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IMPACT MONITORING
OF MINERAL RESOURCES
EXPLOITATION

CONTRACT Nº
2 4 4 1 6 6

Funded by:
European Commission
Framework Programme 7

Cooperation

Thematic Area
Environment 6.4
Earth Observation and assessment tools for sustainable development

WP6 – TOOLS AND SERVICES

DELIVERABLE D.6.1
COMPENDIUM OF METHODS AND TOOLS FOR MONITORING THE ENVIRONMENTAL IMPACTS FROM MINING AND MINERAL EXPLOITATION ACTIVITIES

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SEVENTH FRAMEWORK PROGRAMME

Abstract

This booklet type of document will highlight the bases of how the ImpactMin consortium started to conceptualize and construct the Project's approach towards the appropriate use of available tools and methods for environmental impacts monitoring of mining activates. The aforementioned process was complex (more Work Package activities were involved) and has various items to show. Illustrative examples are given here from the project case studies.

From the beginning of the ImpactMin Project the main goal was to assess and conclude the technical possibilities of Earth Observation in order to fit for the purpose of environmental impact monitoring of mineral resources exploitation. The work was started with reviewing a broad range of documents that contained previous experiences and results of studies dealing with remote sensing techniques suited for environmental monitoring. Tailoring the methods and tools that exist in literature the Consortium here focused on certain techniques that are applicable, based on the requirements of the Project's demonstration sites.

The four main study sites of the ImpactMin project allowed different tools to be used; however some of them were applied at several demo sites. The limitations at sites were for instance the scale of the phenomena that the ImpactMin consortium recognized on the first place e.g.: Vihovici mine – couple of square km, Karabash smelter "effected" zone – couple of tens of square km. Altogether, the project's demonstration sites offered a unique mix of mining activity impacted environments e.g. difference in scale, impacted environment etc.

The carefully chosen project sites enabled the consortium to test different satellite and airborne sensors and also allow comprehensive and complementing studies to be performed (e.g. ground versus satellite based observations and integration of assessment methods). The identified tools allow several investigation types such as multi-temporal analysis or base-line studies that focus on covering the demonstration areas with continuous datasets boosting the advanced spatial data analysis techniques (data integration).

This document on the compendium of tools and methods for the monitoring of environment impacts from mineral exploitation activities builds on the outcomes of the end-user needs assessment and monitoring activities, WP4 - Satellite based EO and WP5 - Airborne based EO. Also the outcomes of the on-going WP6 and WP 7 are included at the respective places throughout the document. Necessarily, in-situ techniques are listed here too based on field work experiences. The latter two work packages are mainly contributing with field based observation results and real life case studies that are conducted during the course of the ImpactMin project. No direct references made here for previous studies since they were already cited in previous project documents.

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1. WP4-5 findings

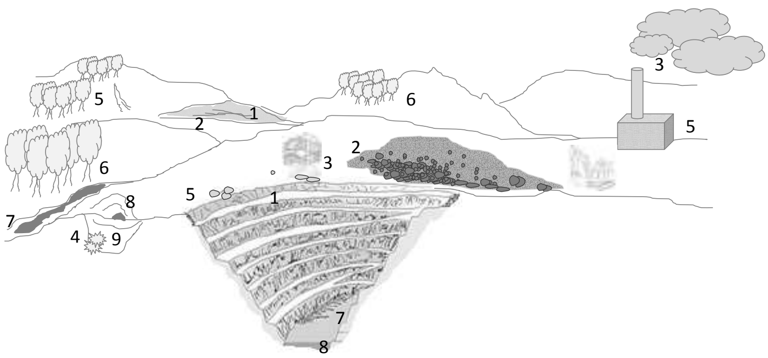
1.1 Relevant environmental variables and remote detection methods

Sensors for monitoring of mining impacts

The use of optical, (multi/hyperspectral, visible, near Infrared, shortwave infrared, thermal infrared), radar and geophysical data for direct measurement of environmental variables associated with mineral mining were thoroughly evaluated. An in depth overview of each sensor, its limitations, advantages and disadvantages is available in the respective project documents downloadable from the project website. The base for the identified tools was literature studies in order to get a good overview on previous use of the different sensors for environmental impact monitoring of mining. We have to note that mainly academic and research studies were used for those compilations.

The extensive literature studies carried out by several partners resulted in the identification of a number of environmental variables, soil and surface variables, associated with mineral mining activities that may be detected with satellite earth observation data. Those variables are directly linked to impacts and effects on natural resources and on the components of functioning ecosystems. The variables were separated into direct and indirect variables. The defined direct variables are related to predictable effects of mineral mining operations, trivial links like emission to air affects vegetation. Indirect variables are caused by mineral mining operations, but occur later in time or farther removed in distance. Indirect variables may include cumulative effects related to induced changes in the pattern of land use and related effects on soil, air and water and other natural systems.

Environmental variables and observables



The above illustration shows a number of mining related activities that have immediate or indirect link to ecosystem alteration. One of the very obvious effects that land-use or land-cover changes around mining sites. In later section we will see examples that remote sensing techniques are excellent tools to detect and monitor several changes that are in question. Some of the observable environment variables require very sophisticated instrumentation for instance airborne geophysical measurements. Other environmental indicators (e.g. vegetation stress) can be detected with relatively well established methods like the production of spectral vegetation indices. Nonetheless, we have to note that the upcoming sensors and platforms that can improve the quality and efficiency of the ground and airborne measurements keeps the research community moving to test and implement novel techniques and data integration procedures.

Classification of satellite and airborne assets

Primarily, the potential of optical imagery to map and monitor environmental parameters clearly depends on the presence of spectral characteristics of the materials that are wished to be monitored (such as quality of air, vegetation, soil and water).

Within those limitations, the sensor parameters that determine the applicability of remote sensing assets for environmental monitoring of mining impact are:

- the spatial and spectral resolution of the sensor,
- the temporal resolution of image acquisition,
- the length of the time series, and
- the cost of image acquisition.

It is widely known that there is a clear tradeoff between the spatial resolution and the cost of image acquisition (i.e. high spatial resolution imagery in general have a higher cost). Also in general, the higher spatial resolution imagery archives cover a shorter time-span than that lower resolution ones because they were developed later in time by the commercial satellite asset procedures entering the market.

The newest and planned satellite sensors constantly open up a wide range of opportunities for innovative research, because they combine both a good spatial resolution and a larger number of spectral bands (e.g.WorldView-2, launched in 2010, WordView-3, to be launched in 2014, and PRISMA – Italy, HyspIRI – NASA and EnMAP – Germany, to be launched in 2013, 2013 and 2015 respectively). At this moment, there are two hyperspectral satellite sensors in operation: Hyperion and CHRIS. For ImpactMin project purposes one of the most promising sensors is the Worldview-2 sensor, which combines both a good spatial resolution with a relatively high spectral resolution (8 VNIR bands vs 4 for other satellites with similar spatial resolution, as well as a 40 cm resolution panchromatic band). Also Landsat’s great imagery archive proves to be of great use for the larger project test sites.

The applicability of a certain sensors for monitoring direct or indirect variables related with the environmental impact of mineral mining was reviewed and assessed based on published results in scientific literature, both related directly to mineral mining and to other fields of science. The table on the next page compares the properties and applicability of satellite sensors in this respect.

ImpactMin classification of satellite sensors suited for project objectives (WP4):

	Optical sensors																				**Thermal sensors**	**Radar sensors**
	IKONOS	RapidEye	SPOT HRV	QuickBird	GeoEye-1	Worldview-2	Landsat 1-3	Landsat 4-5,7	ALI	ASTER	Hyperion	CHRIS	*PRISMA*	*HyspIRI*	*EnMAP*	MODIS	Spot-VGT	MERIS	SEVIRI	NOAA-AVHRR		
Sensor parameters																						
Spatial resolution	***	***	***	***	***	***	**	**	**	**	**	**	**	**	**	*	*	*	*	*		
Spectral resolution	*	*	*(*)	*	*	**	**	**	**	**	***	***	***	***	***	***	*	***	***	*		
Temporal resolution	**	**?	*	**	**	**	*	*	*	*	*	**	*?	*	**	**	**	**	***	***		
Length of time series	*	*	*	*	*	*	**	**	***	***	**	*				***	***	***	***	***		
Cost of acquisition	*	*	*	*	*	*	***	***	***	**	*					***	***	***	***	***		
Applicability																						
Direct variables																						
Minerals			(*)			*		*	*	**	*	**	**	**	**							
Acid mine drainage and ferruginous materials	*	*	*	*	*	***		*	*	**	*	*		**	**							
Atmospheric pollution and windblown particles	*	*	*	*	*	**	*	**	**	**	*	*		**	**							
Temperature increment due to (underground) coal fires								**		**				**							*	
Indirect variables																						
Land use and land cover change	***	**	***	***	***	***	**	**	**	**	**	**	**	**	**		*			*		
Vegetation stress	*	*	*	*	*	**	*	*	*	**	**	**	**	**	**		*			*		
Contaminated surface waters: sediment load and metal contamination	*	*	*	*	*	**	*	*	*	**	*	*	**	**	**							
Changes in soil moisture and groundwater environment	*	*	*	*	**	*	*	*	**	*	*	*	*	*	*	*	*	*	*	*	**	**
Subsidence										*												**

2. Ground segment, in-situ monitoring

The ground based measurements and observation techniques weren't collected in a single document for comparison and for a comprehensive study by ImpactMin project. In this section we will have an overview of these instruments and their applicability.

Measurement	Instrument
Canopy reflectance	Portable spectroradiometer
Leaf reflectance	Portable spectrometer, Leaf probe
Chlorophyll	CCM/SPAD
Absorption CHL	Spectrophotometer, vortex, centrifuge, lab material
Absorption heavy metals	Spectrophotometer, hydrochloric acid, lab material
Soil under vegetation	XRD
Heavy metal concentration in soil under vegetation	XRF
Taking pictures	Photographic camera
Identification of plant species by biologists/ecologists	Visual

Lichen biomonitoring
Particularly sensitive in determining metal-rich particulate emission is the use of lichen transplants. Particulates on the lichen surfaces are analyzed by scanning electron microscopy with energy-dispersive X-ray analysis (SEM-EDX). The elemental compositions of the lichen transplants, as well as dusts, tailings, road dusts, metallurgical slags and top soils, can be determined by quadrupole inductively coupled plasma mass spectrometry (ICP-MS).

Lichen transplants can show a decrease in metal concentrations away from the pollution source following 2 and 3 month exposure periods. Multi-element least-squares modeling can be carried out to determine the relative contribution of particles from different potential sources (smelter, tailings etc.) to the compositions of the lichen planted in the investigated area. Particulate, with relatively high Zn, As and Pb, can be biomonitored with lichen transplant.

X-ray diffraction
Samples of fine granular material can be collected from the weathering surfaces of the exposed rocks, iron-rich precipitates occurring along the streams, tailings deposits. Several samples should be collected at the same points where vegetation stress is determined, in order to test whether a correlation exists between the mineral matrix and the vegetation health. The X-ray polycrystalline diffraction technique (XRD) is used in order to define the mineralogical composition of the concerned materials. The sample is grinded down to a diameter of 0.002 to 0.005 mm, and homogenized, as the crystals should be randomly distributed. The obtained

material is pressed into a sample holder which is placed in the goniometer of the x-ray diffractometer. The obtained spectra are processed and interpreted by using specific software.

X-ray fluorescence

A handheld X-ray fluorescence spectrometer (XRF) can be used that is suited for preliminary site investigations, on soils, sediments, dust, and other materials. It can screen Pb, As, Cd, Cr, and other metal concentrations in the field. Samples of mineral material are collected under vegetation for testing the correlation between heavy metals concentration in soil and vegetation stress.

Atomic absorption spectrometry

The heavy metal contents of water and sediments from the concerned area is good to measure with a flame atomic absorption spectrometer (FAAS). Ground water/surface water samples must be prepared for the analysis. AAS requires careful calibration that is performed through several steps.

Ion chromatography

This method is used for measuring the content of some major anions and cations in solution, as chloride, nitrate, nitrite, sulfate, sodium, ammonium, potassium, calcium, and magnesium. The water samples should be filtered in the field, by using a sterile syringe and 0.45 um (or smaller) filters. Ion chromatography is a sensitive technique, able to measure concentrations down to ppb for some of the ions.

Ground spectra mineralogy

A portable infrared spectrometer will be used both for calibration of the remote sensing data and for systematic mineralogical characterization of the surface materials.

Ground spectra vegetation

A portable Spectral Evolution PSR-3500 spectroradiometer and leaf clip is used to perform reflectance measurements on vegetation leaves and canopies. A portable non-destructive chlorophyll meter will be used to get indications on different chlorophyll concentrations.

Atomic absorption spectrometry

a. Destructive leaf chlorophyll extraction

In order to get a better interpretation of the spectral data related to the processes of plant leaves under stress, destructive chlorophyll a and b extraction can be performed on healthy and stressed leaves. Circular leaves samples used for extraction of chlorophyll a and b. The tissue samples are pulverized with a pestle and ground for a short time with some quartz sand. Subsequently, the samples are placed in a centrifuge to remove particulates and the supernatant is diluted to a final volume of 25 ml with the acetone/Tris buffer. Each sample for pigment analysis is placed in a cuvette and the absorbance of the extract solutions is measured with spectrophotometer. Chlorophyll a and chlorophyll b concentrations are calculated using the extinction coefficients derived by Sims and Gamon (2002):

$$Chla = 0.01373A663 - 0.000897A537 - 0.003046A647 \quad (1)$$
$$Chlb = 0.02405A647 - 0.004305A537 - 0.005507A663 \quad (2)$$

where Ax is the absorbance of the extract solution in a 1 m path length cuvette at wavelength x.

b. Destructive leaf chemical analysis of heavy metal content (i.e., cadmium, zinc, copper and lead with AAS (Atomic Absorption Spectrometry)

For this procedure the plant material (leaves) is disintegrated in a mill and the resultant powder is dried in a drying oven. The samples are then placed in 50 ml borosilicate squat beakers and ashed at 500°C until oxidation was complete. The ash is dissolved in 2M hydrochloric acid with gentle warming and with a final 1/50 ash/acid ratio. The solutions is analysed for copper, cobalt, zinc and cadmium by atomic absorption spectrophotometry using a hydrogen continuum lamp for automatic background correction. Soil parameters under vegetation and heavy metal concentration of soil samples under vegetation are needed to correlate soil parameters with vegetation stress.

3. Definition of tools and methods

In the ImpactMin project the tools means mostly "hardware" assets that consist of satellite "imagery systems" and the imagery itself, as well as airborne imaging systems and outputs. The actual imagery is the imaging sensor system output with well defined parameters (spectral, radiometric etc. resolution). Furthermore tools are the in-situ (ground based) measurement techniques such as spectrometry and well established field data - laboratory analyses "combinations". Methods are the analysis activities that need human resources and logic for interpreting EO data and process it to (geographic) information.

The below table is an overview of the different tools and analysis methods that are mostly employed during the Project implementation. This short list below shows what kind of mining related surveying/monitoring activities are associated with the tools and methods that are suited to observe certain environmental media (examples):

- Planning of operation, follow up (land use change)
- Biodiversity, Land use (vegetation health and status)
- Mine waste and soil inventory (mineral characterization soil - quality, waste)
- Ground Stability (dams, underground workings, etc.)

Information on the Environment	**Observed Environmental Media**	**Analysis**	**Tools**
Biodiversity, Land use	Vegetation, surface objects	Spectral	Ground, Remote Sensing (RS)
Planning of operation, Land use change	Surface objects, vegetation	Spectral	Ground, RS
Status of Air	Air, Plant leaf/stress	Mineralogical, spectral	Ground, RS
Status of Waters	Water and sediments	Geochemical	Ground
Status of Soils (Waste)	Soils	Spectral, Geochemical	Ground, RS
Ground movement	Surface	Motion	RADAR Interferometry

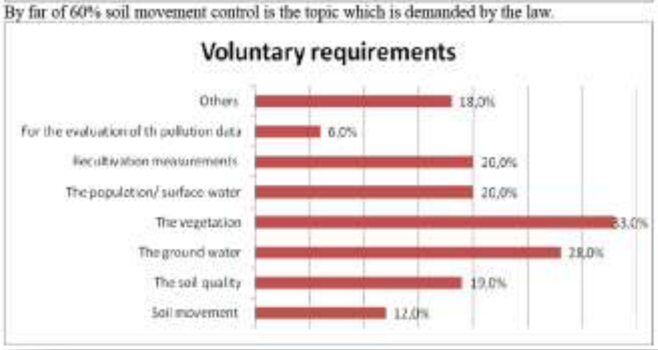
4. Requirements and driving forces - overview

Project activities related to assessing the needs and requirements of end users revealed various aspects that could be taken into account in the monitoring of the environmental impacts of mining activities. When a research project such as ImpactMin identifies users, the “nature” of the identified stakeholders can be very different. A public body like the town hall of City of Mostar can be targeted with data and information covering an area that falls into their territory. Also collaboration with an industry representative can be built up as it was the case with the Rosia Montana Gold Corporation in Romania. The end-users can have different interests and thus data needs:

- official reporting (obligatory elements in of an environment impact assessment)
- clean up efforts monitoring (management plans, spatial planning - cities)
- natural, geotechnical hazards prediction (engineers, local people etc.)
- signalling of environmental damage and its magnitude (environment agencies)

The below illustration shows the requirements in general towards environmental data (based on end user feedbacks)

By far of 60% soil movement control is the topic which is demanded by the law.



Another document of ImpactMin project will be more detailed about current and upcoming monitoring tools and their technical capabilities that are obviously a driving force in environmental monitoring of mineral resources exploitation. However we can see already at this point, that there are demand driven solutions and it is the responsibility of the research projects to develop the capabilities of the tools and create innovative methods for future operational work.

5. Detailed tools and methods and applicability area (based on demonstration site applications)

Airborne hyperspectral imagery

HOLISTIC APPROACH

A generation of airborne sensors operating in the VIS/NIR-SWIR range of 380 - 2500 nm, provides superior spectral and spatial imaging with negligible sub-pixel distortions (smile, keystone). The advanced sensor design has an excellent spatial resolution without compromising the imaging speed and signal-to-noise ratio. The advanced performance from a light weight sensor allows integration into variety of airborne platforms, some of them even unmanned. The compact new technology is particularly designed to increase the spatial resolution of push-broom hyperspectral imagers, and works with detector arrays up to 24 mm wide in the spatial dimension. The design is optimized for operation in harsh conditions, and provides the option of a user exchangeable fore-optic.

The targeted objects for detection with hyperspectral airborne sensors minerals have abundant spectral absorption features throughout the visible/near-infrared (VNIR, 0.4-1.0 μm) and short-wave infrared (SWIR, 1.0-2.5 μm) wavelength ranges. These phenomena result from the interaction of electromagnetic (EM) energy with the atoms and molecules which comprise the minerals. Many iron minerals have subtle spectral features in the 0.4 to 0.9 μm range caused by the electronic processes of Fe-ions. Charge transfer phenomena cause strong absorption in iron minerals at wavelengths smaller than 0.5 μm. The minerals containing a hydroxyl (OH) group have characteristic spectral absorption features in the 2.1 to 2.4 μm wavelength range, which are caused by the vibrational processes in the crystal lattice; in this case stretching of the hydroxyl (OH) bond, in combination with metal-OH bands, which vary.

IMPACTMIN TRIAL

Use of tools

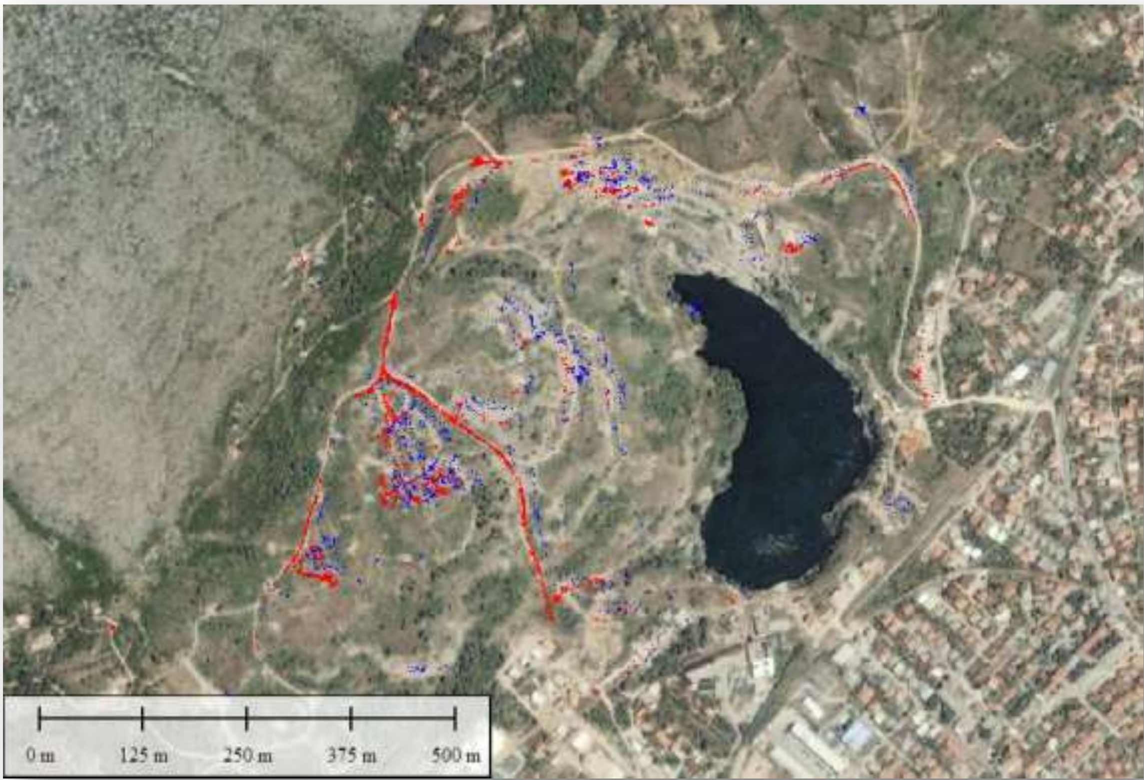
- SpecIM Eagle II sensor selected for the mission because of the best performances of working in challenging conditions
- Numerous areas were flown and covered over Mostar valley inclusive of Vihovici, Neretva River and Red Mud storage area
- Certain areas were flown and re-flown in opposing directions to minimize the effects of glint coming from the roofs and numerous areas of pounded water

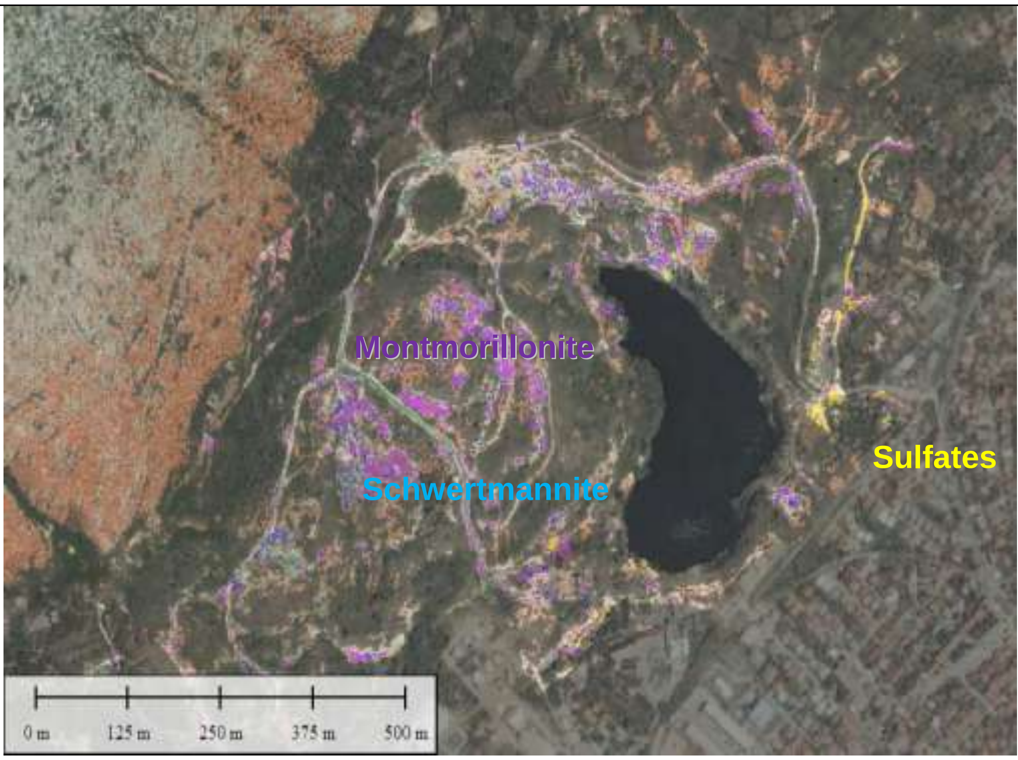
Processing method

- Raw data converted to radiance using SpecIM caligeo software: noted high radiance values because of how SpecIm expresses FWHM

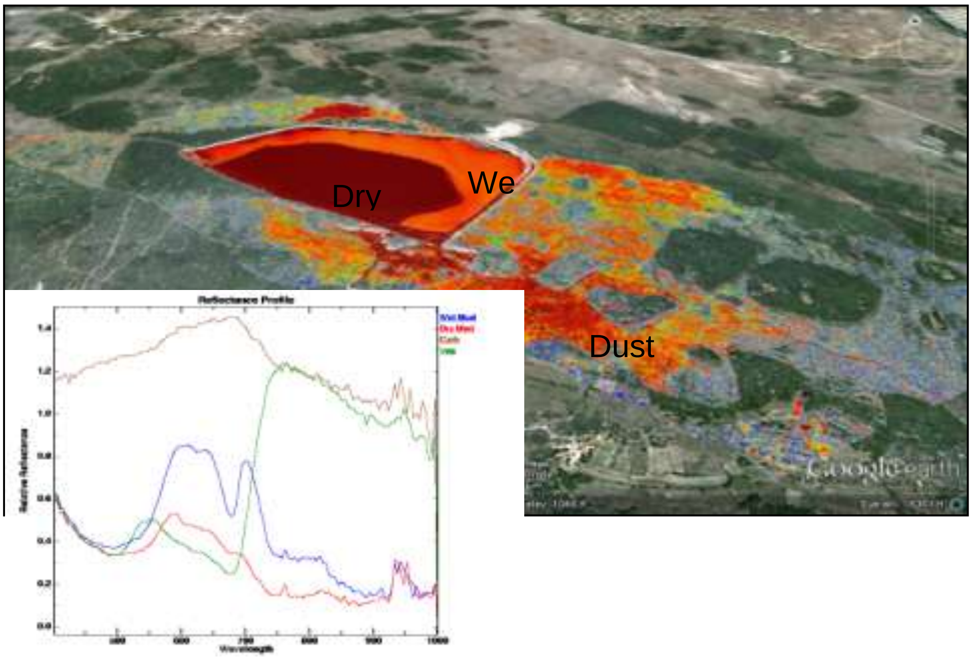
- Re-ran radiance through SpecTIR raw-to-radiance program and spec-cal parameters derived from LabSphere data
- Radiance to reflectance done with ATCOR using 3nm atmospheric model – ATCOR overestimated NIR section, re-adjusted to 5nm model
- Fixed ATCOR reflectance to Empirical Line reflectance using 1 dark (deep water), 1 bright (limestone gravel road) target and then improved using 16 other intermediate ground reflectances
- Input Geometry – Orthogeorectification based on BH Geodetic survey mesh 1:25,000
- Made vegetation index and used it to: determine vegetation stress, make vegetation mask to apply when analyzing for mineral targets
- Used standard ”hourglass” processing to determine potential endmembers in the scene
- Refined endmembers with the actual field data
- Ran classification using MTMF/SAM/Neural composites to isolate target groups of minerals

Iron hydroxide and sulphate minerals as evidence of pollution from sulphur-rich top seam layers of Vihovici





Water-expanding clays (e.g. montmorillonite) which may results in landslide hazards propagation and potential pitwall rupture



Red Mud containment area (Mostar site) and the used red-mud spectral index that was developed on the Hungarian spill

Optical satellite imagery (vegetation monitoring and status)

HOLISTIC APPROACH

Vegetation monitoring
A typical application of optical remote sensing and imagery analysis is to define change by estimating the land use and land patterns over large areas. The nature of the changes that can be investigated can vary considerably. One typical change is the short term land cover change that can be a result of mining activity induced pollution (e.g. acid drainage affected ecosystem degradation) and another type of change can occur due to mining area expansion. This latter can be observed over a longer period of time.

A successful monitoring approach for evaluating surface processes related to mineral mining and their dynamics at a regional scale requires observations with frequent temporal coverage over a longer period of time. This observation technique would enable experts to differentiate natural changes from those associated with human activities. Remote sensing is in most cases the only alternative to field collected observations when a historical record is needed for studying the longer term vegetation cycles (Landsat-type systematic observation is available since 1979). Recognizable impacts on the Earth surface and in particular on vegetation due to open pit mining (e.g. mountain top mining) and mining related activities can be systematically recorded by remote sensing data with sufficient area coverage and temporal frequency. Taking into account the available data archives and the relatively low cost analysis methods optical satellite imagery is a reasonable tool to use for such investigations.

Specific goals and objectives could be to determine the exact extent of a mine induced land transformation with a low cost solution. The satellite imagery data ensures accurate and easy-to -understand (via its visual nature) information source that can be successfully disseminated and demonstrated to many stakeholder groups such as decision makers and to the wider public. Also recently developing mining sites and their effects on the surrounding vegetation can be monitored with newer imagery sources: Ikonos (launch 1999), Quickbird (2000) Spot HGR (2002), have their advantage to have higher spatial resolution (2-5 meter) and already allow to have a range of scenes to capture changes over time.

Vegetation health (Vegetation indices)
In order to identify the green plants on the Earth surface around mine sites and also the status of the vegetation the chlorophyll related vegetation indices, such as the widely used Normalized Difference Vegetation Index (NDVI). In former project deliverables it was shown how remote sensing data is suited to calculate NDVI for individual tree and for larger vegetated area assessments. The individual tree investigations allow identifying some metal-induced photosynthetic inhibition that results in reduction of the enzymes involved in chlorophyll biosynthesis, substitution of metal ions within the chlorophyll molecule, reduction in chlorophyll concentration within the leaf. Derived NDVI difference images are also

promoted as a simple and effective means of identifying vegetation change events over larger vegetated areas.

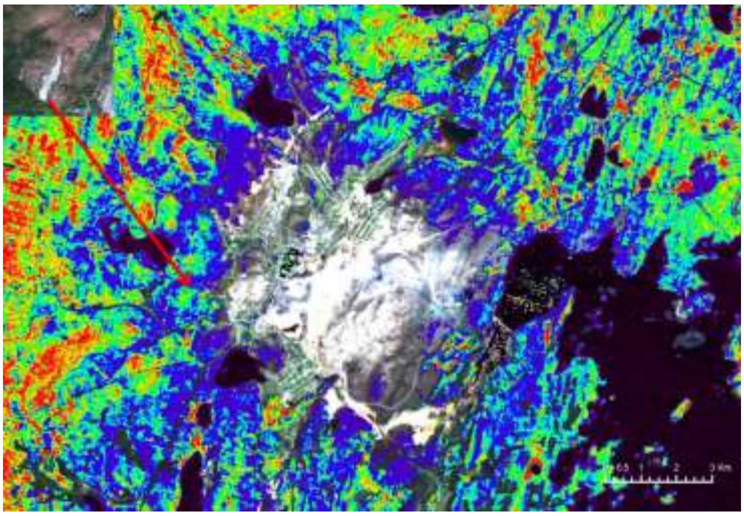
Low resolution optical imagery time series analysis (TSA)
The MODIS time series (1999-), SPOT Vegetation (1998-) and AVHRR extracted NDVI time series (1990–2002) can also aid various aspects of mining impacted vegetation analysis. This type of instruments has the strength of getting images very frequently (minimum one image per one day) thus seasonal variations can be detected in terms of vegetation. Although one cannot focus on local impacts but the derived data and information can sufficiently help to understand the complex affects of different impact sources (e.g. climate change and the natural "greening" of vegetated areas).

IMPACTMIN TRIAL

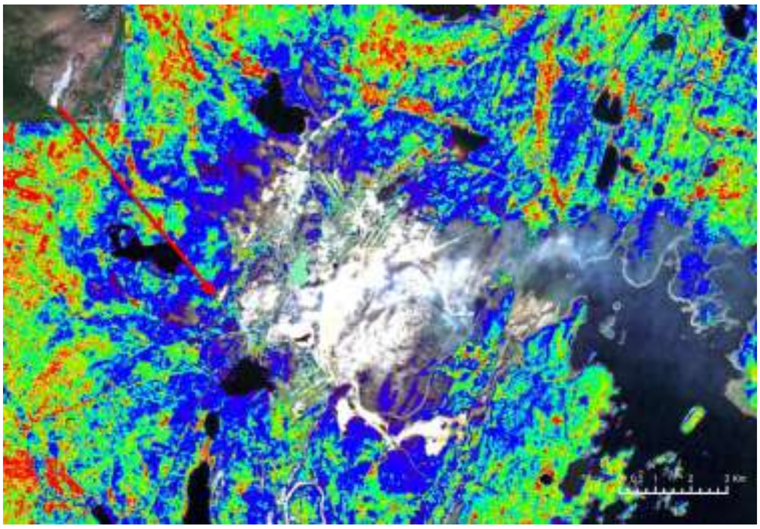
High, medium and low resolution satellite imagery and processing methods have been proposed and used for several ImpactMin demonstration sites. On the one hand the integrated handling of these imagery types proved to be useful in mapping the mining activity impacts and on the other hand some of the image sources could reveal important connections between mining and vegetated environment alterations.

For temporal change detection, detection algorithms can be attributed to: i) Directly comparing different data sources (direct comparison method) ii) Comparing extracted information (post-analysis comparison method) iii) Integrating all data sources into a uniform mode.

The detection elements of direct comparison method include pixel, basic image features and transformed features. The texture features and edge features are always taken as basic image features.

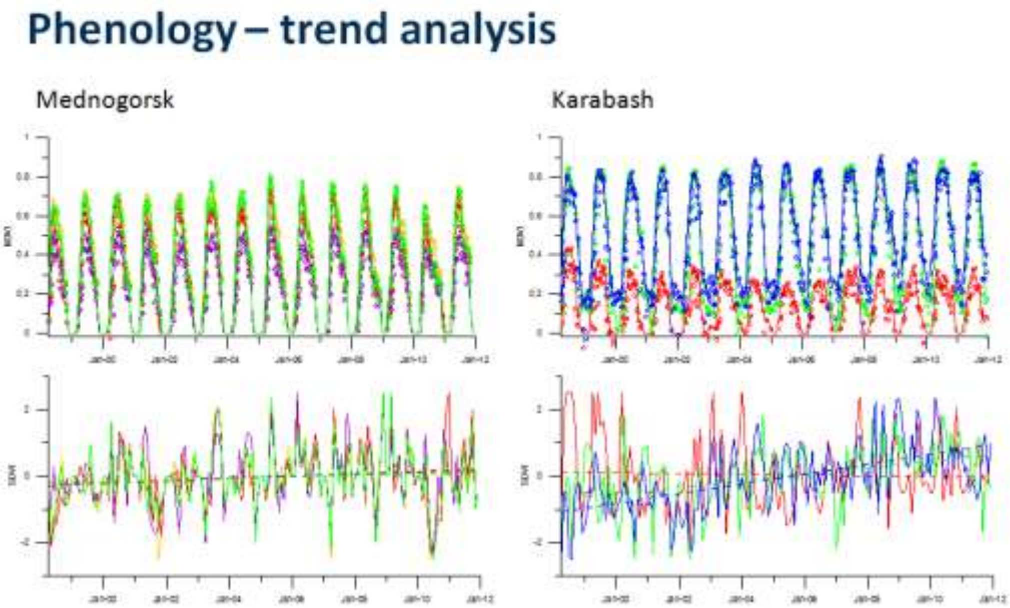


Landsat NDVI 1989 for Karabash area



Landsat NDVI 2011for Karabash area

SPOT Vegetation derived vegetation parameters for the South Urals 2000 - 2012



Low resolution imagery time series pre-processing:

- Smoothing
- Maximum value compositing
- Comparison to the long term average
- Phenology and linear trend analysis
- Spatial variability – relation to the distance to the mining area / smelter

Unmanned Aerial Systems (UAS)

HOLISTIC APPROACH

Generally speaking the application of Unmanned Aerial Vehicles give the environment impact assessment a whole new dimension, because these tools are very flexible to use, easy to mobilize (react on certain issues) and thus it can be tailored to exact objective of the task (e.g. creating ultra high precision DTM). Nevertheless since there are some legislative aspects of operating UAVs “legally” (due to close-to-field activity) the use of such tools requires more advanced planning before actual surveying and data acquisition activity. For the above reasons it needs to be investigated if the purpose of the project can be achieved with already available EO data or if purpose-tailored UAS information is needed. Licensing, safety issues are just some of the aspects in UAS use for mineral resources exploitation monitoring.

Once a careful “limitation check” (above) had been performed the application of a UAS system can greatly enhance the chances for precise characterisation of environment impacts of mining because the very high resolution data that these system can record over the study sites. Moreover the various sensor choices that these platforms can offer (Hyperspectral, Gammaray, CIR etc.) for the purpose give multiple benefits for the data (end-) users. Earlier project documents give sufficient summary of the sensor types and what they offer in terms of information provision thus here we are not going into details but show some case studies below from ImpactMin project.

IMPACTMIN TRIAL

Unmanned survey for the Mostar site

Very high resolution unmanned aerial photography acquisition was prepared for several areas in the Mostar study area, including the open pit area and several sections of the Neretva River that were sampled for water quality analysis. The availability of 4 cm-resolution imagery significantly enhances our ability to interpret the much lower resolution hyperspectral and WorldView2 imagery. In addition the photo’s are used to build accurate and detailed digital elevation models (DEMs), thus these data contribute significantly to the understanding of the distribution of certain soil minerals, and to evaluate the factors that play a role the geotechnical stability in the open pit area.

Unmanned survey for the Kristineberg site

In Sweden, field sampling is performed in 2011 and 2012, directly after the remote sensing (UAV) activity. The combination of field based investigations at each locality that included vegetation samples along transects, the imagery can be classified for impact monitoring purpose (waterborne contamination assessment).

Kristineberg tailings pond aerial ortophoto (2011)

Generated products of the UAS:

- Othophotos (orthophoto mosaics)
- DEM
- Volume estimation (waste heaps)

Because of the high spatial resolution images needs to be further interpreted in complex and highly fragmented physical environments, the understanding of land use patterns can be significantly aided with the use of ultra high resolution optical imagery. In the case of Kristineberg area it is possible to identify single herbaceous plants on the images thus improving the classification of the vegetation. In Rosia Montana, the temporal analysis of satellite imagery becomes much more advanced with the use of UAV image stacks.

Geochemical ground tools (in particular: soil, water, air)

HOLISTIC APPROACH

Lichen biomonitoring

Lichen transplant monitoring is a method for assessing fallout of airborne pollutants whereby healthy lichen thalli are transplanted from unpolluted localities to polluted sites in order to assess pollutant deposition over a fixed exposure period. Lichen sampling, with multi-element geochemical analysis, is widely used to investigate spatial and temporal patterns of metal contamination. One of the most commonly used species is *Hypogymnia physodes* (L.) Nyl., which grows naturally in most parts of Europe. Where insufficient naturally growing material is available, *Hypogymnia* can be transplanted from a relatively little impacted 'reference'site to stations within the zone of contamination. The transplants can be collected after a 3 month exposure and then analysed to determine their metals contents.

SEM-EDX studies are then performed to compare the size, shape and elemental compositions of individual particles on lichen transplant surfaces from the study site and the 'control' site. Particulates in the samples can show high levels metals mainly in the form of 5 to 200 µm sized, commonly spherical sulphide and silicate metallurgical slag particles, similar in composition to the particles that are present in the contaminated area in the air. Particles <5 µm in diameter, and especially those < 2.5 µm, can be poorly represented in lichens either because they are not efficiently captured or they are preferentially washed off or dissolved.

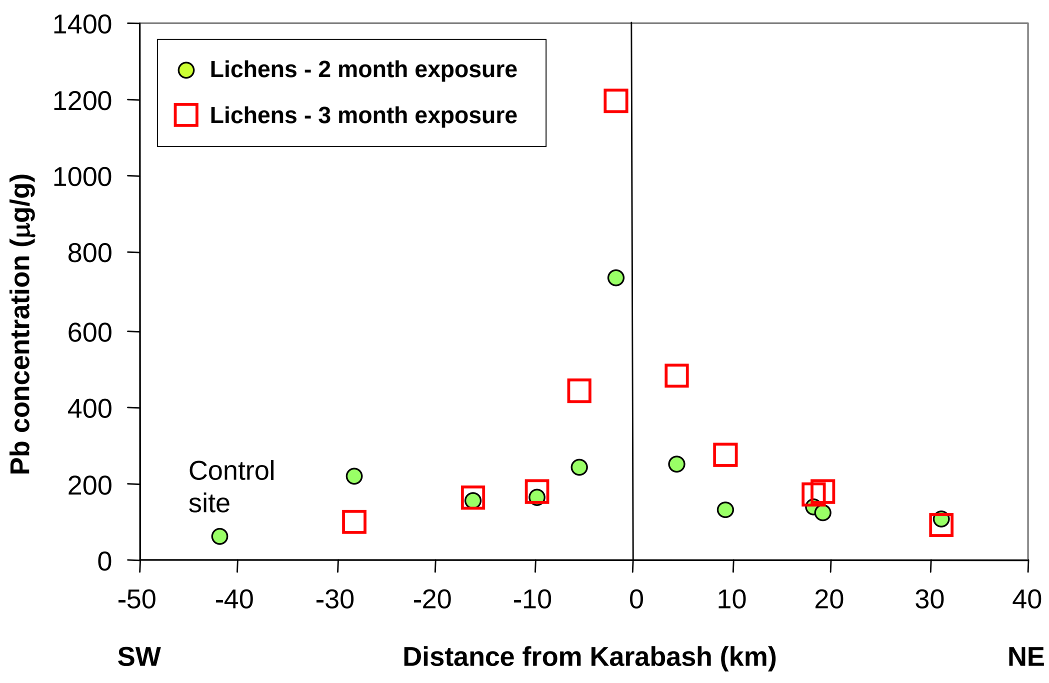


Illustration material from an earlier study (MinUrals FP5)

Heavy metal mapping in native vegetation

The strategy of sampling methodology can be made in a fashion to cover the entire area affected by mining related activity including polluted (waste dumps, open pit, contaminated surface waters) and non-polluted areas. The selected tree species (for laboratory investigations) should be predominant in the mining area and also around the mining area. Leaves samples are kept in polyethylene bags and should be stored in a cooler box for a good preserving before reaching the laboratory. First a non-destructive estimation of leaf chlorophyll content can be performed in the field using an Opti-Sciences CCM-200 meter that calculates the chlorophyll content index (CCI) as the ratios of radiation transmitted to the leaf at two wavelengths (940 nm and 660 nm). CCM 200 chlorophyll meter is indicating chlorophyll content per leaf area unit (0.71 cm2), related to the thickness of the leaf. The destructive method for chlorophyll extraction is performed in the laboratory.

Infrared spectroscopy with a portable infrared spectrometer

Infrared spectroscopy is a very cost-effective, fast and simple method to measure a number of important characteristics of materials such as soils and vegetation, whose condition is likely to be affected by environmental impact as a result of mining. It is an excellent method to rapidly identify subtle changes in soil mineralogy and vegetation health. The method is non-destructive and accurate, and the availability of lightweight portable infrared spectroradiometers such as the Spectral Evolution PSR-3500, allow carrying the spectrometer with us in the field to take in-situ measurements. The ability to take in-situ measurements is particularly important in the case of vegetation, because the properties of leaf material rapidly changes after it is removed from the plant. Also, in-situ spectroradiometer measurements are essential for the calibration of airborne and satellite imagery.

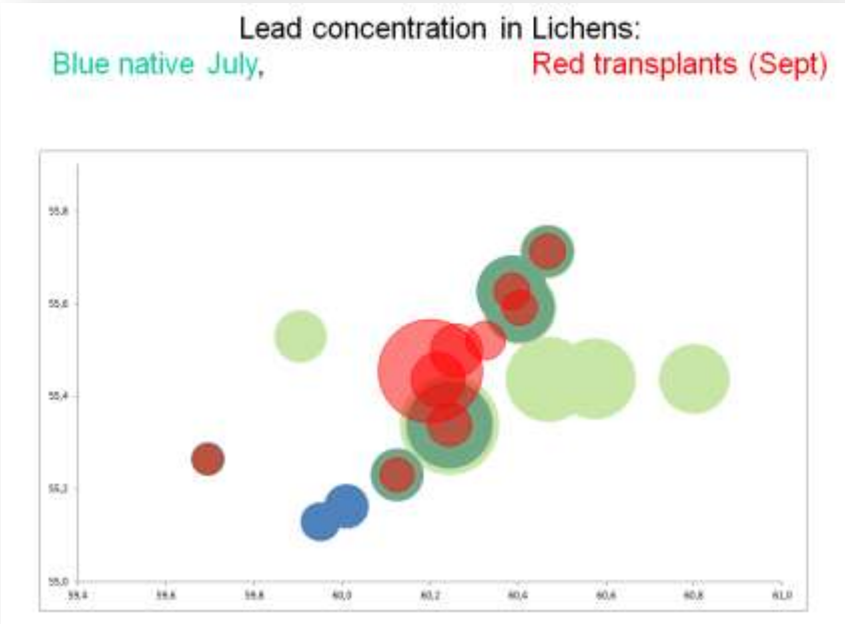
The Spectral Evolution spectrometer is the most innovative spectrometer on the market, as it is based entirely on solid-state technology, which makes the instrument compact and rugged, and produces data with a much higher signal/noise ratio than other spectrometers in commercial use.

IMPACTMIN TRIALS

Lichen monitoring was carried out at twenty two sites in two transects (NE-SW and W-E,) to determine the relative levels and gradients of fallout of metals from the Karabash smelter. For the transplant studies, over 150 twigs colonised by *Hypogymnia* were. Samples were transplanted to stations along the NE-SW transect from Kyshtym to Severnye Peche, 6 km NE of Turgoyak Lake (*33 and 25 km away from Karabash respectively*). All stations were located in medium-aged birch stands at between 280 and 695 m elevation.

Twigs were collected in September 2011 after a 3 month exposure period. In the laboratory, natural and transplanted thalli of *Hypogymnia* were removed from the twigs using powder-free latex gloves and stainless steel knives, and stored dry in zip-lock plastic bags. Samples were bulked for chemical analysis or else treated as replicates and analysed by ICP-MS at the University of Exeter, UK and Institute of Mineralogy, Miass, Russia. The data were plotted on graphs showing levels of metals in lichens (naturally growing and transplanted) with distance from the smelter.

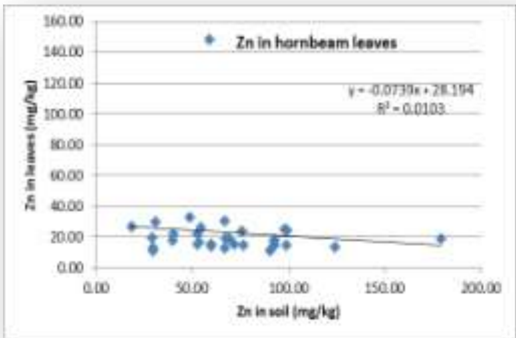
In general, the aim of lichen study is to determine nature and spatial distribution of fallout from the Karabash smelter.



ImpactMin study of lichen biomonitoring - Karabash

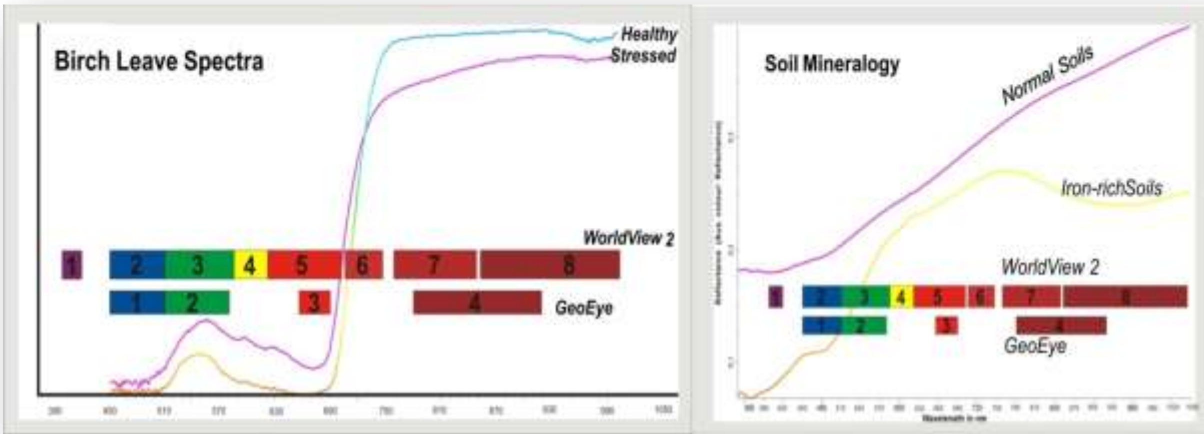
Heavy metal mapping in vegetation

In order to assess the vegetation stress due to past mining activities, a number of 144 vegetation samples were collected in Rosia Montana mining area during different field campaign periods. The measured parameters are chlorophyll content (destructive and non destructive analysis), fluorescence and heavy metals content. The samples represent leaves of Betula pendula, Carpinus betulus and Fagus sylvatica collected from different points of the mining area: near to the open pit and tailings areas, near and inside the waste dumps or far away from the mining site.



On the left the spatial distribution of Zinc concentrations are plotted classifying them into three sub-classes based on Romanian regulations. On the right image the Zinc concentration plots are correlated with Zinc concentration in soil samples covering the Rosia Montana area.

The illustration below is from the Russian demonstration sites where the portable spectrometry was extensively used for determining the impacts of fall out particulates in the environment.



A plot of red-edge position of birch leaf spectra is illustrated on the left image. The inset shows an example of a healthy leaf spectrum (blue spectrum) and a stressed leaf spectrum (pink), and the relative band positions of WorldView 2 and Geo-eye imagery. On the right image the plot of r780/r900 for soil samples can be seen. Higher ratios indicate higher Fe-oxide content. The inset shows a spectrum for normal soil, without Fe-oxides, and a spectrum for Fe-oxide rich soil.

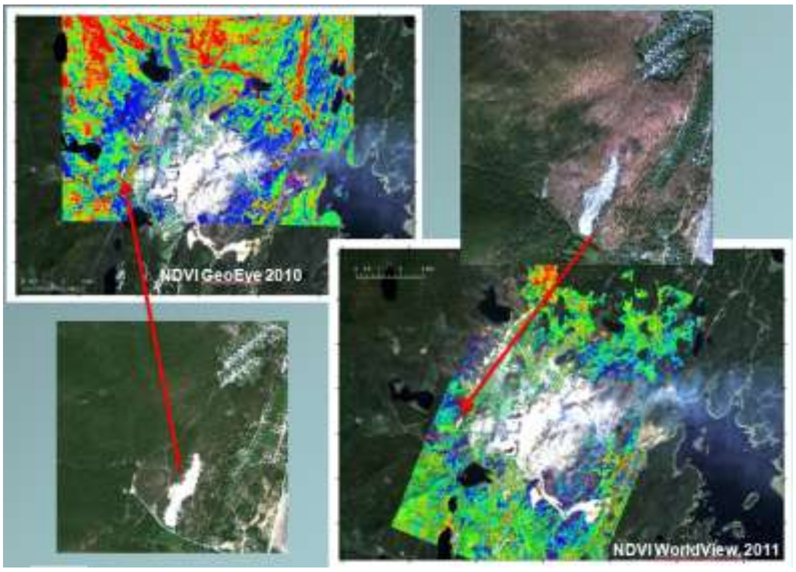
6. Outlook and applicability

Based on the early studies (literature) in the ImpactMin project combined with a comprehensive end-user needs and requirements survey outcomes it can be concluded that a) specific tailored made approaches and b) huge, all-aspect observational systems are very typical in the mining sector. Some sites have their specific issues like the ground movement/subsidence phenomena that needs to monitored and eventually controlled. Nevertheless, current legislation and official practice is quite rigid in terms of flexibility of assessment methods and observable parameters. Mining industries have to fulfil their compulsory reporting obligations that are mostly focusing on measuring the emission values of certain pollution sources. Beyond their obligatory reporting, we experienced (based on the collaboration with RMGC) they not paying attention to other relations and observational methods other than is prescribed. Naturally, mining companies are focusing on getting the permits and giving as precise numbers about their operations as possible. Clearly, innovation regarding environmental earth observation is not their business.

However, the trends in research and technological development shows that the tools and methods are now more suited to give continuous information about environmental phenomena compare to the point source based info-provision. Earth observing devices record millions of data on a daily basis. Providing geographic information via geospatial datasets has several advantages that they are giving the "bigger picture" about the environment and there can be focused measurements that precisely. Nevertheless visual information or visualised information greatly enhances the understanding of natural processes and proposed earth observation tools and methods providing the momentum for this.

With the proposed tools and methods that are discussed in this document ImpactMin consortium proving the stat of the art technology that is available nowadays and the partners promoting the novel tools that are needed for new approaches. These can be listed shortly here:

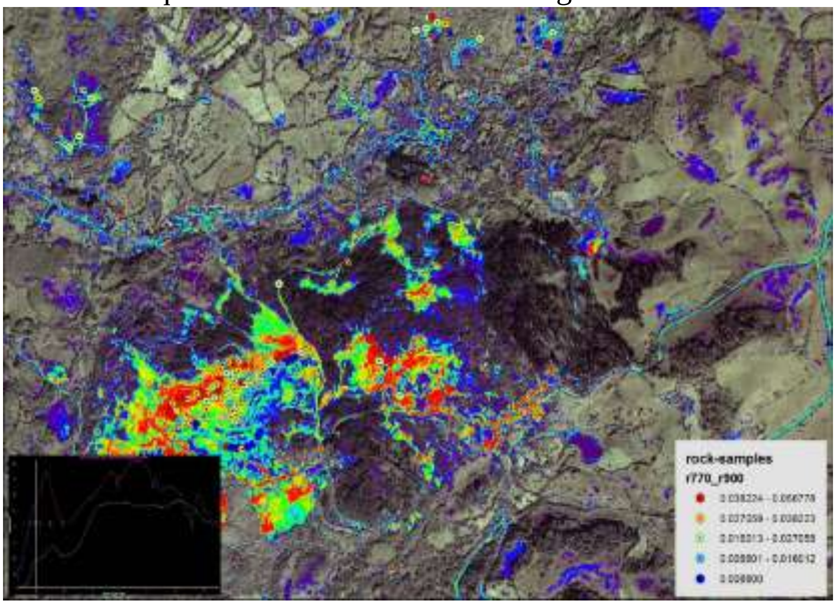
- large area mapping
- impact area delineation
- focus point identification
- intervention point identification



High resolution imagery analysis results on vegetation status

Novel tools and data integration

The ImpactMin study presents a number of new tools and approaches for the collection and interpretation of information that allows us to improve to our ability to monitor environmental impact in an efficient and cost-effective manner. Integrated analysis of data has demonstrated that traditional ground sampling methods, such as geochemistry, can in part be integrated with fast and cheap methods such as infrared spectroscopy, and by a variety of remote sensing techniques using optical sensors on UAV's, manned aircraft and satellite.



New techniques such as lichen monitoring and infrared measurements of vegetation stress parameters are also suitable next to the conventional analytical tools to directly measure responses of vegetation to airborne pollution. Detailed studies of the integration of ground data with ultra-high resolution UAV imagery, very low altitude and low altitude Hyperspectral surveying, very high resolution optical satellite image and conventional Landsat imagery has demonstrated the complementary nature of these different datasets (illustration above shows point based spectrometry results handled and interpreted with satellite imagery analysis results with excellent correlation between datasets).

Outcomes of the ImpactMin form a basis for further research and development in the fields of vegetation monitoring for environmental impact analysis, hyperspectral and multispectral remote sensing, and the use of unmanned aircraft as a cost effective and flexible platform for new miniaturized sensors (image on the left WorldView2 satellite imagery overlaid with an ultrahigh resolution airborne optical imagery acquired by Unmanned Aerial Systems).