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COMPARATIVE CASE STUDY ASSESSMENT – BEST PRACTICE TOOLS AND METHODS IMPLEMENTATION

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SEVENTH FRAMEWORK PROGRAMME

EXECUTIVE SUMMARY

This report presents the summary of the results of the work done in the four ImpactMin study areas, Kristineberg (Sweden), Mostar (Bosnia-Herzegovina), Rosia Montana (Romania) and Chelyabinsk-Orenburg (Southern Urals)
The overall aim of the ImpactMin project was to identify and develop cost-effective tools and approaches for monitoring environmental impacts of mining-related activities, using a combination of ground-based observations and remotely sensed information.

As the ImpactMin project clearly illustrates, the terms "Mining" and "Environmental Impact" cover a very wide range of situations.
In its strictest sense, the term "Mining" refers directly to the activity of extraction of metallic or non-metallic resources from the Earth's crust (Merriam-Webster). More commonly, the term "Mining" also refers to intricately associated processes such as urbanization and development of primary and secondary industries. Besides those physical aspects, the enormous social implications of mining have to be taken into account, and therefore form an integral part of the ImpactMin project.
Mining has taken place since prehistoric times, is taking place today and will continue to take place in the future, and with our living planet under increasing environmental pressure because of growing population and higher standards of living, it is of great importance that the environmental aspects of mining are responsibly managed. Therefore it is essential that appropriate tools and guidelines are developed to monitor environmental impacts.
Revolutionary technological developments are taking place with respect to measuring devices such as optical and geophysical sensors as well as their airborne and spaceborne carriers. The advanced state of these technologies nowadays allows us to make accurate observations of the planet's surface from a distance, providing spatially and temporally continuous environmental information in a highly cost-effective manner.

The study areas that were selected for this project are very diverse with respect to the nature and scale of the environmental impact. This diversity allowed us to explore the use of remote sensing technology under a wide variety of conditions, and to identify appropriate procedures for combining discrete field data and continuous remote sensing data in order to optimize the relation between efficiency of feature detection and cost of data acquisition and processing.
This study clearly demonstrates that the current state-of-the-art in remote sensing is sufficient for the monitoring of a variety of complex environmental processes in surface water, soils and vegetation, related to different aspects and stages of mining.

Mining areas such as *Rosia Montana (Figure.1)*, that have been active producers for thousands of years, are revisited at intervals throughout their history. As extraction technologies become more efficient, it becomes economic to mine increasingly lower grade ores, leading to the displacement of exponentially growing volumes of rock, increasing the areal extent of mining activities, output of waste and disturbance of the surface, with associated environmental impacts.
Many countries have, as a result of increasing environmental awareness over the last two decades, put strict environmental regulations into place for mining. As a consequence, any mine that opens or

re-opens in such a country will have to comply with strict environmental regulations, and will be obliged to monitor environmental impacts and to predict catastrophic events.
Because remote sensing can provide information over large continuous areas at relatively low cost, it is valuable for monitoring the relatively subtle and slow environmental changes that typically take place over tens of years in the life cycle of most mines. Systematic recording of the situation at regular intervals is important in order to monitor changes during mining and subsequent remediation, and may provide important evidence in environmental disputes.

In the case of abandoned mines such as the *Vihovici Coal mine*, often very little or no remediation has been carried out, and this presents us with hazardous situations, such as free access to dangerous open pits, dumps and tailings with high concentrations of toxic substances, and land instability. Illegal dumping of domestic and industrial waste in former open pit areas creates a health-risk for the public. Urban growth leads to construction of new homes in close vicinity to unstable pit walls, whose collapse could cause many fatalities. Responsible authorities are well aware of the situation and need reliable Earth observation data in order to manage these high risks in a responsible manner.

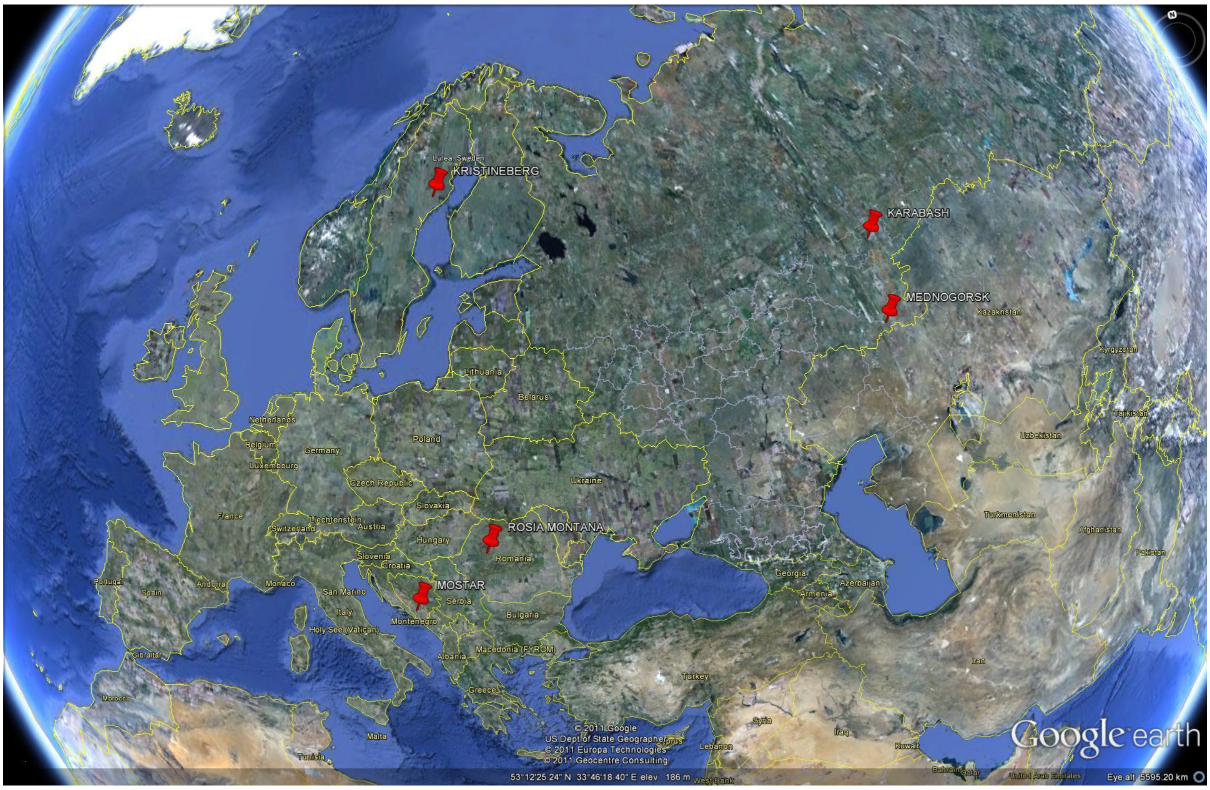

Figure 1. Locations of ImpactMin demo sites.

Mine sites such as those at *Karabash and Mednogorsk* have fallen into the trap of becoming environmental 'monsters' because of a complex set of factors such as failing environmental consciousness , poor planning, economic mismanagement, outdated technology, etcetera. The fact that the local population in these mining centers is at great risk seems to be categorically ignored by the responsible authorities. Access to important information is often denied by the local management, and remote sensing data can therefore provide us with important environmental information that otherwise would not be easily accessible for outsiders.

Mining areas like *Kristineberg* are located in an environmentally sensitive part of the world. Ecosystems in boreal regions are extremely vulnerable and even the smallest footprint of human activity can remain visible for many years. It is crucial that the environmental impacts which mining has on these delicate habitats is investigated in order to understand the extent to which the mining affects wildlife and vegetation. Because of the harsh climatic conditions and generally poor access in these regions, conducting fieldwork to support these investigations is demanding and not without risk. These factors, combined with the short time window for such field-work in this region, create a need to collect relevant information in a fast and efficient manner, and to replace as much as possible the work on the ground by observation from air or space.

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1. INTRODUCTION

As described in the executive summary, the term “Mining-related environmental impact” covers a wide variety of topics. It ranges from the mining itself, to environmental issues directly caused by the mining, (such as acid drainage, dumps, wind-blown dust, damage to the landscape, change of groundwater regime, etc.), to indirect impacts (such as related industries, human settlement, water quality issues etc.), and finally post-mining issues (such as slope stabilization, remediation of open pits and dumps, cleaning-up etc).

Five carefully chosen study areas allowed us to address different aspects of mining-related environmental impacts using a combination of ground and remote sensing methods.
We were able to push the limits of traditional remote sensing data (such as Landsat, Spot Vegetation) and to explore and understand new sources of image data (such as WV2, UAS-imagery, very high-resolution hyperspectral imagery). We were able to collect large amounts of field spectra from tailings, dumps, rocks, soils, stream precipitates, leaves, grasslands etc using the most modern portable field spectrometers. This data, in combination with traditional geochemistry, as well as some innovative “environmental forensics” allowed us to identify diagnostic trends in surface waters, soils, vegetation and air that could be correlated very well with various types of remote sensing data.

During the ImpactMin project large amounts of very valuable data were collected. Most of these data had a clear spatial component and proper spatial data management using GIS-database technology was an important aspect of our work. Such a major investment in data demands standardization and proper data documentation. In order to guarantee appropriate accessibility and integrity of all information, Inspire compliant data documentation was adapted for this project.

2. TEST SITES OVERVIEW

The selection of test sites (*Figure 1*) was done in such a way that we would be able to study different aspects of environmental impact related to mining activities, using different Earth observation techniques and to investigate different methodologies of processing the data:

- Kristineberg (Sweden) (Husson et al, 2012): This is a large district with a long history of mining. It is located in the boreal forest zone and is characterized by a very delicate ecosystem. Our work focused on the assessment of long-lasting environmental impacts by continued release of heavy metals into a delicate ecosystem.
- Mostar (Bosnia-Herzegovina) (Smailbegovic et al, 2012): This lies in an area of abandoned coal mines and partly abandoned heavy industries. There is strong urban development in close proximity to the mine and industrial areas. Underground coal fires continue to burn and cause pollution as well as geotechnical instability. There is significant domestic pollution and poor sanitary infrastructure, partly as a result of recent years of war, causing pollution of surface and ground waters. Our work focused on making an inventory of hazards and risks, which will be used by local stakeholders to support clean-up actions and to mitigate potential future catastrophes.
- Rosia Montana (Romania) (Baciu et al, 2012): This area has seen over two thousand years of gold mining. The last active (open pit) mine closed in 2006, but few remediation measures

have been implemented. Plans to open a new mine in the near future will directly affect an area of more than 15 km^2. Our work focused on characterizing the current situation and on the development of tools for future environmental monitoring.

This work can be used by local stakeholders as a baseline and as a toolset for future environmental monitoring.

- Karabash and Mednogorsk (South Ural Mountains, Russia) (Aminov et al, 2012): These are two industrial areas with over 100 years of mining and smelting. Both areas are highly polluted up to distances of at least 30 km from the smelter. Pollution in the Karabash area is of disastrous proportions. Only 27% of the local population is considered healthy due to severe airborne pollution. Large volumes of acid drainage and untreated sewerage discharge into a freshwater reservoir for the town of Chelyabinsk. A new smelter has recently been built in Karabash, but there are doubts about its effectiveness. Production is expected to double in the near future, and there is therefore concern that this will lead to greatly increased environmental impacts.

  Our work focused on the development of tools that allow long-term monitoring of the impacts on soils and vegetation. The main stakeholders for this work should be the management of the smelters as well as government authorities and environmental/public health organisations. These stakeholders can use our work to monitor the large-scale environmental effects of industrial activities in the two smelter areas, and the effectiveness of any new control measures.

3. KRISTINEBERG TEST SITE

The Kristineberg area is heavily impacted by mining-related activities, although the full extent of these impacts is still not fully established. One river, Vormbäcken, drains large parts of the mining site at Kristineberg. Vormbäcken originates in the Hornträsket lake system (containing the lakes Sörsjön and Norrsjön), close to the mining area at Kristineberg. At 2.5 km downstream of the outlet of Hornträsket, effluents from the tailings impoundment join the river. The river is characterized by a riparian zone, i.e., the transition zone between water and land, of varying width. Riparian zones have important ecological and regulatory functions in aquatic systems. Quantifying plant biomass and related factors, such as geochemistry, has so far been a major challenge at the scale of entire riparian zones. Here, we applied high resolution (5 cm) remote sensing with an unmanned aircraft system (UAS) in combination with field sampling during the vegetation growth periods in 2011 and 2012. We performed the study at three locations (L1–L3) along Vormbäcken, 7, 15, and 23 km downstream of Hornträsket. We quantified diversity and biomass of riparian vegetation at three locations (river stretches of 320 m length) along the mining-impacted river Vormbäcken and estimated the amounts of metals (Cd, Cu and Zn) stored in the dominant species. At each location, a 50 × 20 m area extending along Vormbäcken was sampled. Vegetation was sampled in five 4-m-wide belts (I–V) parallel to the river bank. A vegetation map at the species level was derived from aerial images acquired with the UAS in combination with field sampling of species composition and cover (*Figure 2*). Assessments of biomass (herbaceous and shrub vegetation) and metal contents were derived by combining the vegetation maps with results from field sampling.

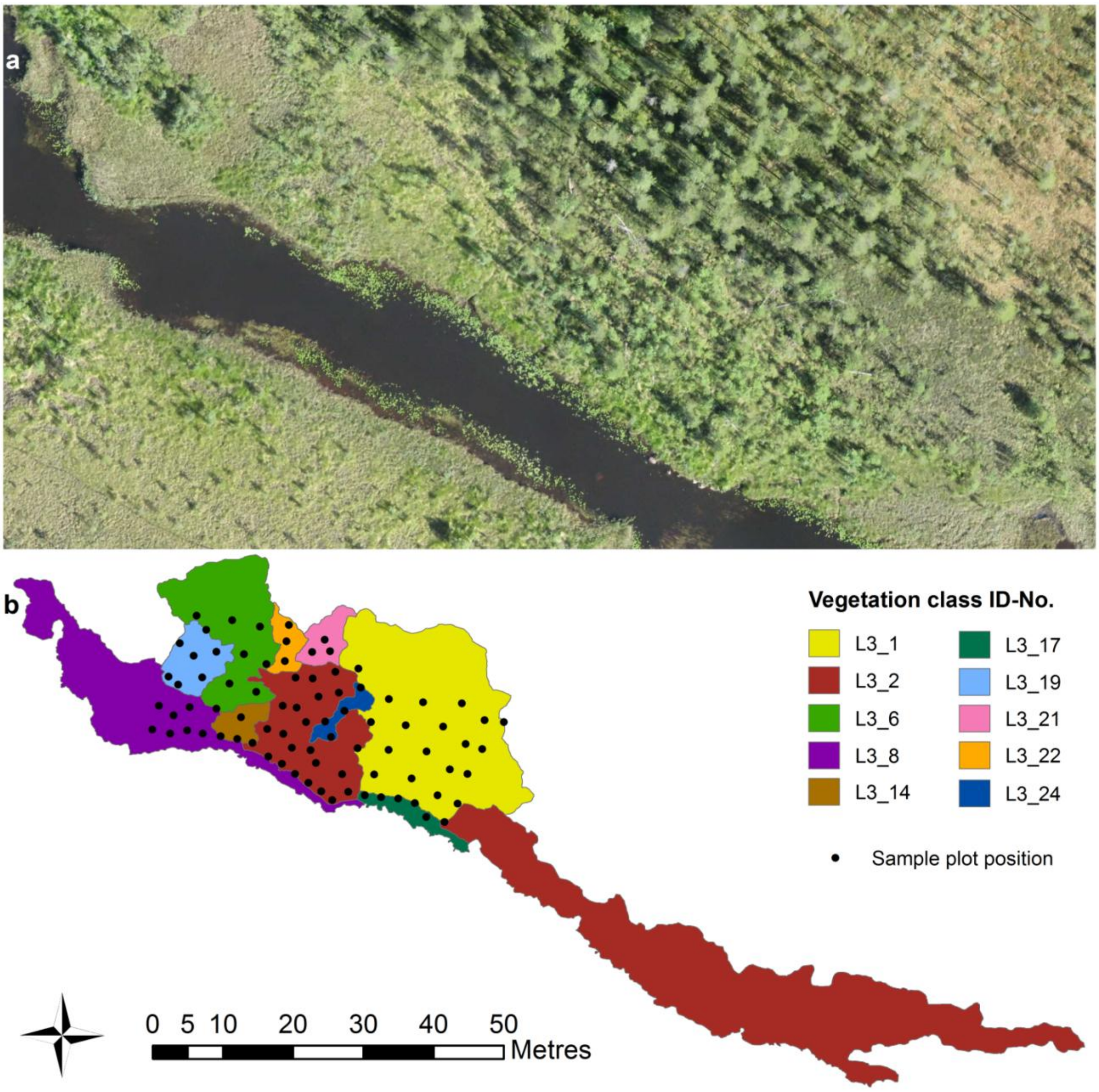

Figure 2. Core zone at location L3, a) orthoimage and b) vegetation map with sample plots

Concentrations of Cd, Cu and Zn decreased with increasing distance from the source of pollution in Vormbäcken. According to the standards of the Swedish Environmental Protection Agency, Cd and Cu concentrations ranged from high to moderate and Zn concentrations ranged from very high to moderate. Assuming the concentrations of Cd, Cu, and Zn in Vormbäcken remain constant throughout the growing season, the total amounts of Cd, Cu and Zn transported by Vormbäcken in May – August 2011 ranged from 3.7 kg for Cd at L1 to 2193 kg for Zn at L3.

Concentrations of Cd, Cu and Zn in riparian vegetation varied among species. *Salix* sp. contained the most Cd and Zn at all locations. Most pronounced was the difference between *Salix* sp. and *Carex rostrata/vesicaria*, which was significant in five of nine cases. *Salix* sp. also differed from *Eriophorum angustifolium* for Cd at L3 and from *Molinia caerulea* and *Trichophorum cespitosum* for Zn at L3. Another significant difference was *Carex rostrata/vesicaria* – *Carex nigra* ssp. *juncella* for Cu at L1. Concentrations of Cu, combined for all locations (including Hornträsket), were higher in vegetation from the river channel than in riparian vegetation that occurred in belt I. Cd, Cu and Zn concentrations, combined for all species in river channel vegetation, did not differ between locations.

The riparian zone at L1 was composed of 31 vegetation classes of which 12 were represented in the core zone. At L2, we identified 12 vegetation classes of which two were represented in the core zone. Location L3 was similar to L1 in terms of vegetation types identified (27 vegetation classes of which ten were represented in the core zone). The vegetation class-specific mean biomass ranged from 0.38–2.22 kg m^{-2}. L1 was the most productive location with 9.4 t ha^{-1}, followed by L2 (7.5 t ha^{-1}) and L3 (5.2 t ha^{-1}).

The total amounts of Cd, Cu, and Zn stored in the dominant species of riparian vegetation were 33, 801, and 13,620 g, respectively. Compared with the total amounts of Cd, Cu, and Zn transported by Vormbäcken during the growing season at L1, L2, and L3, riparian vegetation stored at a maximum 0.7% of Cd (L1), 0.3% of Cu (L2), and 0.4% of Zn. The total amount of vegetation-bound Cd decreased with increasing distance from the source of contamination. The maximum amounts of Cu and Zn were stored at L2.

Salix sp. which was dominant at only one location, contained only 3% of the total dominant-species biomass but 73% of all Cd and 24% of all Zn. *Carex rostrata/vesicaria* contained 85% of all Cu, 66% of all Zn, and 80% of the total dominant-species biomass. At L1, *Salix* sp. accounted for 99, 65, and 92% of the total amounts of Cd, Cu, and Zn, respectively, and for 61% of the total dominant-species biomass. At L2, *Carex rostrata/vesicaria* accounted for 99% of all Cd, Cu, Zn, and biomass. At L3, *Molinia caerulea* contained most Cd and Zn (56, and 41%, respectively), while *Carex nigra* ssp. *juncella* contained the most Cu (39%). At L3, *Salix* sp. was not among the dominant species. However, the amounts of Cd and Zn stored in *Salix* sp. were equivalent to77 and 22% of the total amounts of Cd and Zn stored in dominant species at L3.

There was no consistent trend in the change of plant diversity along Vormbäcken (*Figure 3*). Plant diversity was lowest at location L2, irrespective of diversity index, and didn't differ between L1 and L3. At most, there were 23 plant species (location L3). At location L2, there were in total only six plant species and two of the studied belts included only two species of which *Carex rostrata/vesicaria* was present in both belts.

Our study supports previous studies showing that the closed mines upstream of the Kristineberg mine are the main cause of the high concentrations of metals in Vormbäcken.

The flexibility of the UAS (transportable and operable by a single person) permitted us to carry out remote sensing at exactly the desired locations and times, without being dependent on external image providers. The sub-decimetre resolution (5 cm) of the produced orthoimages allowed for detailed vegetation classification and high-accuracy mapping throughout the riparian zone. It was possible by visual interpretation to delineate vegetation stands on the images and to relate the specific optical appearance of the stands to species compositions derived from field visits, including tree, shrub and herbaceous species as well as non-submerged aquatic species. Because of the narrow spatial extent of riparian zones (often <30 m), high spatial resolution has previously been found to be the main feature needed to improve riparian vegetation classification. Previous remote sensing approaches for riparian vegetation have been unable to resolve herbaceous and shrub vegetation at the species level, mainly due to the inadequate spatial resolution of available remote sensing data or limitations in automated image classification. Discrimination has so far been successful between various land cover/use classes such as agriculture, forest, grass, and shrubs, between a small number of tree/shrub species, including invaders, and for single invasive herbaceous species. Our study demonstrated that plant species differ significantly in their uptake of trace elements. In addition, the studied vegetation stands were generally characterized by multiple species, single-species stands occurring mainly at L2. Biomass assessments conducted by remote sensing using satellite images of varying spatial resolution (1–30 m) have successfully been applied to large-scale single-species stands in wetlands, and in assessing total wetland biomass. Applying such traditional remote sensing with satellite images to the riparian zones studied here, however, would overlook the high spatial variation in vegetation stands, biomass, and trace element uptake. The method presented is suited for a more accurate assessment in terms of vegetation class- and species-specific biomass and trace element contents. This allows for detailed modeling of nutrient and trace element cycling in the riparian zone and of interactions with the adjacent aquatic system. Compared with the large areas covered by satellite-based wetland studies (6–3000 km^2), the reach of our method is limited to river stretches of several hundred meters in length. The two main reasons for this limitation are: a) increasing uncertainty with increasing distance from the core zone, and b) the considerable time required for visual image interpretation, especially manual mapping, and fieldwork to train the interpreter and for biomass sampling. The first reason applies to areas with large spatial variation in vegetation. This variation leads to the occurrence of vegetation classes with species compositions that differ from those of any core zone vegetation class. However, this could be compensated for by distributing the sample plots over a larger area. Regarding the second reason, to make fieldwork more efficient, it could be divided into two steps. In the first step, species composition and cover could be investigated as a basis for vegetation mapping. After the validation of the vegetation map, biomass could be sampled by randomly selecting a certain number of points in each vegetation class, reducing the total number of samples needed. However, samples would then be distributed over a larger area, increasing the time needed for sampling.

Biodiversity and species composition of vegetation appeared to be unaffected by potential contaminates in Vormbäcken. The low diversity of location L2 is probably due to topography. This location is rather flat and hence probably more regularly flooded compared to the other two locations. Regular flooding results in the exclusion of plant species otherwise found in the riparian zone, e.g., *Molinia caerulea*, *Calamagrostis canescens*, and *Andromeda polifolia*.

In planning phytoremediation measures, it is crucial to know the extent to which contaminants accumulate in different plant species. Harvesting of selected riparian species before senescence could then be applied to prevent the release of the accumulated metals to the water. In particular, our study revealed that the removal of *Salix* sp. would be an efficient way to remove most of the vegetation-bound Cd and a considerable amount of Zn by only removing a small portion of the biomass. Similar results concerning the potential of *Salix* sp. to extract Cd and Zn from contaminated soils were obtained in other studies. However, to considerably reduce the burden of metals to Vormbäcken, phytoremediation needs to be applied to river sections that are longer than the studied 320-m stretches.

The application of UAS in addition to field sampling for riparian vegetation monitoring has great potential to improve the accuracy of assessments of biomass and trace element/nutrient content at the scale of entire riparian zones.

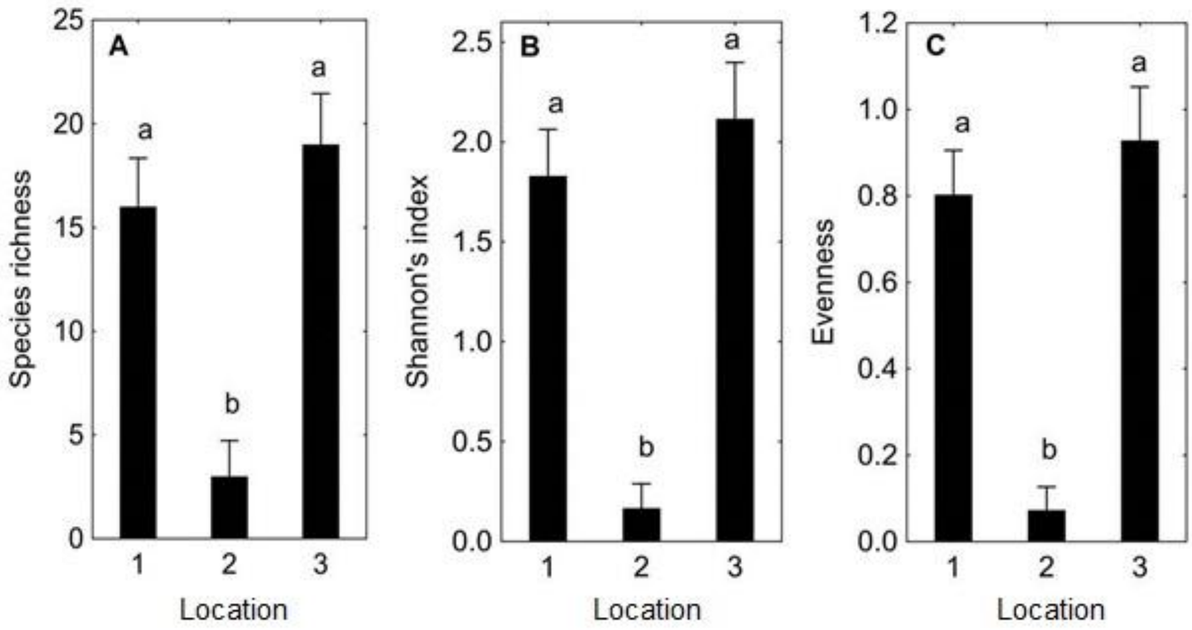

Figure 3. Biodiversity along the three locations at Vormbäcken. Diversity was calculated per belt. Different letters indicate significant differences in diversity (p<0.01).

4. MOSTAR TEST SITE

The City of Mostar, Bosnia and Herzegovina, situated along river Neretva in a narrow inter-mountain valley has been an important crossroad for thousands of years. Significant deposits of brown coal were discovered in the mid-19th century and the mining began soon afterwards to supply much needed coal for railroads and industry springing up in Bosnia and Herzegovina in the Austro-Hungarian Empire. The mining of coal continued almost until the outbreak of hostilities in Bosnia in the 1990s. In addition to coal mining, Mostar was also a center of bauxite-ore processing and aluminum-refining supporting the defense and aircraft industry in the former Yugoslavia.

Mostar Valley now contains at least three sites of possible environmental impact: the abandoned Vihovici Coal Mine, the bauxite-ore waste ponds (red-mud depot) and the City of Mostar itself, rapidly expanding onto the former mining/industrial lands. Industrial facilities have fallen into disrepair and the city itself remains much divided along ethnic lines as a result of the 1992-95 conflict resulting in continued degradation and lack of coherent vision. Of particular interest to the ImpactMin project are the coal mine and the bauxite-waste ponds as the city of Mostar itself is situated in a karst environment with fragile aquatic ecosystem dependent on the river Neretva, which is the main source of water for both Herzegovina as well as southern Croatia.

Near simultaneous acquisition of airborne hyperspectral (HSI), ground-spectral and water-quality measurements coupled with the high-resolution UAS imaging took place in Mostar during May/June of 2011, culminating almost 16 months of background research, identification of suitable detection technologies and mission planning. The primary goal was to correlate the various datasets to establish environmental impacts, but also to use various datasets to improve the overall quality of the acquired airborne data using the ground-based measurements.

4.1. Site Goals

The acquired imagery and data were the first of their kind in Bosnia and Herzegovina and the Western Balkans, in general, and the first real empirical data collected in Mostar for over 20 years. The technology used in the course of the survey was considered cutting-edge and best suited for a complex network and relationship of water and ground targets. The active participants in the Mostar Valley site study locality were Photon llc., Faculty of Civil Engineering at the University of Mostar (Gradjevinski Fakultet Mostar, or the “GFMO”), University of Exeter, Geosense llc. and VITO, the Flemish Insitute for Technology Research (the “VITO”) . All of the participants have contributed various levels of information towards the comprehensive document detailing the work performed at the Mostar Valley study site presented within the ImpactMin Report.

The main goals of the survey campaign within ImpactMin were:

1. Ascertain the success of 2007-2009 remediation and current state at the Vihovici Mine site and point to the areas that are yet to be addressed or have been missed / re-activated from the first remediation attempt
2. Establish the baseline condition of the Neretva river, before Vihovici, after Vihovici Mine, below the city of Mostar and below the industrial area in the southern Mostar Valley (aluminium and agricultural areas).
3. Establish the current environmental baseline for the Mostar Valley and preliminarily evaluate other sites that may have problematic occurrences in the future (i.e. red mud storage which was added as a topic during the project in the light of the Hungarian disaster).

The main advantages of the airborne approach are the abilities to resolve surface detail in high spatial and spectral resolution, over relatively wide areas and low-to-moderate overall cost of acquisition. These qualities make it increasingly popular with industry in mineral exploration, and establishing types of surface cover, distribution of pollutants, anomaly identification and search/recovery. The spectral information provides a fairly robust approach in extrapolating composition of the particular imaged target and its classification or isolation from the background. Furthermore, by using the sheer quantity and redundancy of airborne data, it is possible to increase the level of confidence in target unmixing and detection, reinforcing the advantage over other sensing methods in terms of confidence, time and overall cost effectiveness. Therefore, the airborne component fills the important niche between the in-situ measurements and spaceborne EO sensing.

The Mostar case study is unique because it encompassed a variety of sites in an urban corridor with the satellite, airborne, lightweight UAS and ground/water in-situ sampling. All of the datasets had a particular role and niche to fill in the GEOSS-compliant environment.

Vihovici Mine Site and red mud storage facility are the two main areas of mineral impact concern in the Mostar Valley. Vihovici Mine is located close or within the urban zone, while the risks of the red mud storage are yet to be fully appraised. The proximity of the sites to the urban zone and the important watershed of the river Neretva have called for a detailed study of both sites and their impacts on the environment. A combined campaign using variety of cutting-edge remote sensing assets and analysis tools have yielded the results presented below.

4.2. Vihovici Mine Site (figure4)

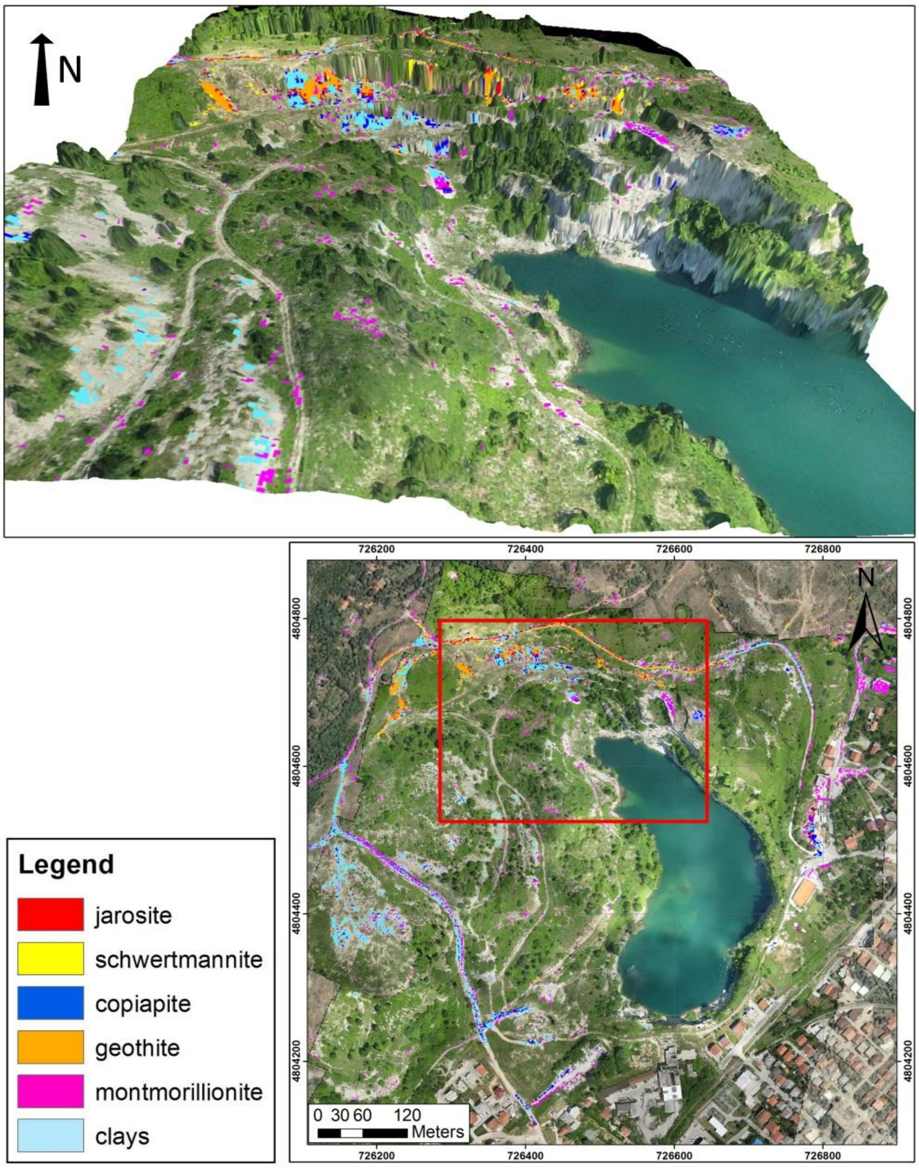

Figure 4. Mineral map and topographic model generated from UAS imagery showing surface mineral concentrations: most important are significant clusters of sulfate minerals (e.g. jarosite) on the northern end.

- The hyperspectral survey has been successful in detecting iron oxide, hydroxide and sulfate minerals that may have a negative effect on the environment. It was determined that hyperspectral data can detect the subtle changes in surface mineralogy as a result of coal-seam fires (*Figure 5*).
- Satellite and airborne HSI data suggest that there are increased concentrations of Fe-minerals (hydroxide and sulfate) in the surface environment at the Vihovici mine site and red mud storage facility, and most can be traced back to the resource extraction and/or processing activity.
- Fe-minerals at Vihovici appear to be mainly confined to the former burn area and waste piles, with the increased concentration of sulfates near the areas of former industrial waste (battery dismantling) and burn areas, but their overall impact appears to be moderate and confined to the mine site (*Figure 4*).

- A much larger potential impactor is the continued, illegal dumping of industrial and household waste at Vihovici Mine and the surrounding areas, which are difficult to control and enforce. We have successfully used a combination of high-resolution imagery from the UAS and airborne hyperspectral data to map and delineate waste accumulations on site (and beyond).
- There are also moderate-to-high concern zones of geotechnical risk developing around the Vihovici mine-site which may be at risk of collapse resulting in a significant mass-wasting of material along the northern segment of the open pit into the pit lake and a potential "tsunami-effect" that could result in lake waters being pushed through the southern embankment, flooding the city with water, waste and debris.

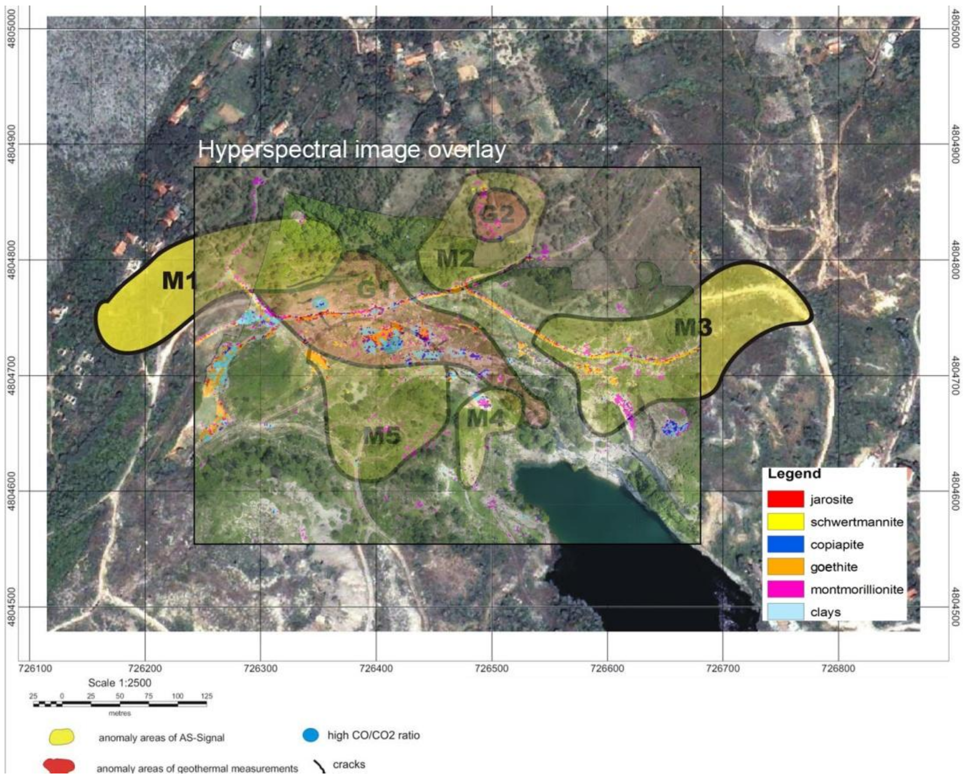

Figure 5. Hyperspectral mineral map overlain on the data from the 2009 remediation effort to identify the zones of burning. Note that sulfate concentration directly correlates with the identified anomalous areas of geothermal measurements (M) using ground magnetic data.

4.3. Red mud depot at Dobro Selo

- A study of the red mud depot (*Figure 6*) was added to the project as an additional potential hazard in the light of the Hungarian disaster at the Ajka Alumina Plant.
- We have modified and adapted the red-mud spectral reflectance index, first used during the Hungarian disaster to match the spectral parameters of red-mud in Mostar, and have correlated the reflectance changes to the particular compositions of the bauxite ore used in Mostar.
- Fe-hydroxides, associated with bauxite/alumina refining at the red mud Storage Lagoon suggest drying and dispersal beyond the containment area and warrant closer inspection, particularly for the risk of heavy metal toxicity and naturally-occurring radionuclides. These may have been present in the ores used, as suggested from the different spectral reflectance phenomena.

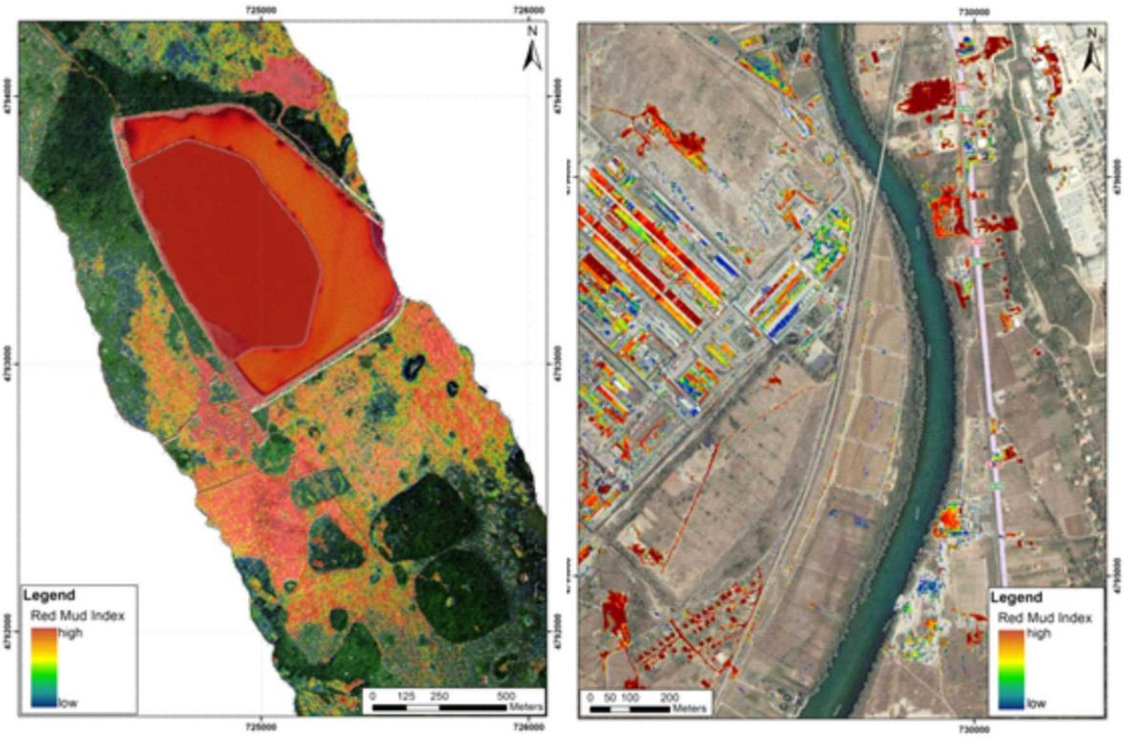

Figure 6.Red mud storage pond at Dobro Selo, south of Mostar and the section of Aluminij factory showing the location of former crusher and alumina production facility with the derived Red Mud Index.

4.4. Monitoring water quality using hyperspectral remote sensing

This part of the study focused on the analysis of surface water quality in the surrounding area of the Vihovici Coal Mine. At the present time, the open mine is filled with surface water which flows into the nearby Neretva river, via surface or subsurface pathways. Water quality is particularly important because the water from the Neretva is used as drinking water by the city of Mostar and cities further downstream. The main objective was to apply airborne hyperspectral imagery to identify the zones of increased nutrient load, increase in dissolved solids or other phenomena suggestive of surface or subsurface contamination of the karst watershed. Along with the airborne campaign, which was carefully planned to avoid sun glint phenomena, an extensive field campaign was organized to take water samples for lab analysis and measure water reflectance (Rw) with the ASD spectroradiometer, according to protocols described in Mobley (1999) and Knaeps *et al*. (2012). The relationship between the Rw field spectra and the different water quality parameters (WQP) shows clearly specific wavelength regions with high correlation (R^2>0.7) with the WQP under investigation (*Figure 7*). For TSM, the highest correlation was found for wavelengths 550 nm to 600 nm. For CHL-a these regions are from 480 nm to 575 nm and around 675 nm, corresponding to values found in the literature. These are also highly correlated with the regions found for nitrates and total nitrogen, as these nutrients induce the growth of phytoplankton, and thus CHL-a, in the water. As the airborne Rw spectra were found to be very similar to those measured in-situ, the linear regression could be inverted to calculate water quality maps (*Figure 8*) for each parameter under consideration. The validation of these maps showed good correlation and small RMSE for most of the parameters.

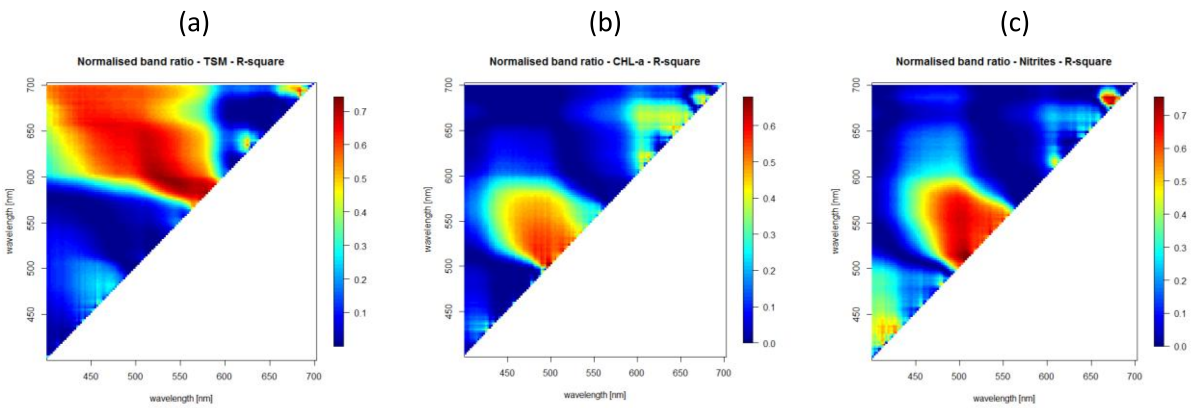

Figure 7.Band ratio significance plot: R2 of the linear regression between the band ratio and TSM (a), CHL-a (b), Nitrites (c).

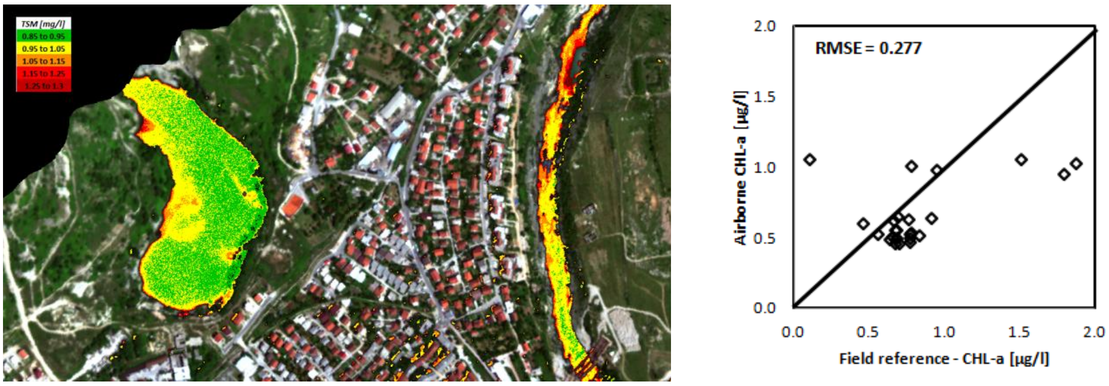

Figure 8.Results of the Mostar Water quality map and ground validation: CHL-a.

4.4.1. Conclusions of the water quality study

- In-situ analysis of water data suggests that the observed water bodies are relatively clean and consistent compared with what would be expected for water bodies in an urban environment, with only rudimentary wastewater treatment.
- We have made suitable algorithm modification to the map of Total Suspended Matter (TSM), chlorophyll (CHL-a) and select nutrients based on remote sensing imagery. For TSM, a highest correlation is found for wavelengths 550 nm to 600 nm. For CHL-a these regions are from 480 nm to 575 nm and around 675 nm. These are highly correlated with the regions found for nitrates and total nitrogen, as these nutrients induce the growth of phytoplankton, and thus CHL-a, in the water.
- A majority of the observed effects from the increased concentrations of chlorophyll/nutrients in the Neretva river occurs within the narrow urban corridor, with the city of Mostar being the largest single polluter of this type.
- There are no observable “spikes” in the data that would suggest direct negative impact from the mineral extraction areas besides the non-point source and untreated sewage-runoff sources, at the city of Mostar.
- Increased concentrations of heavy metals (observed from the chemical analysis of watersamples) do occur within the Vihovici pit lake and downstream, but are difficult to quantify

due to relatively few measurements. The fast-moving Neretva river and constantly-changing waters do not represent the best medium for quantifying this type of measurement and future attention should therefore be directed to analyzing sediment for heavy metals.

- At the cessation of activities, most of the environment has naturally cleaned itself with the potential pollutants remaining encapsulated in the sediment.
- The linear regression analysis between the band ratios and the concentration measurements showed a very strong R^2 for nitrates (0.82) and TSM (0.72) , strong R^2 for CHL-a (0.59 and a weak R^2 for cadmium (0.19).

4.5. Mostar, urban area

- The urban area was imaged only as a background to other datasets discussed above.
- The areas with abandoned industrial facilities and/or alumina refining facilities do show an increased quantity of iron oxide and sulfate minerals resulting from the former activities. This is particularly notable at the aluminum factory, south of Mostar, where waste-product red mud was used as a filler.
- Open lots and former industrial areas, as well as sites left unoccupied following the 1992-1995 conflict are being used as illegal household waste-disposal areas.

4.6. Vegetation

4.6.1. Spatial unmixing based data fusion for a more detailed monitoring of vegetation status

Miniaturization of sensors makes it nowadays possible to capture colour images from 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 hyperspectral 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.

We apply the spatial unmixing technique proposed in Zurita-Milla, 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 end members 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.

VITO implemented and applied the spatial unmixing technique 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 a 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. A Normalized Difference Vegetation Index (NDVI) is calculated from the 5^{th} and 8^{th} 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 *Figure 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*.

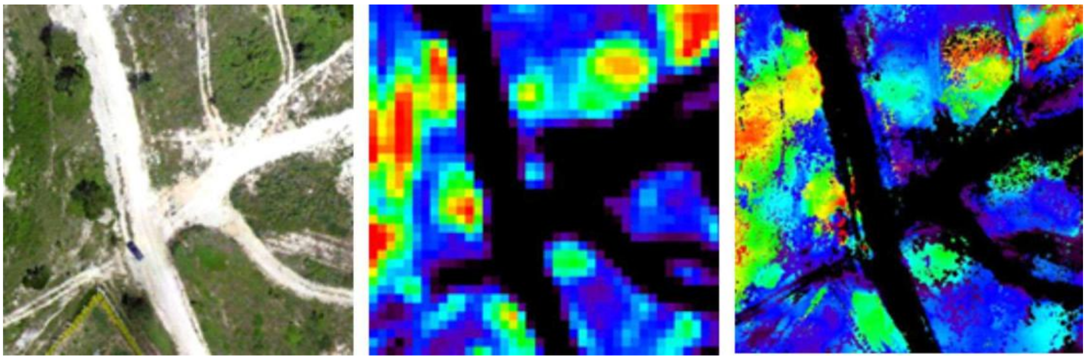

Figure 9.Visualization of the (a) high spatial resolution UAS RGB colour image, (b) NDVI of WV-2, high spectral resolution image, (c) NDVI of the resulting high spatial and high spectral resolution, spatially unmixed image.

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.

4.6.2. Conclusions for Vegetation

- Vegetation stress was also investigated as a supporting element to mapping mineral-related impact at the Vihovici mine site and red mud storage facility.
- Both areas have been rapidly overgrown by vegetation. The presence of water, in an otherwise dry environment, appears to have a positive effect on vegetation growth, regardless of the presence of contaminated soils (e.g. increased sulfate concentration).
- There are several notable areas at the Vihovici mine site where there is notable vegetation stress (near an abandoned battery dismantling factory, burn sites/gas fumaroles and illegal waste disposal areas). Vegetation stress is notable along the areas of abundant sulfate minerals near the burn-sites at Vihovici or along the path of the continued dispersal of gasses (H_2S, CO_2) resulting from the still smoldering coal seams, remaining after remediation.

4.7. Problematic issues identified by the project:

- Continued illegal disposal of household and industrial waste in the abandoned mining and industrial facilities,
- Unstable slopes at the collapsing Vihovici open-pit mine or pit walls, which may result in mass wasting.
- Potential for re-ignition of burning coal seams, now left smoldering following the end of the remediation/extinguishing campaign. Continued smoldering of the coal seams and gas emissions

from the fumaroles resulting in an observed vegetation stress are an indication that the seams may reignite nullifying the two-year extinguishing effort.

- Dispersal of red mud dust during dry intervals or portions of the red mud lagoon, south of Mostar, near the village of Dobro Selo (*Figure 6*).
- Now self-mitigating problems which MAY come back to the forefront if some radical changes occur to the environment (e.g. collapse of the pit wall at Vihovici, earthquakes, brush fires etc.), which may re-mobilize the tenuously-stabilized elements.

4.8. Impact of mineral-related activities on the environment and suggested courses of action:

Mostar presents a good area for studying natural reclamation of former industrial and resource-extraction sites with only moderate anthropogenic-influence on acute problems (e.g. coal seam burning). Observed environmental hazards are:

- Surface mineral contaminants (oxides, hydroxides and sulfates): moderate
- Surface solid waste pollution: moderate to high
- Geotechnical hazards: high
- Water pollution: low to moderate (mainly urban)
- Vegetation stress: low to moderate

4.9. Recommendations for remediation and follow-up efforts :

- Solid-waste cleanup, remediation and enforcement
- Detailed evaluation of geotechnical hazards at the Vihovici mine
- Evaluation of red-mud dispersal at the disposal site
- Analysis of river/stream sediments, near the former extractive/industrial sites, for heavy metals, PCBs and PAHs.
- Monitoring and evaluation of smoldering coal seams; control plan if there is evidence of re-ignition.

4.10. Concluding Remarks / Benefits

It is of extraordinary importance for the citizens of Mostar that the ImpactMin project addressed the sites of environmental concern and that the European Commission had funded it, especially the data collection, which should finally help dispel all kinds of information-manipulations that have existed for the last 20 years, related to the former industrial sites in particular.

The ImpactMin study has realistically addressed the existing and identified environmental issues based on the exact, empirical data gathered by the most contemporary technologies and methods, which were analyzed by a multidisciplinary team throughout the site report. The targets imaged in the Mostar Valley have fallen into disrepair and neglect following the cessation of industrial operations there and outbreak of the hostilities in 1992-95, and have never been repaired. Two decades of neglect have resulted in the sites reverting back to the natural environment, often in an unstable state, rather than in equilibrium, posing risks to local communities.

We strongly believe that the results of this study will force short and long term actions by the local government with an additional help from regional and international institutions and organizations.

As part of the goals of ImpactMin we have commenced dissemination activities in Mostar and other mining-industrial cities in Bosnia and Herzegovina (e.g. Zenica, Tuzla) to present examples and offer learning opportunities on how to address other similar problems.

Furthermore, the data collected at Mostar have provided fertile material for masters and doctoral studies in Bosnia and Herzegovina and the wider region. The research on the Mostar Valley has also provided a subject for further academic research that will result in peer-reviewed articles on red-mud spectroscopic detection and comparisons, hyperspectral mineral mapping of surface anthropogenic alteration as well as water quality studies in Neretva and other trans-boundary water bodies in the region (e.g. Sava River study, a direct analogue to the Neretva River study in ImpactMin).

The research has gathered other interested parties and academia willing to share, collaborate and advance the science of environmental impact monitoring.

5. ROSIA MONTANA TEST SITE

5.1. Site description

Romania has inferred gold reserves of about 700 tonnes, representing about one third of the European total geological reserves of gold. Although Romania has an important potential in gold mining, all the mines were closed prior to 2007, due to economic reasons. The greatest share of the gold reserves is located in the “Golden Quadrilateral” mining district, an area of about 900 sq km, hosting several deposits of various dimensions. Many of them have been extensively mined in the past, but important reserves are still available. Rosia Montana is the biggest of them, and one of the biggest in Europe, with proven reserves of 10 million ounces (more than 300 tonnes) and almost five times more silver.

Rosia Montana offers unique opportunities for environmental research related to mining activities:

1. The history of mining extends over 2000 years, going back to Roman times. Ore was extracted exclusively from underground workings until 1970, resulting in some 140 km of galleries from different periods of time. Portions of the Roman galleries are still in place. After 1970, mining operations were developed in a large open pit in the Cetate area, followed by Carnic area.

   This very long period of mining activity has produced a complex environmental footprint, where the effects of the different time periods are overlapping. Various mining techniques have been used, from the Roman galleries dug by hammer and chisel, to the large open pit Cetate.

2. Mining operations ceased in 2006, and currently there is no extraction activity on site. Consequently, during the last six years, the environment appears to have reached a steady state (*i.e*. environmental parameters have relatively stable values over time; no major changes are expected in a limited time horizon, if the environment is not explicitly disturbed).

3. Under the pressure of current demand for raw materials, and boosted by the increasing price of precious metals on the international markets, mining in the area may restart. A new mining project has been proposed by the Rosia Montana Gold Corporation (RMGC). A detailed Environmental Impact Assessment (EIA) study has been submitted by the company to the national authorities for obtaining the permits to operate. The current state of the environment is described in a Baseline Report (www.rmgc.ro). The work performed by the ImpactMin project team does not only contribute to an accurate definition of the environmental baseline, but it also offers a number of tools to monitor certain aspects of the potential environmental impact using cost-effective remote-sensing based tools and approaches.

In the past 12 years the current owner of the depositnew mining project, Rosia Montana Gold Corporation (RMGC), has collected a substantial volume of environmental data. However, these data were mostly collected as discrete points in the direct surroundings of the deposits, and were not meant to serve as a basis for remote sensing work, which requires a more systematic way of sampling.
A study like ImpactMin, concerning the relations between mining and subtle surface variations in an area characterised by a highly complex interaction between human, geologic/geomorphologic and climatic factors has not been done in Romania before.

5.2. Site goals

Our work focuses on observing and understanding the significance of more subtle indicators that could describe the potential gradual environmental changes over time as a result of renewed mining, using innovative remote sensing approaches such as Very High-resolution hyperspectral imagery, Very High resolution Satellite imagery and Ultra-High resolution UAS-imagery.
Within the context of this work, we have paid particular attention to factors such as degradation of soils and grasslands, and the identification of vegetation stress as markers for increased environmental pressure. A thorough understanding of these fundamental parameters is a prerequisite in order to be able to establish a remote sensing toolset for the environmental monitoring of this region.Ultimately our aim was to develop remote sensing tools that will allow us to monitor these changes in a consistent and cost-effective manner.
In order to be able to assess the spatial extent of potential environmental impact, the investigated area (> 50 km^2) is much larger than the area directly affected by the planned future mining area (< 15 km^2, see). Extending the study area to the adjacent catchment areas ensures that we will be able to compare affected areas and unaffected reference areas over longer periods of time.

To this purpose, an integrated approach was developed, consisting of acquisition and interpretation of very high-resolution airborne hyperspectral imagery, UAS visible imagery and very high resolution satellite imagery,supported with field spectral measurements and chemical analysis of soils, rocks, grass-lands, trees, drainages, open pits, dumps and tailings (*Figure 10*).

5.3. Site conclusions

- The Rosia Montana area is currently in a steady environmental state. There is no active pollution.
- Chemical and mineralogical background values show trends that are related to mineralisation and hydrothermal alteration, but do not indicate wide-spread pollution as a result of past mining.
- Spectral analysis of Birch-tree leaves indicates vegetation stress related to mineralisation
- Our study indicates that the grass-land ecosystems are potentially most vulnerable to environmental impact, and therefore we focused on detecting degradation of grasslands using field spectroscopy and remote sensing imagery
- Given the small scale complexity of the grassland ecosystems, spectral and spatial resolution of the remote sensing imagery are key parameters
- Ultra High-resolution UAS-imagery significantly improves our ability to interpret airborne hyperspectral imagery and very high resolution satellite imagery such as WV2
- Spectral analysis of WV2, hyperspectral and UAV imagery alllows us to map variations in soil quality at different levels of detail and accuracy.
- The information collected during the ImpactMin study provides an excellent baseline for future environmental monitoring
- Harmonized data calibration and analysis methods were developed to enable standardised time-series analysis for long-term monitoring of key-environmental parameters

5.4. Characterisation of Rocks, Soils and Drainages

The starting point of this study was the chemical and spectral characterisation of rocks, soils and drainages. This was necessary in order to be able to identify mineralogical and chemical background values, and to make an estimation of the current extent of anomalously high concentrations of pollutants such as heavy metals and acid forming minerals.
In order to characterize the natural distribution of metals and minerals in rocks, we sampled rocks in three different areas

a. The deposits:
   To this purpose we collected rock samples in the deposit for chemical analysis and mineralogical analysis on the basis of spectral contact measurements.
b. Rocks outside of the deposit but possibly still affected by the hydrothermal alteration system:
   To this purpose we collected rock samples in the surroundings of the deposts for chemical and spectral analysis
c. Rocks oustide of the hydrothermally affected zone:
   For that purpose we collected rock samples on a regional scale for chemical and spectral analysis.

Except for the deposits, the proportion of rock-outcrop in this area is limited. Most of the surface is covered with soil of variable thickness and maturity. It is therefore very important to understand the relationship between rocks and the soils that formed on top of these rocks. This is a very complex

task, as the relationship is often not very straighforward, as it is influenced by factors such as geomorphology, groundwater, agriculture, etc.
In order to obtain a sample set that would be statistically representative for the natural variation of soils within specific zones, we collected soil samples along a large number of profiles on the deposits, their surroundings, and on a regional scale, for chemical analysis, pH-measurements and spectral contact measurements (*Figure 10*).
On the basis of our measurements we can clearly identify correlating spectral/mineralogical (goethite, clay content) and chemical trends (pH, certain heavy metals) in rocks and soils as a function of their proximity to the known deposits.

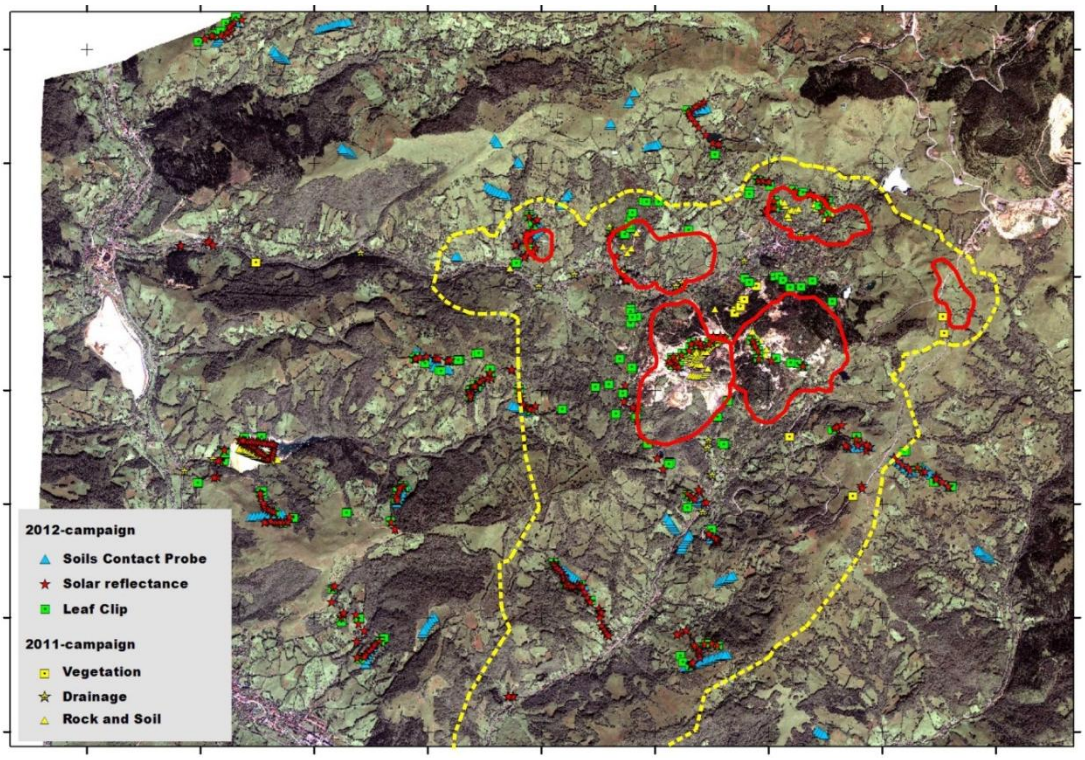

Figure 10.Locations of spectral and chemical samples from field campaigns in 2011 and 2012. Red polygons indicate the approximate outlines of the pits planned by RMGC. The yellow dashed line indicates the limit of the planned Industrial Area.

In addition to the rocks and soils, we also sampled sediments and chemical precipitates from a number of streams for spectral and chemical analysis. While we found very interesting patterns and correlations between the spectral properties and the chemical composition of the stream samples, we decided not to carry on with this topic, because most of the streams were overgrown with dense vegetation, and hence not visible in remotely sensed imagery.

5.5. Characterisation of vegetation.

For practical reasons we have subdivided the vegetation into trees/shrubs, and herbacious cover (such as grasslands). This distiction is important because those two categores have roots at different depths, and will therefore respond differently to environmental parameters such as groundwater/superficial water, metal contamination, human activities, etc.

5.5.1 Trees:

Trees have deep roots that are often in direct contact with the groundwater, the rocks and their weathered substrates. Changes in their condition tend to reflect the more long-term changes in the subsurface environment. In order to be able to detect stress in trees related to these parameters we have collected over 700 spectra from leaves of trees (*Figure 11*). In order to assess the impact of geochemical contamination (e.g. Lead, Copper, Zinc, Cadmium) we have collected birch leaves for chemical analysis. In order to map regional patterns, we collected most of the spectra from Birch trees. However, in order to be able to identify if different tree species respond differently to the abovementioned factors, we have also sampled other species such as Beech and Hornbeam.

The chemical analysis of leaf material did not show a clear correlation between the chemical composition of the leaves and the composition of the soil/rock substrate. However, the spectral analysis of the birch leaves demonstrated enhanced lignine contents in trees that are growing on mineralized rocks (*Figure 11*).
In-depth literature analysis revealed a direct link between lignin and heavy metal content in soils and rocks. Several authors reported that an increase in lignin content is considered as a common plant response to various environmental or stress factors, such as ozone or heavy metal exposure, which may induce or alter lignin synthesis. Serrano et al. (2002) proposed the Normalized Difference Lignin Index (NDLI = [log (1/R1754)-log (1/R1680)]/[log (1/R1754) + log (1/R1680)]) as an index to asses lignin in native shrub vegetation with remote sensing data. They found out that NDLI provided consistent and significant results across vegetation communities and functional types.

Several alternative spectral indices were tested and some of them showed a good correlation with the variations found for the NDLI.

However, we also found some contrasting spectral trends between leaf measurements made in June 2012 and measurements made in late August 2012. Due to the time constraints unfortunately we had no further opportunity to investigate this observation, but the fact that fairly significant changes seem to occur in leaf properties over a relatively short period indicates that the time of data acquisition is a crucial factor. For that reason we certainly recommend that changes in leaf properties as a function of seasonal and climatic variations are studied in much more depth.

Our chemical and spectral study of Birch-leaves has demonstrated that the spectral behaviour of tree foliage is extremely complex. There are still many unresolved issues, such as methods of sampling, variations within a single tree, variations between adjacent trees, size and age of trees, seasonal variations, response to variations rock/soil chemistry and available water, etc. Systematic research is still ongoing on these issues.

5.5.2 Herbacious species:

Approximately 70% of the area is covered with grasslands. The appearance of grasslands is highly variable. It can vary from 100% grass to almost bare soil, depending for example on the quality of the soil substrate and type of agricultural use (e.g. hay-land versus grazing land). Grass has shallow roots, and will therefore respond much more directly and visibly to short-term changes in surface environment. More prolonged environmental pressure on grasslands will lead to increased exposure

of soils, causing further and more permanent deterioration of the quality of grasslands due to enhanced weathering and erosion.
In order to understand the dynamics of the grasslands as a response to human and natural factors such as land use, rainfall/drought and others, we have documented the condition of the grasslands over a region extending beyond the boundaries of the Rosia Montana watershed region.

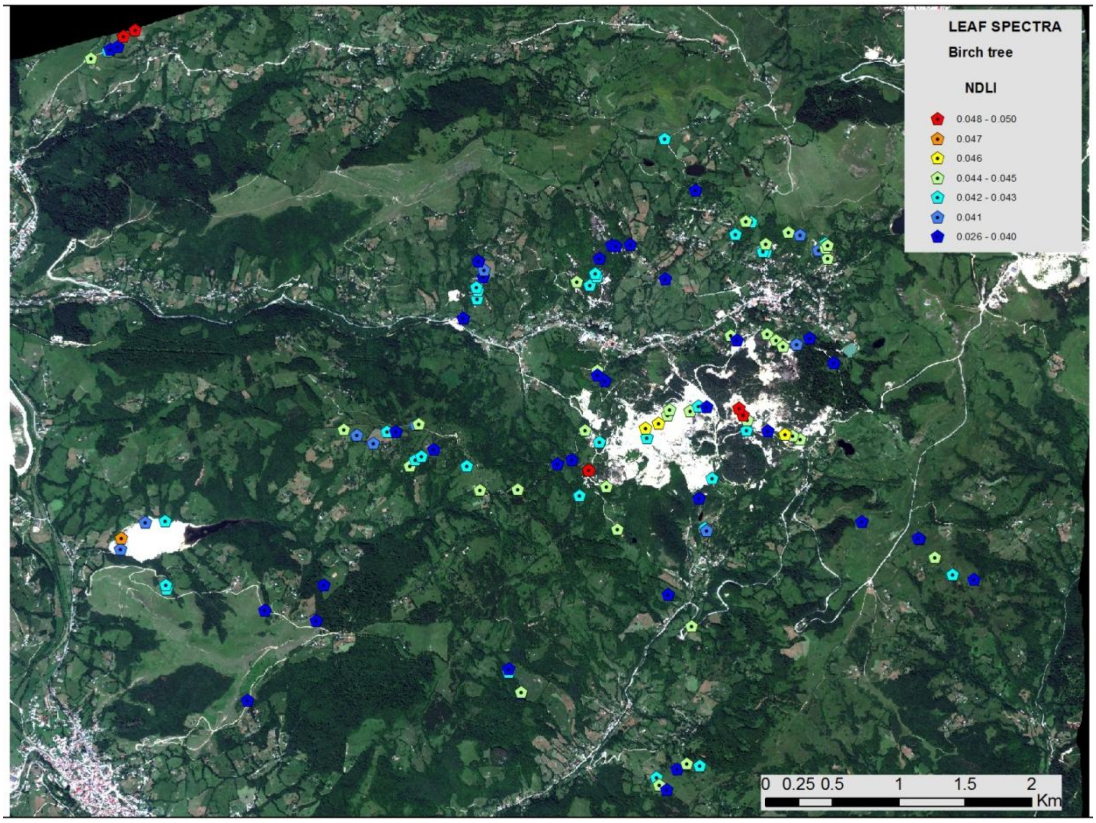

Figure 11. Spectral Normalized Differential Lignin index for Birch-leaves. Higher values are dominant in areas with known mineralisation and may be indicative for heavy metal stress.

5.6. Spectral characterisation of the surface parameters

Succesful use of remotely sensed (airborne or spaceborne) imagery, to map relevant surface variations for monitoring mining related impact over longer periods of time, requires a thorough spectral characterisation of all relevant surface parameters, and hence an good understanding of the relationship between the chemical/mineralogical/spectral properties of materials in the subsurface (described under paragraph A) and the properties of materials exposed at the surface itself (such as for example the proportion of soil/grass in grasslands, Fe-oxide content, humidity, etc).

In order to be able to characterize the exposed surface and to correlate the spectral characteristics of the surface with the results of the earlier geochemical and spectral soil sampling campaigns, we revisited most of these locations (*Figure 10*) using a full-range portable spectraradiometer under solar illumination conditions.Surface variations were carefully documented, and photos were taken of each measured site.
Our study showed that for contact probe measurements, there is a good correlation between the spectral properties of rocks and soils from the subsurface and their surface exposure. However, in

the case of solar reflectance measurements, which samples larger surfaces, the correlation is much poorer, due to the fact that most of the surfaces are mixed grasslands with varying proportions of grass and soil/rock exposed.

Mapping spectral changes in soils underlaying such grasslands using Remote Sensing is hence a major challenge and in order to assess what the spectral consequences will be of changes in grass land properties (such as varying proportions of grass and soils, length of the grass, greenness of the grass etc.), we have systematically studied the spectral signatures of different types of grasslands (*Figure 12*).

The results of this investigation show that, depending on the type of grassland, proportions of grass as low as 25% can completely mask the original soil characteristics. This obviously has very clear implications with respect to our ability to map subtle changes in soil composition using remote sensing imagery, and our image analysis procedures were adapted accordingly.

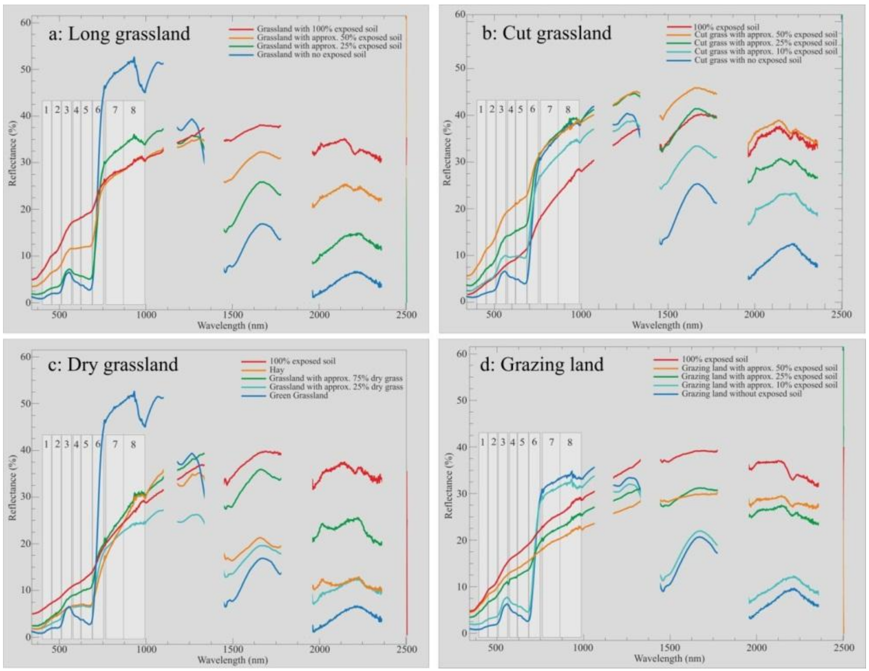

Figure 12. Spectral mixtures for different types of grasslands: a) Long green grass with different proportions of soil exposed; b) Recently cut green grassland with different proportion of soil exposed; c) Recently cut grassland with different proportions of dry grass; d) Grazing land with short grass and different proportions of soil exposed.

5.7. Image Interpretation.

The Rosia Montana study area is a typical Alpine landscape characterized by very complex land-use patterns (*Figure 13*), which probably took shape during many centuries of traditional small scale farming. Traditional farming using manual labour and horse-power is still the current practice. Individual farming parcels are small, which results in a highly patchy and diverse appearance in remotely sensed imagery. This spatial heterogeneity makes the interpretation and spectral analysis of the imagery a very complex task. Combined with our earlier observations concerning the spectral mixing of soils and grass for most grasslands, it is clear that issues related to image resolution had to be key aspects of this study.

Figure 13. Traditional small-scale farming that is typical for this region. Cutting the grass is still done manually using a scythe. Note the difference in appearance in the right image between the long grass, the recently cut grass and the short dried grass. Man-made temporal changes like these will significantly complicate the image interpretation since the image resolution is often not high enough to identify the nature of these differences.

In order to be able to understand the implications and restrictions of spatial and spectral resolution of the various data sources, and to assess what we actually will be able to discriminate using remote sensing imagery –both from a spectral and textural point of view, we have made a systematic comparison for a variety of surface materials between image data with different spatial and spectral resolution and field spectral data:

- Contact probe data: Spatial resolution approx 1*1 cm.
- Solar reflectance data: Spatial resolution approx 20*20 cm.
- Smartplanes Unmanned Aircraft (*Figure 14*). RGB-colour. Spatial resolution < 5*5 cm
- Airborne hyperspectral VNIR (*Figure 14*): Spatial resolution 50*50 cm
- Pansharpened WorldView2, 8-bands VNIR (*Figure 14*): 50*50 cm
- Multispectral Worldview2, 8 bands VNIR (*Figure 14*): 200*200cm

Since we had an excellent solar spectroradiometer dataset acquired simultaneously with the WV2-acquisition in July 2012, we developed all our image calibration and spectral analysis methodologies on the 2012 dataset. The developed methods were subsequently applied to the WV2-images of 2010 and 2011.

The UAS-flights were carried out four days before the acquisition of the 2012 WV2-imagery, and hence these data provided us with an excellent understanding of the land-use situation at the time of the WV2-acquisition. Also, we demonstrated that spectral analysis of the airphotos can be very effective to map changes in soil exposure and in iron-oxide content of soils (Figure 17)

The hyperspectral survey was, after a number of earlier attempts that failed due to bad weather, successfully flown in late August 2012 and data were acquired in the VNIR (450- 1000nm). While the prime objective of these survey data was to map potential effects of environmental impact on vegetation, we found that the imagery was very suitable for mapping certain soil characteristics, such as abundance of iron-oxides and jarosite (Figure 17).

Our work shows that a spatial resolution of 50 cm (such as the WV2-pansharpened and the hyperspectral imagery) is sufficient to identify most of the important spatial features (*Figure 14*).

Comparison of the field spectra (*Figure 15*). with spectra from the multispectral WV2-imagery (200 cm) as well as the hyperspectral imagery (50 cm) demonstrates that it is essential to separate the grasslands into different classes, according to the expected proportions of vegetation, before we can conduct any further spectral analysis (Figure 16).

Comparison of the iron oxide maps (Figure 17), derived from spectral analysis of WV2, Hyperspectral and UAV imagery shows that the higher spectral and spatial resolution of the hyperspectral imagery has a number of important advantages compared to WV2.
However, we also found that very accurate and detailed results can obtained by classification of the UAV-airphotos, even though these are quite “primitive” in a spectral sense. To our knowledge, such a classifiaciton has not been performed before, and it adds a very interesting dimension to the use of such small UAV’s.

Figure 14. Comparison of (a) Worldview2 multispectral (2m resolution), (b) WV2-pansharpened multispectral (50 cm resolution), (c) Hyperspectral VNIR (50 cm resolution) and (d) Smartplanes image (4 cm resolution). The red arrows point to the location of the soil exposure shown in the photograph. This type of soil exposure is found frequently in grass lands used for cattle grazing.

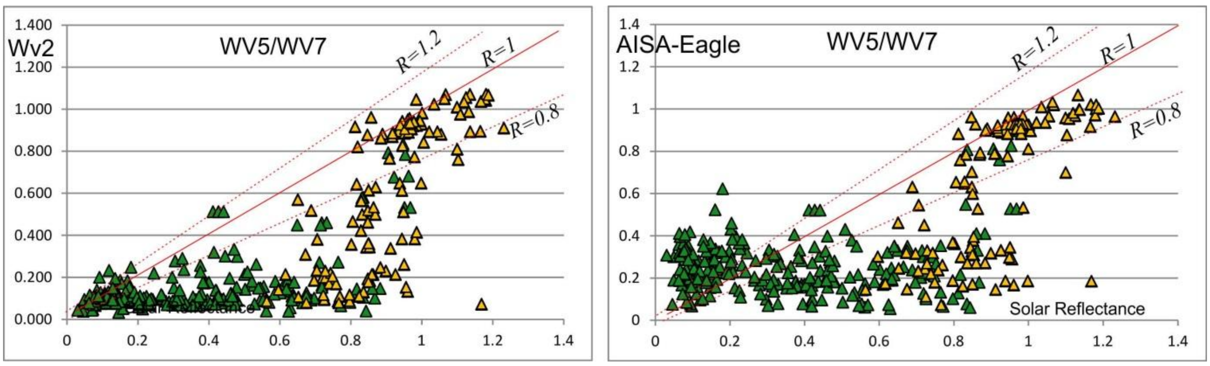

Figure 15. Plots comparing the spectral characteristics of field measurements with spectral characteristics of 2m. resolution-Worldview2 (left) and 50cm. resolution hyperspectral images. Along the horizontal axes are the WV5/7 band ratios for resampled field spectra, along the vertical axes the band ratios for the same locations in respectively the WV2 (MX) and Hyperspectral imagery.

The yellow symbols indicate sample points with more than 75% soil exposed, the green symbols represent sample points with less than 75% soil exposed. The lines marked R=1 indicate a perfect correlation. These figures demonstrate clearly that there is a high correlation only for pure soils and pure vegetation. As soon as there is a small amount of vegetation in a pixel, the correlation decreases significantly.

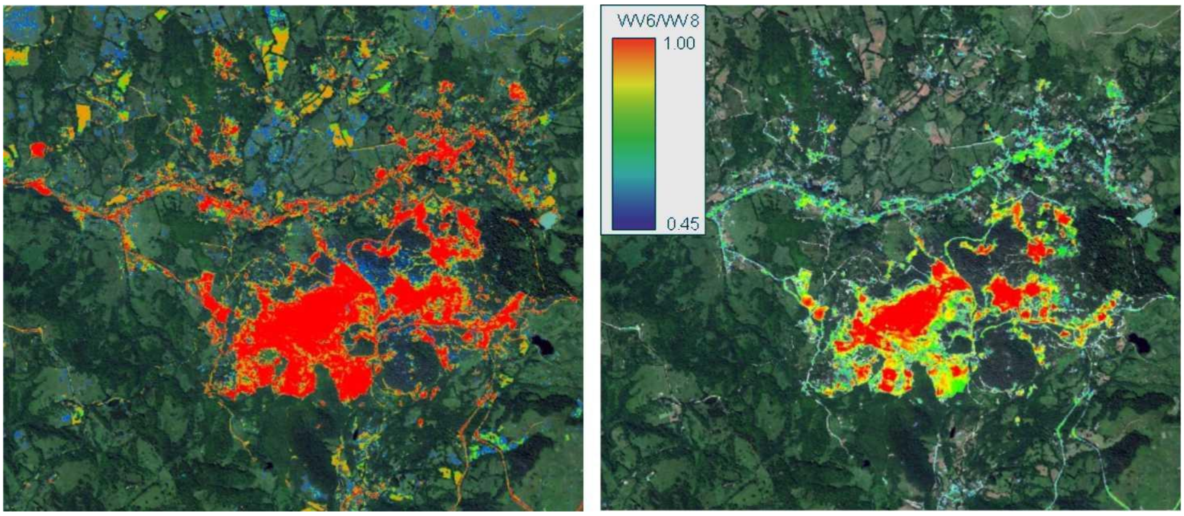

Figure 16. Left: grass land classification of 2012 WV2-image for bare soils(red), scarcely vegetated surfaces (orange), moderately vegetated surfaces (green) and surfaces with minor soil (blue). Right: Results of spectral analysis for the bare Soil class (red in in left figure). Here we used the band ratio of WV6/WV8, which is a good indicator for iron-oxide concentration.

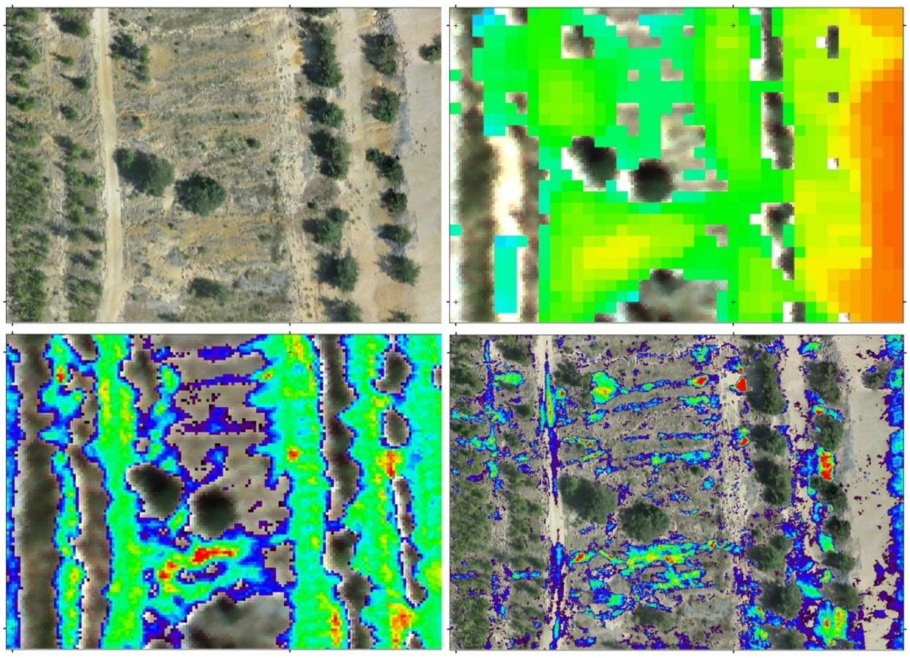

Figure 17. Comparison of Iron-oxide classification on the basis of WV2 and Hyperspectral imagery for face of the tailings dam. A: (top left): Smartplanes Truecolour image; B: (top right) Classification of WV2-imagery; C: (bottom left) Hyperspectral classification and D: (bottom right) Smartplanes classification.

For mapping of vegetation stress in tree foliage, we classified the hyperspectral data using the four best spectral leaf indices (Xantophyll-ratio, Pigments-ratio, Chlorophyll-ratio and Stress-ratio) that were obtained from our ground study.

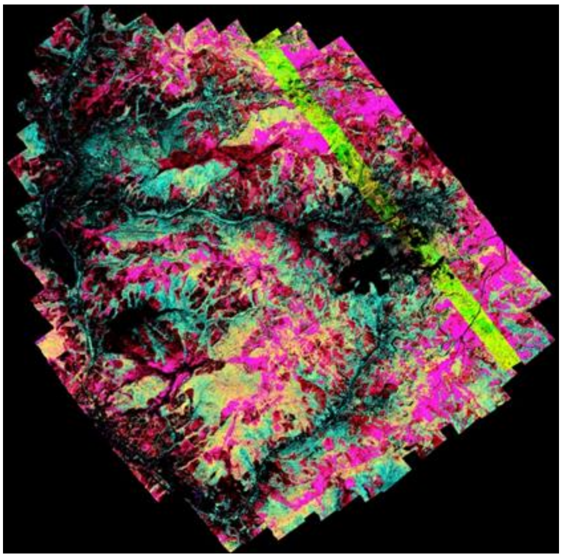

Figure 18. Classification index map for vegetation.

5.8. Multitemporal image analysis

The ultimate goal of the ImpactMin project is to develop remote sensing tools that allow environmental monitoring over longer periods of time. Besides the collection of a dataset that provides a good baseline, it is very important that techniques are developed that can be used in a consistent manner over longer periods of time, and repeated with new datasets that are collected in different points in time.

Our study has very clearly demonstrated that the timing of image acquisition is a crucial factor in order to create consistent and reliable time series analyses. An excellent opportunity to study the relevance of timing of the data acquisition was our 2012 campaign. Field spectra were collected in May, second half of July and second half of August. Smartplanes surveys were flown 4 days before the acquisition of the Worldview2 image, and the hyperspectral campaign was flown on August 22, more than 1.5 month after the acquisition of the WV2-image.

Comparing the field spectra from July and August demonstrated that vegetation properties can actually develop contrasting characteristics. Comparing the Smartplanes image with the WV2-imagery shows that major changes can occur in appearance of the farm lands within 4 days.
Comparing the WV2-image with the hyperspectral data show very clear spectral changes, which are probably related to an early onset of autumn, possibly caused by a very long and dry summer.
The Worldview2-imagery was acquired in late July during three successive years, and we assume that for those years the situation in this period was comparable (but not identical).

For time-series analysis a perfect co-registration is required. However, the data that we collected are all relatively high resolution, and we found that for these types of images, accurate image registration becomes a serious issue, especially in a mountainous region like Rosia Montana. Based on accurate differential GPS data collected in the field, we found that in none of the cases the image telemetry data were accurate enough. WV2-data and hyperspectral data could be several meters off. Smartplanes UAV images for this area have better than 40 cm horizontal accuracy.

In order to be able to use all images for our time-series analysis, we made the assumption that the 2012 WV2-image was correctly positioned, and used this image as a reference to co-register all other data.

Equally important for time-series analysis is a correct atmospheric calibration of the data, otherwise the image spectra cannot be compared. Since we had many spectroradiometer measurements from calibration sites that were taken at the time of the WV2-2012 image acquisition, we decided to use that image as reference for the atmospheric calibration of the other image data. For the hyperspectral imagery, ground calibration spectra were used in combination with an ATCOR atmospheric correction procedure.

After geometric and atmospheric correction all images were treated in exactly the same way as the 2012 WV2-image. After calculating the different soil classes, and their spectral properties (such as in *Figure 16*) we could conduct a change analysis for the period between 2010 and 2012 (*Figure 19*) for each soil class.

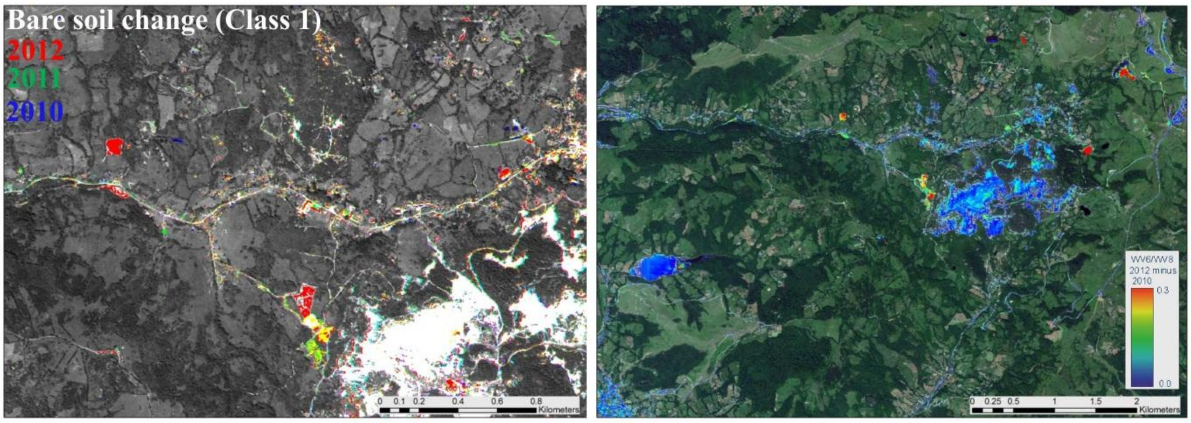

Figure 19. Results of the change analysis using WV2 imagery; Left image: Colour composite showing the bare soils in 2012 (red), 2011 (green) and 2010 (blue). Red colours indicate areas that became bare soil in 2012, Yellow colours indicate areas that were bare in in all three years. Right image: Change in Iron oxide content in bare soils between 2010 and 2012. We can clearly see that the open pit area and the Saliste tailings dam are relatively stable, as they are showing only very minor increase in Fe-oxide content.

6. CHELYABINSK AND ORENBURG TEST SITES

6.1. Site description

The South Ural Mountains of Russia has been a centre for precious and base metal production for well over 3000 years. During the Soviet era, in the early- to mid-20th century, production activities were heavily intensified with little long-term planning or consideration for the environment. 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 (Polluted Places, 2005). 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.

From a practical point of view, environmental monitoring in the Urals is a complex task. For example, no information was available from the smelter on levels of production or emissions, or on the nature of the concentrate being processed. Collection of regional environmental data is difficult because many parts of the area are poorly accessible. In addition, sampling has to be discrete to avoid misunderstandings with local residents who may be concerned that the environmental situation may lead to the closure of the smelter and a loss of jobs. This situation is common to many mining areas across the globe which is what makes our study so relevant. Besides the fact that we have generated highly interesting scientific results for this study area itself, we have been able to demonstrate how a combination of smart and innovative approaches of ground investigations and remote sensing can contribute significantly to the understanding of the nature and extent of environmental impacts, and to our ability to monitor the effects of such impacts over short and long periods of time.

6.2 Site goals

The Urals test areas are known to be heavily polluted. The goals of the ImpactMin project were to determine the nature and extent of the environmental impact on soils and vegetation, in particular in relation to the airborne pollution from the smelters using field data and satellite imagery, and to develop remote sensing tools that can effectively be used to monitor the environmental impact.

The use of satellite imagery in these areas has a number of important advantages compared to field sampling:

- Access in the field is extremely difficult due to scarcity of roads and tracks, and by using satellite imagery even the most inaccessible areas can be sampled.
- The affected area is very large, and it is very costly to cover it with field sampling campaigns. Replacing expensive field campaigns with inexpensive satellite imagery will lead to very significant cost-savings
- Since the area is large and inaccessible, there be a time-difference of weeks between the first and the last field sample. This will particularly affect the spectral signatures of vegetation, as they naturally change with the seasons. Satellite imagery, however, offers simultaneous information over large areas.
- In contrast to field data, which are taken from discrete points, satellite imagery offers, continuous information over large regions, which will enable us to map the spatial distribution of the pollution much more reliably and in a consistent manner.

6.3 Site conclusions

- Chemical analyses on soils and vegetation have clearly demonstrated that the main zone of impact extends up to 15 km from the smelter
- Spectral analysis of Birch Foliage has demonstrated vegetation stress up to 10 km distance from the smelter. On the basis of these analyses, a number of vegetation indices have been identified that can successfully be applied to map vegetation stress in satellite imagery.

- Satellite data like Spot-vegetation and Landsat, and in particular WorldView2, are very suitable to map and monitor various important aspects of the environmental impacts related to smelter emissions.
- There is an excellent correlation in the zonal pattern of impact around the smelter between the data from the IR spectral analysis of birch leaves, the results from time series analysis of multi-temporal satellite imagery and the geochemical data for lichens and soils.
- Time series analysis of satellite imagery from 1987 to 2011 demonstrates that the environmental situation has not significantly improved despite the installation of the new Ausmelt system. This is confirmed by the comparative chemical study of lichen transplants from 2001 and 2011
- The case studies at Karabash and Mednogorsk have shown that the implementation of existing, adapted and new methodologies, whereby in-situ and remote sensing data are combined, may provide a highly sensitive suite of tools for impact monitoring of mining-related activities at different spatial and temporal scales.

6.4 Karabash Smelter area

Karabash was described in 1992 by the United Nations Environment Programme (UNEP) as one of the most polluted towns in the world. The town and surrounding areas have been affected by gaseous and particulate emissions from the smelter, acid drainage from abandoned mine workings, leachates and dusts from waste dumps and contaminated stream sediments. Metallurgical slags from the smelter (containing 614-830 ppm As, 2581-3659 ppm Cu and 417-628 ppm Pb) are used to grit roads in and around the Karabash area. The spatial extent and nature of contamination from this activity is not known. The Sak-Elga river valley contains deep deposits (often > 0.5 m) of pyrite-rich tailings over a length of more than 10 km between Karabash and a freshwater reservoir (Argazi Lake). Untreated domestic wastewater is discharged into the same river. The reservoir is a major source of freshwater for the city of Chelyabinsk (1.2 million inhabitants). Several ponds are filled with acid waters from underground mine shafts. Highly acid and toxic mine waters are continuously released into the environment.

The close proximity of townspeople to these sources of pollution is of most immediate environmental concern. The people living in the town show high rates of congenital defects, central nervous system disorders, cancer and other diseases (La Franiere, 1999). Two-thirds of the children are thought to suffer from Pb, As or Cd poisoning (La Franiere, 1999) and many suffer from asthma and respiratory diseases (Ferreura-Marques, 2003). Vegetation is almost absent from the hills immediately downwind of the smelter and the Sak-Elga river floodplain, to the south of the town, contains 9.2 million tonnes of heavy metal-rich tailings.

6.5 Mednogorsk Smelter area

The Mednogorsk demo-site is located in the Steppe vegetative zone on the western slopes of the South Ural Mountains, with a strong continental climate. The main sources of contamination in the Mednogorsk demo-site area are the Blyava and Yaman-Kasy open pit mines (now pit lakes) and associated waste dumps, abandoned beneficiation mill and the active Cu smelter. The Blyava Cu deposit was exploited via open pit and underground workings from the 1930s onwards, with the main period of activity being between 1936 and 1972. The Yaman-Kasy Cu-Zn deposit was operated via open pit between 1987 and 2002. The currently active Mednogorsk Cu plant has been operational since 1937, having been run as a Cu-S plant between 1954 and 1998. Initially, the plant produced low purity S, but after the second World War, began to produce Cu concentrate (12-17%) which was transported for refining to the Karabash smelter and the Kirovgrad smelter (Sverdlovsk district). Between 1959 and 1962, following the construction of converters, the plant began to produce non-refined copper. In 1960, the plant started processing ores from the Gay deposit and from 1961 produced sulfuric acid (H_2SO_4). Unofficial estimates indicate that the smelter currently emits around 68,000 t/year of gases and dust.

There has been little work on the nature and extent of contamination from Mednogorsk. It would seem likely that the main impacts will be from atmospheric gaseous and dust emissions from the Cu smelter. Of additional concern is contamination of surface and ground waters by acid mine/rock waters from the many waste dumps, open pits and tailings dams in the area. Acid waters of the Zhiriclya River have been treated since 2006, however there is little data on which to assess wheather this treatment is effective.

6.6 Environmental Monitoring

Most of the monitoring/method development activities in the Chelyabinsk and Orenburg case study area were centred on Karabash where the impacts of mining-related activities are most obvious. Within the framework of the ImpactMin project a large number of chemical and spectral data were collected from a variety of sources on the ground in 2011 and 2012 (*Figure 20*) in order to identify the nature and extent of the environmental impact from the smelter.

A particularly sensitive and effective method to monitor heavy metal pollution on the ground was the collection of naturally growing and transplanted lichens in NE-SW and W-E transects centred on the smelter(*Figure 21*).

This method was first tested in the area in 2001, in the framework of the MinUrals project, and repeated in 2011 during the ImpactMin project. It not only clearly demonstrated heavy metal contamination up to distances as much as 30 km away from the smelter, but also provided evidence that that levels of Pb in the environment have increased since 2001 despite the installation of a new and cleaner 'Ausmelt' smelter in 2006. Concentrations of heavy metals in lichens could be correlated very well with field observations of plant species diversity (*Figure 22*), with geochemical patterns in soils (*Figure 23*), snow, etc, and with trends in soil mineralogy and vegetation stress in Birch trees derived from field VIS-NIR-SWIR spectroscopy data (*Figure 24*). The good correlation with the data obtained with the field spectroscopy is very important, because the technique is portable, fast, low-cost, non-destructive and reliable, and thus represents an increasingly attractive tool in environmental monitoring

The determination of twig and trunk bark pH in NE-SW and W-E transects, up to 40 km from the smelter, showed that the effects of SO_2 and deposition of acid aerosols, which causes tree leaf damage, is patchy in its spatial distribution. From our own observations, and those of towns' people, this is likely to be due to the smoke from the smelter hanging in the forest for prolonged periods of time (hours or days) during which time the SO_2 oxidises to form acid aerosols which deposit in solid (e.g. $(NH_4)_2SO_4$) and liquid (H_2SO_4) forms on leaf surfaces. The variable spatial nature of the acid attack on leaves is therefore likely to depend on meteorological conditions (occurrence of temperature inversions, and variations in humidity, rainfall and wind direction) as well as topographic effects. These observations are very clearly supported by observations from multi-temporal satellite imagery

Birch twigs provided a useful additional tool to the lichens as birch grows naturally within the 3 km, up to 8 km, zone where the lichen *Hypogymnia physodes* cannot survive. The metals contents of the twig bark are elevated over a much wider distance than for the lichen transplants, generally as the transplants were exposed for a limited (3 month) period, and have therefore not fully equilibrated, and possibly also because birch may uptake a portion of its metals from soils.

The collection of airborne particulate, using air pump-filter apparatus, and analysis, was carried out in order to determine the nature, including size, shape and chemical composition, of particulate being emitted from the smelter. Particles mainly consisted of <2μm size aggregates of nanoparticles, mainly composed of Pb, Zn and As. These particles are respirable, i.e. small enough to enter the deepest, alveolar regions of the lung, where they can do most harm.

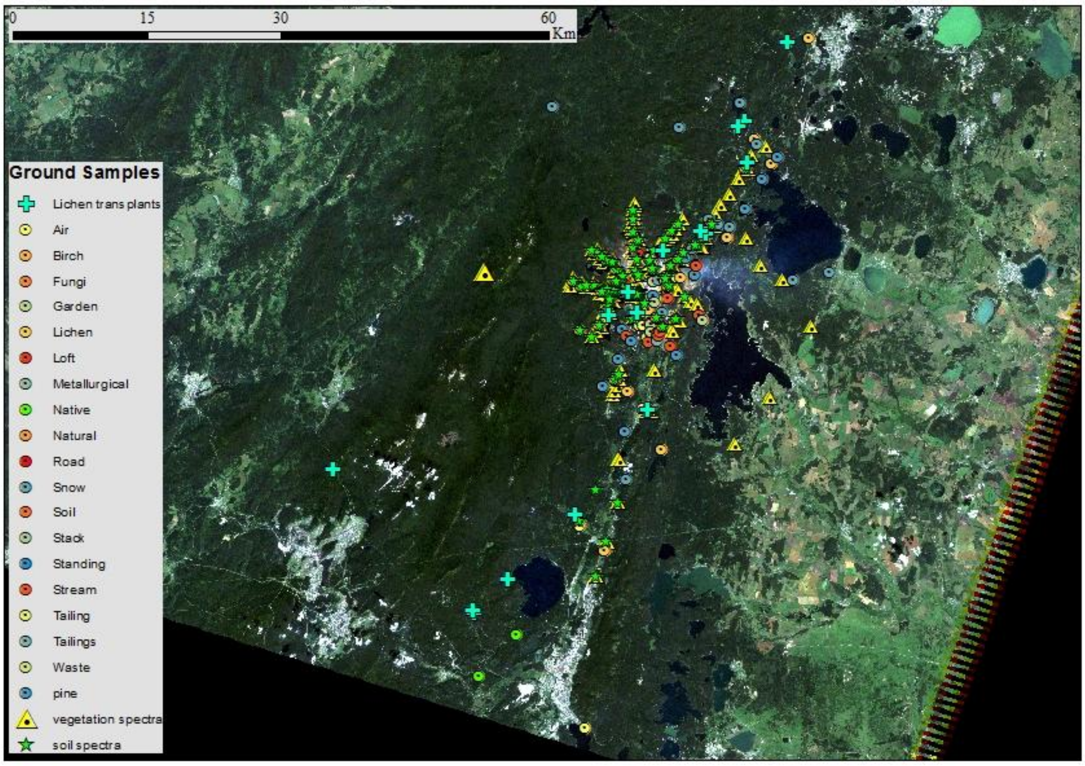

Figure 20. Graph showing the location of different types of samples collected in 2011 and 2012.

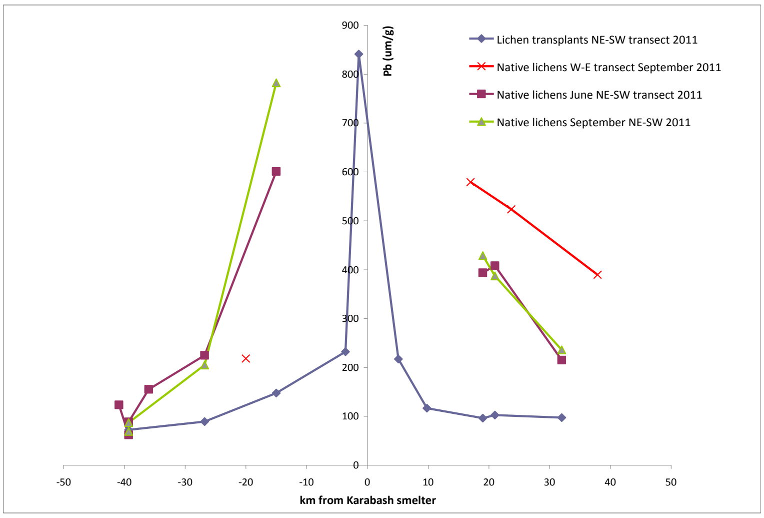

Figure 21.Comparison of Pb and Cu concentrations in native lichens from around Karabash collected in 2001 (analysed at the Natural History Museum, London) and 2011 (analysed at UNEXE and IMIN).

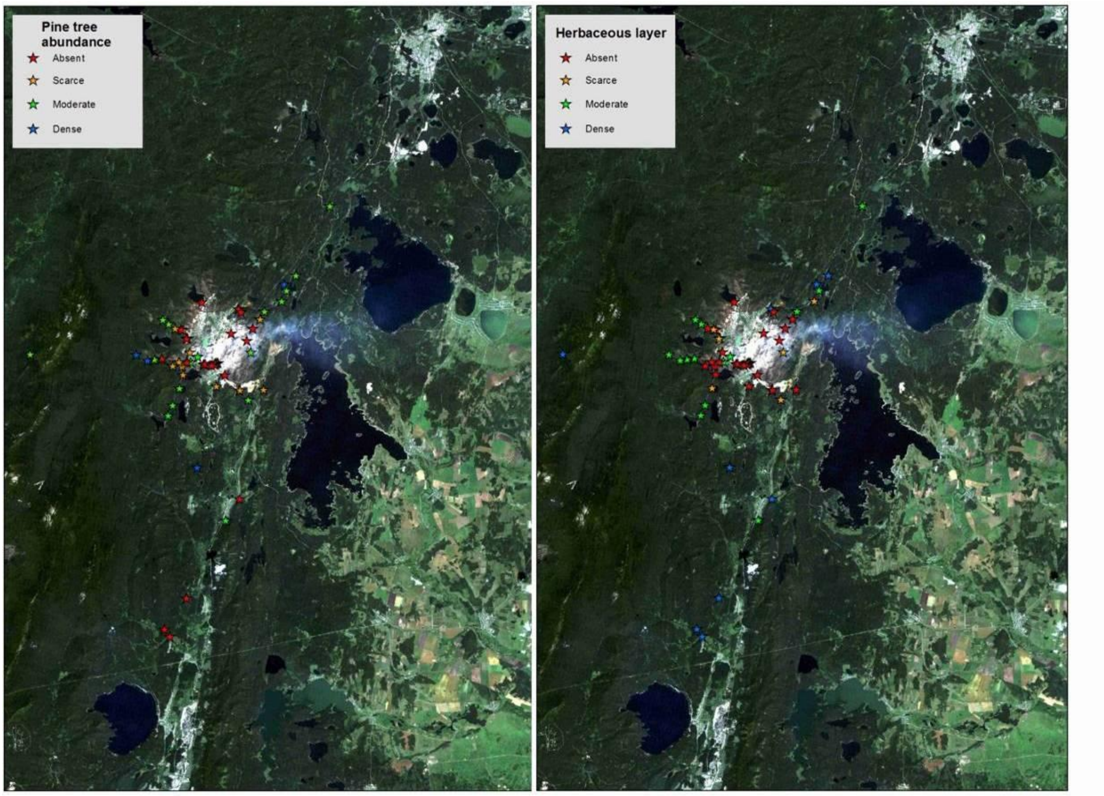

Figure 22. Distribution of pine trees (left) and density of the herbaceous understory (right) at locations where leaf spectra were acquired.

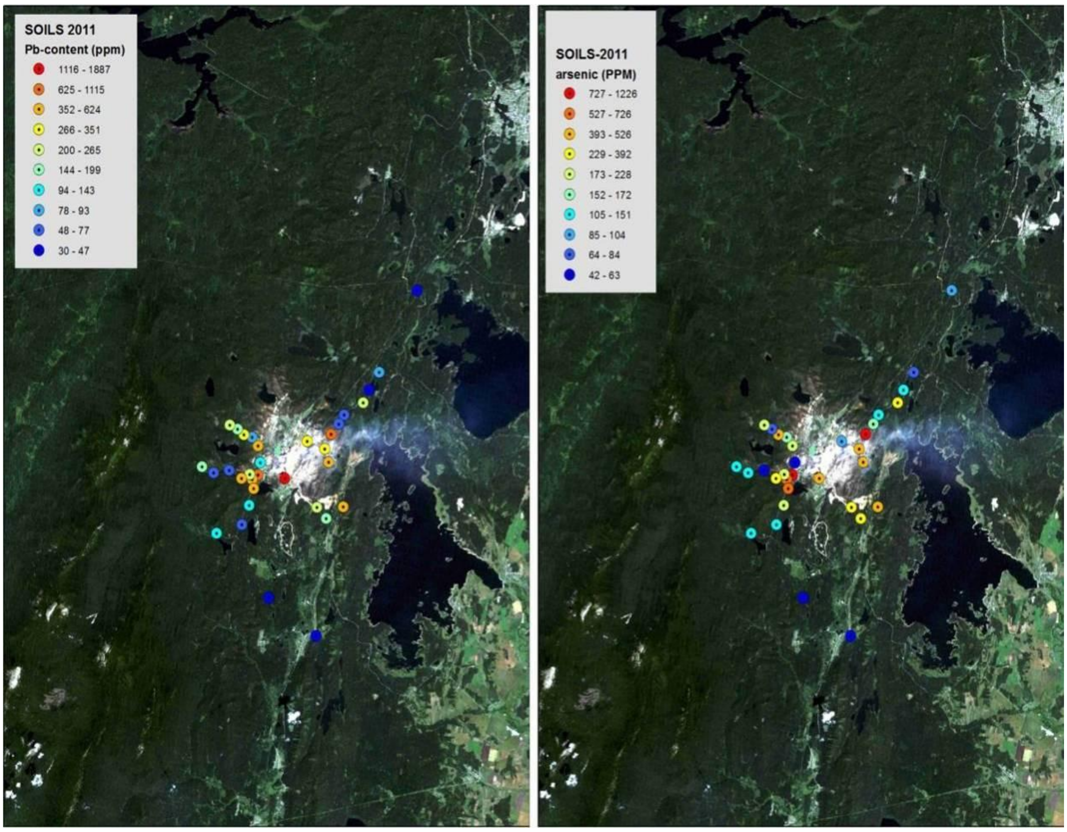

Figure 23.Concentrations of Lead and Arsenic in soils showing values of more than 50 times the background.

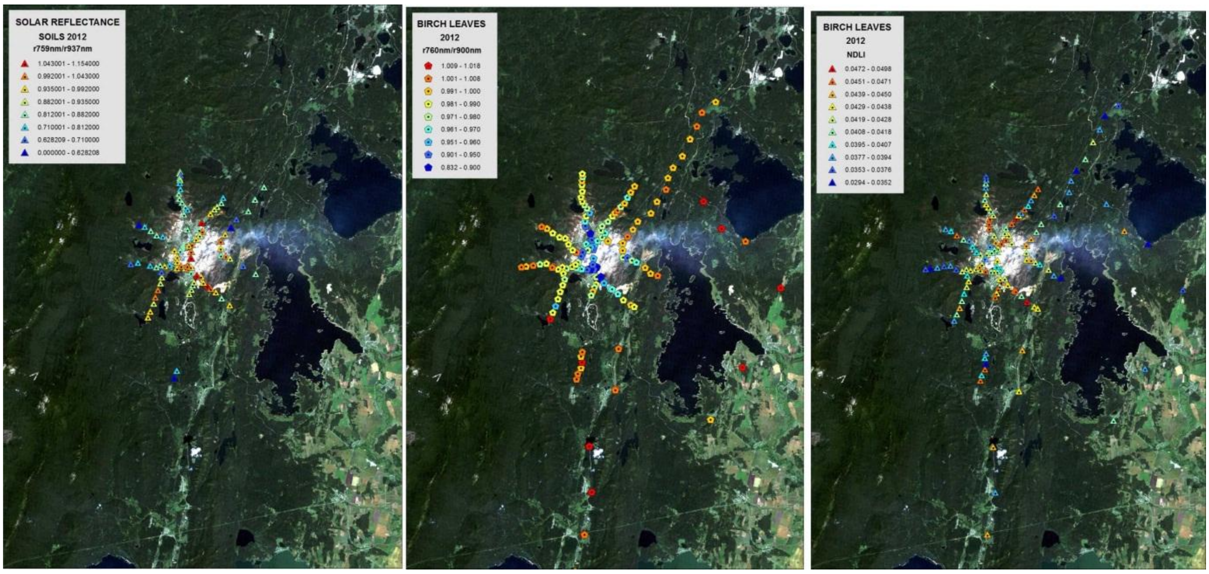

Figure 24. Solar reflectance measurements of soils (left) and vegetation (centre and right), showing pronounced concentric zoning around the smelter areas.

One of the key objectives of our work was to establish methods for monitoring environmental impact using remote sensing technologies. The emphasis was on exploring the possibilities of satellite imagery such as Landsat, Spot, GeoEye and Worldview2, and on the basis of our work we could conclude that data like Spot-vegetation and Landsat, and in particular WorldView2, are very suitable to map and monitor various important aspects of the environmental impacts related to smelter emissions.

For Karabash, and to a somewhat lesser extent also for Mednogorsk it has been demonstrated that with respect to different environmental media/indices (soils, rocks, vegetation diversity, lichens, tree-bark, birch leaf stress), clear trends exist at surface. It has also been demonstrated that these trends can be mapped effectively using spectral ground measurements. We were able to reproduce these trends very effectively in the various types of satellite imagery, obviously at different spatial and spectral resolutions (*Figures 25 – 28*)

Using multi-temporal imagery (Spot-vegetation, Landsat, Worldview2) we were able to map both short-term (weeks to months)changes and long-term(over several decades) changes in vegetation health. The data show that there can be very severe short-term vegetation damage as a result of emissions of sulphuric acid and acid-generating metal sulphate particles (*Figure 29*), which is consistent with the observations made using twig and trunk bark and birch twigs.

From a long-term point of view it was of particular interest to investigate whether the improvements that were made to the smelter between 1994 and 2006 resulted in corresponding environmental improvements.

Using a time series of Landsat images from 1998 to 2011 we could identify different phases of environmental deterioration and improvement. Importantly, we could demonstrate that the environmental situation in 2011 is similar and locally even worse compared to the situation in 1998 (*Figure 30*), which implies that the improvements made to the smelter may not have been as effective as was planned. Comparison of Lichen-transplant data from the MinUrals project (2002) with our recent (2011) Lichen transplant data supports this observation

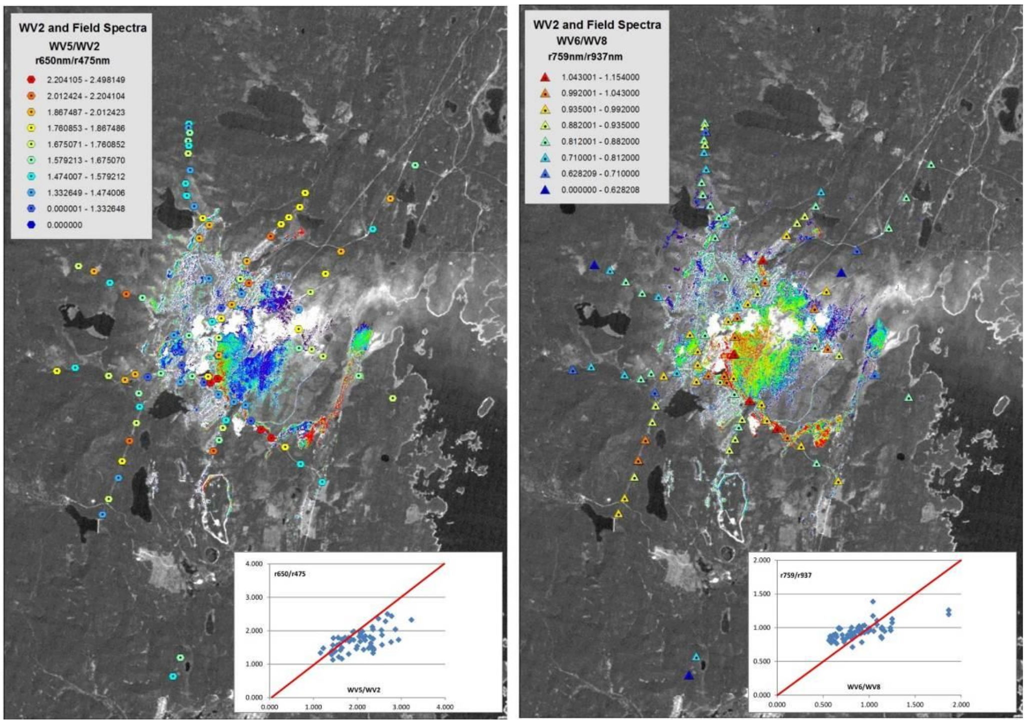

Figure 25. Comparison of "Iron-Oxide" band ratios derived from WV-2 and from field spectra. The symbols for the samples have the same colour scaling as the images. The two images show different patterns. This is due to the fact that the WV5/WV2-image mainly maps goethite, whereas the WV6/WV8 is more generally related to minerals that show a ferric iron absorption feature in the 900nm-wavelength range.

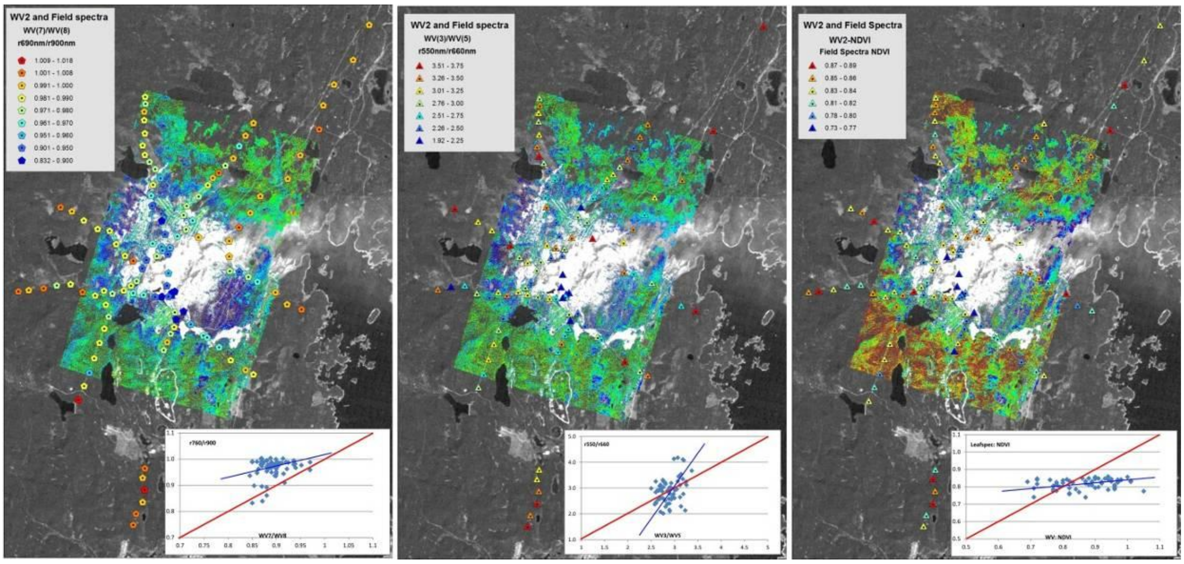

Figure 26. Comparison of vegetation indices derived from WV-2 and from field spectra. The symbols for the samples have the same colour scaling as the images. Red lines indicate a slope of 1. Blue lines indicate the slope for the trends.

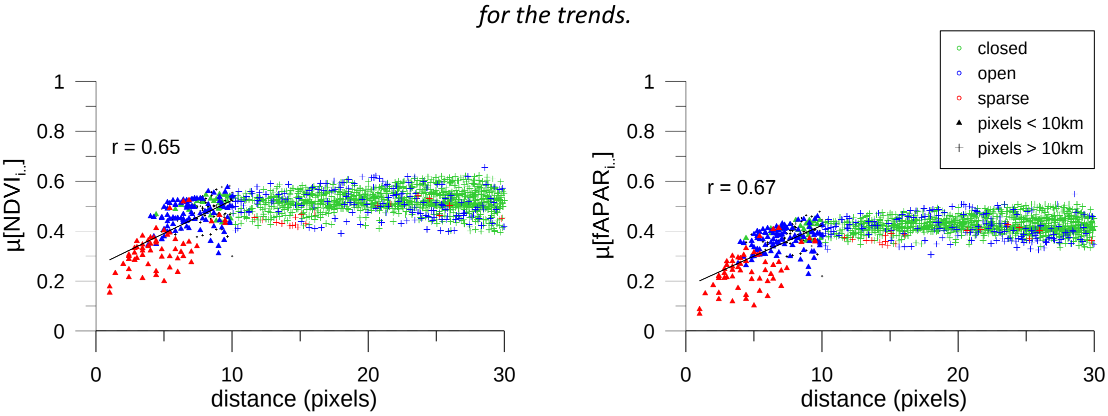

Figure 27. Relation between (1 km-resolution) SPOT-Vegetation derived indices and the distance to the Karabash smelter (in pixels). Pixels within a distance of 10 km are shown as triangles), with correlation and Pearson correlation coefficients, and beyond 10 km as crosses. Land cover types derived from the GlobCover dataset (Arino et al., 2007) include red: 'sparse vegetation', blue: 'open forest' and green: 'closed forest'. This image shows the amount of change in NDVI in vegetation over the last 12 years as a function of distance to the smelter.

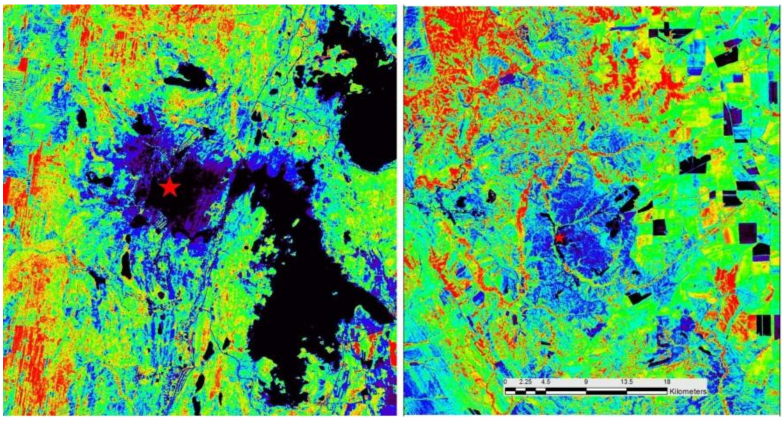

Figure 28. Landsat NDVI images for Karabash (left) and Mednogorsk (right), clearly showing the affected halos around the smelters. The fact that the area around Mednogorsk seems less severely impacted is probably

partly due to the fact that it is in a very dry region, which means that pollutants get more effectively dispersed by wind.

Figure 29. Leaves with sulphate particles on their surfaces; b: leaves with acid damage after formation of sulphuric acid from the reaction of rain with the sulphate particles.

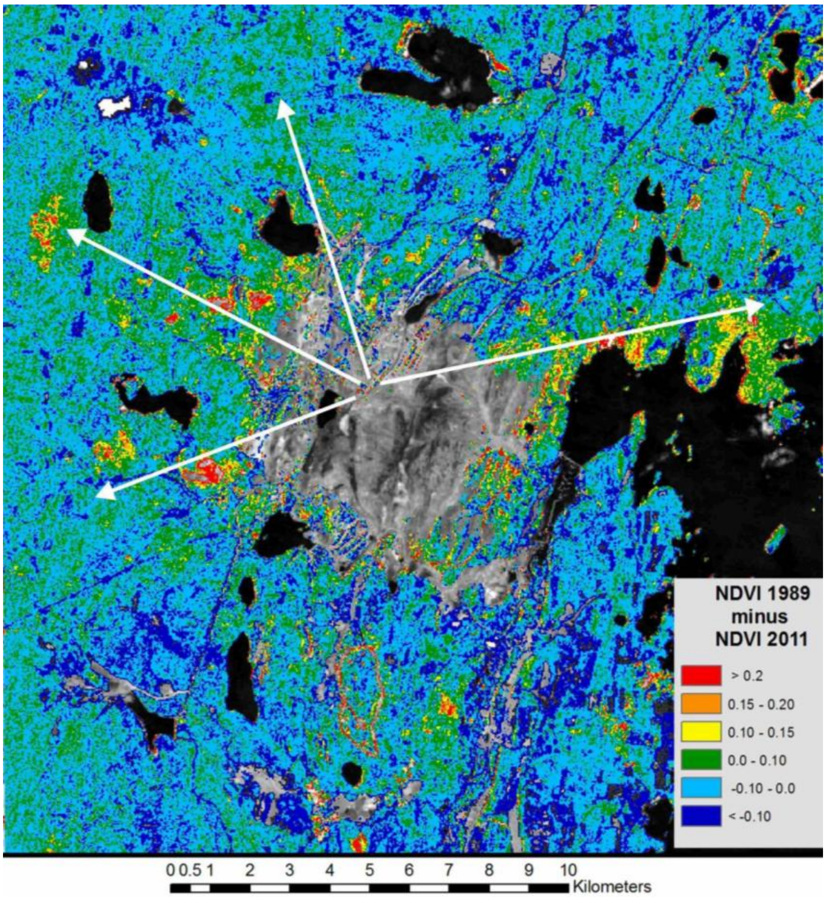

Figure 30. Results of the comparison of the NDVI from the 1989-image and the 2011-image. This image was obtained by subtracting the NDVI (2011) from the NDVI (1998). Values above 0.1 imply that the situation in 2011 is worse compared to 1989, values between 0.1 and -0.1 indicate a more or less similar situation, and values below -0.1 indicate that the situation has improved compared to 1989.
The image demonstrates that while the over-all situation in 2011 is similar to that in 1989, the situation has deteriorated in specific directions (white arrows). This could be related to prevailing wind-directions.

7 SOCIO ECONOMIC STUDY

The socio-economic study aimed to create a better understanding of the socio-economic impacts of mining. Stakeholders were identified across seven ImpactMin demo sites in five countries (Bosnia

Herzegovina, Romania, Russia, Sweden and the UK) and a series of surveys and interviews were carried out in collaboration with local project partners. The aim was to assess views about mining and how mining has affected peoples' lives, and to test how communities prefer to interact with local mining companies. The environmental legacy of previous and current mining, much of which is negative, remains a concern throughout Europe. Given current issues about security of mineral supply, it is likely that mining activity in Europe will increase in the near future and therefore it is important to understand more about the views and concerns of local communities. The extension of the mining activity faces multiple challenges, mainly related to the potential environmental degradation, the limited lifetime of the mining projects, the ratio between the social and environmental costs and the economic benefits for the community. Also a challenge for mining activity is the carbon footprint of the operation. Mines are major energy users as well as consumers of chemicals in the processing plants. Since this aspect of mining was not dealt with in the technical part of the ImpactMin programme, a study of issues and best practice in reducing carbon footprint in the mining industry was carried out.

The results of the socioeconomic and carbon footprint studies link to the technical part of the programme in (a) making the study comprehensive by considering social factors and greenhouse gases as environmental pollution that cannot be directly measured by earth observation techniques and (b) providing information about people's concerns and how they prefer to receive information on environmental issues connected to mining activity which can be used in designing applications for the research outcomes of the project.

The study included descriptions of the ImpactMin demo sites and background socio-economic information. It provided information on what the socio-economic impacts of mining have been at each of the sites, including how mining companies develop social responsibility programs, how they engage with different stakeholders and ultimately, what the stakeholder perceptions are, from people who have participated in the interviews and surveys. Overall, because the socio-economic impacts of mining are tied to the environmental impacts that mining may have, many of the questions in the survey and interviews explored how people feel about their physical environment, including looking at their perception of what changes mining has had on their physical environment and how these changes have affected their lives.

Despite the current emphasis on companies maintaining effective stakeholder relations in order to gain their 'social licence' to operate, findings of this study revealed a wide variation in community expectations across the seven sites. These variations reflect the current status of mining within the community, as well as the socio-economic background and the nature of existing engagement with mining companies already operating in the region. The individual's perception on mining is very often divided between the economic benefits, even on a relatively short term, and the environmental damages that can be produced by the mining operations. This dual view is more significant in the East European mining localities, and emphasized in Russia, where the economic status of the community is generally poor. It is very likely that the startup of a new mining project will boost the economic development at a local and even regional scale, at least for the lifetime of the project. The modern mining projects are generally based on extraction procedures in large scale open pits, with a precise time planning of the operations. Part of the stakeholders are concerned about the depletion of a potential resource that in some cases has been the basis of the local economy for centuries, and will not be available in the future. A post-mining economic development plan is essential for the community, and the participating operators should be deeply involved in assuring the success of this plan. New industries or alternative economic activities should be created, including the occupational retraining of the people that have been directly involved in mining.

The environmental concerns are also critical in the stakeholders' perception of mining. In many cases, the sites have been already impacted by previous mining activities. It is important to assess the evolution of the environment during the mining operations, but also the result of the remediation actions that need to be foreseen for the post-mining stage. The preservation and/or restoration of the natural resources that could be affected by mining, such as soil, water, biodiversity, landscape, etc., are essential. These would be key factors in the post-mining economic conversion and development of the locality. These few examples clearly highlight the direct link between the socio-economic and the environmental issues, and the opportunity to integrate the two fields in a unitary analysis of mining as an economic activity, with multiple effects on the community. For many new mining projects, the two components are currently combined in a unitary study called Environmental and Social Impact Assessment (ESIA). A simple scheme of the ESIA process, built by the EIA Center of the University of Manchester (CSI, 2005) is presented in Figure 31. The ESIA includes a comprehensive analysis of the environmental and social impacts likely to occur throughout the life-cycle of a mining project. It also recommends measures to prevent and/or mitigate the expected negative impacts.

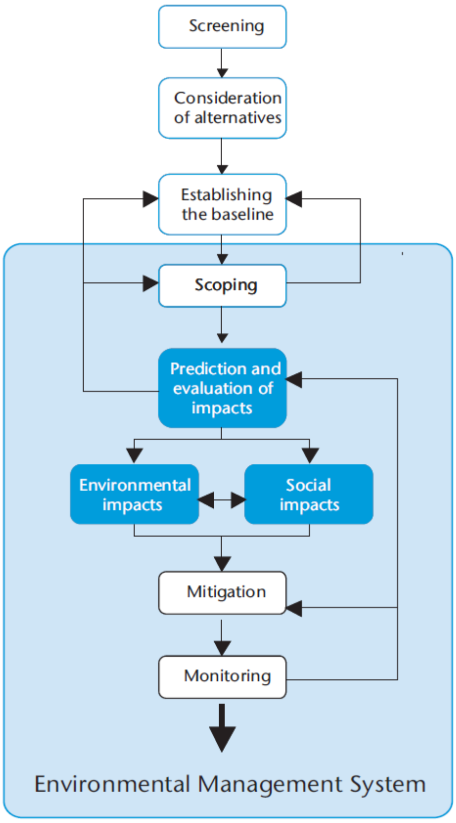

Figure 31. Diagram of ESIA process (CSI, 2005).

The results of the social survey (Adey, 2011) have shown that the communities with a long tradition in mining, such as Cornwall and Roşia Montană, consider that mining is a distinctive part of their identity. Therefore there is strong support for continuation of the mining activity. However, the community, and especially the younger generation request a responsible approach of the companies regarding the environmental and social issues that may arise as a result of mining. People's perception of mining may become predominantly negative in places heavily affected by environmental damage, as the South Urals sites. The survey also revealed the essential need for companies to assess and continuously work at meeting people's expectations. Much more can be done for filling the deficit of engagement of the companies with the local community. It was also noticed that in providing information and consultation with the local community, most of the respondents prefer public display and public meetings as means of communication with the company. There are few general recommendations for the companies regarding their relations with the community. They always should adapt their strategy to the specificity, traditions, and mentality of the region concerned.

The majority of people interviewed at the demo sites had a positive view of mining, mainly because of the jobs the industry provides. This is in contrast to the general portrayal of mining as an activity that people would not want nearby. The highest proportion of positive responses about mining was in Roşia Montană where a major gold project is delayed. The lowest proportion of positive responses was in the highly polluted town of Karabash, Russia (Figure 31). Environmental damage was the key negative factor in people's opinions about mining. There was demand for improvement in how mining companies consult and engage with stakeholders and how they try to meet expectations or 'manage expectations'.

Stakeholders' expectations of mining companies vary between demonstration sites, highlighting the idea that CSR activities should be planned for each project individually and cannot be defined in a one size fits all approach.

The environmental boundaries of a project are much easier to identify than the social boundaries, which are wider and harder to define.

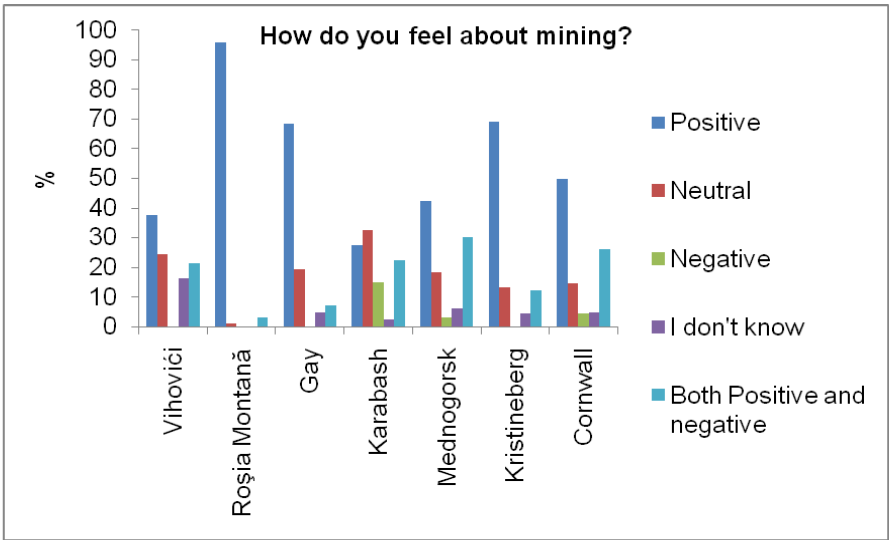

Figure 32. Results of the ImpactMin survey in 2010 asking for local people's views on mining. Karabash with its high environemental pollution has the smallest Positive response.

7.1. Suggestions for best practice for mining companies relating to corporate social responsibility

1. It is difficult to have firm guidelines on interacting with communities as each community is unique (based on their socio-economic background, culture and past experiences with companies). Thus a first stage is to research the background to the community and establish local issues and preferences.

2. The mining company is not responsible for solving every problem – this must be clear. They must, however, add value to a community.

3. Honesty and openness about the anticipated social and environmental impacts of the project and transparency throughout operations. The remote sensing of environmental impacts can play a key role here.

4. It is important to balance and manage community expectations – 'don't make promises that cannot be kept'.

5. Ensure that CSR actions extend beyond the time-frame of the anticipated mining project to be purposeful and add value. CSR is not about buying the support of local people.

6. CSR initiatives should help educate people within the community to select the long-term gains rather than short-term offerings.

7.2. Best practice in Carbon footprint reduction in the mining industry

The study was conducted by literature review, interviews and correspondence with mining companies and a case study of the plans for the gold mine at Rosia Montana. Mining is a major user of energy, the industry has been calculated to use between 7 and 10% of the World's energy supply. Energy use is a major cost to the mining industry. For example, about 35% of the cost of copper production is the energy that is required. A mining operation may be divided into various stages: (a) geological exploration (b) mining the ore from the ground, (c) extracting the ore mineral from the rock, and, (d) further processing and/or extraction stages that isolate and refine the metals or minerals of interest. Besides energy, other contributors to the carbon footprint (via various greenhouse gas emissions) include explosives used in mining and acids used in extraction. Stages a, b, and usually c are carried out on site, but d may be carried out on the mine site or far away, even on another continent. Exploration (a) has low carbon emissions relative to the other stages and is not considered further here. Stage (d) covers smelting and electrowinning which are large energy users but it is excluded from consideration here because it is not necessarily connected to the mining operation itself. Within the mining phase, it is usually the crushing and grinding (comminution) in (c) that uses the largest amount of energy. Diesel fuel used in haulage is a major component and chemicals such as explosives and acids using in processing also add to the carbon footprint.

There is no single standard set to govern "best practice" guidelines regarding carbon footprint and CO_2 emissions in the mining industry. Although carbon footprint "best practices" exist throughout governments and businesses, there have been fewer initiatives in the mining industry. While legislation and metrics for acceptable levels of CO_2 emission do exist, they vary around the globe and lack detailed plans of action, recommendations, or standards specific to the mining industry about how it is expected to control and reduce its carbon footprint. Where best practice guidelines are being employed it is almost certainly due to the initiative of the company as opposed to any independent accrediting or governing body. The EU has set the goal of a 20% reduction in GHG emissions by 2020; if this is to be obtained carbon footprint reduction in the mining industry will play a crucial part. There are an increasing number of regulations and voluntary codes, such as the ISO 14000 environmental management system and the Kyoto Protocol and Copenhagen Accord. The ISO 14000 management system is adopted by many of the large mining companies and provides guidelines for carbon footprint quantification and reduction. Fewer smaller companies have adopted this system however.

Current best practice in reducing carbon footprint can be divided into three categories.

1) Energy demand reduction procedures and use of energy efficient technologies include simple measures such as from careful driving, roadway maintenance and simple power systems management measures that all mines can implement. However, large investment is required for measures such as in pit crushing and conveying and trolley assist to reduce haulage energy use and these are usually only suitable for large and deep open cast mines. There are also a range of measures suitable for underground mining, such as use of coal bed methane to generate energy, and research is taking place on these.

2) Use of low carbon energies, either in a national or local context. We found that all of the large multinational mining companies are carrying out projects using renewable or lower carbon energy (Table 1). Mining companies can work with the national power suppliers to improve use of low carbon energy. An example is the installation of a wind far in Chile. The national grid solution mentioned most often was hydropower but only the large multinationals are likely to influence these solutions. Use of renewable energy on mine sites to give direct power to the mine is increasing but still uncommon. It is difficult to satisfy the large and constant power demands of a mining operation with renewable energy. Even at Lisheen Mine in Ireland where wind turbines have been installed, they are connected into the grid rather than directly to the mine. An example of direct use of renewable energy are the wind/diesel combinations designed for smaller remote mine site operations. Use of biodiesel has the advantage of lower particulate emissions for underground operations as well as lower carbon emissions. It is being used in various grades on mine sites. We also found that some mines are maintaining the use fossil fuel but changing to natural gas power because this reduces their carbon footprint (Table 1).

Table 1. Use of low carbon energy by mining companies

Company	Wind	Solar	Hydro	Biofuel	Geothermal	Natural gas	Trolley Assist	Reforestation
Barrick	X	X	X	X	X	X	X	X
Anglo	X	X	X	X		X		X
BHP		X	X	X		X		X
RioTinto	X	X	X	X		X	X	X
Goldcorp		X	X	X	X	X		
Teck			X			X		X
Newmont		X	X	X		X	X	X
Xstrata		X	X	X		X		X
Gold Fields	X	X		X				X
Vale			X	X		X		X

3) Offsetting carbon emissions either by reforestation or carbon trading is the third main way of reducing carbon footprint. In many situations, especially in the developing world where energy generating capability is limited, this form of carbon footprint reduction is inferior to energy saving measures. Planting trees can however be attractive and is widely adopted (Table 1). It can require very large tree-planting programmes. For example, at Roşia Montană it was calculated that planting 8000 hectares of forest would make the project carbon neutral in 17 years. However, the mining company has committed to just 1000 hectares of reforestation in the local area and this will require some 39 years to achieve carbon neutrality, assuming Romania changes its current energy generation mix to meet EU targets on greenhouse gas emissions. There is no reason for reforestation to be confined to the local area and an offset could be achieved by planting anywhere in the world. International emissions trading of carbon credits is also a possible way to offset carbon emissions.

7.3. **Suggestions for mining companies relating to CSR:**

- Difficult to have firm guidelines on interacting with communities as each community is unique (based on their socio-economic background, culture and past experiences with companies).
- The mining company is not responsible for solving every problem – this must be clear. They must, however, add value to a community.
- Honesty and openness about the anticipated social and environmental impacts of the project and transparency throughout operations.
- Balance / manage community expectations – don't make promises that cannot be kept.
- Ensure CSR extends beyond the time-frame of the anticipated mining project to be purposeful and add value. CSR is not about buying the support of local people.
- CSR initiatives should help educate people within the community to select the long-term gains rather than short-term offerings.

Figure 33. An Interview being carried out with the Mayor of Karabash.

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