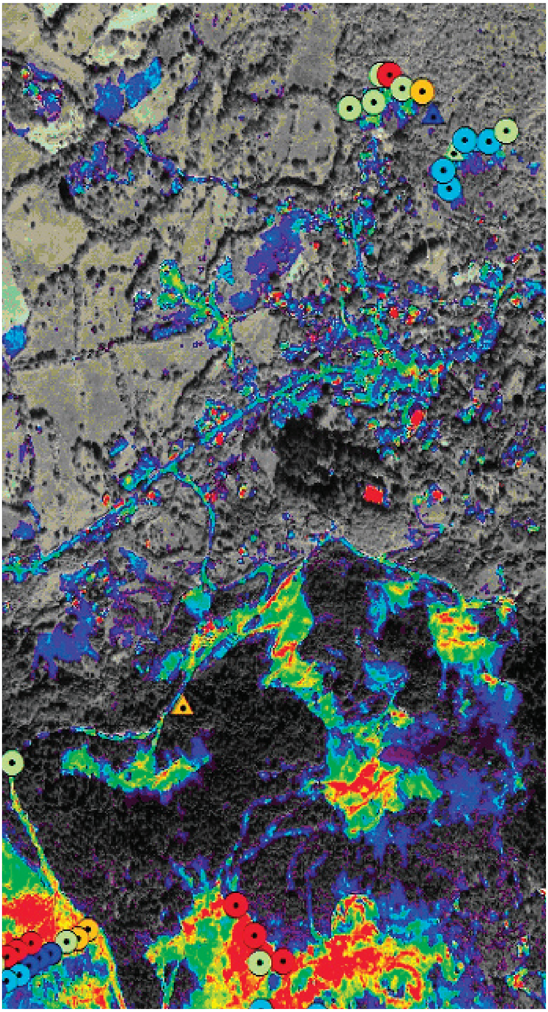

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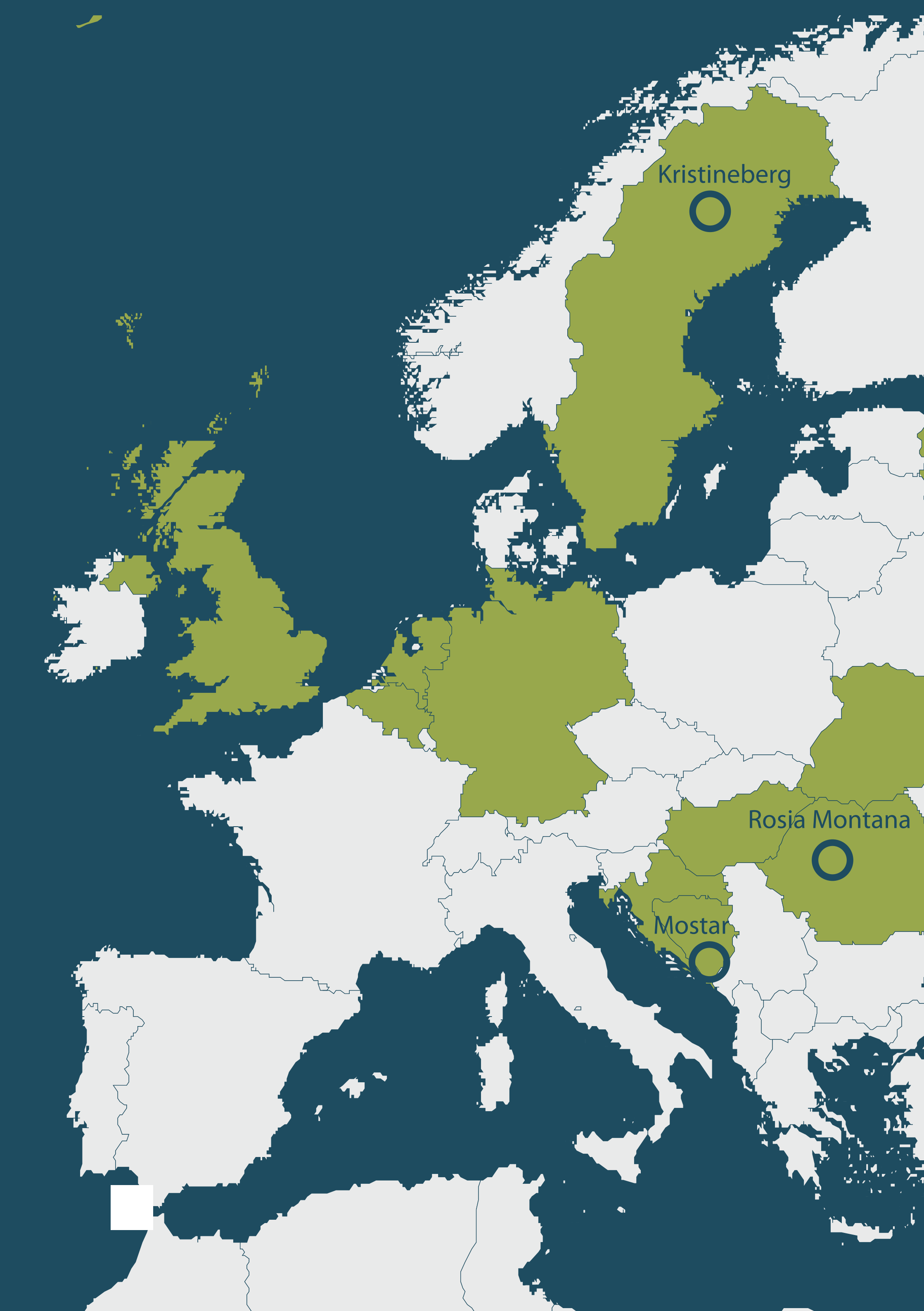
SEVENTH FRAMEWORK PROGRAMME



Kristineberg
Rosia Montana
Mostar


Karabash
Mednogorsk
GEONARDO Geonardo Ltd, Hungary
GEOSENSE Geosense, the Netherlands
UNEXE University of Exeter, Camborne School of Mines, the UK
LTU Lulea University of Technology, Sweden
PHOTON Photon LLC, Croatia
GFMO University of Mostar, Bosnia and Herzegovina
IMIN Institute of Mineralogy, Russian Academy of Science, Russia
UBB Babes-Bolyai University, Romania
ULRMC Ukrainian Land and Resource Management Center, Ukraine
DMT DMT GmbH & Co.KG, Germany
VITO Flemish Institute for Technological Research, Belgium

Content

DEMONSTRATION SITES INTRODUCTIONS

1. Kristineberg *(Sweden)*

Geography: The Kristineberg mining area (~300 ha) is located at approximately 175 km south-west of Lulea in Lycksele municipality, a municipality in Västerbotten County in northern Sweden. The mining area comprises a large tailings area and five mines, a large central industrial area which includes an old concentrator and three open pits. The population of the municipality is 12,506 and the surface area of the whole municipality is 563,600 hectares, therefore the population density is 2.2 people per hectare. The topography can be described as mostly hilly with an abundance of forest and scattered lakes.

Figure 1 – Kristineberg (Sweden) - an extensive industrial area in the heart of Swedish boreal zone

Current situation: The mine has been operating since 1918. The mill was closed in 1991 due to decreasing tonnage to the mill and increasing milling costs due to the closure of a number of small mines. Today, the ore is transported to the Boliden concentrator using 50-ton highway trucks, which are also used for transporting backfill tailings to the mine. The main products recovered from the ore are zinc, copper and lead concentrates. Five ponds are located along a valley between two mountain ridges. Initially, the tailings were deposited in two ponds; later, new ponds were constructed in the south of the confluence between Rävlidmyrbäcken and Vormbäcken.

At closure, the tailings area consisted of five individual ponds containing pyrite rich tailings, including three old drained ponds containing weathered tailings, one recently operated pond containing unweathered material, and one pond containing substantial quantities of precipitates from the treatment of acidic mine water.

Proposed activities: The latest technology of UASs is proposed to sample vegetation at a mining site and at several localities downstream the mining site. Localities upstream the mining site will serve as reference sites as well as the localities at different cardinal points of the compass.

2. Rosa Montana *(Romania)*

Geography: Rosia Montana is a small village in the forested mountains of western Romania. The site of gold deposits is believed to be the largest in Europe. The Rosia Montana Project (RMP) is located near the village of Rosia Montana in west-central Romania, approximately 50 km north-west of the regional capital, Alba Iulia, in the Metaliferi Mountains, which belong to a larger, regional mountain unit called the Apuseni Mountains of Transylvania.

Figure 2 – Rosia Montana (Romania) – two millennia of environmental disturbances and societal implications

Current situation: The Rosia Montana region represents a complex geological-mining environmental interaction area, exhibiting over two millennia of surface and underground mining and milling operations. Mountainous, vegetated and water-saturated setting of the area gives additional complexity in characterizing the area from the environmental standpoint. Due to recent developments and planned mining operations, Rosia Montana is expected to be the largest open-cast gold mine in Europe.

Proposed activities: A combination of EO measurements (at different spatial resolution) and in-situ measurements will be used to assess the environmental legacy of over two millennia of mining in the context of a new operation is expected to be launched in full scale in the upcoming years (depending on the Romanian Goverment decision).

3. Mostar Valley *(Bosnia and Herzegovina)*

Geography: The city of Mostar, located in the southern portion of Bosnia and Herzegovina (BiH), was one of the main areas of aluminium extraction, fabrication and aircraft industries. Mostar is situated on the river Neretva and is the fifth-largest city in the country. Three demonstration sites are proposed for investigation. The first is on the northern part of the city, which is a red mud disposal site. The second one is an abandoned coal mine near the city center, and the third one is in the south of the city and is a planned lignite mine.

Current situation: The second site is an ongoing rehabilitation project in the former coal mine Vihovici, a site of great threat to the local population and the environment due to toxic gas emissions, landslides and volatile organic compounds (VOCs) into the water supply.

Figure 3 – Mostar Valley (Bosnia and Herzegovina) - complex environmental and human system of an abandoned coal mine and the river Neretva

Proposed activities: The sites are selected for follow-up identification using satellite imagery, hyperspectral remote sensing, gamma-ray spectroscopy, field-spectroscopy, and geochemical sampling.

4. Orenburg *(Russia)*

Geography: The Ural, in geological and geographical meaning, is a fragment of Paleozoic fold area expressed as a mountain chain and has a width of 150 to 300-400 km and a length of about 2,000 km. South Ural Mountains of Russia (700 km) contain mainly massive sulphide deposits. It has a continental climate, with extremes of temperature, and lies within the South Taiga and forest-steppe zones.

Current situation: Today, many of the mineral deposits are exhausted or are uneconomic in current world markets. The extraction technologies used in most operations are inefficient and environmentally unsound. In certain areas, pollution from past and current mining-related activities is known to be heavily impacting on human and environmental health. From a political and sociological perspective, large-scale closure of operations is currently impossible as mining industries are major employers, which underpin the economy of the region.

Figure 4 – Orenburg region (Russia) - uncontrolled impacts of the mining industry

- Karabash, located in the South Taiga vegetative zone of the Chelyabinsk district of Russia, is host to a large copper smelter and several abandoned mine workings, tailings dams, waste dumps and stockpiles of concentrates. In 1995, the Russian Ministry of the Environment and Ecology designated the town as an ecological disaster zone.
- Mednogorsk, located in “steppe mountain” zone, is host to a large copper smelter and several abandoned mine workings (with two open pits with pit lakes’ water depth of 39-45 m), tailings dams, waste dumps and stockpiles of concentrates.

Proposed activities: The territory of Southern Ural represents a continuous mining area with several large mining operations, broken landscapes, huge environmental problems, and due to recent mine closures, enormous socio-economic difficulties. An essential task is to demonstrate the use of spatial modelling and applied remote sensing methods for the combined monitoring of environmental and socio-economical changes. Such an approach would also be supported by the local industry.

Environmental impact of mining in Mostar Valley using airborne hyperspectral data (Photon llc.)

Introduction

Hyperspectral imagery was used to investigate for the potential sources of aquatic, atmospheric and land pollution from the mine waste tailings, bauxite-ore waste storage and other areas of interest. The hyperspectral data were intended to may iron oxide and sulfate minerals in the high-sulfur, sub-economic coal seams piled on the fringes of the old mine, vegetation stress and water quality degradation in the river Neretva and the old mine-pit within Vihovici as well as distribution and condition of the red-mud in the bauxite-ore containment in the southern Mostar valley, partially as a result of lessons-learned from the Ajka-Kolontar, Hungary red-mud spill in October of 2010, where Photon llc. had also participated in the acquisition and analysis of hyperspectral data. It must be noted that the red-mud storage facility in Mostar was appraised as a target of opportunity in the light of the Hungarian disaster (“better safe than sorry” adage), which had occurred during the duration of the ImpactMin project.

Methodology

Near simultaneous acquisition of airborne hyperspectral, ground-spectral and water-quality measurements coupled with the high-resolution UAS imaging had taken place in Mostar during May/June of 2011. The primary goal was to correlate the various data sets in establishing the environmental impact, but also to use various data-sets to improve the overall quality of the acquired airborne data using the ground-based measurements. The airborne hyperspectral data, acquired by SpecIMs Eagle-2 were calibrated and corrected to reflectance using specialized ATCOR atmospheric correction software and improved using various ground-based spectral measurements with the empirical-line calibration method using bright and dark ground targets.

The reflectance data were analyzed using Spectral Angle Mapper (SAM) and Mixture -Tuned Matched Filtering (MTMF) to indicate the areas of highest concentration of iron oxide, hydroxide and sulfate minerals based on the ground-measurements and various spectral library matches (NASA-JPL, USGS, ASU). Several different spectral-matching techniques have been used to isolate particular spectral mixtures and focus on the areas of interest, described by the previous researchers as potentially problematic. The data were also analyzed for any non-library occurring minerals and/or unusual spectral signatures that might be indicative of other, unexpected materials present in the mine.

Similarly, the vegetation analysis was conducted using standardized difference vegetation index (SDVI) and normalized difference vegetation index (NDVI) to outline the areas of potential vegetation stress correlated to the areas of waste-minerals. Lastly, the red-mud facility was investigated, as a target of opportunity, using red-mud classification index, developed during the Hungarian disaster, to show the areas of occurrence, thickness and wetness of red-mud. No water-quality analysis has taken place at the time this summary was being prepared, but it is undergoing and the results are expected to be presented in the final site-assessment report.

Figure 5 – View of Vihovici mine looking west, showing preliminary hyperspectral-data analysis results for various mineral types

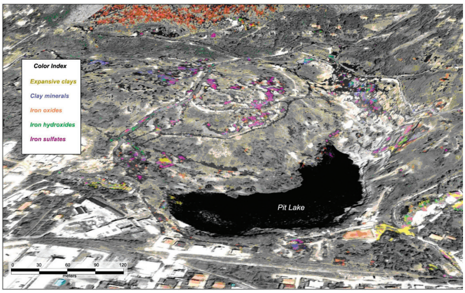
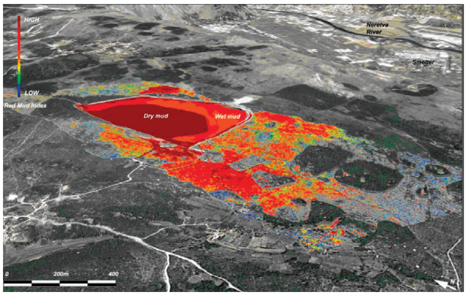


Figure 6 – View of bauxite-ore waste containment facility imaged with hyperspectral data and analyzed with red-mud index derived from the Hungarian spill.



Results

The first over of the results from the airborne hyperspectral campaign suggest an increased concentration of sulfate and hydroxide minerals in the old waste piles on the periphery of the mine and sulfate/clay minerals on the walls of the pit. The areas of sulfate concentration appear to cause negative effects on the scraggly vegetation covering the mine, suggesting that there are potential venues of acidic-transport or pollution hot-spots. The presence of sulfates and hydroxides can be attributed to the reportedly high concentration of detrital sulfur present within the coal itself but also in the sub-economic layers often removed in the mining process and dumped on site. Not-related to mining, but to the episode of unregulated dumping, variety of areas of the old mine have been used to dump car and truck batteries and other automotive chemical waste, all of which contain significant quantities of sulfur that upon leaching can react with the environment.

Additionally, the spectral analysis had indicated a presence of possible water-expanding clays (e.g. montmorillonite) in some of the retaining pit walls, suggesting potential for formation/ propagation of landslides and/or collapse of the section of the pit walls within the open-pit now filled with water. The expanding clays are notorious for their ability to retain water sometimes at 200% their mass, causing expansion and increase in the loading factor that can propagate landslides/ mass-wasting episodes. At the red-mud storage site, the hyperspectral data have shown that some of the red-mud has been distributed beyond the containment, possibly as a result of wind-blown dust or possible compromise in the revetment itself. At present the results do not appear overly alarming and suggesting of an impeding catastrophe as in Hungary, but the impact of the dumped materials beyond the initial containment site is evident, probably as a result of wind/ water transport.

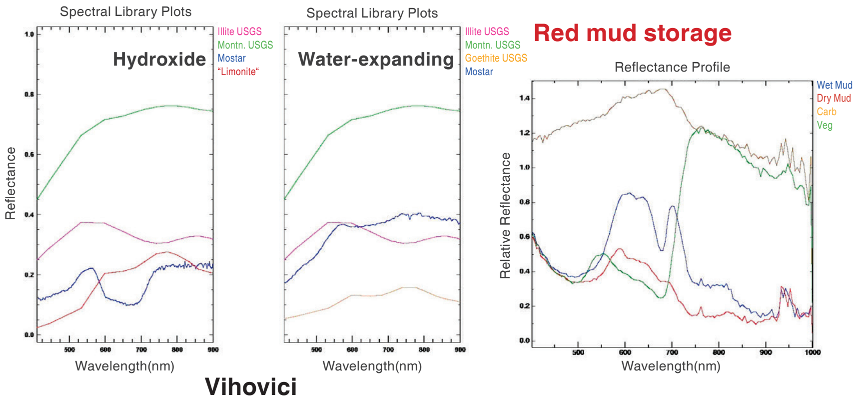


Figure 7 – Some reflectance spectra derived from the airborne hyperspectral data and compared with various spectral library mineral samples to aid in mapping and classification

Further Work

The results of airborne analysis need to be validated and confirmed by the analysis of ground-acquired data and eventual follow-up on the imaged sites. Of particular interest are the sites identified as problematic from the standpoint of sulfate mineral concentrations and the dispersal of the red-mud beyond the containment area. Based on the information that there are apparent regions of vegetative stress, a more in-depth analysis of the data and ground-correlation will be attempted. Similarly, a more detailed appraisal of the potential geo-hazards at the mine is also recommended based on the information gleaned from the airborne data. No water-quality analysis has yet been completed (in-process) and is an important element in the continued investigation of any potential impact of the areas to the aquatic ecosystem.

Spatial unmixing based data fusion for environmental impact monitoring of mining operations in the Mostar Valley (VITO, GEOSENSE)

Introduction

The three principal activities of the mineral resources mining industry – mining, mineral processing and metallurgical extraction – all produce waste. The environmental impact of these activities depends on many factors, in particular, the type of mining and the size of the operation. The effects of the mining (extraction) stage tend to be mainly local, associated with surface disturbance, the production of large amounts of solid waste material, and the spread of chemically reactive particulate matter to the atmosphere and hydrosphere. Many studies have shown the potential of remote sensing for environmental impact monitoring. However, its applicability has been limited due to the inherent spatial-spectral and temporal trade-off of most sensors.

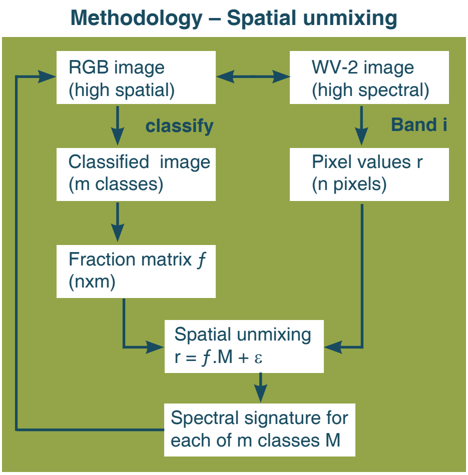


Figure 8 – Schematic overview of the spatial unmixing technique

1. *Classification of RGB*
2. *Sliding window size.WV-2*
3. *Generate class proportion matrices*
4. *Spatial unmix for each band*
5. *Add spectral signatures to central pixel*
6. *Iterate over all bands, whole image*

More recently, miniaturization of sensors makes it possible to capture colour images from unmanned aerial systems (UAS) with a very high spatial resolution. In addition, the UAS can be deployed in a very flexible manner, allowing high temporal resolution imaging. More detailed spectral information is available from multi-or hyper-spectral images, albeit at lower spatial resolution. Using fusion techniques such as spatial unmixing, both types of images can be combined. This can help to overcome the spatial-spectral trade-off and provide a new tool for more detailed monitoring of environmental impacts.

Methods

We apply the spatial unmixing technique proposed in [Zurita-Milla et al., 2008] which is based on the idea that a linear mixing model can be used to perform the downscaling of the spectral information of one image (high spectral resolution image) to the spatial resolution of the other image (high spatial resolution image).

In contrast to spectral unmixing which can be seen as a quantitative analysis procedure to recognize endmembers and obtain their mixing proportions from a mixed pixel, spatial unmixing tries to recover the material spectra for classes within a pixel whereby linear unmixing is solved for all pixels at once, but for one band at a time. Thus, if the material fractions are unknown, but the class signatures can be estimated, then the equations are put in a standard spectral unmixing form. On the other hand, if the material fractions can be estimated, but the class signatures are unknown, then the equations are put in a spatial unmixing form. The material fractions can be deduced from the high spatial, low spectral resolution image. Figure 8 shows a schematic representation of the spatial unmixing technique.

The spatial unmixing technique is implemented in C++ by VITO and applied to images of the 'Vihovici Coal Mine' area, located in the Mostar Valley, Bosnia and Herzegovina. RGB colour images with a 0.20 m spatial resolution (degraded from 0.05 m to 0.20 m), acquired by a SmartPlanes UAS and provided by GEOSENSE, are used as the high spatial resolution input. A WorldView2 (WV-2) satellite image, which provides 8-band multispectral data with a spatial resolution of 2 m, is employed as high spectral resolution input. The result of the data fusion algorithm based on the spatial unmixing technique applied to both images is a 0.20 m spatial resolution image with 8 spectral bands.

Results

A Normalized Difference Vegetation Index (NDVI) is calculated from the 5th and 8th spectral band of the WorldView2 (2 m) and the spatially unmixed images (0.20 m). NDVI values below 0.7 are masked from the image in order to obtain only dense vegetation pixels in the resulting images. Results are visually depicted in Figure 9b and 9c, respectively. The RGB image obtained by the SmartPlanes UAS with a spatial resolution of 0.20 m is shown as reference image in Figure 9a.

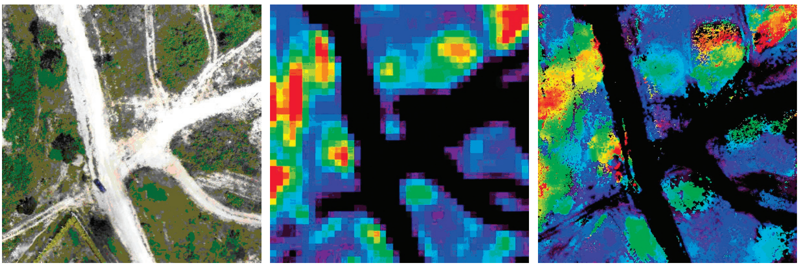


Figure 9 – Visualization of the (a) high spatial resolution UAS RGB colour image, (b) NDVI of WV-2, high spectral resolution image, (c) NDVI of the resulting high spatial and high spectral resolution, spatially unmixed image

From Figure 9, it can be concluded that the spatially unmixed image allows for a more detailed interpretation of the vegetation health status in the field. This example based on NDVI values is only meant to illustrate the possibilities of spatial unmixing. Further studies will focus on detailed mapping of environmental stresses due to mining practices.

Environmental Impact Monitoring at Kristineberg using an unmanned aircraft system (LTU, SMARTPLANES)

Figure 10 – Automated aerial photography with lightweight unmanned aircraft system (UAS)

Figure 11 – The mining area in Kristineberg

Introduction

The Kristineberg mining area (~300 ha) in northern Sweden comprises a large tailings area and five mines, a large central industrial area that includes an old concentrator and three open pits.

Previous sampling showed that the concentration of Cd, Cu and Zn in the tributaries of Vormbäcken was much lower than those encountered in Vormbäcken. Main focus of the remote sensing campaign in the Kristineberg area is on biomass and biodiversity of aquatic and riparian vegetation. So far, it is unknown if waterborne pollutants in Vormbäcken, the recipient of the Kristineberg mine, affect biodiversity downstream of the mining area.

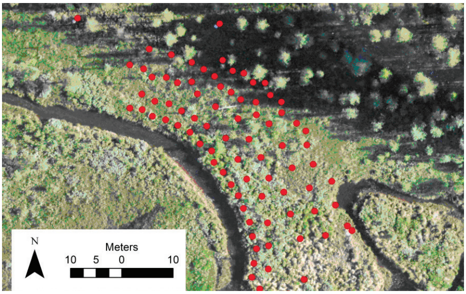
The main approach applied in Kristineberg combined field sampling and remote sensing. Field sampling was performed at three localities downstream of the mining area. At each locality, a 50 m long area that stretched along Vormbäcken was sampled. The width of the area depended on the vegetation type of the riparian zone.

Methods

Sampling was only done in the area that was under the influence of the water of Vormbäcken. Vegetation was sampled along Vormbäcken in five belts (I-V) 5 m width. In belt I we randomly placed 20 sample plots (50 x 50 cm) and in belt II-V 15 sample plots. For each sample, the cover of the five species with the highest cover was recorded according to a five-graded scale. The above-ground living biomass of the five dominating plant species was taken from each sample plot. For chemical analyses of vegetation, we took representative samples from the two dominating plant species at each locality. At each locality, samples for water chemistry were taken.

Analysed variables included trace elements as well N-tot, TOC, pH, absorbance (420), conductivity and alkalinity. The remote sensing campaign was performed in summer 2011 at the mining area and the three localities sampled for vegetation and water chemistry ca. 1 km up- and downstream of each locality. The UAS technique applied in ImpactMin was a Smartplanes Personal Aerial Mapping System (PAMS) and allowed for high resolution (ca. 5 cm) aerial photography. The system consists of the SmartOne Unmanned Aircraft (UA), ground control station

Figure 12 – Orthoimage derived from the UAS at locality 1 along the stream Vormbäcken (left) and image of the field and tree layer at the same locality (right)



(GCS) with Mission Planning an Flight Control software, digital camera with calibrated optics and special software as well as aerial mapping software for automated on-site production of georeferenced high resolution photo mosaics.

Results

The data from the field sampling and remote sensing are currently evaluated. The concentrations of Cu and Zn in water showed a significant decrease along the spatial gradient of Vormbäcken, but were above threshold limits at all localities. In contrast, the concentrations of e.g. Zn in riparian vegetation increased along the spatial gradient. These preliminary analyses highlight the importance of including exposure time of the aquatic and riparian vegetation to the water of the stream.

Conclusions, further work

In the forthcoming analyses, we will focus on the link between water chemistry, biodiversity, biomass and concentration of trace elements in aquatic and riparian vegetation. Based on the UAS images, the results at the scale of each locality will be up-scaled to areas 200 m up- and downstream of each locality.

Environmental impact of mining in Karabash using time series analysis (VITO, UNEXE, GEOSENSE, IMIN)

Introduction

The town of Karabash, located in the southern Russia Urals, has been a centre for mining and metal production for well over 3000 years, and these activities were greatly intensified in the early to mid-20th century. The area is extensively forested apart from small agricultural plots and the conspicuously de-vegetated western slopes of the nearby Karabash Mountain facing the smelter. In 1910, a copper smelter was built close to the centre of the town, which specializes in the production of 'blister copper'. Since the opening, the smelter has produced around 30 million tons of metallurgical slags and other wastes. Since the closure of the last mine in 1991 the smelter began to process concentrates produced in other towns and about 30% of the

Figure 13 – Pictures of the Karabash demo-site and surroundings: taiga forests, mine tailings and acid drainage (left), gaseous and particulate emissions from the Karabash smelter (right)

smelter's operations are now believed to be of a secondary nature, including the recycling of Pb batteries. Before the political changes in 1991, official SO_2 emissions estimates were in the order of 90,000 to 150,000 t/yr. In 2006, the Russian Copper Company has modernized the smelter in Karabash. Ausmelt Ltd claims the smelter is now one of the most modern plants of its type in Russia and the complex is among the most up-to-date and environmentally safe copper smelters globally. However, environmental impact of (historical) mining in Karabash is extremely severe.

The ore processing and smelting operations have had a major impact on the local environment, especially on rivers and woodlands. Karabash was described in 1992 by the United Nations Environment Programme (UNEP) as one of the most polluted towns in the world. The area was characterized as an 'ecological disaster zone', based on chemical analysis of soil samples in the area. Karabash and the surrounding areas are affected by gaseous and particulate emissions from the smelter, SO_2 emissions, fall-out of bioavailable metal-rich smelter particulates, acid drainage from old mine workings, effluents from the smelter and leachates and dusts from waste dumps, and contaminated stream sediments. Several studies have looked into the environmental effects of atmospheric pollution in Karabash and many trees in the town are reported to have yellow leaves even in early July and show premature autumn colors. Terrestrial lichens were shown to be heavily impacted for many kilometers downwind of the smelter due to acid rain or metal fallout from the smelter.

Methods

A time series of 10-daily NDVI images from SPOT-Vegetation (S10 April 1998 - December 2010 at 1km² resolution, www.vgt.vito.be) is analyzed. In order to account for missing values and undetected clouds affecting the observations, the 10-daily time series was smoothed and monthly maximum value composites (MVC) were created. To remove seasonal vegetation changes and thus facilitate the interpretation through the historical record, a Standardized Difference Vegetation Index (SDVI) was calculated for each pixel and for each record of the time series. The SDVI is a z-score representing the deviation from the mean in units of the standard deviation. Next, trend analyses are applied on the SDVI time series.

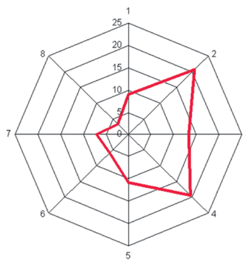
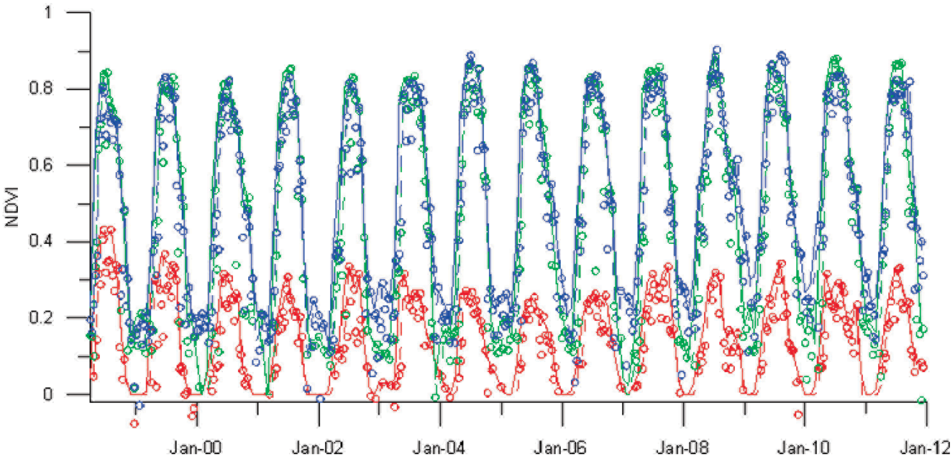


Figure 14 – Predominant wind direction (in %) in the Karabash area, based on 1242 measurements (2009-2011) (UNEXE)

Figure 15 – NDVI profiles derived from SPOT-Vegetation for individual pixels in the Karabash area. Red: sparse (< 15%) vegetation; blue: open (15-40%) needleleaved deciduous or evergreen forest; green: closed (> 40%) broadleaved deciduous forest (> 5m). Circles: 10-daily observations. Dashed line: smoothed 10-daily profile. Solid line: monthly composites



Results

Trend analyses of SDVI depict a general tendency of increasing photosynthetic activity in the area at 10-50 km distance of the mining area, which confirms observations by other authors and can be related to climate change. However, with closer proximity of Karabash (< 10 km), the trend gradually decreases, reaching a steady-state situation at Karabash town. This relative impediment is strongly related to the distance to the smelter and to Pb concentrations observed in lichens. Red-edge positions derived from 32 in-situ ASD vegetation spectra correlate with the slope of the SDVI trend over time, confirming vegetation stress hampers the increase in photosynthetic activity which is observed at larger distances from Karabash.

Conclusions, further work

The first results of the time series analysis of low resolution NDVI images in the Karabash area show that vegetation in the closer surroundings of the smelter is stressed as a consequence of high concentrations of metals in the soils. This situation impedes the increase of photosynthetic activity over time, which is the general tendency in the wider area.

Further research will include the in depth analysis of different phenological parameters, since the increase in photosynthetic activity due to climate change is probably the result of an increase in the length of the vegetative season, while trees in the town are reported to show premature autumn colors. The results also need to be compared with field measurements, wind direction maps, etc. in order to fully understand the mechanisms of mining impact on the vegetation surrounding Karabash.

Environmental impact of mining in Karabash using Worldview-2 imagery and Landsat (Geosense, UNEXE, IMIN)

Introduction

The ImpactMin project, funded by the EC 7th Framework Programme, aims to develop integrated remote sensing tools for the monitoring of environmental impact from mining-related activities. In this study we present results of field sampling, field spectroscopy of soils and vegetation, aerial photography with unmanned aircraft and spectral analysis of Worldview-2, GeoEye, Landsat and SPOT-Vegetation for two study areas, the smelter town of Karabash in the South Urals, and the Rosia Montana gold deposit in Romania. These data are used to map systematic changes in soils and vegetation as a function of time and distance to the centres of mining-related activities.

Figure 16 – Lead-content of Lichen transplants with distance to the smelter

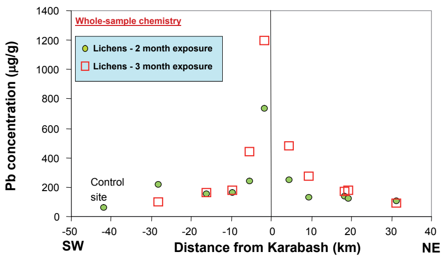
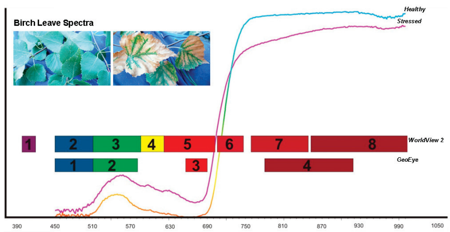


Figure 17 – Examples of spectra of healthy and stressed Birch-leaves



Methodology

Spectral analysis of birch leaves (Figure 17) demonstrates clear trends in vegetation-stress as a function of distance to the smelter, and these trends can be very well identified and monitored using Worldview-2 and Landsat (Figure 18) data, and even at a much larger scale, using Spot-Vegetation.

Spectral analysis of soils also demonstrate very clear mineralogical changes as a function of distance to the smelter, and these changes can be mapped using satellite imagery such as WorldView-2 (Figure 19) and Landsat.

Results

Systematic studies of metal fallout using lichen transplants (Williamson et al., 2004), have demonstrated enhanced lead contents for distances of at least 30 km away from the smelter (Figure 16, Spiro at al. 2004). At 15 km from the smelter the condition of vegetation, soils and fauna visibly start to deteriorate. Irregular clouds of highly acid smoke from the smelter-stack are able to severely impact on vegetation overnight, including local kitchen gardens.

Conclusions

In this study we have demonstrated that changes in soil mineralogy and vitality of vegetation, related to environmental impact of mining can be identified using field spectroscopy. However, these changes can also be efficiently monitored using a variety of satellite imagery. Optimisation of such monitoring is achieved by integration of ground data, unmanned aerial photography, hyperspectral imagery, Worldview-2 imagery and Landsat.

Figure 18 – Image showing increasing NDVI (from blue to red) with increasing distance to the smelter. The inlay shows one of the areas that is considered to be affected by an SO_2-rich plume

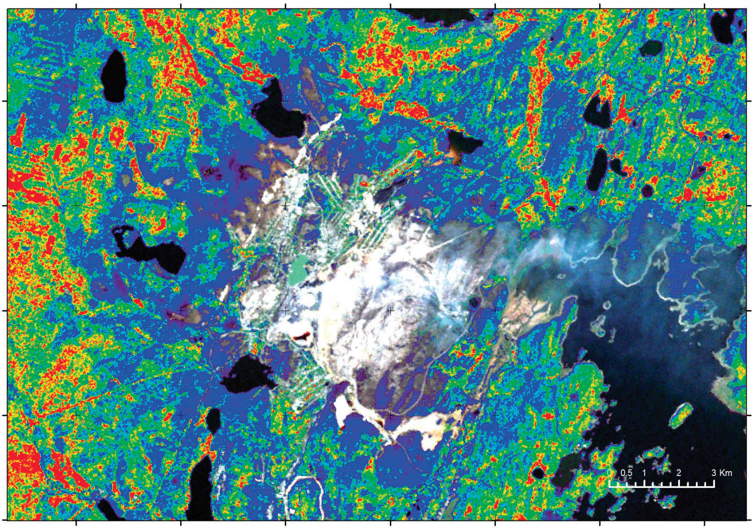
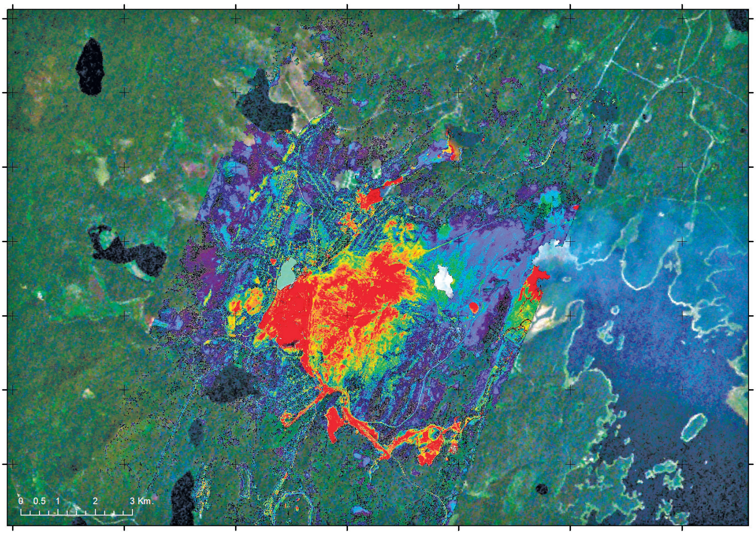


Figure 19 – Iron oxide abundance (red=high, blue=low) in soils using Worldview-2 Band ratios.



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Lulea University of Technology, Sweden *www.ltu.se/?l=en*	LTU
Photon LLC, Croatia *www.photonsplit.com*	PHOTON
University of Mostar, Bosnia and Herzegovina *www.gfmo.ba/index_eng.htm*	GFMO
Institute of Mineralogy, Russian Academy of Science, Russia *www.mineralogy.ru*	IMIN
Babes-Bolyai University, Romania *www.ubbcluj.ro/en*	UBB
Ukrainian Land and Resource Management Center, Ukraine *ulrmc.org.ua*	ULRMC
DMT GmbH & Co.KG, Germany *www.dmt.de/en/home.html*	DMT
Flemish Institute for Technological Research, Belgium *www.vito.be*	VITO