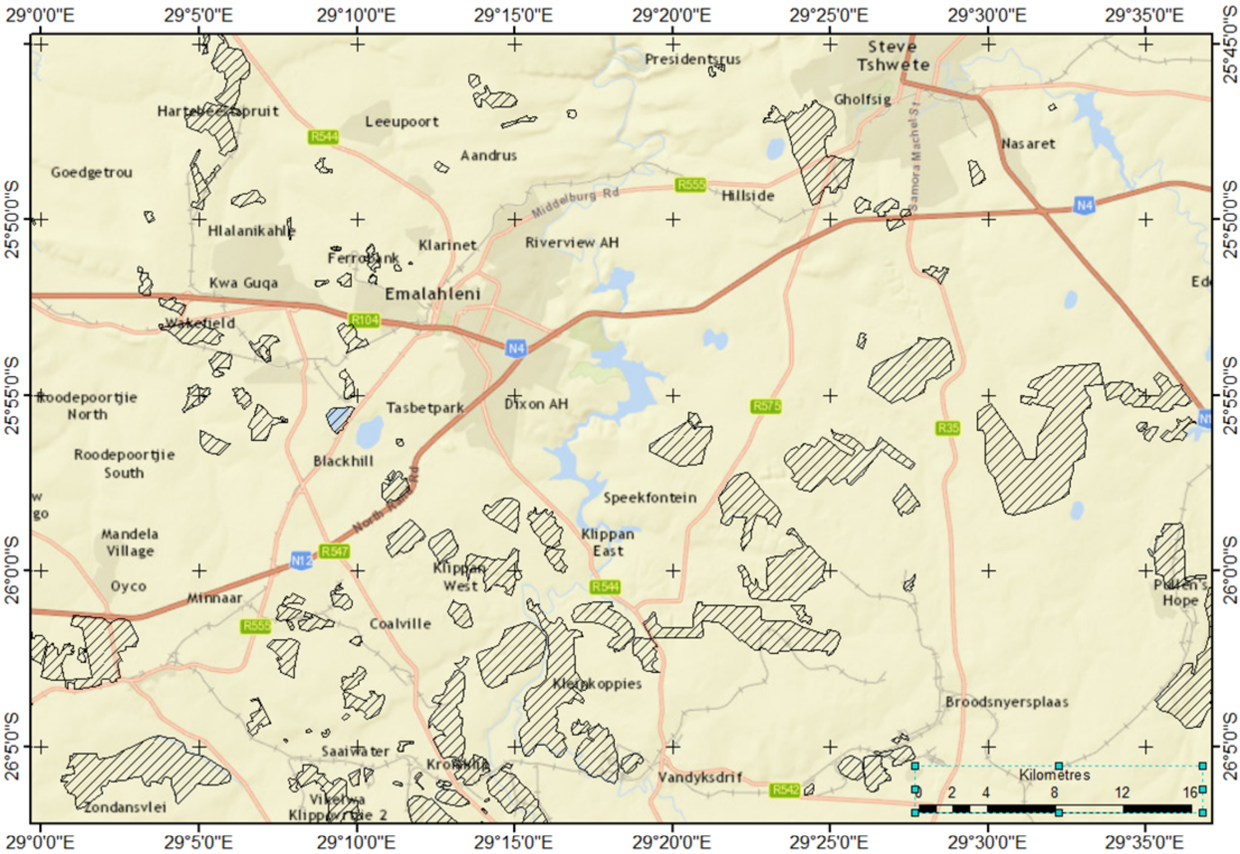

Figure 5: The eMalahleni mining area with (source World Street Map – ESRI) with active and abandoned mining footprint overlaid

2.3 Makmal gold mine and processing plant, Kyrgyzstan

The Makmal deposit is located in the Toguz-Toro district of the Jalal-Abad oblast of Kyrgyzstan, 630 km from Bishkek city and 47 km from the Kazarman town (Figure 6). The Makmal deposit is located at 2350-2800 m above sea level.

Refining of gold concentrate takes place in a gold-extracting plant using cyanide located some 30 km northwards. The neutralised tailings slurry (0.074 mm class) generated from the gold mineral processing is discharged into a tailings impoundment in the form of pulp. The tailings pond is located 12 km south-south-west of the Kazarman town. Existing and future tailings management facilities are zero discharge types, which is achieved through evaporation and recycling of the water in the plant.

The primary release mechanisms at the facility are related to the movement of water through the contaminant sources. Typically this is the result of infiltration of snowmelt and precipitation; infiltration of surface water; groundwater discharge to surface water; groundwater table fluctuations; erosion, and sediment transport. The efficiency of the drainage system in the prevention of contaminant migration to receiving surface water cannot be evaluated due to lack of surface water monitoring points and a drainage network map that would allow assessment of the proximity of the mine tailings to watercourses and preferential flow patterns. Acquiring this information is a requirement to improve understanding of the migration pathways.

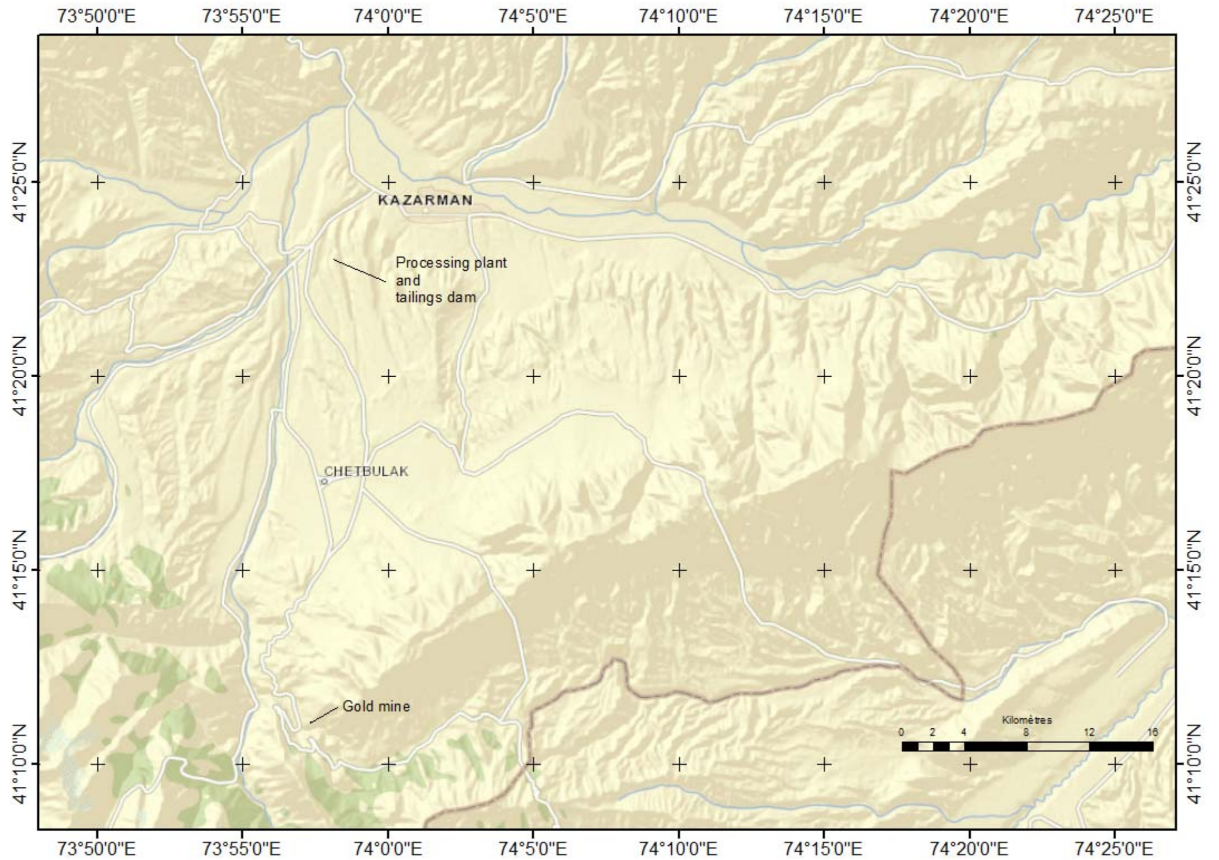

Figure 6: Location of the Makmal gold mine and processing plant (source World Street Map – ESRI)

3 Some examples of EO data integration schemes.

The site-specific developments carried out intend to contribute to the development of generic EO data integration schemes, EO products and EO-driven environmental modelling scenarios adapted to various situations that fulfil the stakeholder expectations and whose reliability and objectivity cannot be disputed by parties involved in any stage of a mining project.

Integrated data include, satellite and/or airborne and/or in situ collected data and derived thematic layers, gathered into GIS data bases.

3.2 Integration of LiDAR airborne survey with other EO methods in South Africa

The main advantage of LiDAR compared to DEMs based on space borne optical stereoscopic systems is it provides information on the ground surface elevation (i.e. a Digital Terrain Model, DTM) while the latter ones provide a digital elevation (DEM) of the first hit only (e.g. top of canopy or building elevation).

LiDAR hence is suitable for mapping terrain models, detecting subtle surface elevation differences and providing advanced topographic information. LiDAR DTMs are of particular interest in mining areas where they provide invaluable quantitative information on terrains modified by the mining activities, such as subsidence (Figure 7), mining-related engineering works, waste volume calculation, etc.

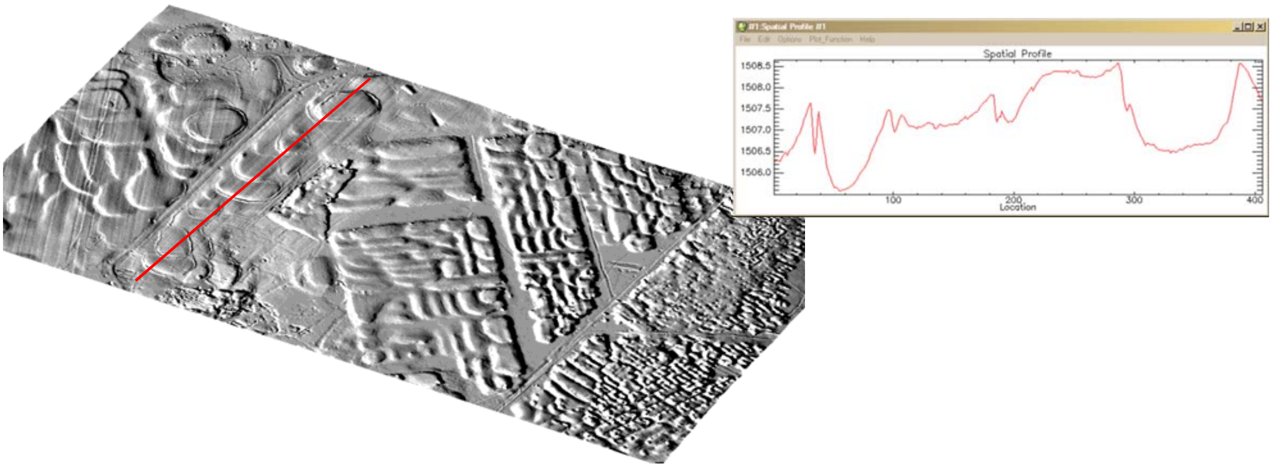

Figure 7: LiDAR shaded DTM showing subsidence features due to underground coal mining and assoiiated topographic profile

3.2.1 Mapping thermal anomalies from thermal infrared airborne surveys

Uncontrolled combustion of coal is a serious problem on a global scale. Since coal can easily be oxidized and often has a prominent "self-heating" capacity, many coal types have a tendency to combust spontaneously once sufficient oxygen is available and natural cooling is prevented.

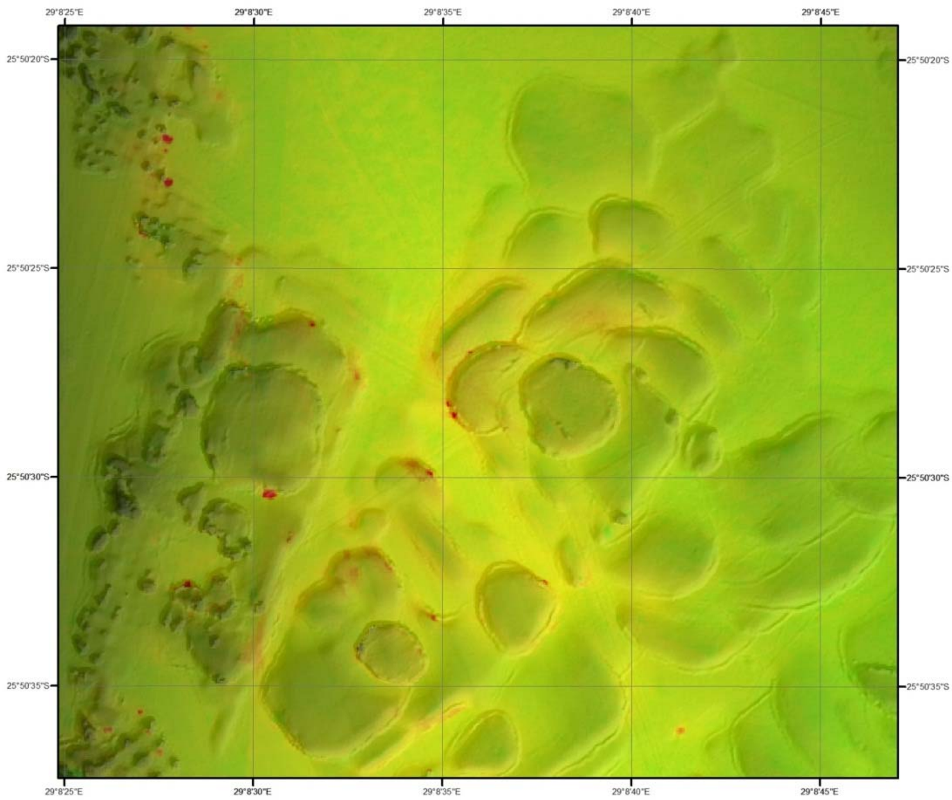

Figure 8: Airborne thermal image of an area affected by subterranean coal fires and subsidence

FLIR cameras mounted on board of airborne platforms have been used in identifying areas of underground combustion, and, if possible, identifying areas of contaminated groundwater flow.

Figure 8 shows the correlation between hot-spots (warm colours) and areas of subsidence (from LiDAR DTM) where heat from the underground fires can rise to the surface.

3.2.2 *Assessing surface water ingress potential from computed drainage pattern*

Very high resolution DTMs enable computation of accurate drainage pattern, being of natural or anthropogenic origin. Mining areas, where topography has been considerably modified, can take benefit from such patterns.

The LiDAR data collected over the eMalahleni test site have been used to derive (Figure 9):

- an image showing areas of internal drainage within the study area (in blue)
- a run-off model showing the surface water flow pattern (in purple).

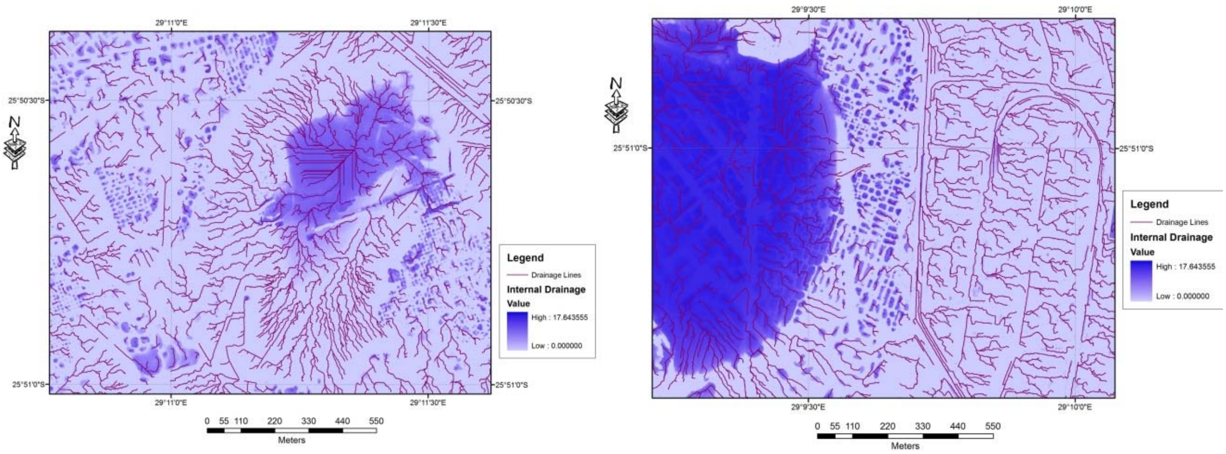

Figure 9: Internal drainage and run-off model computed from DTM

A comparison of these two data sets makes possible determining the water ingress potential within the Mpumalanga mining area. The left image shows an area where a relatively large surface area contributes run-off to the underground mine workings, making this an area with a high potential for water ingress and the generation of acid mine drainage. The right image shows an area where an artificial trench acts as a cut-off trench, diverting surface run-off away from the underground mine workings.

3.2.3 *Mapping potential surface drainage contamination*

Specifically designed modified flow accumulation algorithm enable computing upstream and downstream drainage from any particular point over a given area covered by an accurate DTM (Figure 10).

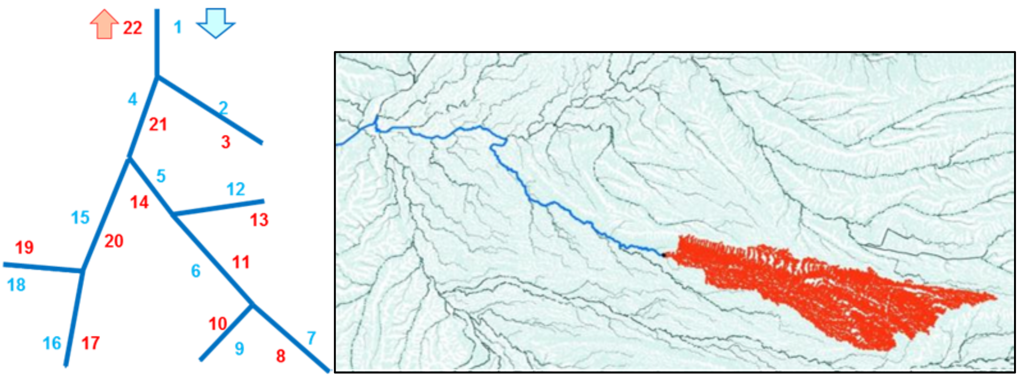

Figure 10: GIS data organisation for upstream (red) and downstream (blue) investigation of drainage pattern

Applying this technique to very high resolution DTM makes possible computing the potential downstream contamination pathway from a contamination source identified from very high spatial and spectral resolution optical imagery, following the procedure illustrated in Figure 11.

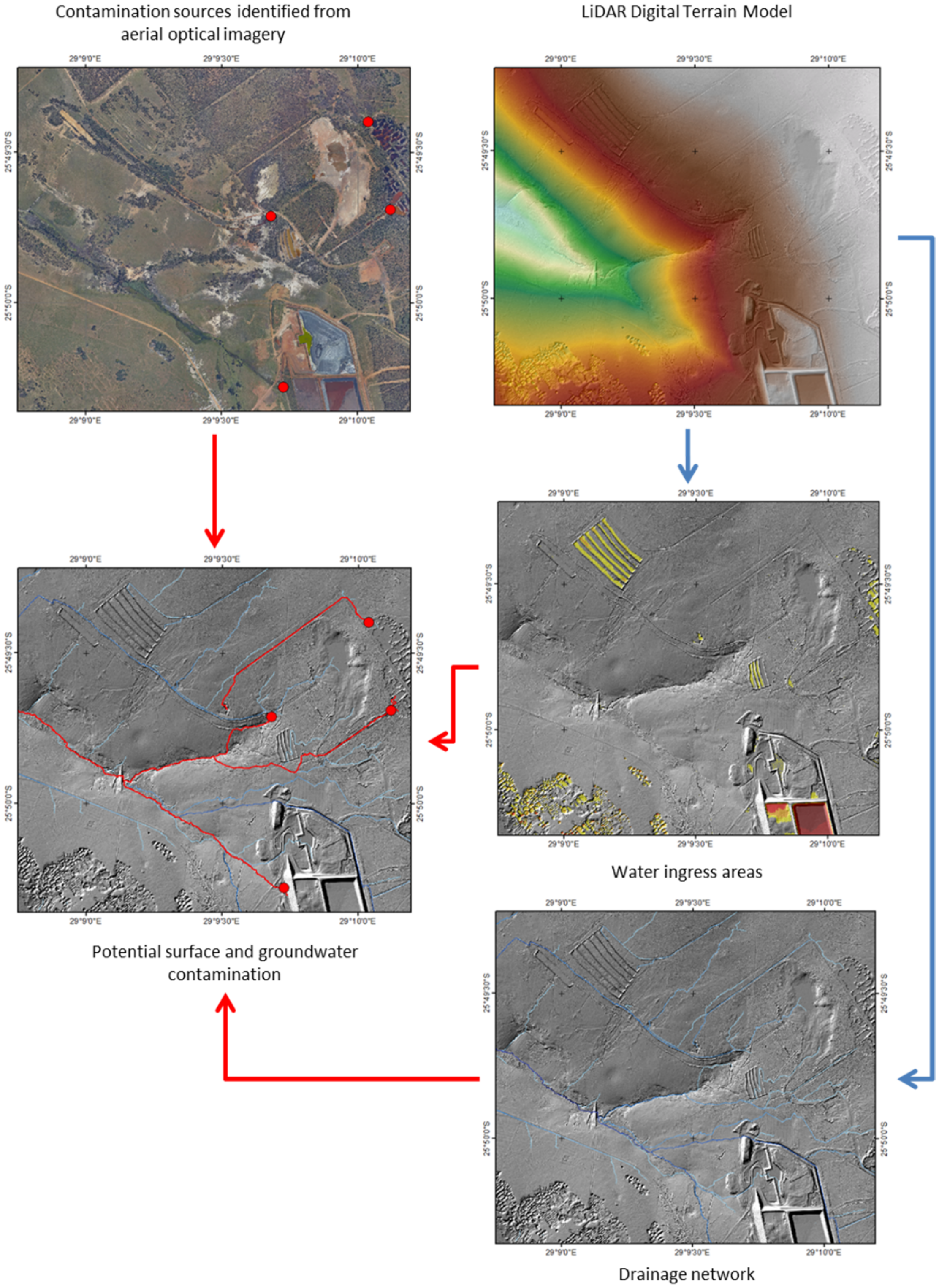

Figure 11: methodological approach to map potential surface drainage contamination

3.2 Mapping AMD mineral and soil quality from hypespectral airborne imagery

Spatial mapping of the source of acidification, its pathways and possibly affected areas are of key interest. Mapping of the spatial distribution patterns of the various key minerals and mineral groups can support the evaluation of the soil quality, the risk assessment of possible contamination of surface and ground water bodies, the planning of specific remediation efforts or the assessment of the (future) economical usage potential of former mining sites.

3.2.1 Mapping AMD minerals in South Africa

AMD is commonly seen in eMalahleni area, with large pool of AMD formed above flooded mine workings, small dispersed seeps through residential areas with evidences in gardens, streets and potholes, AMD marshes formed in a number of residential gardens killing part of the garden vegetation. AMD also flow in small streams towards the Olifant River.

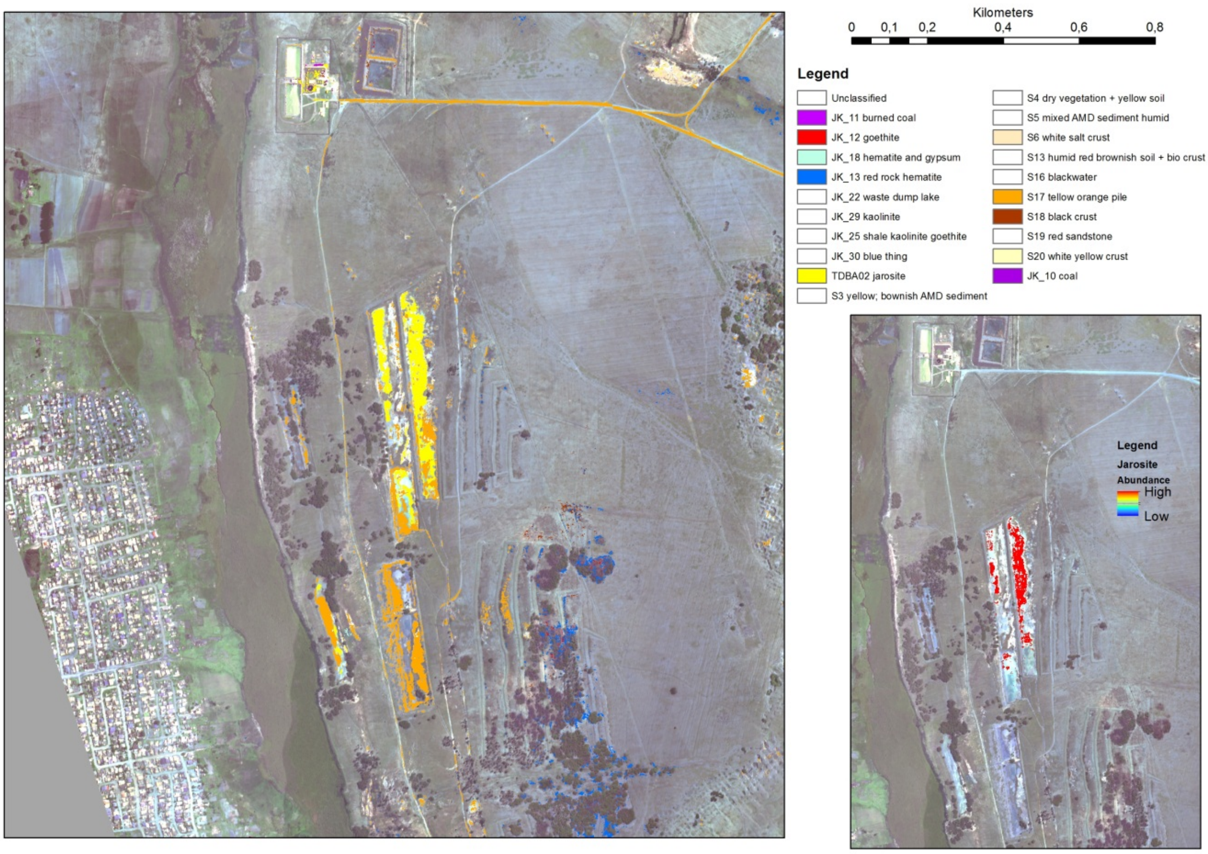

Figure 12: Mapping AMD minerals (jarosite in yellow) from hyperspectral imagery over eMalahleni coal field. Note the similar result obtained from WorldView_2 VNIR imagery a year before (jarosite in red in the bottom-right cartridge)

Using reference reflectance spectra collated on the field, VNIR – SWIR hyperspectral imagery enabled mapping various mineralogies associated with coal mining and in particular minerals typical of AMD. The presence of jarosite, a mineral stable at pH below 3, has been mapped in retention cells (Figure 12) downstream of the main coal related industrial area (Ferrobank). Worth to note is jarosite mapped in the same location a year before acquisition of the hyperspectral imagery, using only VNIR high resolution imagery (WorldView_2 images).

3.2.2 Deriving a predictive map of soil pH from hyperspectral imagery

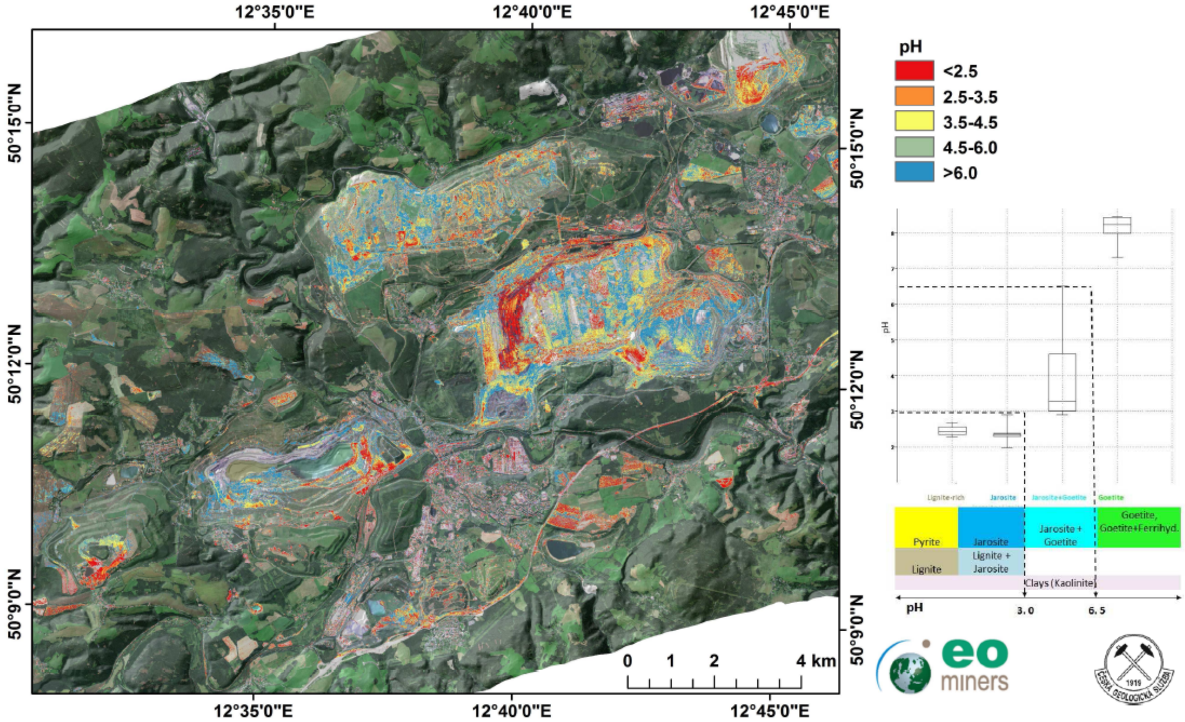

Figure 13: Soil pH map derived from mineral and mineral association mapping using hyperspectral imagery

Hyperspectral imagery supports mapping minerals and mineral associations that are responsible for AMD and soil acidification, hence enabling the derivation of a predictive soil pH map (Figure 13). Diagnostic minerals of low (pH < 3) pH are pyrite, jarosite and lignite. Jarosite in association with goethite indicates increased pH (3 < pH < 6.5), while goethite alone characterises nearly neutral pH (pH > 6.5).

3.3 Risks associated to tailings dam leakage and potential dam failure

Tailings dams leakage might be responsible for the release of contaminated water into the environment and contamination of downstream surface waters. The downstream flow from the Makmal tailings dam in Kyrgyzstan, displayed in red on Figure 14, has been computed using the algorithm mentioned in 3.2.3, applied to a 1-meter resolution DEM derived from a WorldView_II satellite stereo pair. It clearly shows that a potential cyanide contamination of the surface drainage by leakage from the tailing dam should not affect the town of Kazarman, but may however contaminate the Naryn River downstream.

Modeling the downstream extension of a possible mud flow would be a valuable tool in securing downstream populations and ecosystems as well as in implementing new tailing dams. The brown area on Figure 14 represents the maximum possible downstream extension of a 5-meter thick mud flow resulting from the failure of the tailings dam. It has been computed by taking into account a constant thickness of 5 metres, whereas in reality the thickness should decrease with distance from the source, depending on the mud viscosity. According to this model, only the most western part of the Kazarman town might be affected by the flow, while however a large area of the floodplain might be affected by tailings mud, leading to potential grassland contamination.

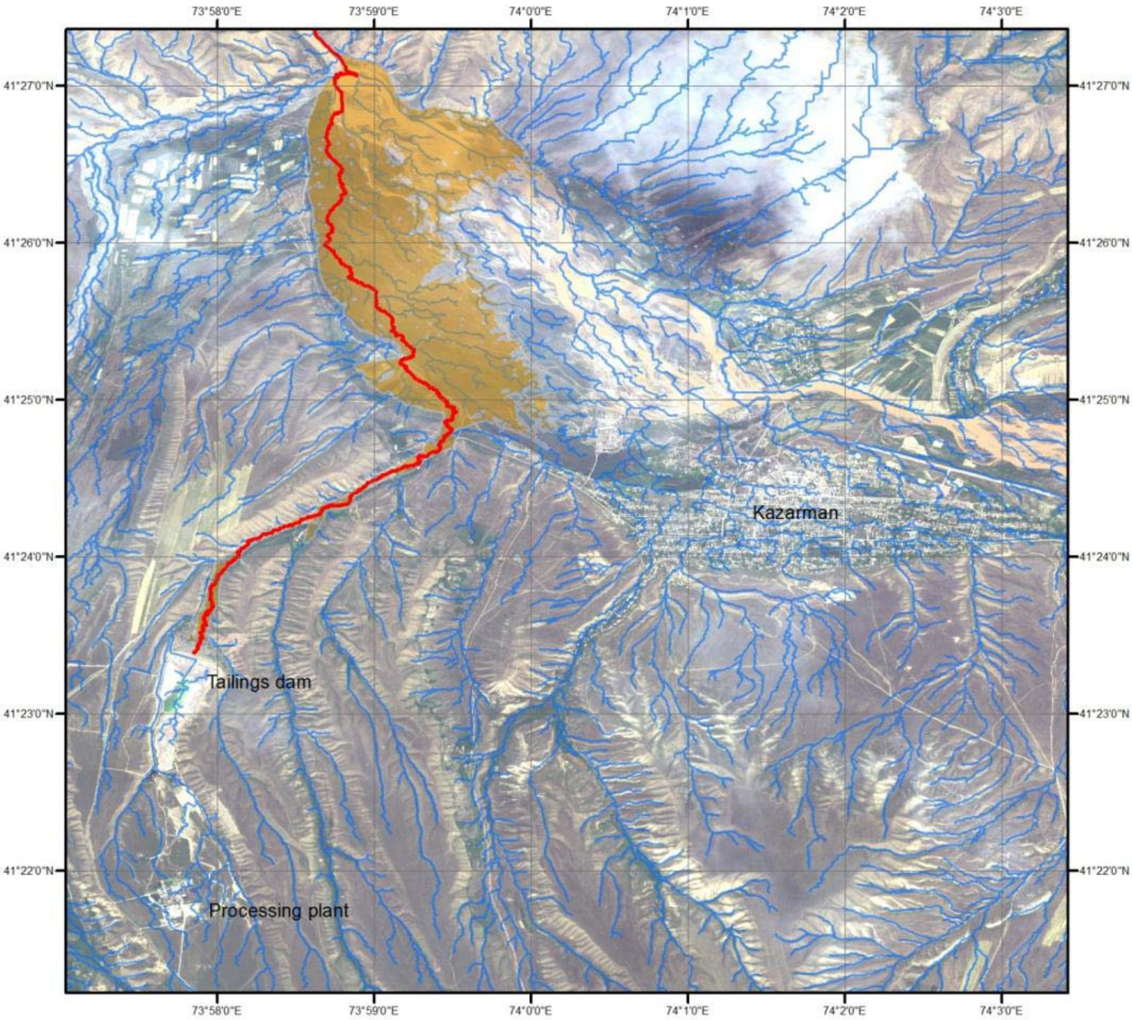

Figure 13: Potential surface drainage contamination (red) and maximum possible extension of a 5-m thick tailings mud flow (brown), Makmal tailings dam, Kyrgyzstan

4 Product generation and presentation to stakeholders

From the integration schemes developed in part 3 above and in order to make the EO-based products understandable to the wide range of stakeholders several product formats we developed by combining essential thematic EO data layers with auxiliary GIS layers, as illustrated in Figure 2 and including geographical information (e.g. towns, rivers, roads) and background imagery. The product formats that were delivered include: paper maps (A0 and A3), digital maps (two-dimensional GeoPDF format), 3D PDFs, Google Earth visualisations (KML/KMZ format), digital 3D visualisations (in GeoVisionary™ format) and, animated fly-throughs.

The EO Products were presented to the stakeholders at workshops at the mining sites in the Czech Republic, South Africa and Kyrgyzstan. The presentations included displays of the paper maps, both in English and local language, as well as live demonstrations of, and interactions with, the full range of digital products. In order to provide an overview on the EO product development achievements, a printed booklet was prepared in local language and distributed for each demonstration site that showed the diverse EO products presented at the workshops.

5 Conclusion

As a conclusion, a summary of the stakeholders' feedback highlighted several clear outcomes:

- The products were well received, with comments that they are attractive tools that present the information in an easy-to-use form
- It was noted that the products are appropriately sophisticated, responding to the diverse user needs
- Beyond the paper maps and posters, the use of 3D technology was "much appreciated" to help describe the often complicated 3D nature of the system being monitored
- They served the purpose of informing the trialogue, as epitomised by the quote "The maps and data are able to help developing a common language and base of communication between otherwise separate stakeholder discourses, among civil society and administration (and ideally also mining sector)"
- Confidence in the results was raised (particularly in Kyrgyzstan) where independent, often international sources, were thought of as more trustworthy
- Some stakeholders recognised that long term monitoring (often encompassing seasonal variability) is required, and that the products need to be updated appropriately over time
- Limitations of the EO Products were also identified, in particular related to the health impacts of the measurements. This was a lesson that was learnt during the project and the products were adapted not only to provide quantified measurements but also to state clearly if the measurements registered could pose a health risk to the local population.

Acknowledgement

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