Earth Observation for Monitoring and Observing Environmental and Societal Impacts of Mineral Resources Exploration and Exploitation

Project no: 244242, call 2009, Theme 6, Topic ENV.2009.4.1.3.2

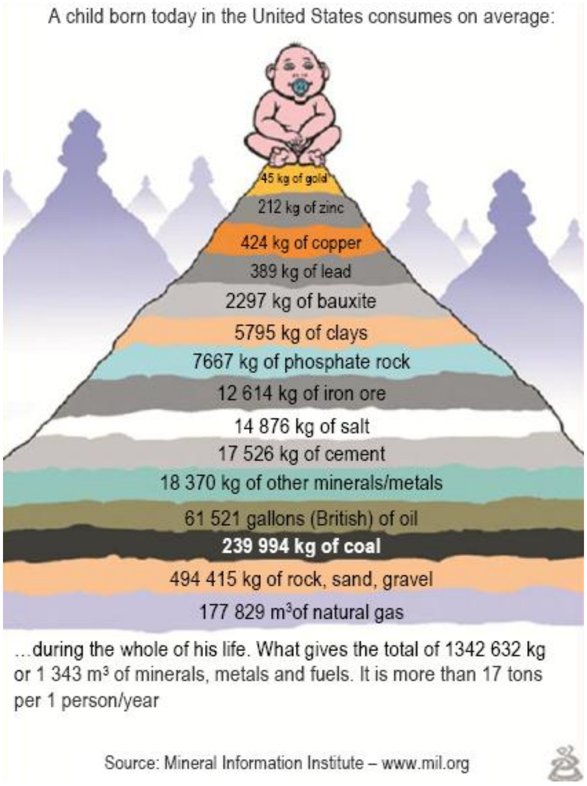
Final report

Content

1. Summary description of the project context and objectives

The mining and extractive industry has played, and still plays, a significant role in the development of many countries all over the world. The industry has been, and continues to be an important contributor to both national and regional economies and is critical to national defence. Mining, and the industries it supports, is among the basin building blocks of a modern society.

Most sectors, such as construction, chemicals, automotive, aerospace, machinery and equipment sectors depend on unimpaired access to raw materials, providing a total value added of € 1,324 billion, and employment for some 30 million people in the EU.



The world today is facing an increasing mineral resource demand. This was illustrated in 2007 by the European Commission Vice President Günter Verheugen, responsible for enterprise and industry policy, who said: "*European industries need predictability in the flow of raw materials and stable prices to remain competitive. We are committed to improve the conditions of access to raw materials, be it within Europe or by creating a level playing field in accessing such materials from abroad*".

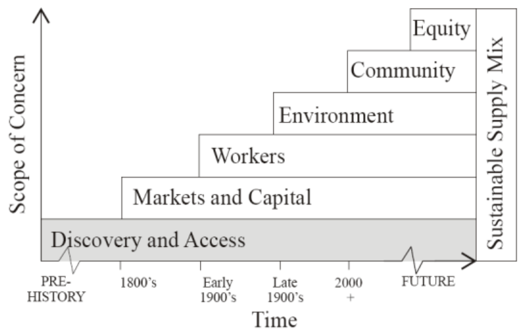
In recent years, the EU's total material requirement has remained at a constantly high level – roughly 50 tonnes a year per head of the population since the middle of the 1980s. But in this time the weight of imports and their environmental impacts have considerably increased (EEA 2003).

The benefit of mining to those countries has been significant, but it has come at a cost to the environment. Early mining operations have left a historical legacy of negative environmental impacts that affect our perception of mining. As countries have matured, there has been increasing recognition that environmental protection is as fundamental to a healthy economy and society as is development. The challenge is to simultaneously promote both economic growth and environmental protection.

The bulk of this increase is attributable to ores, mineral fuels, metalware and products such as glass, ceramics and precious stones. These four categories account for most of the ecological impact of imports. More than half of these originate in the developing countries, while fewer resources are extracted in Europe itself. Numerous mines have closed in Europe during the last few decades, either because of natural exhaustion or due to environmental and societal concerns, or because they were not profitable. With the closure of mines, environmental pressure has been reduced in Europe but increased in other regions. The environmental footprint of EU material consumption has shifted from Europe to other regions. One tonne of imports leaves behind an average

of 5 tonnes in mining waste, emissions and erosion in the exporting country. This ratio has more than doubled over the past twenty-five years, and in the case of ores has quadrupled from 1:4 to 1:16 tonnes.

The responsible management of Earth's environment is one of today's most pressing concerns and a central motivation for the Group on Earth Observations (GEO). Sound environmental management of mining activities can avoid high remediation costs, which frequently might drain public funds. Surface and groundwater pollution, soil contamination, and terrain instability all cause damage that can affect urban and sub-urban areas. Understanding and monitoring pollution processes in mining areas is therefore of concern to a very wide user community, including central government bodies or agencies, local authorities, industry, environmental groups and individual citizens. When also faced with legal and social pressures, the mining industry is interested to minimize the impacts on environment and society.



Mining vs Society

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 surface mining activities and reclamation. From ore discovery and access, markets and capitals, worker safety, environmental issues, the scope of concern is moving towards taking communities and equity into account.

EO-MINERS is a Research and Technological Development project funded by the European Commission to help EC improve its raw material policy and better exploit mineral resources from the European territory and its mineral supplying countries. It also aims to demonstrate how to improve the capacity of Europe in implementing new mining sites, and to improve interaction between the mining industry and the society.

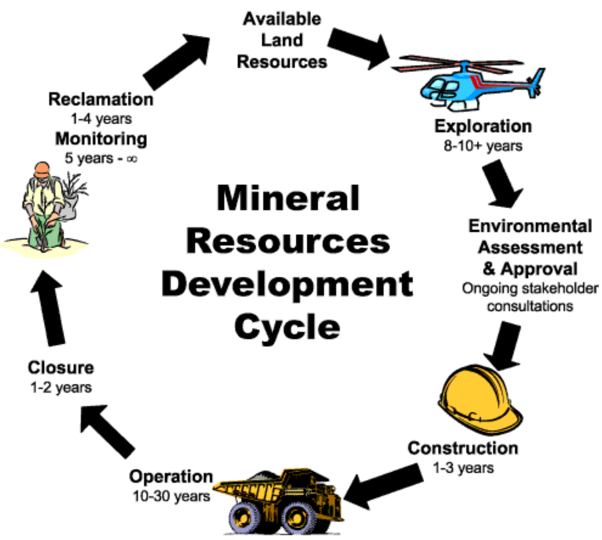
The overall objective of the EO-MINERS project is to bring into play EO-based methods and tools to facilitate and improve interaction between the mineral extractive industry and society, for its sustainable development, while improving its societal acceptability.

The social acceptability of a mining project, from exploration to closure, is among the major key issues to be dealt with. 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 Earth Observation (EO); ii) use existing EO knowledge and carry out new work on demonstration sites to demonstrate the capabilities of integrated EO-based methods and tools in monitoring, managing and contributing to reducing the environmental and societal footprints of the extractive industry during all phases of a mining project and iii) contribute to making available 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.

Given the vital role of the non-energy extractive industry in the EU's economic development, an improved understanding of the environmental, socioeconomic and social impacts of mining is crucial.

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. It includes:

- Spaceborne and airborne imagery
- Ground and airborne geophysics
- Geochemistry
- In situ measurements
- Monitoring networks
- 3D modelling
- …



http://www.mineralsed.ca/s/MinDevCycle.asp

EO-MINERS also addresses GEO (Group on Earth Observation) and GEOSS (Global Earth Observation System of Systems) processes and tasks, by using the project outputs to define core elements of an environmental observing system and examining how this system fits in GEO and contributes to building GEOSS.

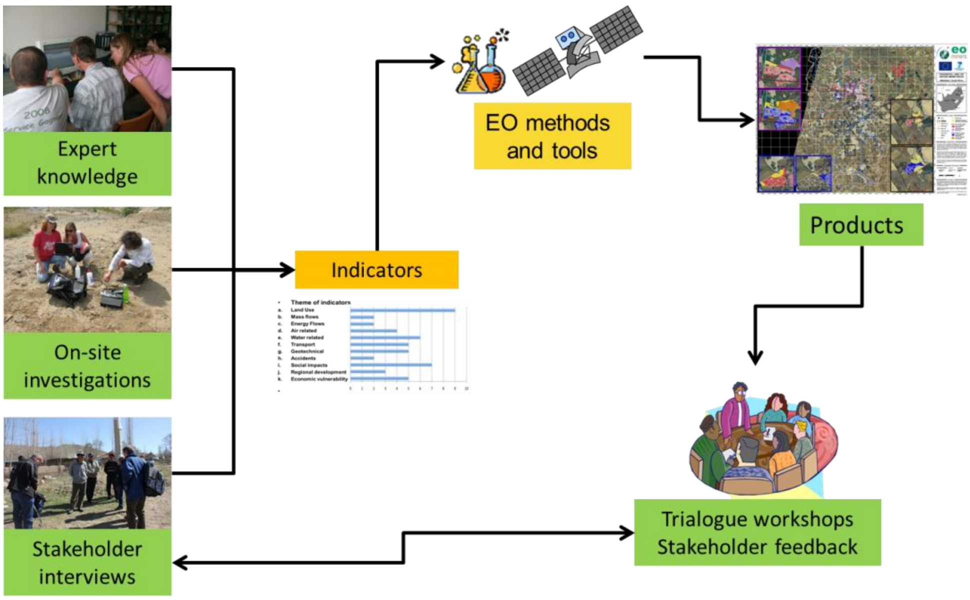
2. Description of the main Science & Technology results and fore-grounds

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

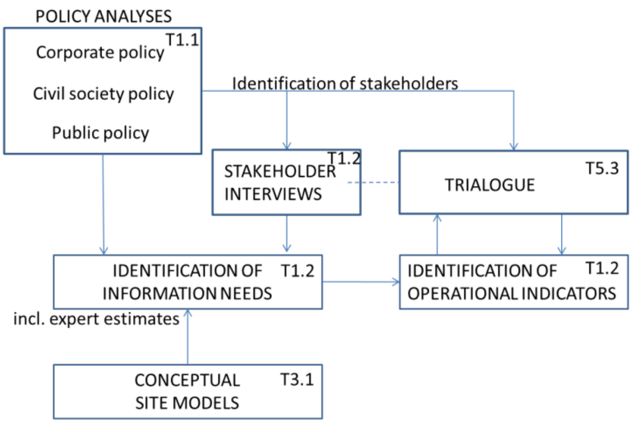
- The Sokolov lignite open pit in western Bohemia, Czech Republic
- The Mpumalanga coal field, the largest coal field in South Africa, near the town of eMalahleni
- The Makmal gold mine and processing plant in Kyrgyzstan, near the town of Kazarman

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 for industrialists, governmental organisations and stakeholders. To this end, the project continuously took care of robust and reliable standards and protocols that guarantee the repeatability of the methods deployed.

The overall methodological approach is illustrated below and described in more details in later sections.



2.1 Policy analysis and indicator definition



With respect to the first scientific and technical objective, the overarching task here was to identify information needs derived from policies to inform the selection of appropriate Earth Observation techniques and products.

EO-MINERS identified policies that address the environmental and social footprint of mineral industries or corporations, public authorities and civil society. Based on this policy analysis, expertise of the project consortium members, and targeted interaction in the form of interviews with stakeholders, specific information needs were derived that represent the basis for the development of indicators of the footprint of mining activities.

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.

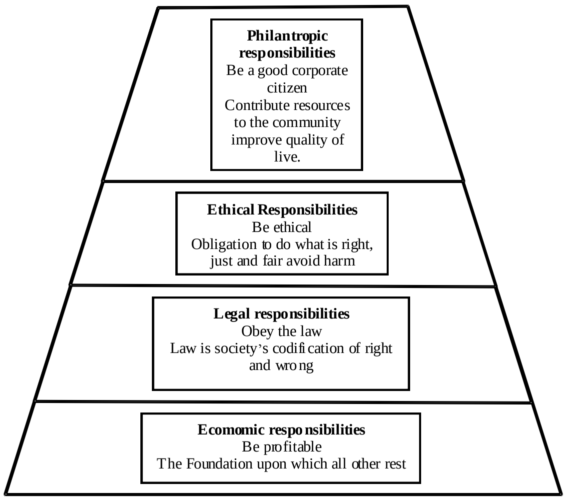
Appropriate indicators were selected for answering the information demanded by local stakeholders, e.g. via corporate sustainability reporting (CSR), and macro-economic indicators for governmental policy-making. These results were on the one hand undertaken to feed directly into the "trialogue" workshops organised by the project, while on the other hand they are also fed by results of the discussions during these "trialogue" events.

These analyses defined the demand for the development and application of Earth Observation products and services, respectively, and thus provide a reference frame for their applicability.

2.1.1 - Corporate policy analysis

Mining companies increasingly adopt corporate responsibility in both the societal and environmental realm as guidance for their actions.

The mining sector is a particularly interesting field with respect to corporate policies. Mines have a long tradition of setting specific corporate policies, namely with respect to health and safety issues, but also with respect to business protection and social aspects. Some mines are early examples of Corporate Social Responsibility (CSR), the mine owners having created a comprehensive set of infrastructure. Conversely, there are also numerous examples, where CSR has been completely perverted, resulting practically in bondage or serfdom of the miners by forcing them into debt e.g. by exaggerated prices for daily necessities in company stores etc.



The definition of Corporate Social Responsibility (CARROLL, 1991)

The ways that mining companies address environmental issues are not only determined by the local situation or the regulatory framework at the various levels, but also by the ways that mining companies place themselves into the world-wide context. It was noted that corporate policies strongly reflect the corporate setting, i.e. whether the corporation operates more locally or globally.

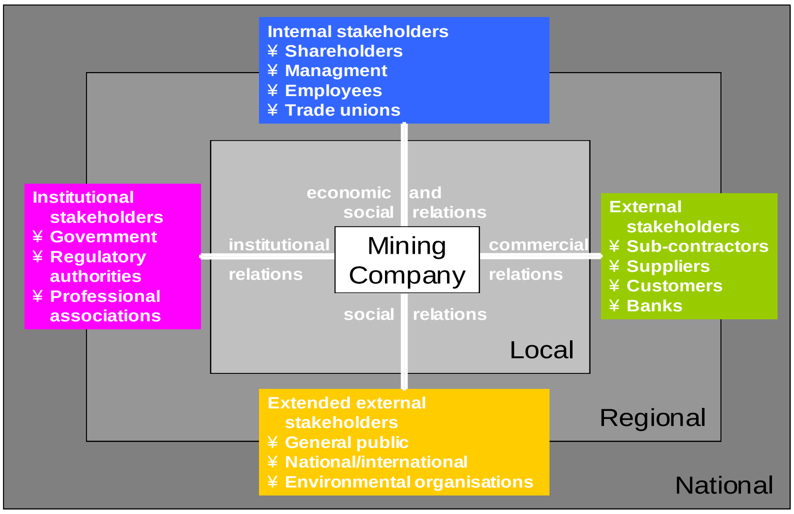
The results of the corporate policy analysis can be found in the project deliverable D1.1.1 entitled "Corporate Policies in a Mineral Extraction Context"[1].

2.1.2 - Policies in civil society

The significant socio-economic and environmental impacts that are often associated with mining operations have generated an increasing number of claims by civil society and regulators. These have

[1] http://www.eo-miners.eu/data_public/deliverables_final/EO-MINERS-D1-1-1-V2.pdf

resulted in a variety of new actual or perceived obligations on the side of the mining operators, who had been traditionally focusing almost exclusively on their economic profitability.



The mining company and its stakeholders (FAUCHEUX *et al.* in CHAMARET, 2007).

Civil society and their interest in and their attitude towards mining is very diverse. The emphasis that is given to any one of the different aspects may vary considerably even within these groups of stakeholders. Stakeholder views and agendas will be shaped by the performance of the mining operation with respect to these issues and in particular by specific events, such as environmental incidents. The attitude of external stakeholders is also significantly shaped by company policies and governance paradigms chosen.

The results of the corporate policy analysis can be found in the project deliverable D1.1.2 entitled "Civil Society Policies in a Mineral Extraction Context"[2].

2.1.3 - Public policies

The analysis of international and EU policy frameworks shows that there are a number of policy arenas relevant to EO MINERS:

- Sustainable Development: The political discourse about sustainable development is often rather general, relating environmental, economic and social problems to each other. It is thus primarily relevant for agenda-setting in the strategic policy environment of EO-MINERS.
- Resource Policies and Initiatives: The discourse about sustainable development is a key driver of resource policies. However, the relevant resource policy frameworks at international and at EU level put emphasis on different aspects. At international level, the focus is mainly on developing or transition countries. Social aspects like the management of resources and revenues and good governance are the main concerns of global initiatives. The emphasis on socio-economic and financial issues suggests that EO does not have a key function in this context. On the EU level resource policies are mainly about two central themes, i.e. a) decoupling environmental impacts from resource use and b) Security of supply. Primarily the first aspect is most relevant for EO-MINERS.
- International activities: Contributing to initiatives such as the Extractive Industry Transparency Initiative (EITI)
- General Environmental Policies: General environmental policies provide broad reporting, assessment and monitoring frameworks on any activity with the potential to impact negatively on the environment, including mining. At international level, the Kiev Protocol on the Pollutant Release and Transfer Register (PRTR) provides such a general reporting system. In the EU, the environmental *acquis communautaire* comprises several precautionary directives and regulations such as the Directive concerning Integrated Pollution, Prevention and Control (IPPC) and the Directive on the Assessment of the Effects of Certain Public and Private Pro-

[2] http://www.eo-miners.eu/data_public/deliverables_final/EO-MINERS-D1-1-2-V2.pdf

jects on the Environment (Environmental Impact Assessment, EIA) which create information requirements related to mining activities.

- Specific Environmental Policies: There are a number of environmental policies, which address specific environmental qualities which can be affected by mining activities, such as the biological diversity of a site, air and water quality. The specific policies can also aim at specific risks of extractive activities, such as the release of waste, hazardous substances and other emissions.

These different arenas have their own historical development and stakeholders on different political levels, corresponding to specific information requirements.

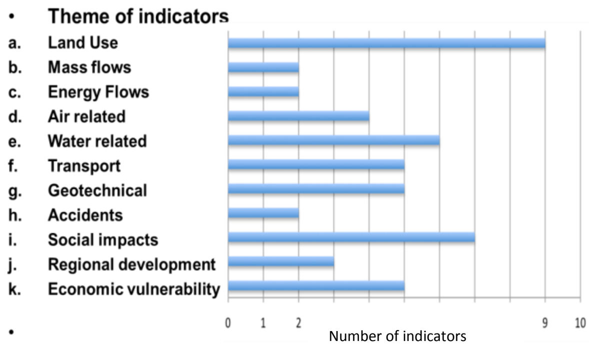
The results of the public policy analysis can be found in the project deliverable D1.2 entitled "Public Policy Analysis"[3]. The deliverable D1.3, entitled "Report on Public, Corporate and Civil Society Policy Analyses" summarises the results of these three policy analyses[4].

2.1.4 - Identification of information requirements and operational indicators

The information, which is generally needed to adequately assess the environmental footprint of mineral industries, as well as its social implications, has been identified. For the different test sites this has been supported by an on-site mapping of information needed by local stakeholders by means of interviews and also during discussions in workshops organised by the EO-MINERS consortium. Meetings with local stakeholders in South Africa, Kyrgyzstan and the Czech Republic were organised at the test sites based on the support by the local EO-MINERS partners

These interviews and assessments of the site-specific situation were the basis for selecting appropriate "micro indicators", i.e. indicators applied on the local level.

Specific information needs on the macro level were also identified. A recent development has been the development of the Europe2020 flagship initiative "Resource Efficient Europe". The implications of the flagship initiative and the resource efficiency roadmap for the mining sector in general and more specifically for EO-MINERS were analysed and thus framed the planning of the European Trialogue.



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 (see § 2.2.1 and deliverable D3.1), 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. The consolidated set of candidate indicators informed the process of EO product development and was subject to final stakeholder evaluations towards the end of the project (see deliverable D5.6). A complete list of indicators is provided in Annex 1, while Annex 2 provided the indicators relevant of each of the demonstration sites.

[3] http://www.eo-miners.eu/data_public/deliverables_final/EO-MINERS_D12_v1.pdf

[4] Insert link

The results of this step are presented in deliverable D1.4 entitled "Candidate Indicators for Mining-Related Environmental and Societal Impacts"[5] and deliverable D1.5 entitled "Final Report on Information Needs and indicators"[6]

2.1.5 - Status quo of monitoring environmental indicators by Earth Observation

The aim here was to summarise what had already been achieved in this field at the start of EO-MINERS in order to learn from these lessons. An extensive literature survey was performed, including the two former complimentary projects: MINEO (www2.brgm.fr/mineo) and PECOMINES (http://viso.jrc.ec.europa.eu/pecomines_ext/). It led to an assessment of the technical advantages and disadvantages of measurement methods, which are required to populate the indicators or allow the development of EO products, respectively, including the assessment of available satellite, airborne, and ground sensors.

The results are provided in deliverable D1.8 "Status quo of monitoring candidate environmental indicators by EO services"[7].

2.1.6 - Resonance analysis of selected indicators and EO services

The resonance analysis methodology has been specifically dedicated to match policies with indicators. It has been further developed for EO purposes and tested in the FP6 project Global Monitoring for Environment and Security (GMES) network of users (GNU). Resonance analysis collects empirical evidence on whether and how specific EO services or products can be related to phases of the policy cycle (e.g. agenda setting, implementation, and evaluation). On the basis of desktop research, stakeholder interviews and the trialogue workshops, assumptions about the function of EO services, which were developed by the project, in corporate and public policy-making have been tested. The results of this task could be seen as a contribution to the quality control of the project and for raising awareness on the potential of EO services and products for the mineral industry and for non-governmental stakeholders with regard to environmental and social footprinting.

Results of the resonance analysis are discussed in Deliverable D1.6 entitled "Resonance Analysis of selected Earth Observation specifications"[8].

2.2 Use of existing knowledge and new development in monitoring and assessing mining impacts from EO

The fulfilment of the second scientific and technical objective of the project consisted of using existing EO knowledge and carrying out new developments on demonstration sites to:

- Further demonstrate the capabilities of integrated EO-based methods and tools to monitor, manage and contribute to reducing 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.
- Contribute to making available 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.
- Summarize and document the developed models and algorithms, as well as the results of the "trialogue" to establish a baseline for a compendium of best practice approaches that will assist the on-going and necessary dialogue between society and the mining industry.

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Methodological developments have been carried out over the Czech, Kyrgyz and South African demonstration sites, to allow observing, monitoring and where possible quantifying social and environmental footprint caused by the mining activity. Integration of satellite, airborne and in situ (see table below) monitoring methods and tools has been the unifying thread all along these developments.

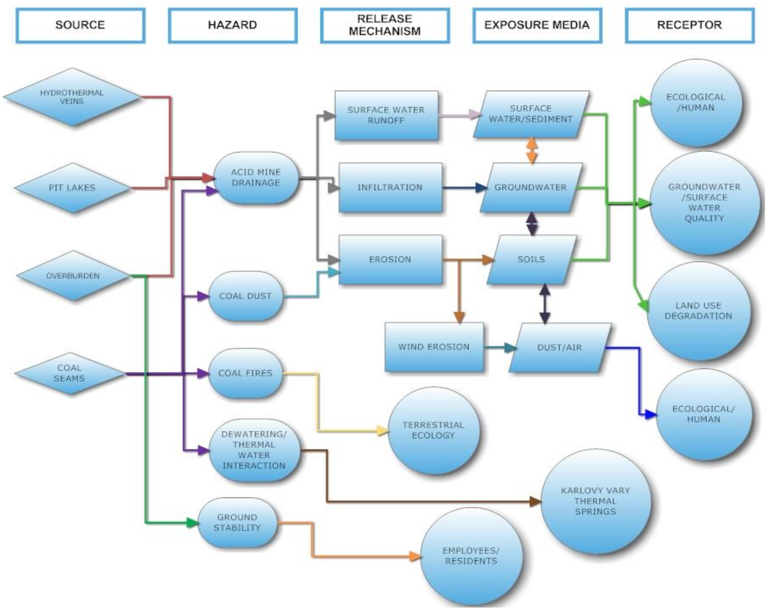
In parallel, particular attention was paid to robust and reliable standards and protocols that guarantee the repeatability of the methods deployed.

In situ measurements	Airborne data acquisition	Satellite imagery
• Ground monitoring networks • In situ point measurements (temperature, pH…) • Field spectroradiometry campaigns (VNIR, SWIR, TIR) • Information and/or measurements about vegetation, soil, groundwater and dust • Chemical Model and 3D characterization of the contaminated soils	• Airborne imaging spectroscopy (hyperspectral) surveys • Thermal infrared (multi and single band) • LiDAR	• Conventional optical sensors: Landsat Thematic Mapper, SPOT, ASTER • Very high resolution optical sensors as WorldView-2 • Radar sensors (TerraSAR-X)

The site-specific developments carried out intended to contribute to the development of generic EO data integration schemes, EO products and EO-driven environmental modelling scenarios adapted to various situations, whose reliability and objectivity cannot be disputed by parties involved in any stage of a mining project. Such products aim to characterise affected ecosystems, populations and societies and become an authoritative basis for a sound “trialogue” between industrialists, governmental organisations and stakeholders.

2.2.1 - Conceptual site model

The approach to assessing and predicting environmental and societal impacts of mining is based on the source-pathway-receptor framework, where there must be a linkage (i.e. pathway) from the source of a known or potential hazard to a receptor. The Conceptual Site Model (CSM) is one of the primary tools that can be used to support this assessment, by providing a framework where available information is collated and key linkages among system components are set out. Development of the CSM helps identify data gaps in the assessment process and guide further investigation.



Conceptual site model for the Sokolov lignite open pit, Czech Republic

A CSM can be used by all of the stakeholders, providing a framework to help communicate ideas and understanding of the site conditions in an effective manner. Mining or environmental engineers use them to understand the technical components of the environment, while they are also used to explain potentially complex situations to policy makers or members of the public.

Typically, a mining CSM should include consideration of the topics listed below:

- Site description
- Geology, topography
- Climate
- Hydrogeology
- Water Balance
- Geochemistry
- Distribution of receptors and exposure pathways.

Deliverables D3.1 (one per demonstration site) entitled “Report on site description and site conceptual model[9]” provide a general description of the site and its impacts as well as the associated conceptual model.

2.2.2 - Relevant data collection and quality control

Once an indicator is defined, a list of relevant measurable parameters is established, along with the potential to address them through EO techniques. For each parameter, the relevant EO data to be collated and made accessible to the project are then listed. These include:

- Satellite imagery, either from archive imagery (e.g. Landsat TM, SPOT, ASTER, CARTOSAT) or resulting from specific tasking requests (e.g. WorldView_2);
- Airborne data acquisition surveys: hyperspectral, very-high resolution orthophotos, thermal imagery, LIDAR;
- In situ measurements and data acquisition during dedicated field campaigns;
- Existing publicly available data and GIS layers from various national or regional agencies and organisations e.g. orthophoto mosaics, DEMs, land use maps, geological and hydrogeological maps and information, meteorological data, socio-economic data, etc.

A comprehensive list of data acquired within the project frame is provided in Annex 3, while deliverable D3.2 entitled “Data acquisition and validation[10]” describes all data acquired together with associated metadata and copyrights.

Developments carried out during the project rely on data that fully comply with protocols and standards, e.g., data calibration, data validation and data quality assurance, from upstream (data acquisition phase) to downstream (the added-value EO-based product delivery phase) as well as through

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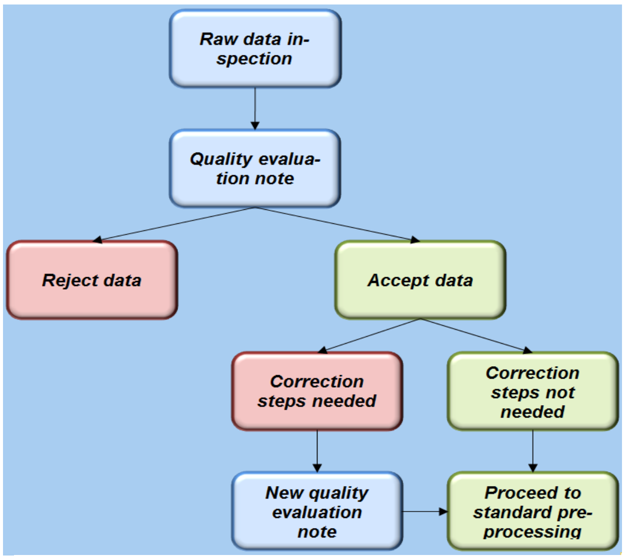
the processing chain (algorithms). Robust and reliable standards and protocols guarantee the repeatability of the methods deployed.



Basic steps for raw data quality evaluation

A protocol to assess the quality of the different field measurements and acquired EO data has been developed, taking already existing standards widely accepted and used into account.. Quality assurance/quality indicators (QA/QI) are being developed for all available data, and the specific protocols for potential users have been gathered with alignment of the QA/QI developed within the framework of the EUFAR (European Facility for Airborne Research) project, the HYQUAPRO group and beyond.

Among other things, this includes development of a protocol for raw hyperspectral data quality indicators which include Radiance to Reflectance ratio (Rad-Ref), Radiance to Reflectance Difference Factor (RRDF) and Image noise Indicator (INI).

Deliverable D2.2 entitled "Data inspection[11]" screens all the methods that were used to inspect remote sensing (satellite, airborne and proximal) data during the project.

2.2.3 - Data pre-processing

2.2.3.1 - Introduction

The goal of the EO-MINERS research project is to use EO tools to help identify mining-related environmental and societal footprints. In order to achieve this goal, the data collected have to be objective and accurate. The different data sets that have been collected using remotely sensed methods, integrated with in situ information, fulfil these criteria. From a Remote Sensing point of view, the different data sets can be grouped into different major groups:

- Hyperspectral remote sensing (imaging spectroscopy) for material detection and quantification,
- High resolution multispectral optical satellite and airborne data, covering different parts of the electromagnetic spectrum, used for precise mapping aspects, and medium scale optical satellite imagery used for mapping information on a regional scale
- Active satellite and airborne systems, like synthetic aperture data (SAR) and active systems that measures distance by illuminating a target with a laser and analysing the reflected light (LIDAR).

2.2.3.2 - Basic principle of optical remote sensing

Optical remote sensing and in particular Imaging Spectroscopy has shown the potential to assess not only general surface, land-cover and land-use properties over large areas, but also quantify selected parameters. This is accomplished by taking advantage of the characteristic interactions of incident radiation and the geo-physical-chemical properties of the surface and its cover types, which allows remote sensing-based approaches to study surface parameter patterns, their quantification and their possible changes over time. Those measurements can be transferred to large geographical regions of

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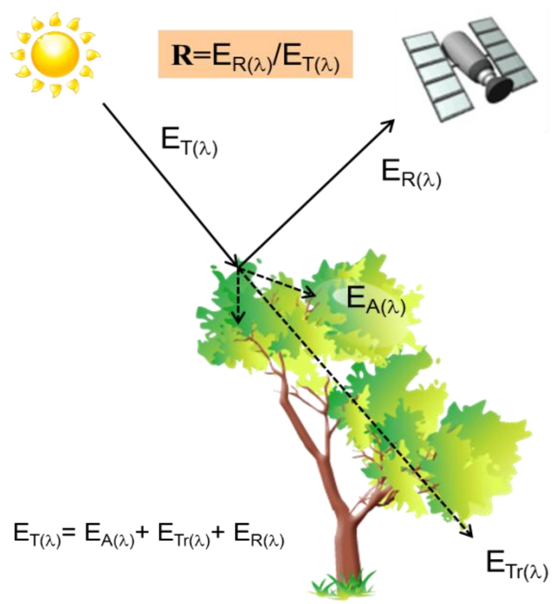
similar climatic and geo-physical and geo-chemical conditions after atmospheric correction has been applied.

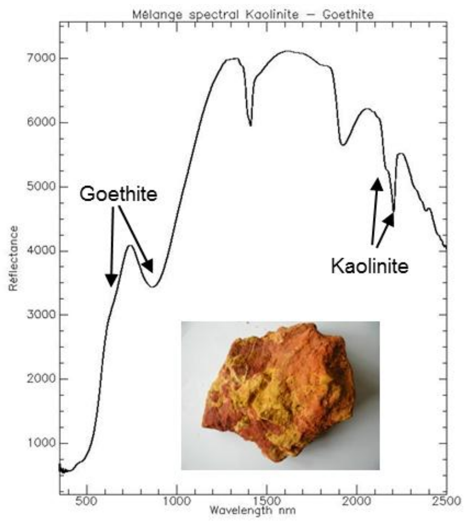
2.2.3.2.1 - Reflectivity domain



Mapping Earth's surface composition using optical remote sensing is based on the concept of reflectance and spectral signature. A target at the Earth's surface illuminated by solar energy radiation ($E_{T(\lambda)}$) either absorbs ($E_{A(\lambda)}$) transmits ($E_{Tr(\lambda)}$) or reflects ($E_{R(\lambda)}$) this energy, the energy budget being divided in these three quantities.

The **reflectance** is defined as the fraction of the total incident energy which is reflected by the target ($R=E_{R(\lambda)}/E_{T(\lambda)}$). The reflectance varies according to the wavelength and the nature of the target.

The way radiation is reflected from a surface depends on the surface's characteristics. Measuring and plotting the variation of the reflectance with the wavelength for a given target makes possible to draw its spectral reflectance curve. Being a characteristic of the target, this variation represents its **spectral signature**.



These properties are responsible for the "colour" of the earth's surface features on satellite images such as the ones used on Google Earth.

Each target hence presents distinctive spectral absorption/reflection feature(s) that enable its unique identification from spectral criteria, and are the basis for material identification, compositional analysis, abundance estimation and physical parameter retrieval.

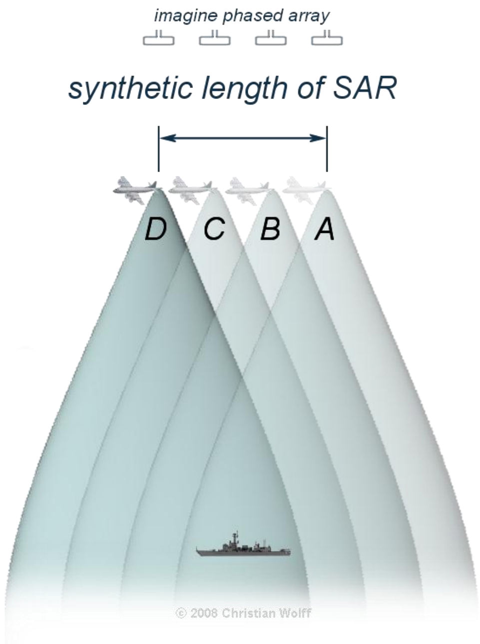
Material identification and derivation of quantitative information is based on analysis of the wavelength position of the absorption features and parameters describing their shape, such as depth, width, symmetry…

2.2.3.2.2 - Emissivity domain

For the thermal infrared (TIR) domain the Earth surface itself is the radiation source. The surface's actual energy budget is dependent on a variety of material specific and environmental parameters such as heat capacity, heat conduction, evaporation, long- and shortwave irradiation, etc. This imposes a major problem as for n-spectral measurements (sensor bands) there are n+ 1 unknown (spectral emissivities plus temperature). Specific algorithms have been developed to separate emissivity and temperature in TIR spectral measurements.

2.2.3.3 - Principle of radar remote sensing

A Synthetic Aperture Radar (SAR) is a coherent mostly airborne or spaceborne side-looking radar system which utilizes the flight path of the platform to simulate an extremely large antenna or aperture electronically, and that generates high-resolution remote sensing imagery. radar pulses can detect dielectric properties of the earth's surface, and can distinguish texture. Particular benefits of this system are the ability to see through clouds (and at night time) and to detect features such as soil moisture and ground movement.



2.2.3.4 - Principle of LiDAR remote sensing

An airborne LiDAR (Light Detection and Ranging) system pulses a laser beam onto a mirror and projects it downward from an airborne platform, usually a fixed-wing airplane or a helicopter. The beam is scanned from side to side as the aircraft flies over the survey area, measuring between 20,000 to 100,000 points per second. When the laser beam hits an object it is reflected back to the mirror. The time interval between the pulse leaving the airborne platform and its return to the LIDAR sensor is measured. Following the LiDAR mission, the data is post-processed and the LIDAR time-interval measurements from the pulse being sent to the return pulse being received are converted to distance and corrected to the aircraft's onboard GPS receiver, IMU, and ground-based GPS stations. The GPS very accurately determines the aircraft's position in terms of latitude, longitude and altitude. The LiDAR sensor collects a huge amount of data and a single survey can easily generate millions of points totalling several terabytes. The initial LiDAR data can be further enhanced using additional post processing, some of which can be automated and some are manual. Further processing utilises the multiple return signals from each laser pulse. By evaluating the time differences between the multiple return signals the post processing system can differentiate between buildings and other structures, vegetation, and the ground surface. This process is used to remove surface features to produce bare earth models (DTM) and other enhanced data products[12].

2.2.3.5 - Main data preprocessing issues

2.2.3.5.1 - Atmospheric correction of hyperspectral imagery

The objective of any radiometric correction of airborne and spaceborne imagery of optical sensors is the extraction of physical earth surface parameters such as spectral albedo, directional reflectance quantities, emissivity, and temperature. To achieve this goal the influence of the atmosphere, solar illumination, sensor viewing geometry, and terrain information have to be taken into account. Although a lot of information from airborne and satellite imagery can be extracted without radiometric correction, the physically based approach offers advantages, especially when dealing with multi-temporal data and when a comparison of different sensors is required. In addition, the full potential of imaging spectrometers can only be exploited with this approach. One widely used physical model is the ATCOR software package. ATCOR can be easily adapted to new sensors once their data becomes available. Special features of ATCOR are the consideration of topographic effects and the capability to process thermal band imagery.

[12] Source : http://www.lidar-uk.com/what-is-lidar/

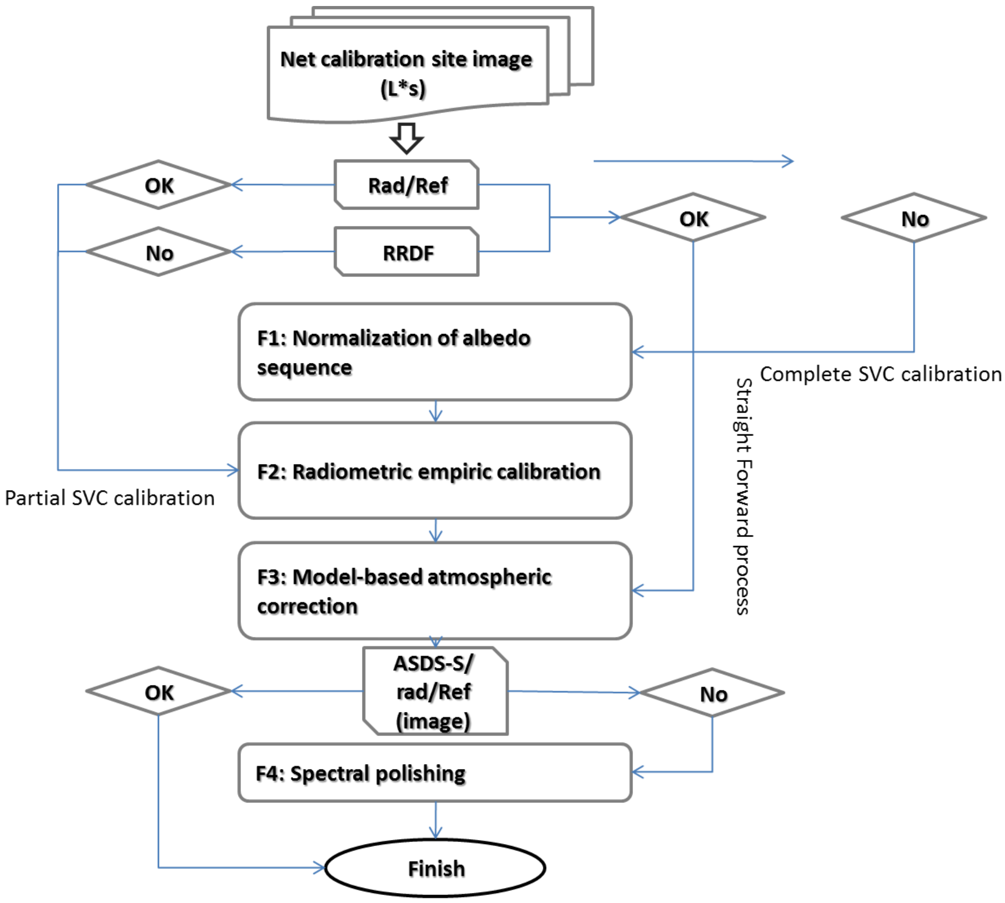
Atmosphere correction of hyperspectral data have been studied using different available methods. It was found that for vegetation and land, different attitude has to be taken and the merge of several methods is required. In this regard, a supervised vicarious calibration technique has been examined for the first time based on agricultural black net in different densities.

A new innovative method to inspect the quality of hyperspectral data has been developed. This inspection process is done on both the radiometric and reflectance data and is based on the Supervised Vicarious Calibration (SVC). Two physical indicators were developed for that purpose: RAD/REF (at-sensor Radiance divided by ground truth Reflectance) and RRDF (Radiance to Reflectance difference factor). Both are based on the radiance and reflectance response of selected ground targets. The SVC methods call to use “agriculture net” in different densities but other targets are also permitted.

Deliverable D2.3 entitled “Atmospheric correction protocol and validation results[13]” details the methods and protocols followed for atmospheric correction of airborne hyperspectral data sets.

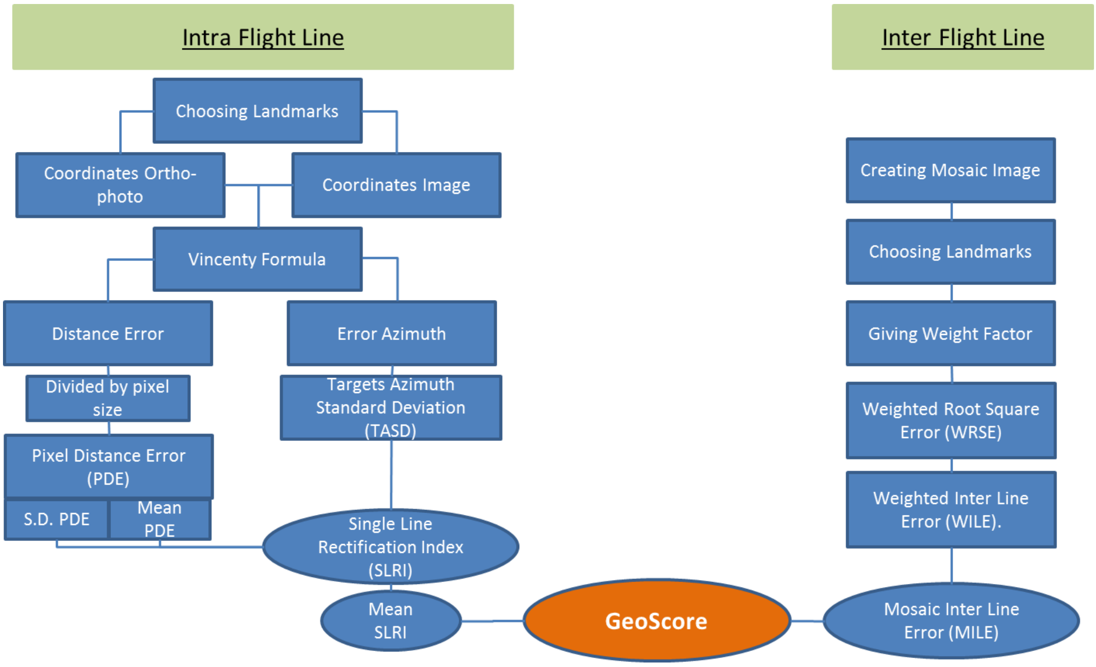
2.2.3.5.2- Correction of geometric distortion in hyperspectral airborne surveys

Different approaches and methods to inspect geometric distortion have been developed. This was found to be a crucial stage when several flight lines are used to cover large areas. Comprehensive documentations exist and protocol how to apply these methods has been issued and used in all data sets within the EO-MINERS project.



[13] Insert link

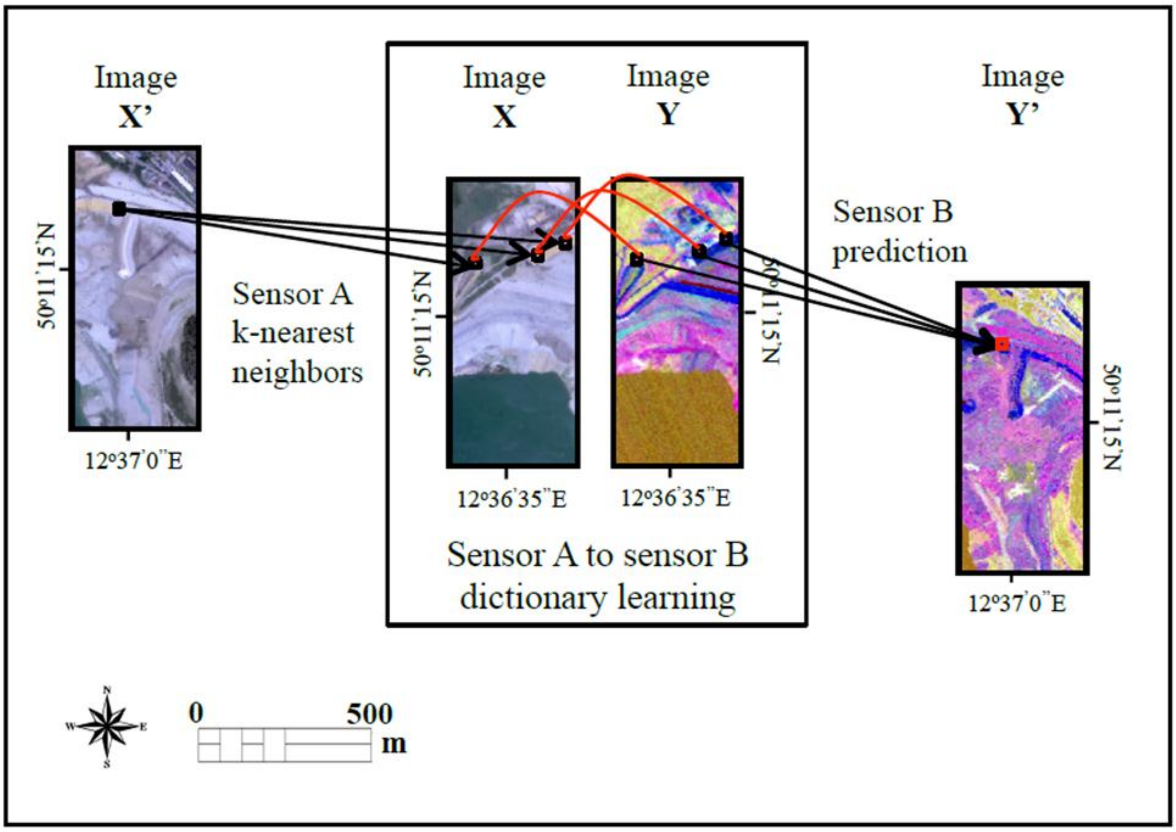
Flow chart of the SVC method using the RAD/REF and RRDF indicators



Flow chart to inspect geo correction performance using one flight line (Inter) and several flight lines (Intra)

2.2.3.5.3- Completion of missing data in hyperspectral thermal infrared imagery

A new innovative method to complete missing data of hyperspectral sensor operating in the thermal region from other hyperspectral sensors that are active in the optical region has been developed. It terms SENTOS (Sensor to Sensor) and used the AHS data acquired over Sokolov area for demonstration.



•Image Y' is a predicted LWIR (sensor B) image using a VIS (sensor A) spectral image X'.
•The nearest neighbors of every pixel in X' are found in the VIS (sensor A) spectral image X.
•Each of those neighboring pixels has a corresponding LWIR (sensor B) spectral signature, and these are then used to generate the predicted LWIR (sensor B) image Y' by a weighted average.

The SENTOS algorithm

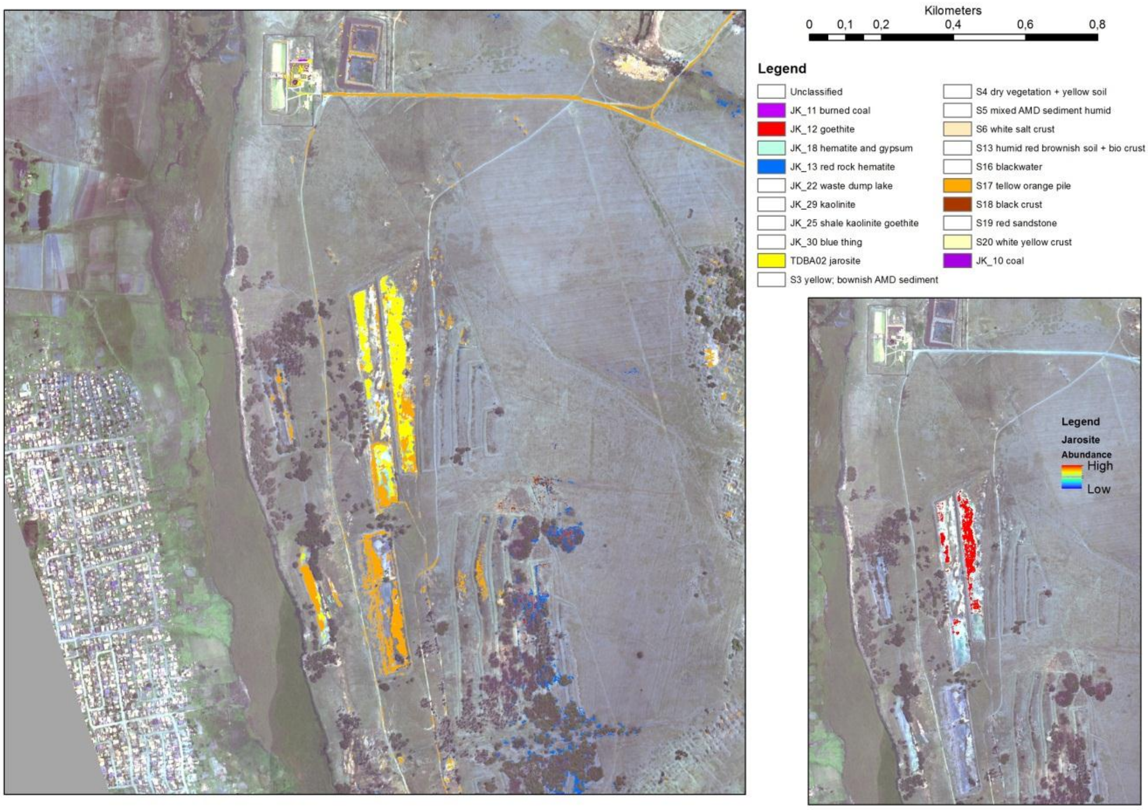
2.2.3.6 - Data processing, data fusion, algorithm development

2.2.3.6.1- Mineral mapping from VNIR – SWIR hyperspectral airborne imagery

Mineral detection and mineral mapping haven been demonstrated for the two demonstration sites Sokolov and eMalahleni. Both sites are characterized by active and closing open pit mines, dump sites and ancient mining remnants, responsible for Acid Mine Drainage (AMD). AMD is acidic water (pH <5.0), laden with iron, sulphate and other metals, that forms under natural conditions when geologic strata containing pyrite are exposed to the atmosphere or oxidizing environments. Much of the acid drainage worldwide is commonly thought to be associated with coal mining, but acid drainage can occur under natural conditions or where sulphides in geologic materials are encountered in metal mining, highway construction, and other deep excavations. Acidic waters are harmful to aquatic organisms and responsible for the mobilisation of heavy metals and their dissemination in the environment. This induces an adverse environmental impact on aquatic life, vegetation and soil fertility.

Spatial mapping of the source of acidification, its pathways and possibly affected areas are of key interest. In summary, 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.

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.

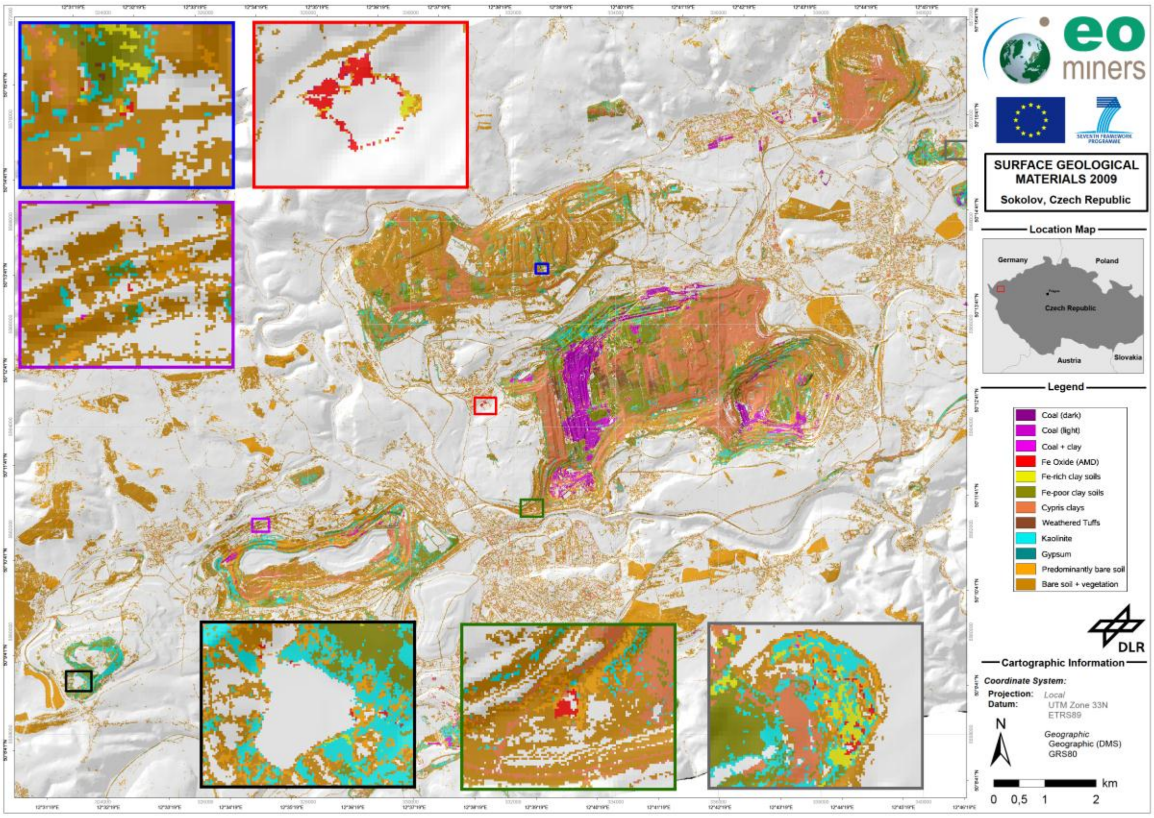


Mapping AMD minerals (jarosite in yellow) from hyperspectral imagery over eMalahleni coal field. Note the similar result obtained from WorldView_2 VNIR imagery a year before (jarosite in red in the bottom-right cartridge)

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 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).

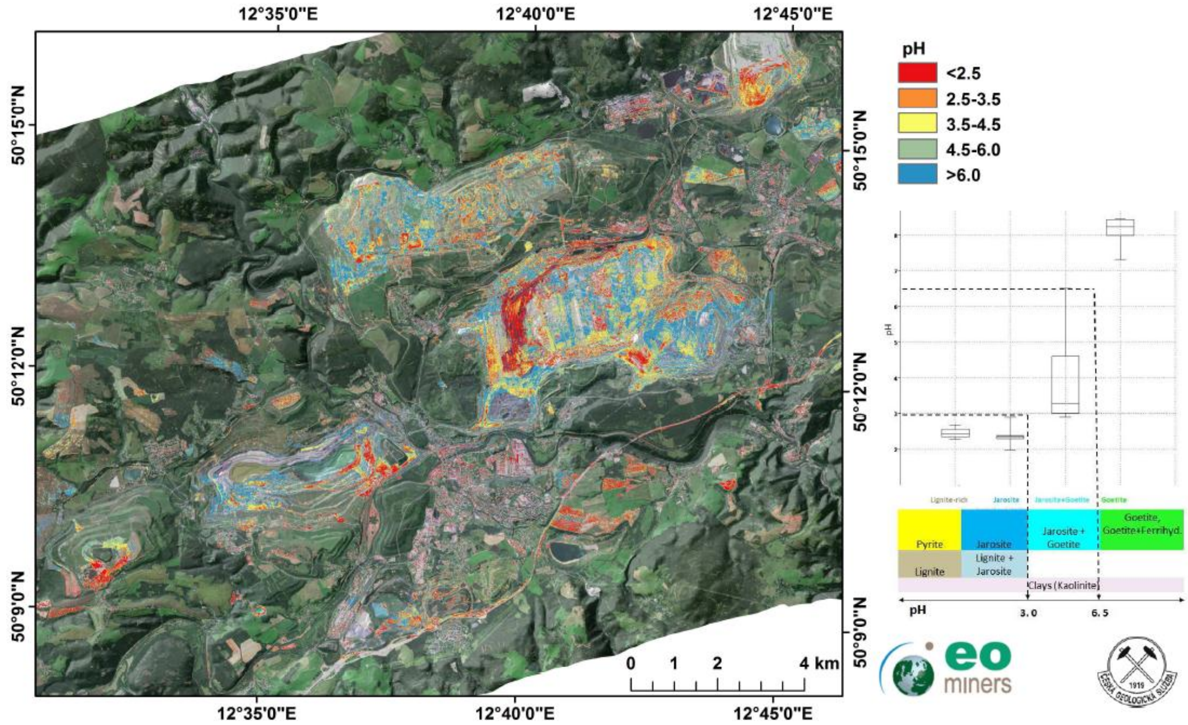
The 2009 and 2010 HyMap airborne data of Sokolov, Czech Republic, was use to derive a set of image endmembers to be used for subsequent classification of soils and geological materials. Endmembers were extracted from the reflectance imagery that was not geo-corrected and had no cross-track illumination or BRDF correction applied. Of the 125 atmospherically corrected bands by using ATCOR, 14 of those occurring near the main 1.4 and 1.9 µm atmospheric water absorption features and noisy bands longer than 2.45 µm were removed from the data, leaving 110 bands. For endmember extraction no masking of the data was applied.

Sixty-five ground samples that were collected in 2010 that represent a limited number of soil, clay, and iron-oxide mixtures were used to help identify the endmember reflectance spectra derived from the images. Reflectance spectra of the samples were measured and compiled into a single library and then re-sampled to the 110 HyMap bands. This allowed for a direct comparison and evaluation with endmembers derived using endmember extraction tools. This allowed for endmember extraction to be applied to the full hyperspectral data set for both 2009 and 2010 simultaneously.



2010 HyMAP thematic map showing the surface geological materials and soil cover for the Sokolov region.

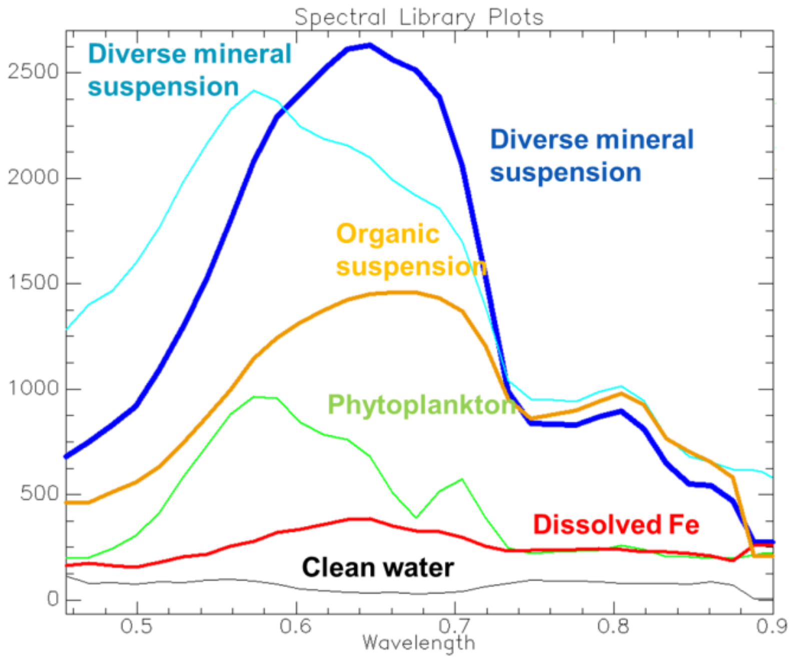
In Sokolov low-quality effluents are observed, in particular areas which have led to an acidification of soils and of surface waters.



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

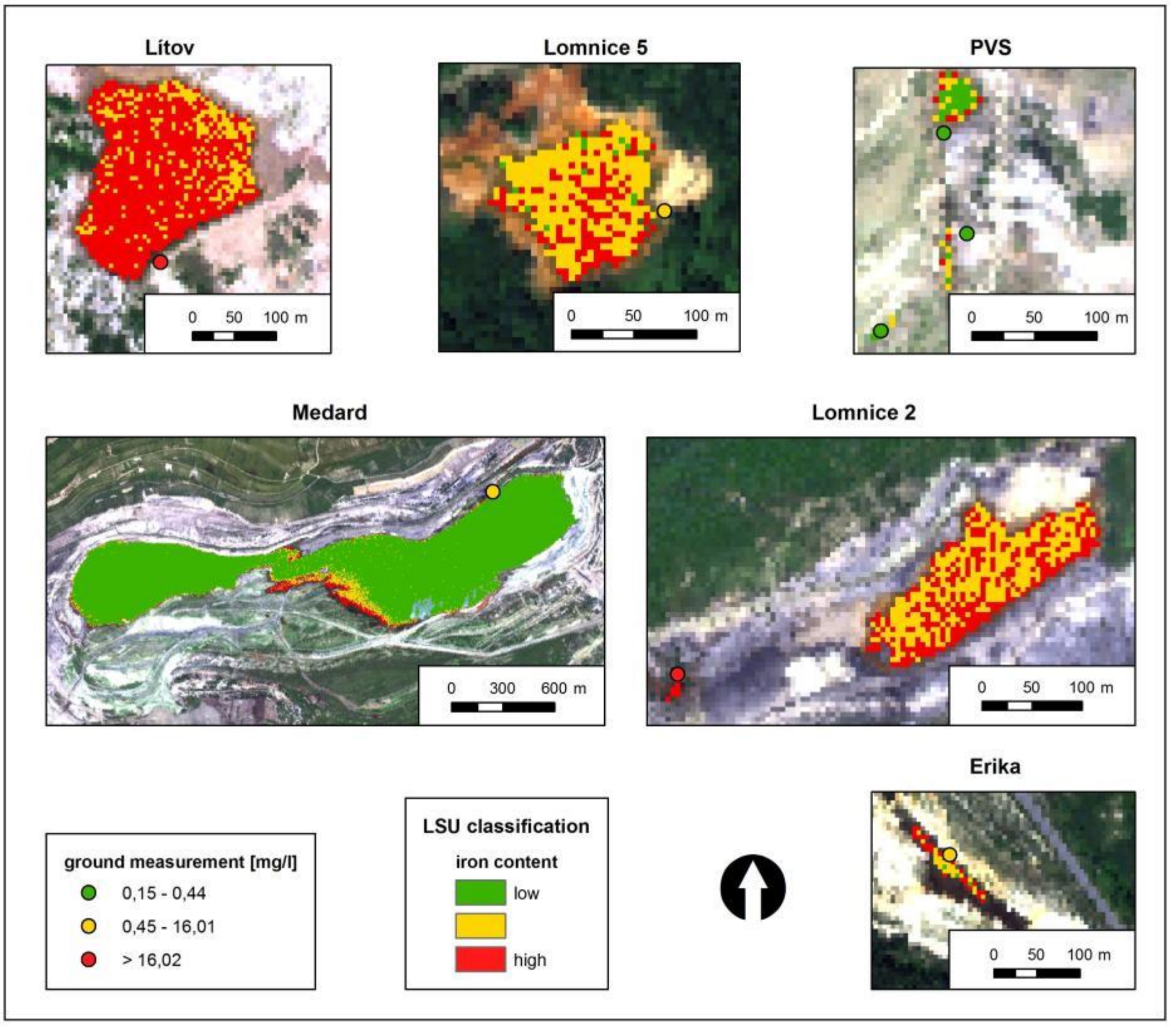
Here also, hyperspectral imagery supports mapping minerals and mineral associations that are responsible for AMD and soil acidification, hence enabling the derivation of a predictive soil pH map. Diagnostic minerals of low (pH < 3) pH are pyrite, jarosite and lignite. Jarosite in association with goethite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

2.2.3.6.2- Mapping surface water parameters from VNIR hyperspectral imagery



Mapping surface water parameters, including estimated dissolved iron content, dissolved organic matter content (DOC) and estimated inorganic matter suspension have been carried out over the Sokolov open pit area.

Linking spectral properties of surface water reflectance with specific chemical-physical parameters makes possible a semi-quantitative mapping of these parameters in the VNIR range of hyperspectral imagery.



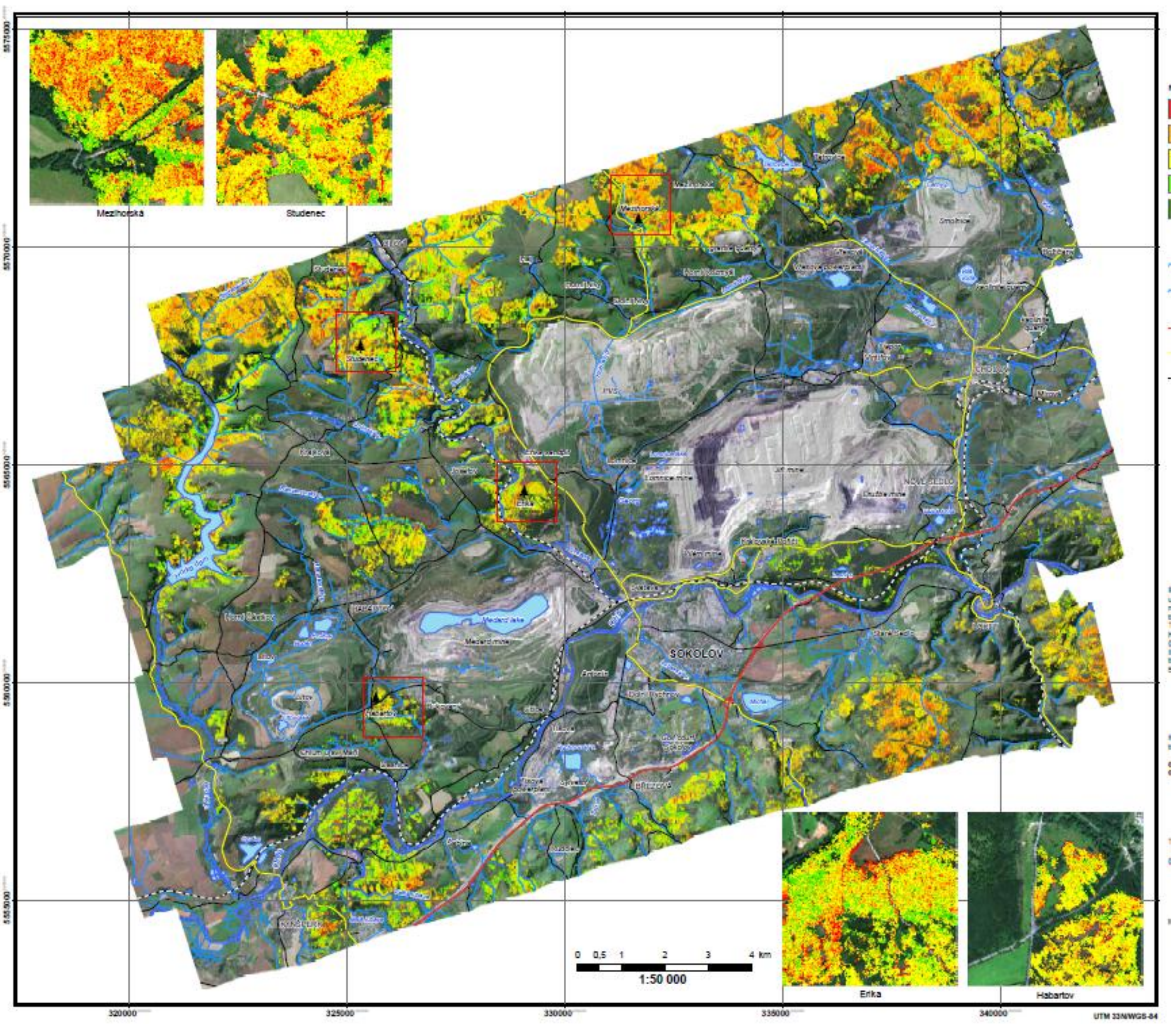
Estimated dissolved Fe content in waters, Sokolov open pit area. Ground measurements of dissolved Fe which were used for validation are also displayed

2.2.3.6.3 - Mapping vegetation health status from VNIR – SWIR hyperspectral imagery

The biochemical composition of spruce needles with their longevity and exposure to environmental conditions is often used as a bio indicator of soil or air contamination. Particularly the contents of photosynthetic pigments are closely related to photosynthetic performance and can serve as early-warning symptoms of plant stress, before macroscopic changes are detected.

In Sokolov open pit area, physiological status of macroscopically undamaged foliage can be assessed from hyperspectral imagery and stress can be detected prior the symptoms are visually expressed. Reflectance spectra for each Norway spruce health class were calculated from the HyMap image data sets and stress-related trends changing canopy reflectance were identified. Changes in VIS/NIR reflectance can be explained by chlorophyll degradation on one site and carotenoid content increases on the other site, whereas changes in SWIR document falling water consumption as a reaction to the stress

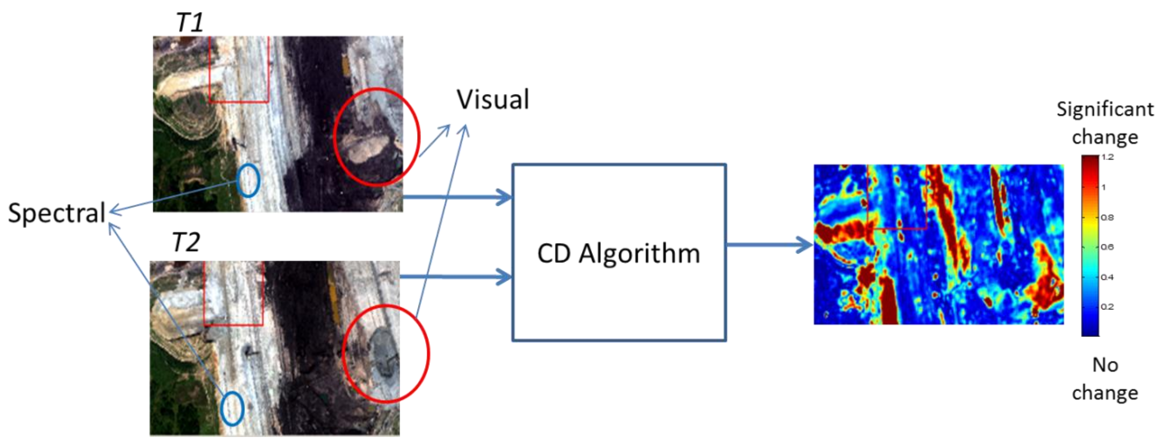
The method proved suitable as the hyperspectral image classification results are in accordance with the statistical assessment of the biochemical properties of the sampled trees as well as with the geochemical properties of the forest sites.



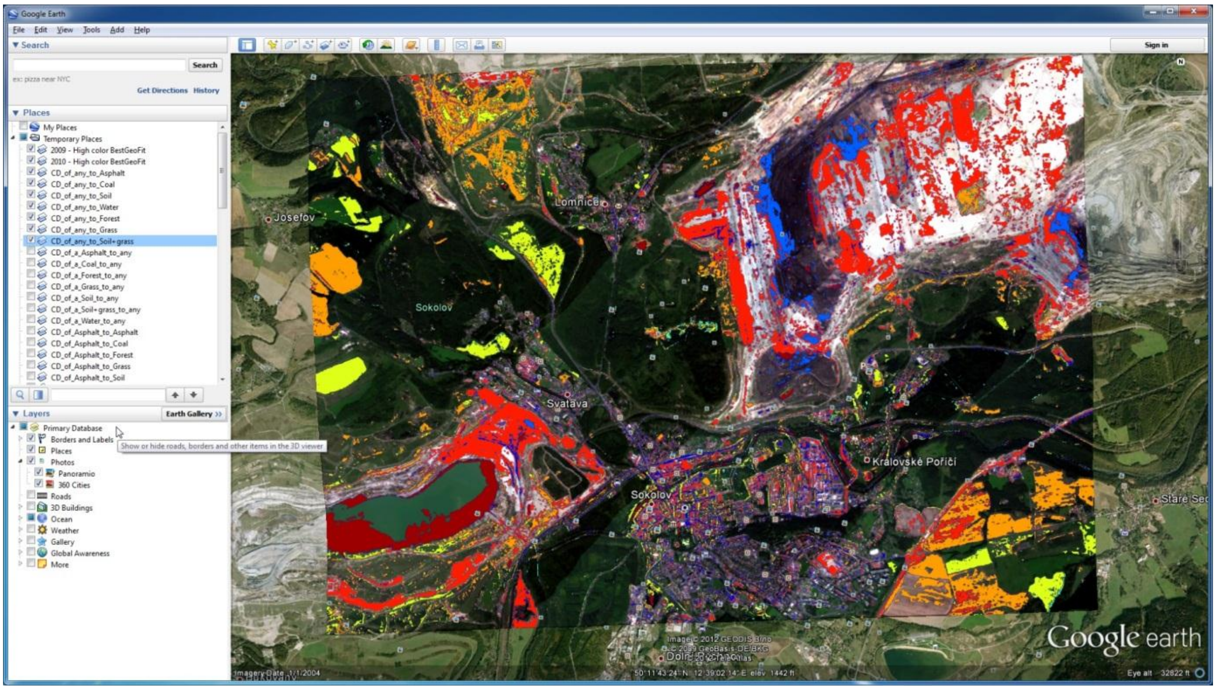
Forest health status map over Sokolov open pit area. Healthier status in red and yellow, worse status from green to blue

2.2.3.6.4 - Change detection in mining areas from VNIR – SWIR hyperspectral imagery

Temporal changes are important in monitoring mining activities. Changes over two images acquired at two different dates can either be visible (spatial changes) or not visible (spectral changes).

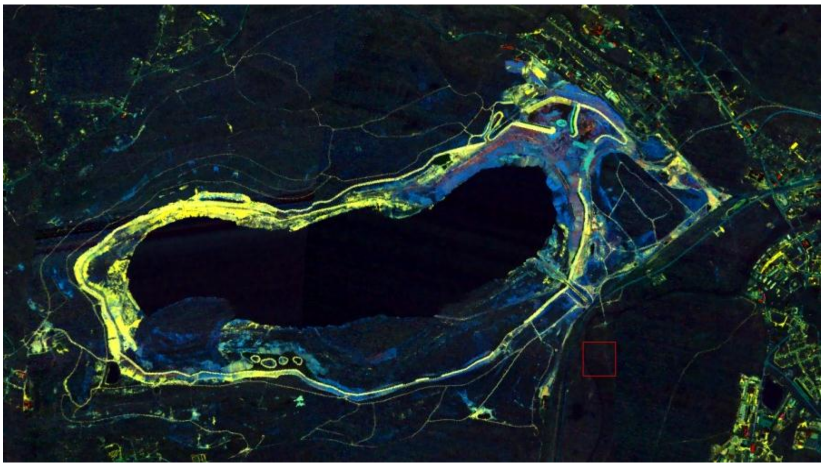


Applying dedicated change detection (CD) algorithms to hyperspectral imagery enables mapping land cover changes according to spectral characters. Such change detection highlights the progress of lignite exploitation to the west (any to coal) and overburden removal (any to clayey soil) to the west and its backfilling in the eastern part.



2009-2010 land cover changes from hyperspectral imagery, Sokolov open pit area. Blue = any to coal, red = any to bare clayey soils, dark red = any to water, yellow = any to grass, orange = any to soil and grass

2.2.3.6.5- Mapping minerals from hyperspectral TIR imagery



Relative abundance of sandy soils (in yellow) vs. clayey soils (in blue) over Medard open pit, Sokolov area

Some minerals like quartz and silicates do not present specific absorption features in the VNIR – SWIR spectral range and can only be discriminated from their emissivity spectral signature in the TIR range.

This information can be used to derive soil properties like fertility and acidity buffering capacity, which are relevant for localized reclamation efforts, assessing soil quality and selection of appropriate reclamation methods. In addition, the data can support evaluating the reclamation success; the yellow areas on the above image correspond to geotechnical engineering banks and trails.

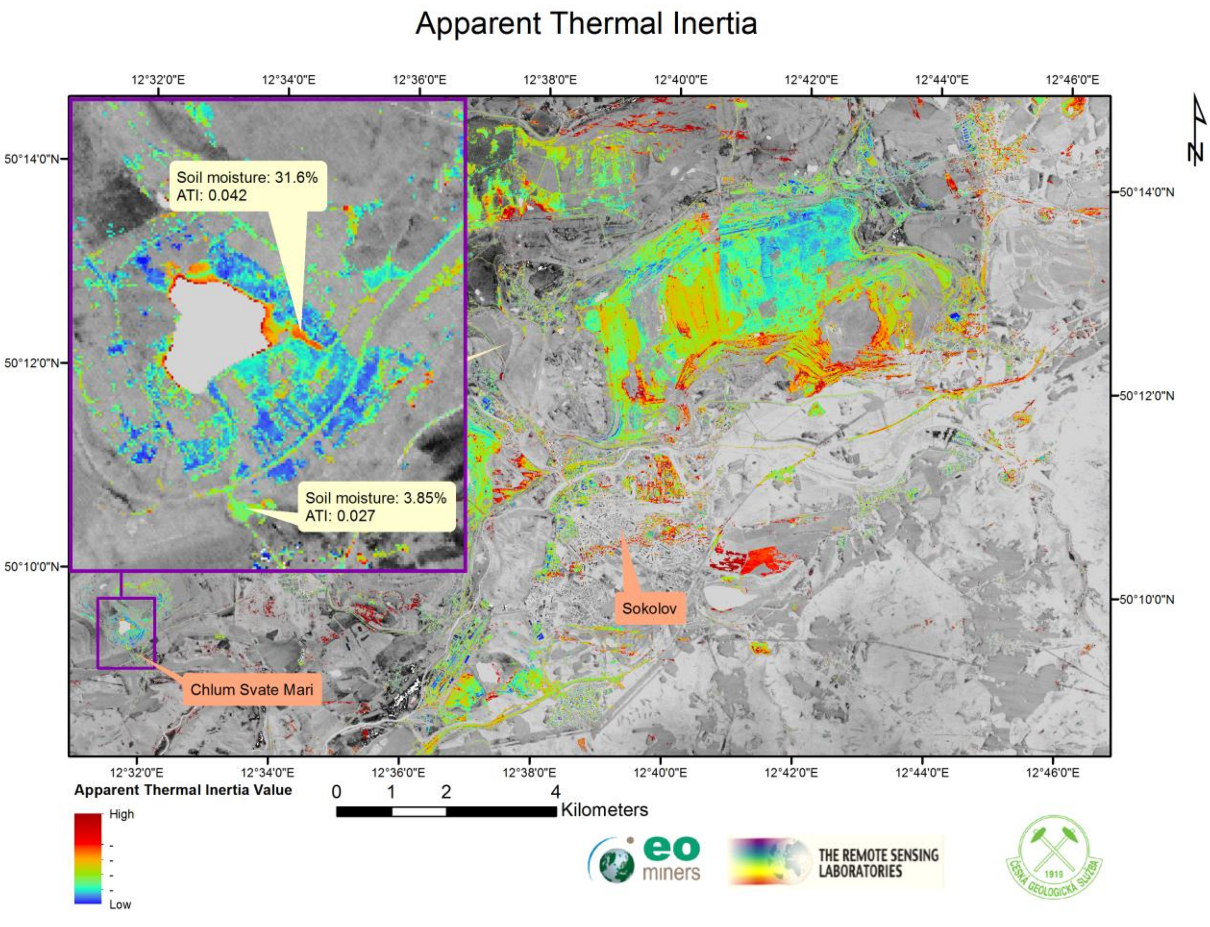
Beyond clay and quartz separation, processed thermal infrared data can be used to improve land-use/land-cover mapping approaches as many common minerals show distinctive spectral emissivity signatures in the thermal domain.

2.2.3.6.6- Mapping apparent thermal inertia from TIR hyperspectral imagery

Water content in soils is an important parameter in monitoring soil stability, a major concern in mining areas. As mentioned above, hyperspectral imagery in the TIR domain can provide information on surface emissivity and surface temperature.

A new technique to assess soil moisture was developed using the thermal and visible information acquired by the AHS airborne sensor. After processing the data the Apparent Thermal Inertia (ATI) was calculated on a pixel by pixel basis and correlation with the soil moisture values in selected areas was done. It was found that this simple method can provide soil moisture content

The Apparent Thermal Inertia (ATI) of soils was retrieved from AHS airborne day and night surveys in the Sokolov area. High ATI values may indicate soils with high water content, whereas low values may indicate soils with low water content.



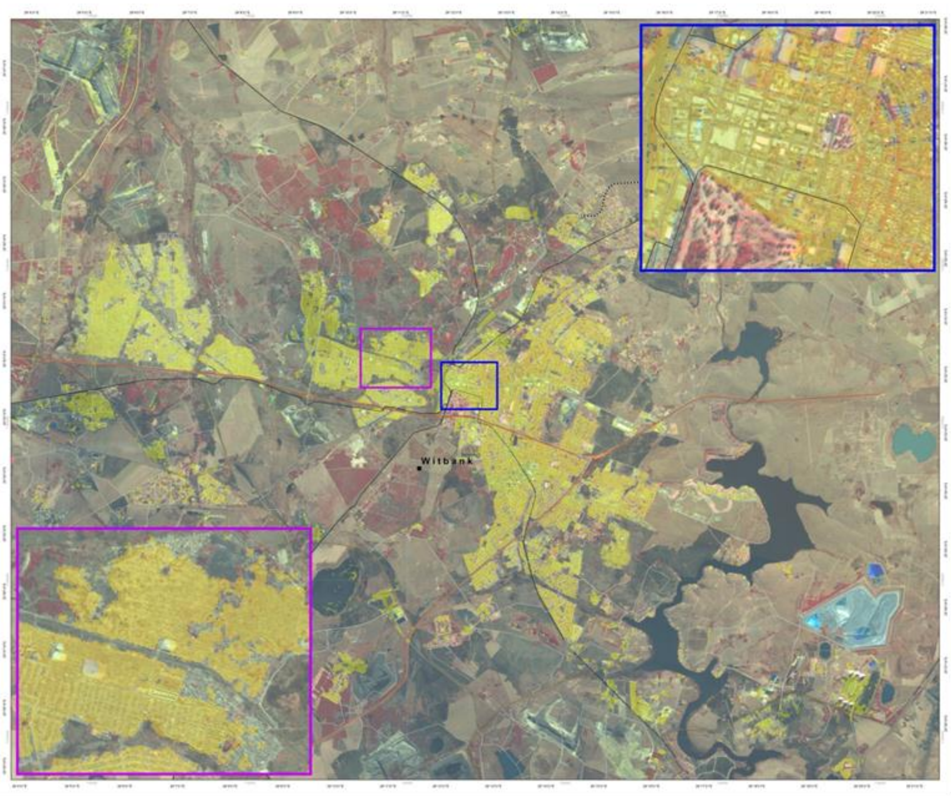
Distribution of Apparent Thermal Inertia in the Sokolov area

2.2.3.6.7 - Mapping urban footprint from radar imagery

Mining often is associated with uncontrolled urban sprawling. Effective planning requires a reliable current extent of urban ares. In developing countries often no official records are available and heavy informal settlement regularly occurs.

The objective of the Global Urban Footprint (GUF) initiative is to generate a global high-resolution binary mask of urban areas (i.e., built-up) from very high resolution SAR data acquired in the framework of the TanDEM-X Mission. The GUF will serve as a basis for the analysis of human settlements worldwide

The German TerraSAR-X add-on for Digital Elevation Measurement (TanDEM-X) mission collected two global data sets of very high resolution (VHR) synthetic aperture radar (SAR) images between 2011 and 2013. Such imagery provides a unique information source for the identification of built-up areas in a so far unique spatial detail. In particular, with respect to optical sensors, the weather-independent, day and-night data acquisition capability and the low sensitivity toward atmospheric effects of SAR systems make them particularly suitable to provide temporally and radiometrically consistent global data coverages.



Urban footprint in eMalahleni municipality

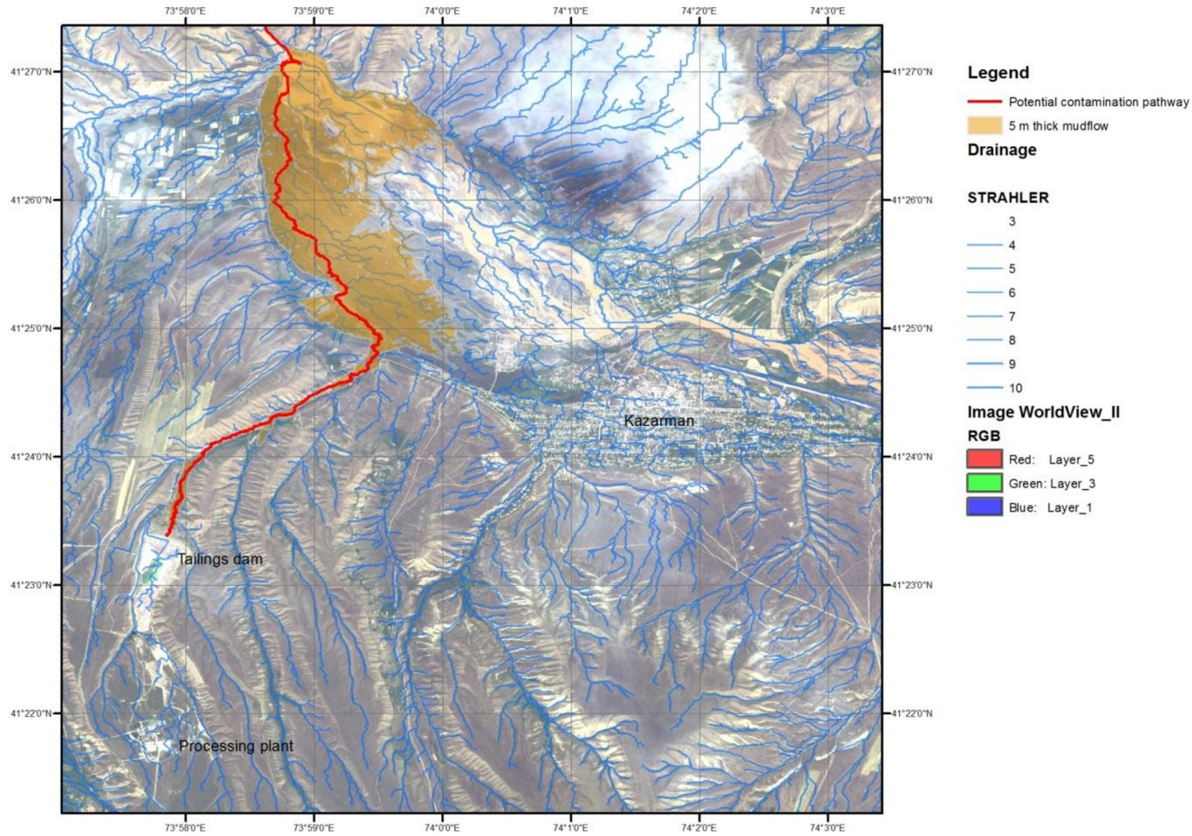
2.2.3.6.8 - Exploitation of high resolution DEMs derived from optical satellite imagery

Digital Elevation Models (DEMs) are required for several tasks like generation of orthoimages, generation of contour lines and for many geographic information system applications, including spatial risk assessment. DEM based on spaceborne systems are a cost effective alternative in comparison to more expensive airborne surveys.

Stereo satellite sensor systems, as WorldView-II take advantage of its motion over its orbit to change its viewpoint. In order to still image the same area, the satellite slightly changes its attitude (de-pointing capabilities). In a typical setup, the satellite will, slightly before overpassing the area of interest, rotate and acquire an image of the land-strip in front of him. Just after having bypassed it, it will be rotated backward and takes a second image from its new position. This de-pointing capacity is critical, hence limiting stereo-imagery to satellite being able to rotate along their track.

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 the following image, has been computed using a specifically designed flow accumulation algorithm, applied to a 1-meter resolution DEM derived from a WorldView_II satellite stereo pair. It clearly shows that the potential 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.

Tailings dam failure and associated mud flows represent a major threat in mining areas and have been responsible in the past for many casualties. 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 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 urban area might be affected by the flow. It shows however a large area of the floodplain might be affected, leading to potential grassland contamination by tailings mud.



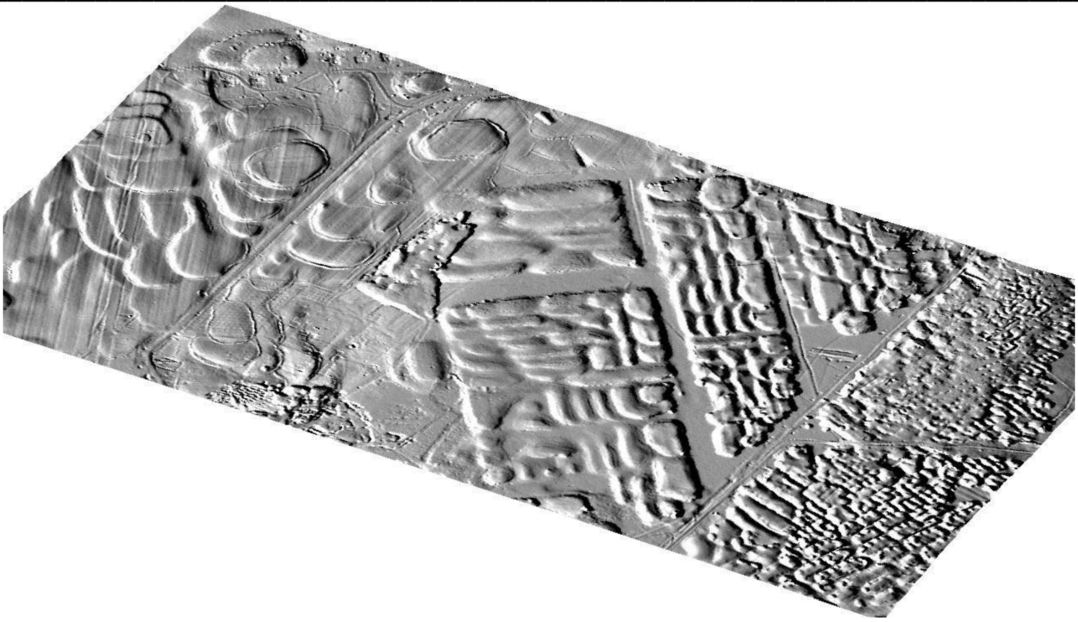
Potential surface drainage contamination (red) and maximum possible extension of a 5-m thick tailings mud flow (brown), Makmal tailings dam, Kyrgyzstan

2.2.3.6.9 - Exploitation of very-high resolution DTMs from LiDAR airborne survey

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).

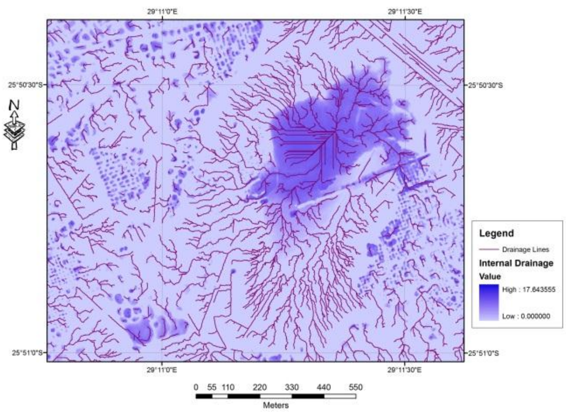
LiDAR hence is suitable for mapping terrain models, detecting subtle surface elevation differences and providing advanced topographic information.

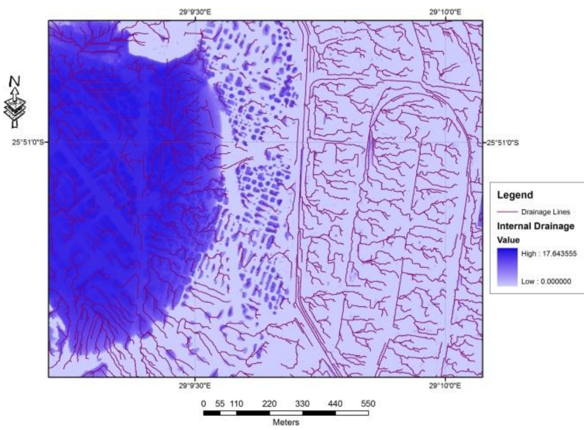
LiDAR DTMs are of particular interest in mining areas where they provide invaluable quantitative information on terrains modified by the mining activities, such as subsidence, mining-related engineering works, waste volume calculation, etc.



Surface disturbances and subsidence due to underground coal exploitation using chamber and pillar methods, Mpumalanga coal field, South Adfrica.

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.





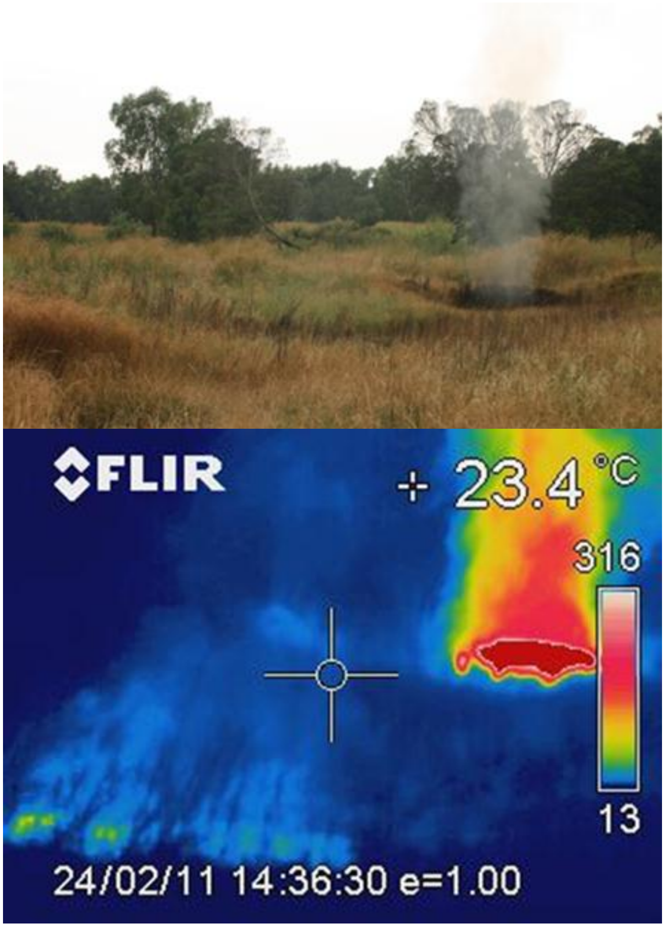
The LiDAR data collected over the eMalahleni test site have been used to derive:

- 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).

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.

2.2.3.6.10 - Mapping thermal anomalies from Thermal Infrared airborne survey

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 com-combust spontaneously once sufficient oxygen is available and natural cooling is prevented.



The rapid expansion of often insufficient controlled small-scale coal mining activities and the increasing amount of not adequate closed down and now abandoned coal mine sites are supposed to have led to an increase of human-induced coal fires.

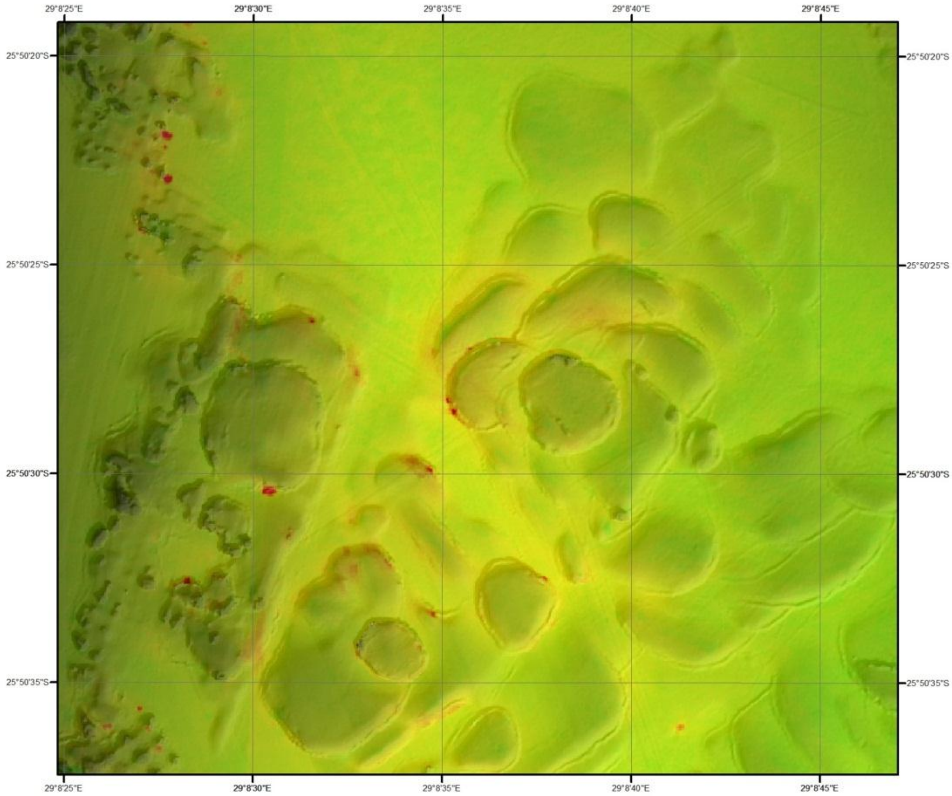
According to the National Database of Derelict and Ownerless Mines, based on the Council for Geoscience's SAMINDABA (South African Mineral Deposits Database) database, there is close to 150 coal deposits in the Mpumalanga Province which had been mined in the past, but which was no longer mined and operating mines. Thus, these coalfields need to be not only inventoried at regional and local scales through rapid and cost effective methods, but also assessed, monitored and secured, wherever appropriate.

Thermal infrared cameras can be used on ground to locate otherwise invisible and monitor coal fires, in particular regarding underground coal combustion, as well as in temperature measurements.

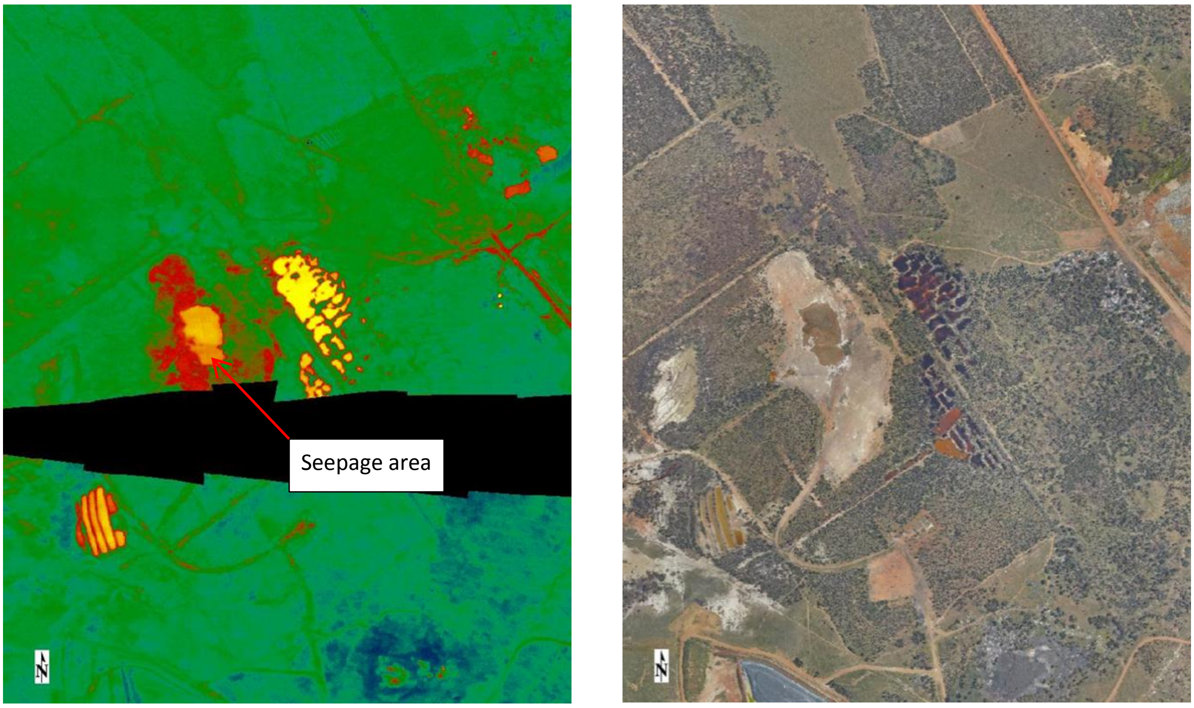
FLIR cameras mounted on board of airborne platforms have been used in identifying areas of underground combustion, and, if possible, identifying areas of contaminated groundwater flow.

Thermal airborne survey carried out over the Mpumalanga coal field has been able to identify areas of active coal combustion as well as identifying areas of mine water seepage. In the survey flown, seepage areas showed up as zones of elevated temperature, due to two factors:

- The survey was flown in the early hours of the morning, before sunrise. Under these conditions, water saturated soil will have cooled slower than dry soil due to its higher thermal inertia and heat capacity.
- In some cases, water is heated by underground coal fires, resulting in persistent higher water temperatures, the effect of which can be measured using thermal sensors



Airborne thermal image of an area affected by subterranean coal fires and subsidence, Mpumalanga coalfield. Note the correlation between hot-spots (warm colours) and areas of subsidence (from LiDAR DTM) where heat from the under-ground fires can rise to the surface.

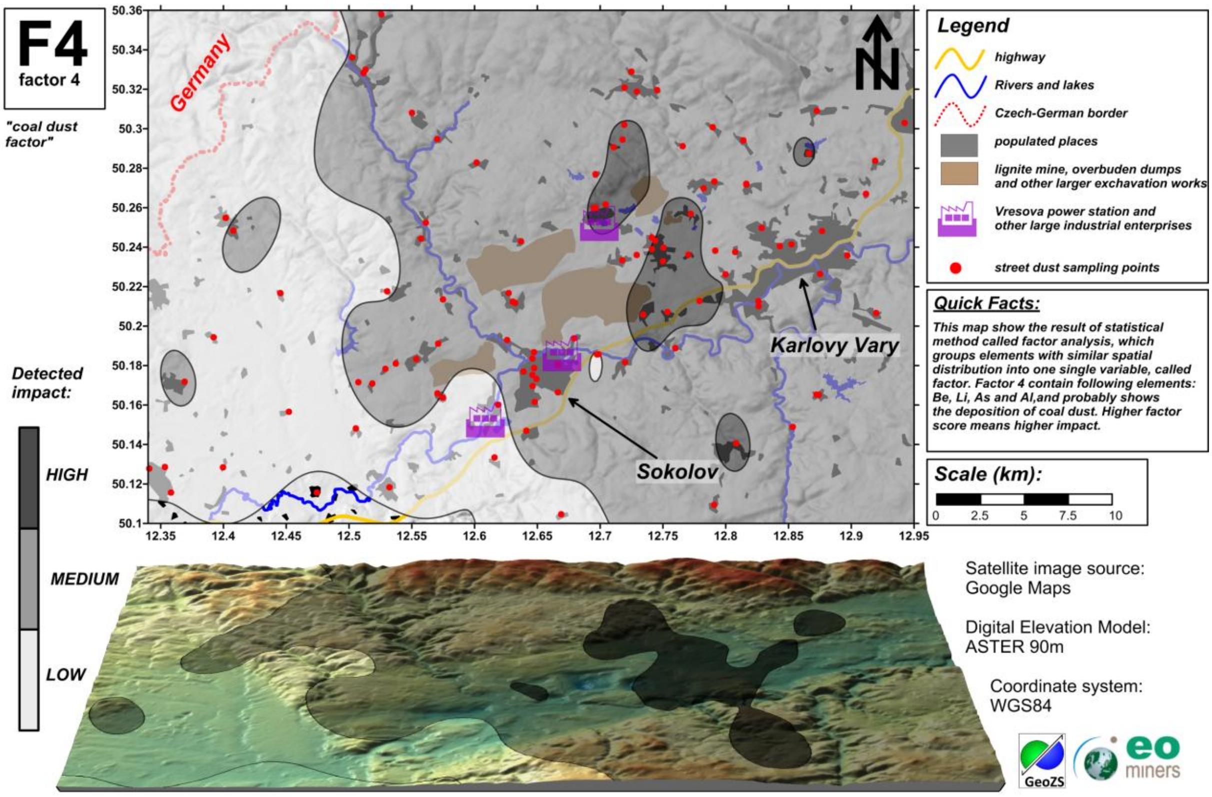


Airborne thermal image (warmer colours represent higher temperatures) (left) and aerial photograph (right) of an area affected by acid mine drainage seepage. Note the warmer temperatures associated with the surface seeps to the west of the collapsed underground mine.

2.2.3.6.11 - Analysing dust for monitoring airborne contamination

Analysing dust collected in the neighbourhood of mining activities provides information about aerial pollution plumes around mining areas.

The map below shows the result of statistical method called factor analysis, which groups elements with similar spatial distribution into one single variable, called factor. Five factors were extracted, and one of them, named factor 4, possibly reflects the amount of coal dust in the atmosphere. It joins the distribution of following elements: Be, Li, As and Al into a single variable. Higher factor score means higher impact. Such results can be useful for monitoring of impacts and for planning of measures which prevents the mobilisation of dust.



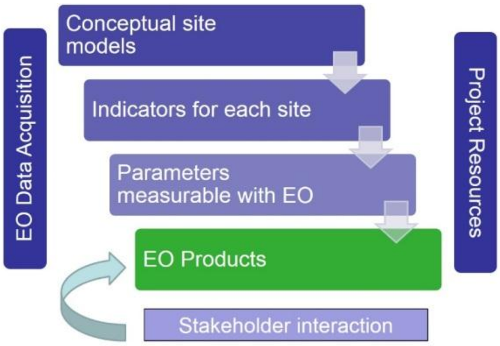
Spatial distribution of factor 4 (Be, Li, As, Al) in the Sokolov area

Deliverable D3.3 entitled "Presentation of algorithms[14]" describes the processing steps used for the different data sets, while deliverable D2.4 entitled "Thematic accuracy and validation[15]" presents the methods used to validate the thematic data and the thematic accuracy of the processing results. Deliverable D 3.4 entitled "Report on methodological developments for site footprint and risk analysis, considering possible "generic" aspects" explains possible risks and risk assessment strategies[16].

[14] Insert link
[15] Insert link
[16] Under review

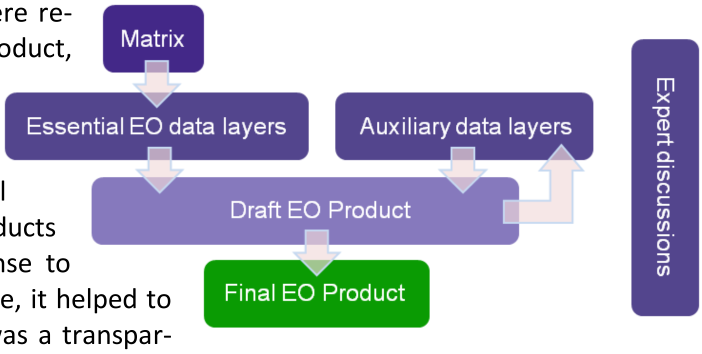
2.2.4 - From indicators and data processing to EO-based products

It was recognised that single EO datasets rarely meet a particular need for environmental or societal information in isolation, but that it is necessary to integrate several different types of measurement. This step examined how the EO datasets (from space, aircraft and in-situ) acquired and processed during the previous stages could be fused and/or integrated into one (or several) products to meet the environmental indicators identified and the environment concerns documented in the Conceptual Site Models.



It was necessary to establish a mechanism to assess the data and to consider and decide what EO-based products would be made. 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 Site Models (CSM) along with the EO data available to the EO-MINERS project.

The matrix clarified which input layers were required to make each possible EO-based product, and stipulated deadlines for data delivery, including their format and the partners responsible. The matrix 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.



It is important to note that EO-MINERS did not make a product relating to every indicator at each site. This was not possible due to limitations of resources, EO data and time within the project duration. Nevertheless, the generic approach developed (conceptual site models, indicators and the required EO data) can easily be adapted for additional indicators or time series analyses, which could not be targeted in detail during the project life time.

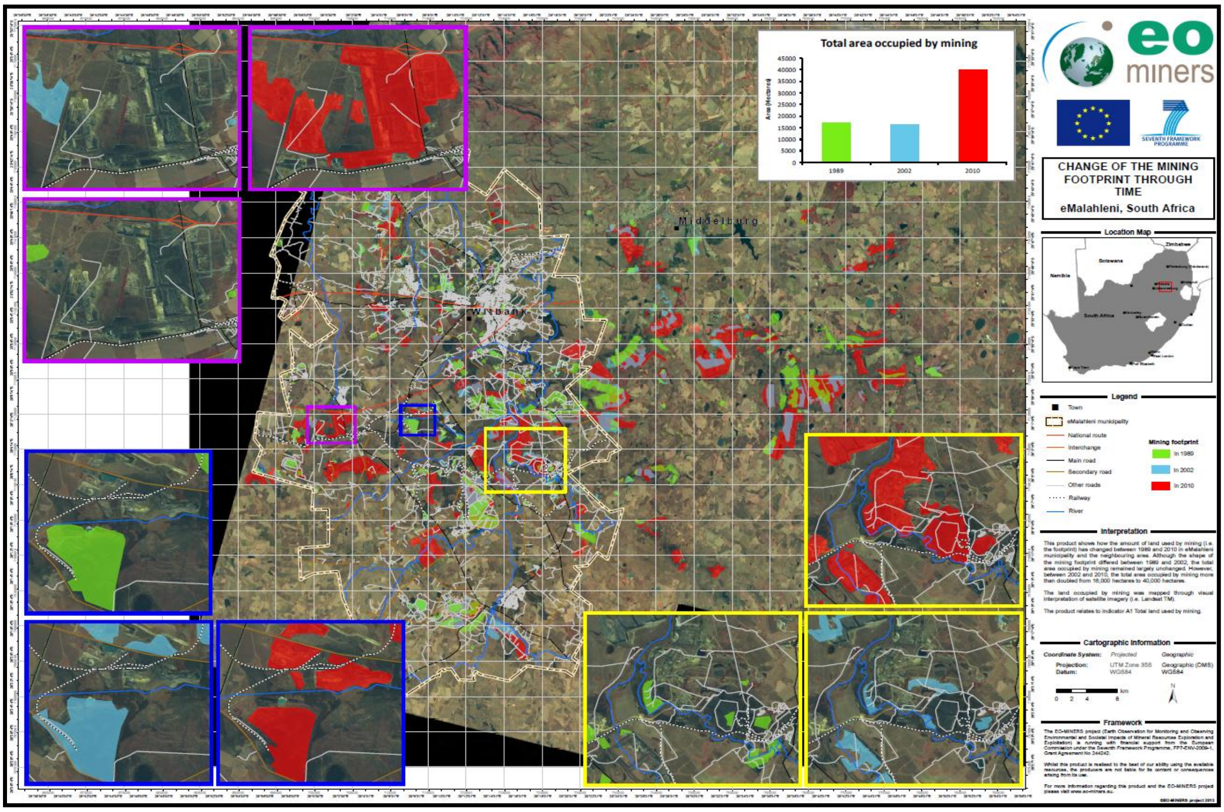
In total, 22 integrated products were developed, based around the thematic areas of land use, air quality, water quality and geohazards. Annex 4 lists all of the products and the associated Indicator, along with the primary EO datasets used to construct the product.

Initial interviews with the stakeholders highlighted that there was a wide range of expertise and understanding. Some already had experience of EO datasets and were users of GIS software while others had no experience of any EO data whatsoever. In order to make the EO-based products understandable to the wide range of stakeholders several product formats we developed. 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)
- 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 (see 3.3.1). The presentations included displays of the paper maps 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 and distributed for each demonstration site that showed the diverse EO products presented at the workshops[17].



Example of paper map product: change of the mining footprint over time, eMalahleni, South Africa

Deliverable D4.1 entitled "Earth Observation Product Review[18]" details all the approach and presents the matrix and all developed EO-based products.

2.2.5 - Modeling urban sprawling

Interpretation of medium resolution satellite (Landsat Thematic Mapper) imagery over the period 1989 – 2002 – 2010 shows a strict correlation, in eMalahleni and Middelburg municipalities, between development of mining activity and urban sprawling, without being able to understand the type of relation yet.

The activity here aimed at defining a conceptual model to simulate mining-related urban sprawl of the eMalahleni municipality, with more detailed aspects on social and economic criteria to be con-

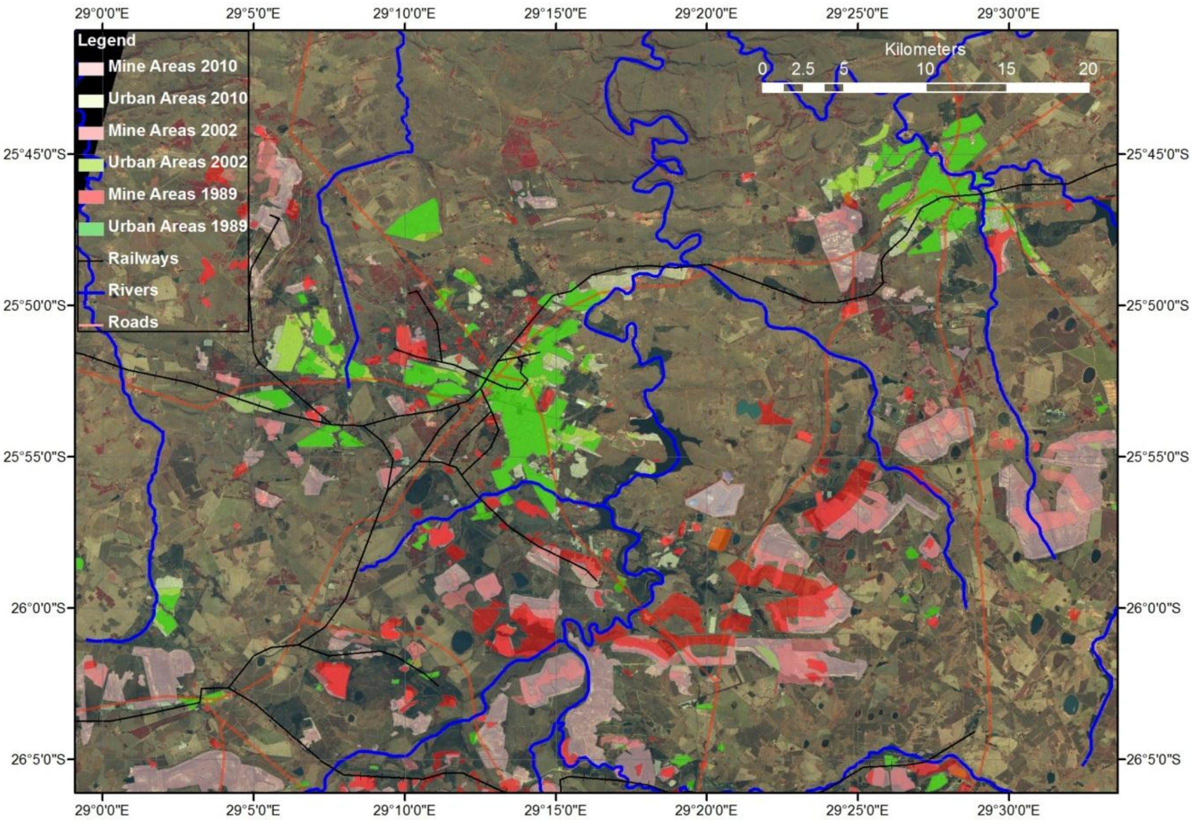
[17] http://www.eo-miners.eu/data_public/sokolov_booklet.pdf, http://www.eo-miners.eu/data_public/emalahleni_booklet.pdf, http://www.eo-miners.eu/data_public/makmal_booklet_eng.pdf

[18] insert link

sidered. The spatial dimension would have enabled taking into account demography while time series would enable the simulation of the dynamic evolution of urban sprawling.

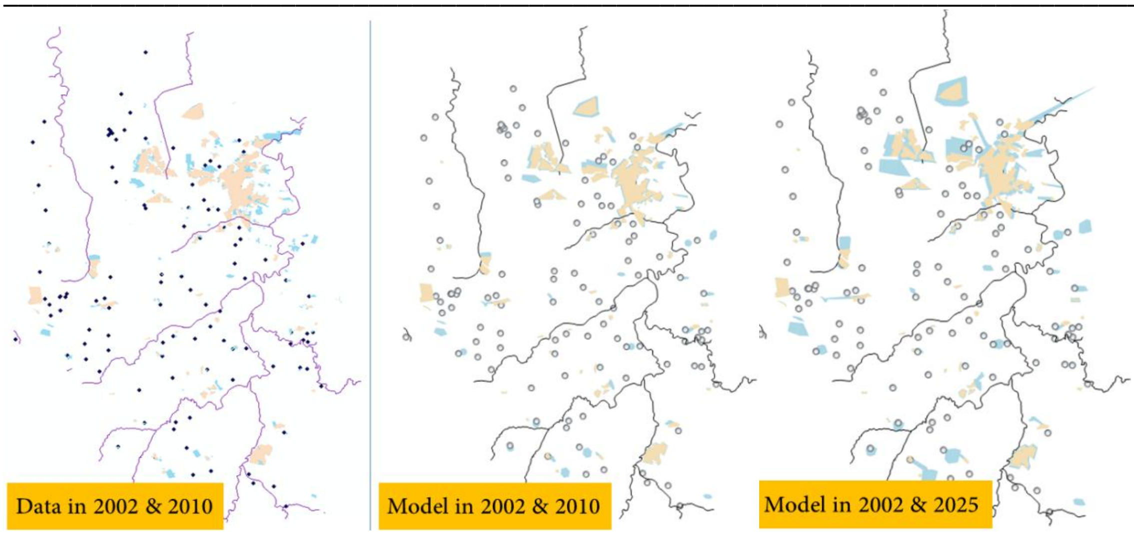
The level of detail to be considered regarding the spatial dimension has been the most pressing concern as it depends on the level of detail of the relevant data collated. Unfortunately, very few of the required data could have been made available to the project and in particular no time series of socio-economic data have been made accessible.

The work hence consisted in building a minimal model which features essential (extensions, constraints...) functionalities. The objective is thus not to present a directly operational result for experts or policymakers but rather to lead to a demonstration of the potential of the approach as well as the deriving tool in terms of simulation of this type of problem.



Mining and urban extension from 1989 to 2010, eMalahleni and Middelburg municipalities

The first step consisted in calibrating he model using 2002 and 2010 data (2002 in brown, 2010 in blue). In second step, possible urban extension was simulated for 2025 from the model.



Deliverable D4.2 entitled “mine site simulation platform[19]” describes the methodology and the results of this simulation.

2.2.6 - EO-MINERS and GEO

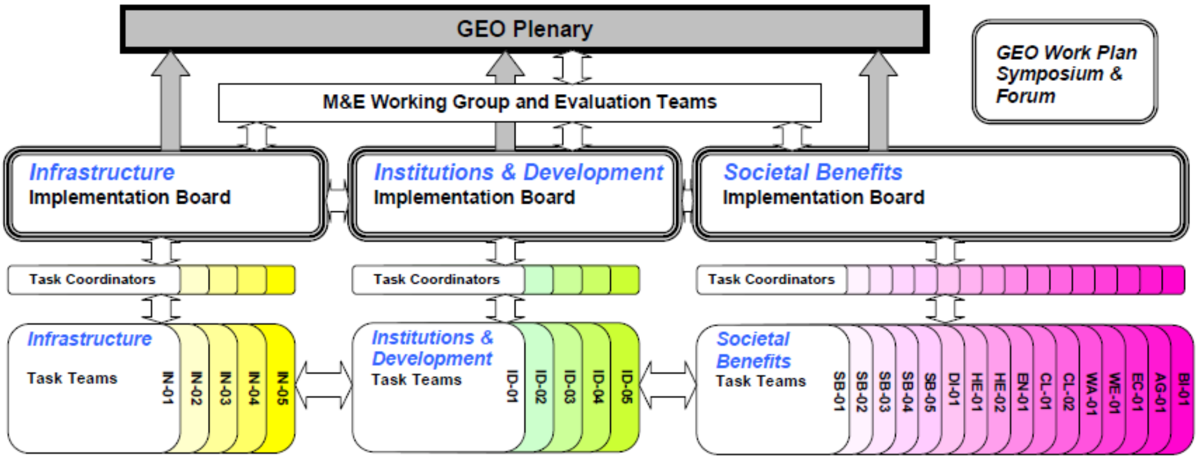
The key objective of this activity was to advocate the expansion of the GEOSS to include observation systems and applications relevant to minerals issues. During the project period, the focus was on securing the inclusion of Minerals Tasks in the next GEO Work Plan, 2012-15. To this end, text was submitted on minerals during the Work Plan review, both by EO-MINERS partners and GEO Members. The aim was to ensure that the minerals-related Task(s) already appearing in the draft Work Plan were retained and the text improved to reflect minerals issues better. This was supported by lobbying to include minerals in the Work Plan and by a series of workshops and presentations at GEO European Project Workshops, Work Plan Symposia and Plenaries, that culminated in a EuroGeoSurveys presentation during a EuroGeoSurveys side-event at the GEO Plenary VIII in Istanbul, November 2011.

The Work Plan was adopted by GEO Members and Participating Organisations at the Istanbul Plenary, November 16th - 17th 2011 and included two Tasks on minerals issues:

- SB-05 (Impact Assessment of Human Activities), Component C2 (Impact Monitoring System for Geo-Resource Exploration and Exploitation) focused on pollution and waste aspects
- EN-01 (Energy & Geo-resources Management), focused on exploration and exploitation

EO-MINERS and its Partners are noted as a contributor to both of these tasks and the coordinator has been appointed as Point of Contact for the Task SB-05-C2. The diagram below shows where these Tasks fit into the new GEO structure, both reporting to the Societal Benefits Implementation Board.

[19] Insert link



EO-MINERS maintained its high level of engagement with GEO after this significant change was achieved. As a result, it is among the 8 projects mentioned in the 4-pages GEO Fact Sheet Brochure[20] that was distributed at the GEO X Plenary and Ministerial Summit Ministers in Geneva, January 2014 and among the projects of key achievements included in the GEO "Report on Progress" 2011 - 2013[21].

Looking to the future, several partners' ongoing activity within GEO has led to them being invited to either co-chair or participate in the GEO Working Group of Coal and Environment (WGCE) that held its first meeting during the GEO X Plenary in Geneva, January 2014.

GEO aims to build a GEOSS that meets all the critical observational requirements of its societal benefit areas. Without question, this now includes minerals and related mining impacts. This leads to a new set of EO requirements being placed on GEOSS. EO-MINERS has shown what these are and this information can be used to describe the earth observing system necessary for minerals applications. Doing this is revealing as it is clear that some of the required components only exist on aircraft platforms or as part of a short-lived spaceborne experiment. EO-MINERS work on this sets out a clear agenda for GEOSS to develop in this application domain. If we are to measure and monitor minerals in the environment, a key requirement is to have continuity of spaceborne hyperspectral sensor systems.

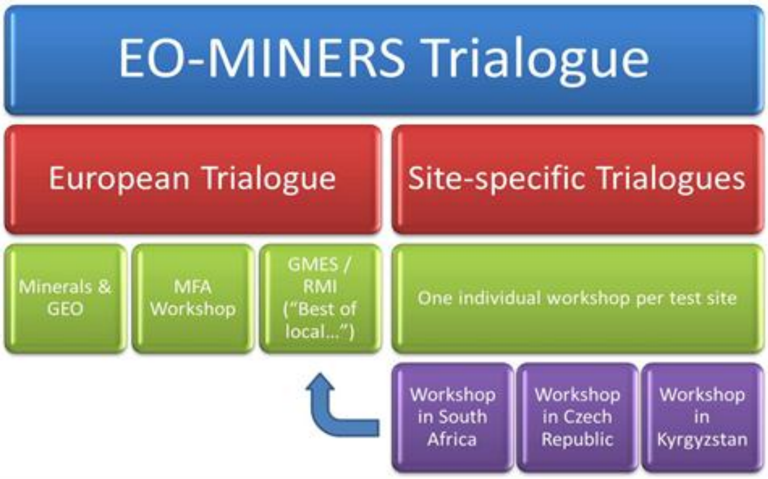
3. Potential impact and main dissemination activities and exploitation results

The third objective of EO-MINERS focuses on dissemination, promotion and capacity building actions in order to provide bodies involved and interested in impact assessment of mining activities as well as all other interested parties with the results of the project work. Further, it also concentrated on developing means for a sound "trialogue[22]" between the three main groups involved, the industry, governmental organisations and other stakeholders (e.g. NGOs). This "trialogue" intends to assist towards the reconciliation of interests in order to reach common agreement upon actions to deal with environmental and social impacts of mining activities.

[20] http://www.earthobservations.org/documents/publications/201401_GEO_Fact_Sheet.pdf
[21] http://www.earthobservations.org/documents/ministerial/geneva/MS3_GEO%20Report_on_Progress_2011_2013.pdf
[22] Definition: "An interchange and discussion of ideas among three groups having different origins, philosophies, principles, etc."

3.1 Trialogue activities

The trialogue methodology was finalised and agreed among the project partners. In principle, the trialogue dealt with any kind of stakeholder interaction activities in the sense that the outcomes of such events were considered in the conclusions of the trialogue of EO-MINERS. Therefore, the EO-MINERS trialogue comprised two parts:



a) Trialogue related to the European level ("European trialogue") , aiming at determining the way of presenting the project contribution to policy requirements, and,

b) 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.

3.1.1 Site specific trialogue

The site-specific trialogue workshops were held at:

- Sokolovska uhelna open-cast lignite mining area, Czech Republic, in March 2013, split between the mining company and general stakeholders;
- Mpumalanga coal field around eMalahleni (Witbank), South Africa, in April 2013 as a "all in one" workshop;
- Makmal gold mine, Kazarman, Kyrgyzstan with local stakeholders and mining company and, in Bishkek with national stakeholders, in June 2013.

The participants of the site-specific trialogues were provided with the results of the interviews made during the site visits and the derived site-specific indicators. Results of EO measurements (field measurements, remote sensing, etc.) were prepared for presentation as well as EO-MINERS products available at that time. The set of actions was completed with a moderated discussion to retrieve the general perception of the stakeholders and their perception of indicators, suitability of EO measurements and EO products.

All this served as input for the trialogue workshop and helped the moderator(s) to give an introduction into the problems to be tackled and to moderate the discussion. The workshop itself ran 100% in local language (simultaneously translated to English and vice versa).

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 be-

tween 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
    - The first 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. This was still not sufficient to appease some stakeholders who requested that medical practitioners should be included in order to take relevant blood or tissue samples.
    - Secondly, whilst no local stakeholder mentioned this issue, an attendee at the GEO & Minerals Workshop (Brussels, 2013) raised the issue that the project did not address the exploration phase of the mining lifecycle. This is a result of the fact that we had to replace the test site in Chile with the site in Kyrgyzstan, therefore none of our test sites were actively involved in exploration.

The positive feedback from stakeholders is clear evidence that EO-MINERS has successfully demonstrated the development and application of EO Products to the mining sector at the three test sites. In spite of the numerous EO Products developed (we produced twenty-two EO Products in a range of formats), we were unable to address every indicator, but that was expected at the outset of the project.

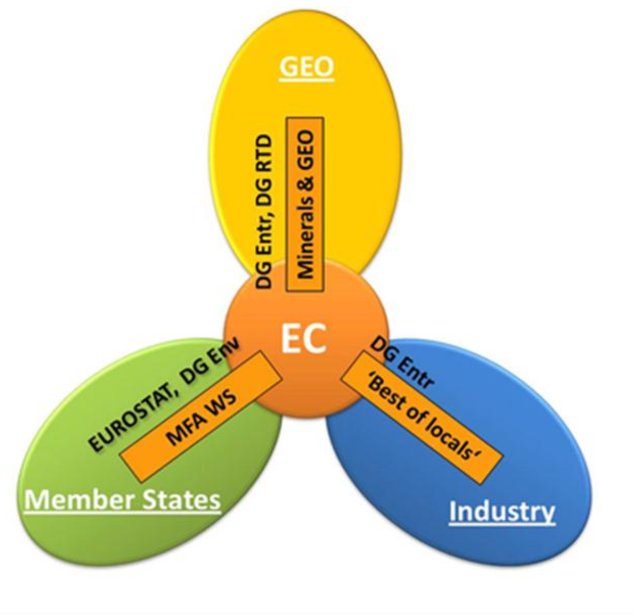
The tools and methodology developed in EO-MINERS are exportable to other sites worldwide. Furthermore, new data sources (in situ, airborne and satellite) are constantly becoming available (e.g. EO-MINERS used WorldView-2 to map AMD, and WorldView-3 will have improved spectral resolution) and these will increase even further the number of social and environmental issues (indicators) that can be monitored, as well as increasing the confidence in the measurements gained compared to those achieved currently with existing sensors. The financial cost of producing the EO-Products has not been calculated because this is a research project. Nevertheless it is expected that costs will be reduced in future with streamlined methodologies and the new range of sensors. This include the upcoming fleet of ESA's Sentinel sensor systems, whose data sets will be free of charge aiming in stimulation and supporting wider use and the development of further service elements within Copernicus and beyond.

A summary of trialogue activities and results is provided in Deliverables D5.6 (one per site[23]). Deliverable D3.5 entitled "Feedback on interaction with stakeholders and capacity building[24]" reports on feedback from stakeholders.

[23] Insert links
[24] Insert link

3.1.2 European trialogue

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).



Three trialogue activities, all combined into a meeting held on 18-19 September, 2013 in Brussels, were proposed at European level, addressing different target groups: the GEO community, the Member states and the industry:

1. The "Minerals and GEO" workshop consisted of presentations from GEO and EO-MINERS, followed by a panel discussion. It was stressed that sustainable mineral resources have risen up the agenda in Europe and internationally, and discussions focused on the following:
    - How should initiatives like GEO evolve to reflect that?
    - What kind of observing system is needed to support these changes?
    - And how can we work through initiatives like Copernicus to realise the key elements of that observing system?

2. The "Resource Flows and Economics" (MFA) workshop consisted of presentations from DG ENV, International Resource Panel and Italian Institute for Environmental Protection and Research. It was followed by a panel discussion focusing on:
    - The contribution of EO methods to the development (population) of Resource Efficiency macro/meso scale indicators - with a particular focus on mining activities
    - At which scale are the potentials highest? How could indicators benefit from EO data regarding: accuracy, timeliness, costs?
    - The applicability of EO methods to improve the current material accounting schemes, on European flows, on global material flows

3. The "EO-MINERS project" (best of locals) workshop focused on presentations about the EO-MINERS approach and product developments together with the stakeholders' feedback from the site specific trialogue workshops. The discussion centered on:
    - the potential contribution of the EO-MINERS developments to the policy requirements and policy developments,
    - their effectiveness in monitoring, meeting high environmental standards, and contributing to the improvement of public acceptance
    - their applicability at local, regional and global scales.

The people attending represented a very good mixture of the stakeholders addressed. The following key messages were obtained:

- Objective, reliable and verifiable data are key to discussion
- Results must be transformed into applicable services
- Tools must be easy to use
- Project didn't consider economical based indicators
- EO has a major role in sustainable development
- EO can have an important role when delivering data quicker than established mechanisms
- EO must have a clearly define application
- The term 'indicator' caused intensive discussion, because different groups understand the term differently

3.2 Dissemination activities

The results of the work undertaken the EO-MINERS project need to be made known to related and also other interested parties. To this effect, a wide variety of dissemination media were proposed including written, oral and visual presentations in order to inform and actively involve governmental organisations, industry and societal groups during the project as well as in its aftermath. A lot of presentations were given at related external events or conferences or at special events. The purpose was to inform the public about general project achievements. Targeted audience was the industry and their trade organisations and governmental organisations. Society organisations did participate as well but they were not the main focus due to the more technical content of the presentations. These groups were addressed by other means (see trialogue activities).

Several scientific papers have also been issued. They were published in international journals and in this way increased the dissemination of project results.

The project web site was another means of dissemination. The project web site is populated with a lot of results and other materials so that the "outside world" can have access to the EO-MINERS achievements.

The project issued a series of non-technical leaflets and a promotional video to address the general public (all downloadable at http://www.eo-miners.eu/additional_material/publicity_materials.htm).

Specifically, towards the end of project, the results of the project and its achievements and consequences are collated and presented in a book/brochure edited within the frame of the project and published using an established publishing house (Deliverable 5.5, entitled "Guide for Good Practice"[25])

3.3 Exploitation of results

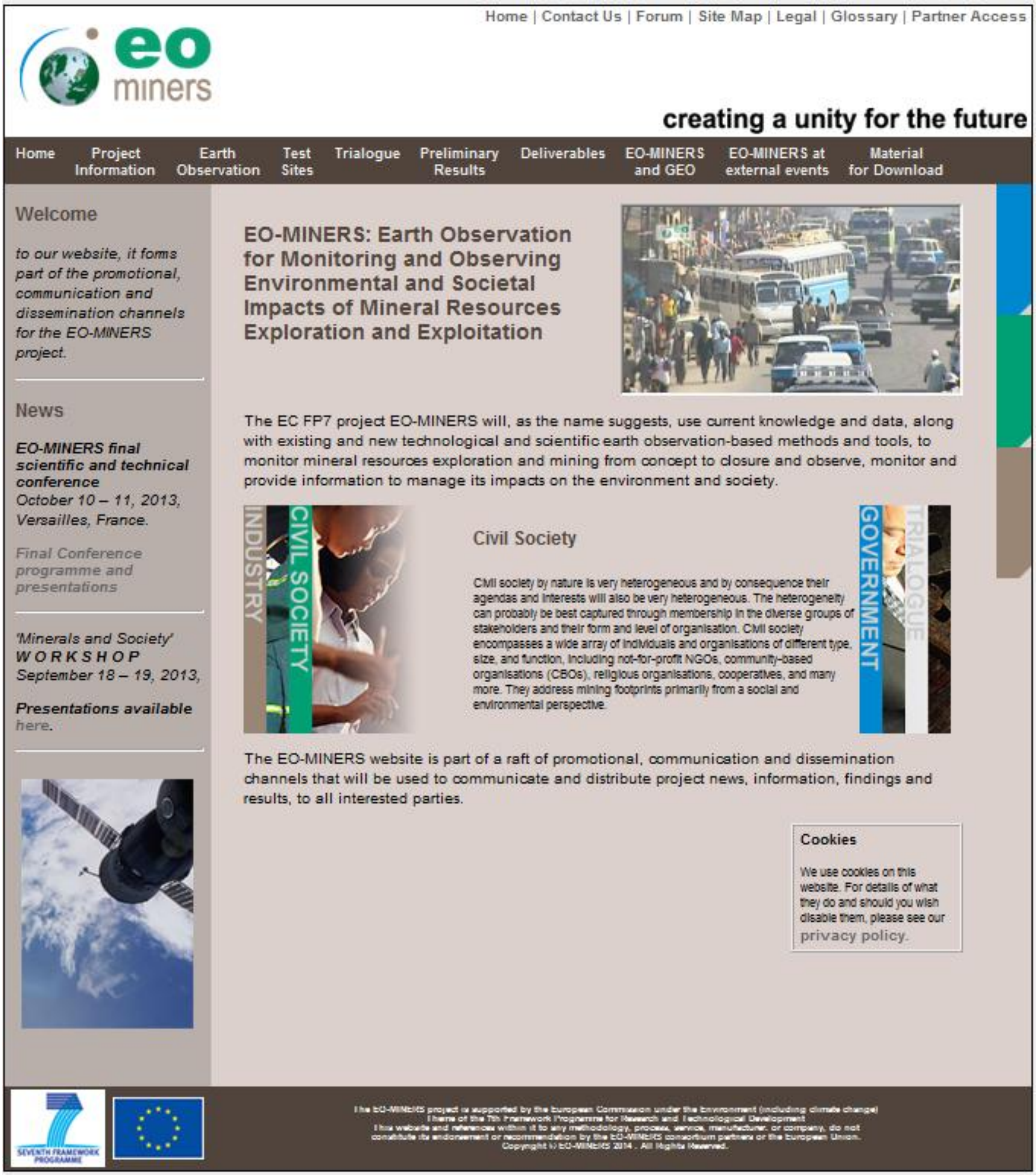
There are no protection measures foreseen. The results obtained in the project will be used in the day-to-day business of the project partners and form the basis for further development of EO products. Other organisations who view the products and results may wish to produce similar outputs for other mine sites.

[25] Insert link

Details of any IP related issue are reported in the project deliverable D5.7 entitled "Final Plan for the Use and Dissemination of Foreground[26]".

4. Address of project public website and relevant contact details

4.1 - Web site



EO-MINERS - Home page : http://www.eo-miners.eu/
Contact: webadmin@eo-miners.eu, ian.martin@miro.co.uk

[26] Insert link

4.2 - Project partners and contact details

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Česká Geologická Služba	**Czech Republic**	**Dr. Veronika Kopačková** Coordinator of the Dpt. of Remote sensing Czech Geological Survey Klárov 3 Prague 1, 118 21, Czech Republic Tel: +420 257 089 481 veronika.kopackova@seznam.cz veronika.kopackova@geology.cz
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Central Asian Institute for Applied Geoscience	**Kyrgyzstan**	
KyrgyzAltyn	**Kyrgyzstan**	**Galina Cheban**

CARROLL, A.B. (1991): The Pyramid of Corporate Social Responsability: Toward the Moral Management of Organizational Stakeholders.- Business Horizons, July-August 1991: 39-48.

CHAMARET, A. (2007): Une démarche Top-Down/Bottom-Up pour l.'évaluation en termes multicritères et multi-acteurs des projets miniers dans l.'optique du développement durable.- Doctoral thesis, Université de Versailles-Saint Quentin-en-Yvelines,

CHAMARET, A., O'CONNOR, M., RÉCOCHÉ, G. (2007): Top-Down/Bottom-Up Approach for Developing Sustainable Development Indicators for Mining: Application to the Arlit Uranium Mines (Niger).- Internat. J. Sustainable Development, **10**(1/2): ?-?, Versailles.

Annex 1: Consolidated list of indicators for the EO-MINERS project

A	Land-use
A1	***Total land-use by mining and milling*** - topographical footprint. The total area used by the mine/mill is an overarching proxy for a variety of environmental and social impacts. The assumption is that the larger the area the larger the impact.
A2	***Mining land-use intensity*** – topographical footprint vs. amount of marketable product. A time series of this indicator gives an impression of the space occupied by the mining and milling/energy conversion operation vs. the amount of end product that leaves the operation as marketable product. Changes in space intensity can point to less efficient residues management, lower quality of ore/coal, or deeper mining required.
A3	***Artisanal and Small-Scale Mining*** – topographical footprint of ASM sites. Number of operating/abandoned sites of artisanal and small-scale mining (ASM).
A4	***Residential land use*** - residential developments around mining areas. The spatial relationship between residential and mining areas could be an indicator for potential use conflicts and impacts on health and safety.
A5	***Informal settlements*** – sprawl of squatters areas, slums. Mining areas attract a variety of people and can cause the development of informal settlements in areas where there is not sufficient enforcement of zoning regulations. These suffer from poor piped water quality and in-house air pollution caused by using the bottom quality coal they collect.
A6	***Sites set aside, protected areas*** – nature reserves, wetlands, sites of spiritual value and similar. On the basis of the current land use planning/zoning regulations at the site, this indicates constraints on mine development and also indicates zones sensitive to environmental impact arising from the mine.
A7	***Surface water courses*** – percentage area covered by surface waters. Changes in surface area of lakes, rivers etc. can point to mining-induced changes in the water balance
A8	***Recultivation success on mined-out areas and waste/spoil heaps*** – designated mining areas covered by specific vegetation (grassland, forest, water bodies, ...), area returned to agricultural use. The remediation of mining and milling sites, including waste management areas (waste/spoil heaps) may include the recultivation of residues management sites with predetermined plant communities. Ground-covering vegetation is the best provision against wind erosion and an easy-to-monitor measure of recultivation efforts. Background information required: Legal provisions regarding submission of remediation plans (environmental, also employment) upfront, backed by a sufficient deposit payment to make remediation economically sensible.

A9	***Areas indirectly affected and its potential use*** - Impact of mining on the potential use of operation and surrounding areas, impact on land value / prices (opportunity cost). The type and economic value of potential alternative uses are location specific; the relevant characteristics need to be identified. Once described And validated by ground work, they can potentially be monitored by EO techniques.
A10	***Existence and legal status of environmental impact assessments*** – for the operation and the remediation phase. Related to A7, but exploring the legal basis and indicating whether a lack of regulation or a lack of enforcement is the main course in case of negative impacts
B	**Mass Flows and Energy Flows**
B1	***Waste volumes generated*** – volume (change) *vs*. amount of marketable product. This indicator is related to A1, but would require the determination of volume changes in deposited materials. Such an indicator points towards the ore-grade mined, the depths of the mine and the efficiency of the mining technique. When properly contextualised, this indicator allows comparisons between mines/mine types and the analysis of time series for a particular mine.
B2	***Erosion*** – erosional losses on residues heaps. Erosion of residues heaps can lead to the dispersion of contaminants and the degradation of agricultural soils.
B3	***Total energy consumption per ton of coal / lignite /ore produced.*** This indicator gives an impression of the energy efficiency of the operation. It is related to Indicator B1. In addition to allow intercomparison between different (types of) mines and in a time series also allows to assess efficiency gains.
B4	***Energy Return on Energy Investment (EROI).*** EROI is a measure for assessing at policy-making level, whether a mining operation for fuel materials makes sense from an energy balance point of view.
C	**Soil quality**
C1	***Contaminant concentrations.*** One or more indicator that describes toxicological or radiological contamination relevant elements or compounds. In the case of radiological contamination, this could also be gamma-fields.
C2	***Soil fertility of remediated mine areas.*** Related to A3 and A4, but assessing the potential, rather than the actual vegetation. Also focusing on agricultural plants, rather than perennial plants.
D	**Air quality and other nuisances**
D1	***Aerosols – particle concentration in off-site air.*** Aerosols, dust, in itself constitutes a nuisance or a health hazard, in particular if they contribute to high concentrations in in-house air, e.g. in worker dormitories. At the same time it can be an indicator of the quality of operational and residues management.

D2	***Volatiles*** – emission of gases from waste deposits (composition and sources). Volatiles released can be a nuisance (odour) health hazard (e.g. carcinogenic) as well as a technical risk (e.g. if combustible). In addition, they can jeopardise recultivation, e.g. methane in the soil can suffocate plants.
D3	***Air-related health impacts*** – incidence of health problems due to air-borne pollutants. Besides gaseous emissions (D2) particulate matter (partly from erosion, partly from production processes) can cause air-related health impacts; metals like Cr6 are of particular health relevance. Could become part of risk maps generated based on EO results.
D4	***Air-related soil degradation*** – soil fertility loss due to particulates deposited. Besides gaseous emissions (D2) particulate matter (partly from erosion, partly from production processes) can lead to soil quality degradation.
D5	***Noise from blasting and machinery*** - proximity and impact on settlements.
D6	***Vibrations from blasting*** - proximity and impact on settlements, damage to houses and other risks.
E	**Water quality**
E1	***Hydrological balance*** – relates the natural water balance to the use of the catchment area. Measurements of the amount of precipitation, evaporation, discharge and abstraction per catchment area, i.e. total water natural and anthropogenically induced flows in and out of the catchment area.
E2	***Process waters and contaminated surface run-off / storm water*** – volumes of waters treated/untreated/directly discharged to surface-water courses.
E3	***Aqueous contaminant releases*** – contaminant concentrations in (surface) water bodies.
E4	***Acid Drainage Generation Potential*** – distribution of sulfidic minerals. Acid drainage from mines and residue heaps can have significant impacts on water courses. The distribution of sulfidic iron-minerals indicates the potential for acid drainage generation.
E5	***Seepage from engineered structures*** – quantity and quality. Seepage, e.g. from tailings ponds, can be a vehicle for contaminant release and also an early indicator for problems with dam stability. Seepage can affect surface-water courses and ground waters.
E6	***Drinking/irrigation water availability*** – quantity and quality. Amount of clean(able) drinking and irrigation water that can be supplied in a sustainable way.
F	**Transport**
F1	***Road / rail freight volumes from/to operation sites*** – frequency and type of traffic.
F2	***Land fragmentation by transport infrastructure.*** ‚Length of infrastructure', or (better) ‚density [km/km^2]', ‚median and maximum size of not fragmented patches', and ‚distance to next undisturbed site' measure the dominant pressure an operation enacts on biodiversity and other aspects of the environment.

F3	***Local air, noise and accident impacts from transport.*** Impacts from transport outside the operational area (see also D)
F4	***Transport infrastructure quality.*** Heavy mine traffic may use public roads and add to their degradation without adequate compensation.
F5	***Accessibility due to mine-related transport infrastructure.*** Mining companies may build transport infrastructure that also can be used by the local population, thus improving access.
G	**Geotechnical hazards and accidents**
G1	***Grade of slopes*** – steepness of engineered slopes *vs*. height. A too steep slope of residues heaps or dams can indicate potential geotechnical risks of failure. The indicator can be used for initial assessment and problem scoping, but will have to be related to the materials properties determined on the ground for a more detailed assessment.
G2	***Ground stability*** – changes in the elevation of areas unaffected by residue disposal. Subsidence, pothole formation and other ground movement indicate inadequate underground mining techniques when exceeding certain rates of change. Sudden major losses of recultivation area indicate planning and/or management mistakes (not taking into account extreme events).
G3	***Dam stability*** – water saturation in retaining dams. As was demonstrated recently in Hungary, failing retaining dams of tailings ponds can have a significant environmental impact and threaten life and property. Water saturation, leading to subrosion and piping can be an early indicator for impeding disaster.
G4	***Underground and mining waste deposit fires*** – number, duration and area affected. Underground fires of coal seams or bituminous materials, and mining waste fires can be caused by natural processes or be the result of (mining) accidents. They mean loss of natural resources, but also CO_2 emissions and nuisance due to smoke.
G5	***Flooding risks*** – area that may be exposed to flooding. Mapping of areas that could be under threat from flooding due to breaking retaining dams of tailings ponds etc.
H	**Industrial and other accidents**
H1	***Accidents in the mining / milling operation.*** Working days lost and other societal costs due to workplace accidents
H2	***Accidents in the operation environment (transport, construction etc.).*** Working days lost and other societal costs due to workplace accidents

Annex 2: Indicators for each of the demonstration sites

Site	Indicator
eMalahleni (Witbank), South Africa	A Land use A1 - Total land use by mining and milling; A3 - Artisanal and small-scale mining; A4 - Residential land use; A6 - Sites set aside, protected areas; B Mass flows B1 - Waste volumes generated; D Air quality and other nuisances D1- Aerosols; E Water quality E4 - Acid drainage potential; E5 - Seepage from engineered structures; F Transport F2- Land fragmentation by transport infrastructure; G Geotechnical hazards and accidents G1 - Grade of slopes; G2 - Ground stability – small and large scale subsidence; G4 - Underground fires.
Sokolov, Czech Republic	A Land use A1 - Total land use by mining and milling - topographical footprint; A2 - Mining and Land use intensity - topographical footprint versus amount of marketable product; A4 - Residential land use – residential developments around mining areas; A6 - Sites set aside, protected areas – nature reserves, wetlands, sites of spiritual value and similar ones; A8 - Recultivation success on mined-out areas and waste/spoil heaps – designated mining areas covered by specific vegetation; A9 - Areas indirectly affected and its potential use – impact of mining on the potential use of operation and surrounding areas, impact on land value/prices; A10 - Soil fertility of remediated mine areas; B Mass Flow B1 - Waste volumes generated; D Air Quality and other nuisances D1 - Aerosols – particle concentration in off-site air; E Water quality E4 - Acid Drainage Potential – distribution of sulfidic iron-minerals; E5 - Seepage from engineered structures; G Geotechnical hazards and accidents G2 - Ground stability – small and large scale subsidence; G3 - Dam stability – water saturation in retaining dams.
Makmal (Kazarman), Kyrgyzstan	E Water quality E3 - Aqueous contaminant releases E5 - Seepage from engineered structures G Geotechnical hazards and accidents G3 - Dam stability The advanced, final shortlist of indicators was determined at the expert meeting in Ljubljana, July 2012 (after KG2); it is the final shortlist generated before the KG trialogue workshop: A Land-use A1 - Total land use by mining and milling; D Air quality and other nuisances D1 - Aerosols; D2 - Volatiles; D3 - Air-related health impacts; E Water quality E1 - Hydrological balance; E2 - Process waters and contaminated surface run-off/storm water; E3 - Aqueous contaminant releases; E5 - Seepage from engineered structures; E6 - Drinking/irrigation water availability; G Geotechnical hazard and accidents G3 - Dam stability; I Social impacts I5 - Health-care and welfare infrastructure provided by mining companies.

Annex 3: EO data acquired during the project

site	Satellite	Airborne	In situ	Data type	Date of acquisition
SOKOLOV		**Hyperspectral survey**		**HyMap sensor VNIR, SWIR 1, SWIR 2**	**July 2009**
		Hyperspectral survey		**HyMap sensor VNIR, SWIR 1, SWIR 2**	**August 2010**
		Hyperspectral survey		**AHS sensor VNIR, SWIR 1, SWIR 2, MWIR, LWIR (TIR)**	**July 2011**
		Aerial photography		Orthophoto mosaic, DEM	2005
			Field spectroradiometry	**ASD FieldSpec 3 spectrometer, VNIR, SWIR 1, SWIR2**	**2008-2012**
			Field spectroradiometry	**µFTIR spectrometer, TIR**	**2011**
			Surface material sampling	**Trace elements, heavy metals, XRD analysis, pH, sulfur, total organic carbon (TOC)**	**2011**
			Water sampling	**pH, dissolved organic matter, conductivity, suspended matter**	**2011, 2012**
			Dust sampling	**Analysed with ICP - MS**	**2011**
			Soil profiling	**Trace elements and heavy metals, carbon, sulphur, pH**	**2010**
			Vegetation sampling	**Leaf pigments, water content, heavy metals, trace elements**	**2009-2011**
			Temperature	**FLIR camera**	**2011**
			Soil moisture		**2011**
	ASTER			VNIR, SWIR, TIR	2005, 2008
				DEM	
	Various GIS layers from different data sources				
Witbank					
	Landsat TM			Mulitispectral	Time series 1989 - 2010
	SPOT 5			Multispectral VNIR, 2.5 m	
	WorldView_2			**Panchromatic 0.50 m, multispectral VNIR 2 m DEM**	**December 2011**
		LIDAR survey		**Optech Orion**	**November 2012**

				M200 ALTM DEM, DTM	
		Hyperspectral survey		**AISA Dual, VNIR, SIR1, SWIR2**	**August 2012**
		Multispectral imagery		**Rollei AIC Ortho-photomosaic at 15 cm resolution**	**November 2012**
		Thermal imagery		**FLIR P640 and SC660, 2 m resolu-tion**	**Nov-Dez 2011**
			Field spectroradi-ometry	**ASD FieldSpec 3 spectrometer, VNIR, SWIR 1, SWIR2**	**2010 - 2012**
			Temperature measurements	**Raytek Rayngar MX**	**February 2011, November 2012**
			Soil moisture	**Handheld sensor**	**November 2011**
			Electrical resistivi-ty tomography	**Syscal Pro Switch 72**	**September 2010 and September 2013**
			XRF	**Niton XRF**	**February 2011 and November 2011**
			Chlorophyll con-tent	**SPAD-502**	**February 2011**
			Temperature measurements	**FLIR ThermaCAM E45 handheld camera**	**February 2011**
			Dust sampling	**Analysed with ICP - MS**	**February 2011**
	Various GIS layers from different data sources				
Makmal					
	Landsat TM			Multispectral	Achieved data 2012
	SPOT 5			Multispectral VNIR	Achieved data 2012
	WorldView-2			**Panchromatic 0.50 m, multispectral VNIR 2 m DEM**	**2011**
			Groundwater level		**2012 - 2013**
			DGPS measure-ments		**2012-2013**
			Water and soils sampling	**Cyanide analyses**	**2013**
			Radioactivity measurements		**2012**
	Various GIS layers from different data sources, including : Maps and reports from the State Agency on Geology and Mineral Resources, Maps from the State Registration Service, Data from Kyrgyz Head Institute of Engineering Surveys, Reports from the Chui Ecological Laboratory, Meteorological data on Kazarman station, Technical data on the tailing pit from the state registry of tailing pits, etc.				

Annex 4: EO-based products and associated data for the demonstration sites

eMalahleni (Witbank), South Africa

	Product Title	Related Environmental & Societal Issue (Indicator)	Primary EO Datasets
1	Change of the mining footprint through time	**Land Use: A1** – Total land use by mining and milling	- Multi-temporal Landsat TM satellite imagery
2	Residential land use around mining areas	**Land Use: A4** – Residential land use (residential developments around mining areas) **Land Use: A5** – Informal settlement (sprawl of squatters areas, slums)	- Multi-temporal Landsat TM satellite imagery - Multi-temporal SPOT satellite imagery - Census data showing extent of residential developments
3	Urban footprint	**Land Use: A4** – Residential land use (residential developments around mining areas) **Land Use: A5** – Informal settlement (sprawl of squatters areas, slums)	- TerraSAR-X Radar satellite data - SPOT satellite imagery
4	Mining and areas of ecological importance	**Land Use: A6** – Site set aside, protected areas (nature reserves, wetlands, sites of spiritual value and similar)	- Landsat TM satellite imagery - GIS of habitat classes
5	i) Distribution map of antimony (Sb) dust contamination ii) Distribution map of chromium (Cr) dust contamination iii) Distribution map of vanadium (V) dust contamination iv) Distribution map of barium (Ba) dust contamination	**Air Quality and other Nuisances: D1** – Aerosols (particle concentration in off-site air)	- Multi-elemental dust analyses - SPOT satellite imagery - GIS of industrial sites
6	Acid mine drainage contamination potential	**Water Quality: E4** – Acid drainage generation potential (distribution of sulphidic iron minerals)	- WorldView-II satellite imagery - WorldView-II DEM - Drainage network derived from WorldView-II DEM - Potential contamination pathway derived from WorldView-II DEM
7	Density of road per km^2	**Transport: F2** – Land fragmentation by transport infrastructure	- SPOT satellite imagery - GIS of industrial sites
8	Geotechnical hazards and ground stability	**Geotechnical Hazards and Accidents: G2** – Ground stability (changes in elevation of areas unaffected by residue disposal)	- Airborne LiDAR DEM - Aerial photographs - WorldView-II satellite imagery - Airborne LiDAR-derived slope map

9	Geotechnical hazards: mining-related fires	**Geotechnical Hazards and Accidents: G4** – Underground and mining waste deposit fires	- Airborne thermal infrared imagery - Airborne LiDAR DEM - Aerial photographs

Sokolov, Czech Republic

	Product Title	Related Indicator	Primary EO Datasets
1	Dust pollution and vegetation health	**Air Quality and other Nuisances: D1** – Aerosols (particle concentration in off-site air)	- HyMap airborne hyperspectral imagery - Vegetation health index derived from airborne hyperspectral imagery - Multi-elemental dust analyses - Landsat TM satellite imagery - Photogrammetric DEM
2	Spatial distribution of iron oxides possibly associated with acid mine drainage	**Water Quality: E4** – Acid drainage potential (distribution of sulfidic iron-minerals)	- Multi-temporal HyMap airborne hyperspectral imagery - AHS airborne thermal imagery - Photogrammetric DEM - Drainage network derived from photogrammetric DEM
3	Soil composition and acid mine drainage-producing minerals		- HyMap airborne hyperspectral imagery - AHS airborne thermal infrared imagery - Photogrammetric DEM
4	An example of acid mine drainage contamination potential		- HyMap airborne hyperspectral imagery - Photogrammetric DEM - Potential contamination pathway derived from photogrammetric DEM
5	Acid mine drainage-producing minerals and water quality		- HyMap airborne hyperspectral imagery - AHS airborne thermal imagery - Photogrammetric DEM - Drainage network derived from photogrammetric DEM

Makmal, Kyrgyzstan

	Product Title	Related Indicator	Primary EO Datasets
1	Change of the mining footprint through time	**Land Use: A1** – Total land use by mining and milling	- Multi-temporal Landsat TM satellite imagery - WorldView-II satellite imagery - WorldView-II DEM - SRTM DEM
2	Air and surface water contamination potential	**Water Quality: E2** – Process waters and contaminated surface run-off / storm water	- Multi-elemental analyses of topsoil, tailings, alluvial sediment and dust - WorldView-II satellite imagery - WorldView-II DEM - SRTM DEM - Drainage network derived from WorldView-II DEM
3	Soil and surface water contamination potential		- WorldView-II satellite imagery - Measurements of cyanide content in soil samples - GIS of land-use/land cover - WorldView-II DEM - Drainage network derived from WorldView-II DEM - GIS of spring locations
4	Cyanide concentration in water bodies	**Water Quality: E3** – aqueous contaminant releases, contaminant concentrations in (surface) water bodies **Water Quality: E5** – Seepage from engineered structures (quantity and quality)	- WorldView-II satellite imagery - Measurements of cyanide concentration in water samples - WorldView-II DEM - Drainage network derived from WorldView-II DEM - GIS of spring locations
5	Tailings dam stability	**Geotechnical hazards and accidents: G3** – Dam stability (water saturation in retaining dams)	- WorldView-II satellite imagery - WorldView-II DEM - Drainage network derived from WorldView-II DEM - Potential contamination pathway derived from WorldView-II DEM - Mud flow model computed using WorldView-II DEM - Landslide risk map - Seismic risk map

6	Radioactivity	Radioactive contamination	- WorldView-II satellite imagery - In-situ radioactivity measurements - Measurements of the thorium content in topsoil, tailings, alluvial sediment and dust samples - WorldView-II DEM
7	Cadastral information	Cadastral collection of data for Kazarman	- A selection of relevant datasets to provide a summary of the different types of EO data available to the project