Innovative monitoring measures in the phase of post-mining

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Abstract

Mining activities often influence huge areas, which can only be observed efficiently with remote sensing methods. Recently the European Programme of Earth Observation – called Copernicus – began to offer the opportunity to pursue this monitoring with innovative attempts in the production phase as well as in the post-mining phase. The combination of spatial data gained from satellite-supported sensors allows a precise verification of mining-induced environmental impacts with high resolution in time and space. This paper describes early experiences with innovative monitoring measures and discusses the perspectives of a sustainable mining process.

Key words: Ground movement, mine water, environmental impact, Copernicus programme

Introduction

Mining processes worldwide are a subject of a life cycle that begins with granting mining rights and licenses, then continues with the exploration and production stages, and ends with the closure of the mine. What follows is the stage of post-mining which stretches over a very long period of time depending on the complexity of the previous mining activities.

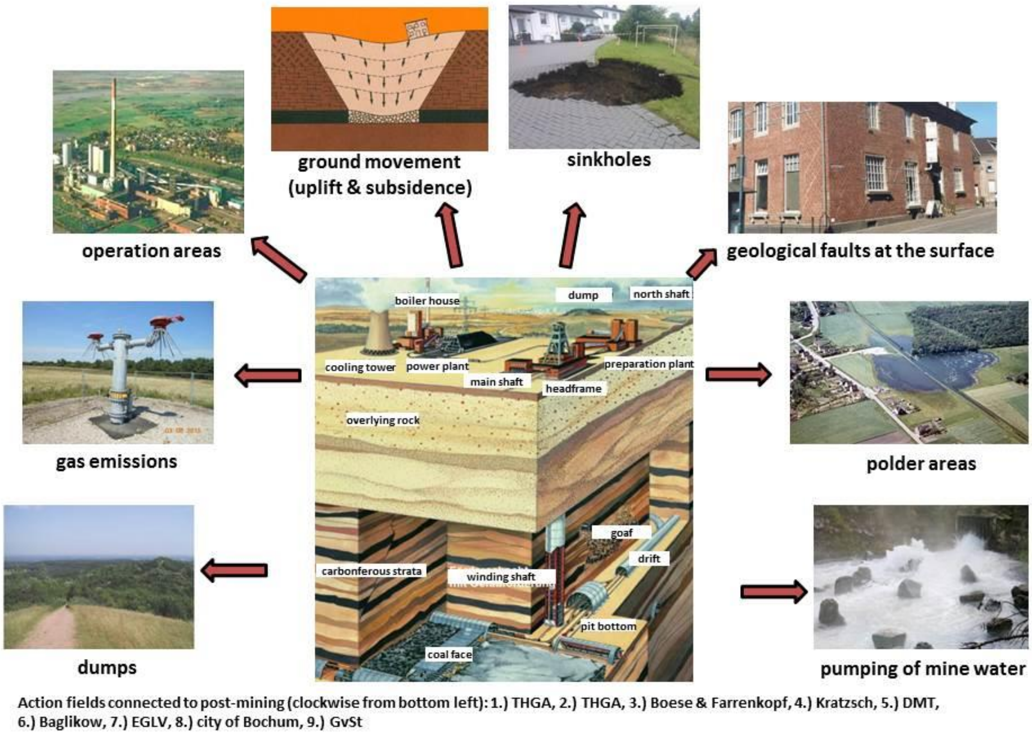

***Figure 1** Action fields connected to post-mining*

The challenges of post-mining involve factors of the environment, structural change, society and economy (Figure 1). In summary, we are facing impact on the elements of water, soil and air: the drainage of mine water affects the hydrochemistry of the receiving waters; shaft constructions, mining works close to the surface and large-scale underground cavities can cause instabilities at the ground surface; the air pathway at coal heaps and settling ponds is potentially polluted by dusting.

Such problems are international problems. They also encompass the conversion of former mine works surfaces, funding of the withdrawal and a successful management of structural change in the mining regions. In many cases, the challenges mentioned have already occurred during the production stage (Melchers et al. 2015).

Sustainable management of post-mining can only be successful if the future closure of a mine is already envisaged when planning mining activities. To achieve this, monitoring of the mining environment and the mining impact on its surroundings is required. The centre of the monitoring process is the element of water as this element is continuously changed in its mineralisation by the mining water drainage. Thus, the water bodies affected are facing changes in their plant and animal life. Ground movements at the surface lead to changes in the depth to water table and thus to changes in the vegetation. Pumping measures to keep open-pit mines dry have a similar effect.

Now, in Germany, the responsibility of the last mining company for how to cope with the closure and post-mining phases is clearly defined by German mining law and by rulings of our supreme court. But we can see that other nations too have developed an awareness of the necessity to properly organise the mining heritage and the opportunities and risks that emerge from that.

Such a responsible management with the opportunities and risks of (post-)mining requires a comprehensive understanding of the relevant processes where possible. In science and technology, it is common practice to observe, to measure, to develop models and to later compare the actual situation to the model; based on that, the models can and will be revised and improved.

The term monitoring has been established for such regulated cycles, not only in technology. Referring to the initial situation described, the question arises what mining objects and activities are concerned, what is their impact on the environment and what potential observation procedures can be applied.

A typical specific feature of mining processes is the fact that they eat up and impact large areas and that they are operated over long periods of time. Contrary to that, there are certain processes that happen on a small scale and in a short period of time. One example of such local impacts are the discontinuity zones at tectonic faults or subsidence at shaft constructions. The latter ones, looking at the speed at which they occurred, are similar to e.g. the breaks of dams at tailing lakes. Consequently, we need to search for methods and combine such methods that achieve a high score and reliability regarding the process to be monitored.

Copernicus Programme

At this point now, the space strategy of Germany's federal government issued in 2010 gains new impetus. This strategy states explicitly that space travel has become an essential instrument for business, science, politics and society at large. Special emphasis is placed on the importance space travel has for innovation, growth, the job market, standard of living and environmental protection. One example of how this strategy is implemented is the Copernicus Programme launched by the European Union and the European Space Agency (ESA). Copernicus provides an up-to-date and high-performing infrastructure for earth observation and geo-information services. This project aims at supplying high-resolution data of remote sensing for both space and time. The Copernicus Programme provides free environmental data to its users.

Copernicus has seen the development of the Copernicus Sentinels – seven satellite missions that were especially developed for this programme and that monitor space. They are at the heart of the space component (Figure 2). The earth observation satellite Sentinel 1A has been in the orbit since April 2014 and supplies data on ground movements and parameters of soil physics. In June 2015 Sentinel 2A was launched according to schedule; this satellite is equipped with a multi-spectral sensor that generates images of the land surface. These images are used to analyse land coverage and land use. Sentinel 3 A has been in its orbit since February 2016; it carries a number of instruments to observe the surfaces of land mass and oceans.

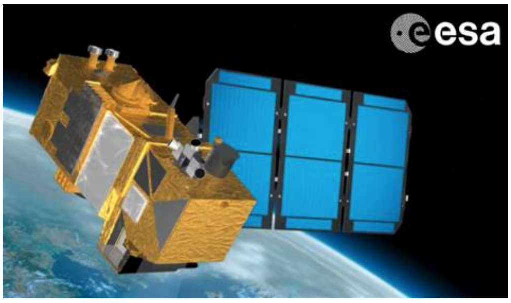

Figure 2 *Sentinel 1A and Sentinel 2A (© ESA).*

The Sentinel satellites move in polar orbits at a height of approximately 700-800 km. Their observations cover nearly every point on the Earth's surface every five days. In their final stage, the satellites are supposed to be used in pairs. The Copernicus Programme is aimed at reliability and sustainability. Until 2018, another nine satellites are going to be launched and plans have already began to continue this programme far beyond the year 2027.

One major topic in this context is of course "Big Data". Indeed, the Sentinel satellites generate gigantic amounts of data that have to be processed, provided to users and, in particular, stored for a long period of time. By 2018 alone, the data volume will have risen to approx. 18 petabytes.

Together with EFTAS and other partners, the Research Institute of Post-Mining works on the use of satellite data for remote sensing and for monitoring actual processes of post-mining. The focus lies on the following aspects: the hydro-chemical balance of lakes and rivers; the ground water level; the land use; the land coverage, and the ground movements. Regarding the potential that is offered by the Copernicus Programme and the reliability of the data supply, monitoring can be innovated by linking the information generated by the satellite-supported sensors with terrestrial expertise, something that we call the in-situ component. This process can help to mitigate the risks of post-mining and to strengthen its opportunities, for example, providing new use and value to the old mining infrastructure to generate renewable energies.

Monitoring

As part of an ongoing research project, the Research Institute of Post-Mining is currently compiling an extensive catalogue of which monitoring methods are currently available for previous and new mining activities. Another objective is to utilise published information to describe how those individual methods can be used and how efficient they are. As a second step, selected methods shall be tested on practical examples. The third phase sees the development of recommendations for the selection and appropriate combination of such methods to meet specific requirements.

The Space Component

Now, which options are provided and what can we actually expect from those data that the satellite-supported earth observation provides us with?

The following examples are extracted from the R&D project GMES4Mining (www.gmes4mining.de) They demonstrate the potential of Copernicus for the monitoring of mining-induced environmental impacts.

The study site Kirchheller Heide, a heath located in the northern Part of the Ruhr area, was used in GMES4Mining to develop change detection methods for water bodies and soil moisture due to mining-related ground movement.

Mine-related flooding can be evaluated either directly by monitoring changes in water distribution or indirectly by observing changes in vegetation provoked by changes in soil moisture and water emergence. The sudden emergence of water in surface in a relative short time generates a unique pattern in the surrounding vegetation that can help in discriminating mine-related flooded areas from other types of water bodies. This information cannot be retrieved from the simple observation of changes in water distribution (Garcia Millan et al. 2014).

GMES4Mining evaluated the effects of emerging waters in vegetation. Plants around mine-related flooded areas often simply die, and rings of trees in different stages of decay can be observed (Figure 3)

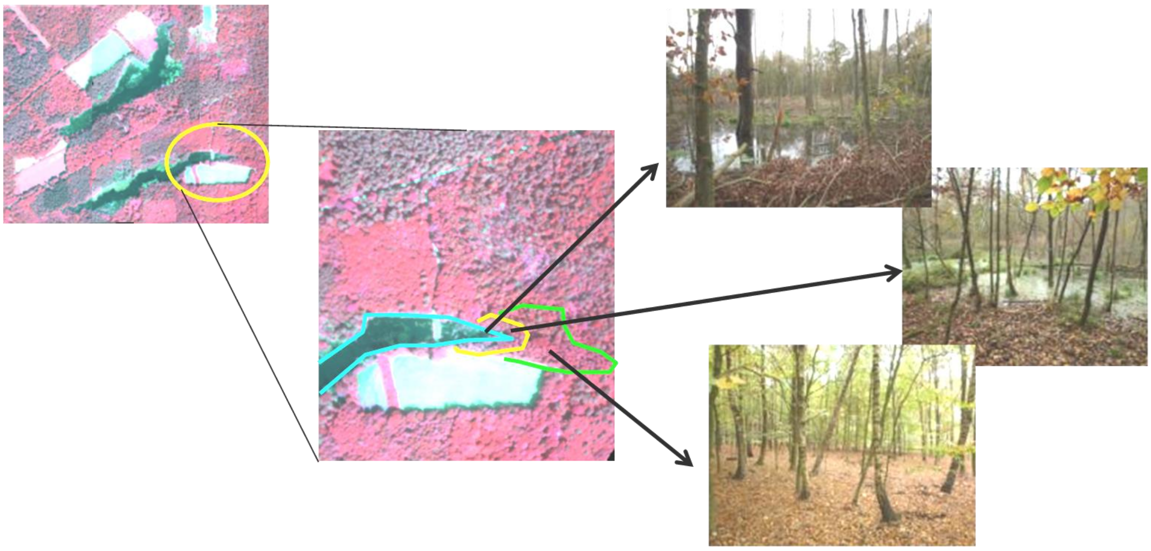

Figure 3 *Flooding stages in Kirchheller Heide. AISA-Eagle airborne sensor infrared composition. Photos taken in October 2012.*

Different stages of vegetation damage can be clearly differentiated by analysis of the hyperspectral dataset of the AISA-Eagle sensor (Figure 4). Nevertheless, an expensive aerial flight campaign can be replaced by the Copernicus Sentinel 2 mission data, which have been available free of charge since 2015. The vertical lines in Figure 4 represent the relevant infrared bands of Sentinel 2.

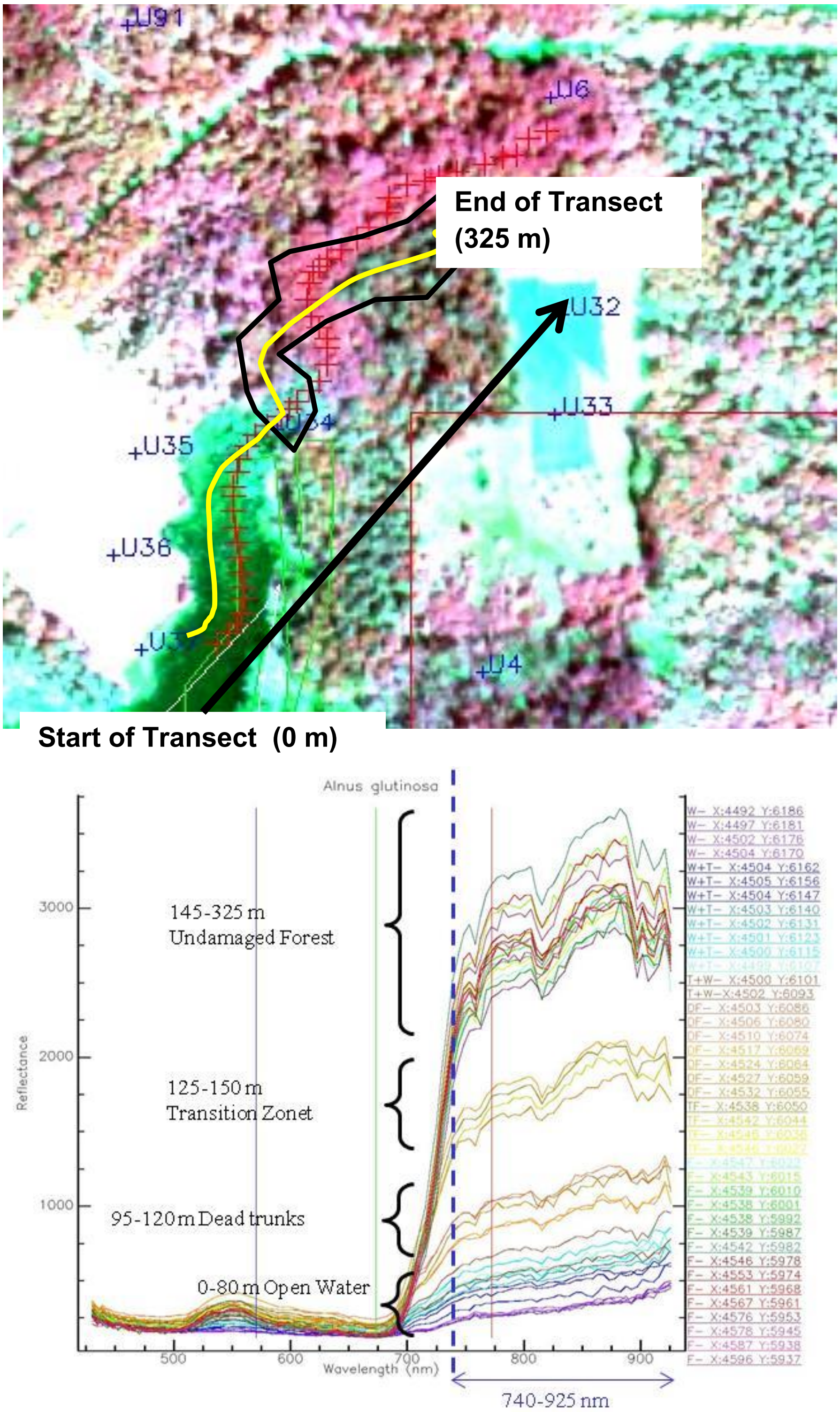

Figure 4 *Vegetation damage transect at study site Kirchheller Heide ranging from open water body to undamaged forest. AISA-Eagle airborne sensor data as graphs and Sentinel 2 bands as vertical lines.*

In addition to the analysis of vegetation damages, change detection of open water bodies can also be carried out with the help of Copernicus data. Water masks calculated with low albedo and using a threshold based on the data histogram can be summed up together in order to detect water bodies that experienced changes during the monitoring period. In low albedo water masks, water bodies are represented by a value of one, and everything else by a value of zero. Therefore, water bodies in this accumulated low albedo raster are represented by values different to zero. Water bodies which did not experience changes in the given time frame, independently of their nature (natural or human-made;

rivers, ports, lakes, etc.), present the maximum value (value 9 in Figure 5) and can be discarded. Water bodies that changed (including mine-related flooded areas) are represented in the intermediate values of Figure 5. The result of this exploration (accumulated low albedo masks) highlights not only mine-related flooding, but can be evaluated by experts in order to decide which areas are potential mine-related flooded areas and to discard other events (i.e. enlargement of a port, change of river beds).

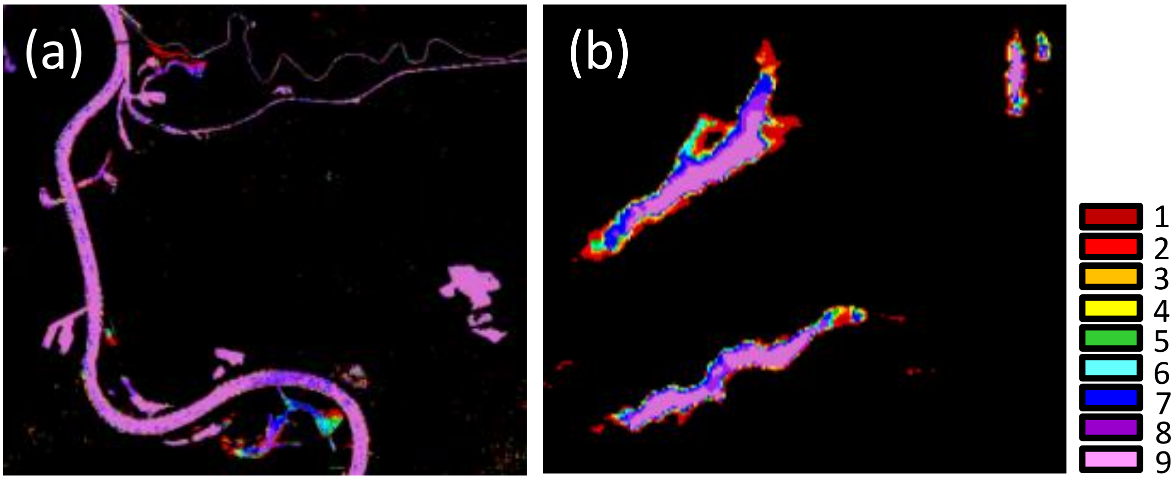

Figure 5 *Results of the change detection using nine RapidEye images between April 2009 and September 2012 for the Ruhr Valley, Germany (a). Known flooded area in Kirchheller Heide (b).*

Mining activities do cause ground movement. The use of satellite-supported remote sensing methods allows implementing monitoring of such ground movements without local installations being necessary. Since the TerraSAR-X radar satellites were launched in 2007, the ground resolution has been reduced to less than 1m.

Subsidences that are determined by radar interferometry receive the abbreviation PSInSAR. In urban areas, a sufficient number of reflectors, known as Persistent Scatterers (PS), are available. In rural regions, artificial radar reflectors, for example corner reflectors, can be erected.

Radar interferometry is an appropriate option for monitoring large-scale surfaces. As recent evaluations have shown, an accuracy of +/-1.5 mm can be assumed for subsidence/settlement monitoring of buildings and landscape formations where TerraSAR-X data are used.

Ground movement monitoring of larger areas, e.g. the entire Ruhr area, at high temporal frequencies is an option, not at least because of the higher intake capacity of the Copernicus radar mission Sentinel 1, which will enable a repeat rate of 1-5 days for radar interferometric measurements relying on two satellites of identical construction; the starting date is scheduled for mid-2016.

The In-situ Component

The Copernicus Programme provides a definition of in situ that is wider than that of other contexts. Here, the in-situ component refers to observation systems that are not operated in space.

Such systems are, for example, the following:

- Surveying results of geodesy and mine-surveying
- Air-based remote sensing instruments
- Site inspection
- Photography and photogrammetry
- Meteorological measuring facilities
- Probes at weather balloons
- Measuring buoys, stream gauging devices

Likewise, information products that are derived from such observations are part of the in-situ component. Those include, for example:

- Digital topographic maps
- Digital elevation models
- Ortho-photos
- Road networks
- Topical maps (e.g. forest areas, settlements, water bodies)
- Mining charts

The in-situ component is decisively shaped by the expertise of the specialists involved. The transparency of the available data is of importance, too. In this context, the information platforms of geo-data infrastructure play a special part. One example to be referred to here is the GEOportal.NRW. This platform allows all users simple research and visualisation of the geo-basis and specialist geo-data provided by the State Administration of North Rhine-Westphalia and also accommodates a specialist portal called “Hazardous underground potentials”. This portal provides information on the spread of underground hazards that are caused by geological and mining factors.

Outlook

The Research Institute of Post-Mining at TH Georg Agricola in Bochum was founded as an initiative of the RAG Stiftung, a foundation set up by the legal successor of the German mining companies, RAG. The foundation also endowed a professorship to support both the research institute and the master study programme “Geo-Engineering and Post-Mining” (Melchers & Goerke-Mallet, 2015).

Against the background of the developments in the subsidised German hard-coal mining sector, the RAG Stiftung pursues the aim to ensure the qualification and availability of specialists who are needed to manage the perpetual tasks that mining has left us. Moreover, intensive work and research need to be done at the knowledge base of post-mining.

Mining processes help to supply people with resources – in other words, mining is as old as humankind itself. Facing the development of the world’s population and of technological advancement there will be mining done in future around the world. Whereas the operation of any underground or opencast mine is necessarily time-bound, the impact the activities have on the environment can be of a much longer time period or even infinite.

Thus, it needs to be our aim to organise the post-mining process of former and current mine activities in an environmentally acceptable manner. The knowledge of how such mining processes impact the environment will enable us to plan, monitor and control processes so that they will become more and more sustainable.

In this context, monitoring is of particular importance. Only high-performance monitoring methods allow for a comprehensive understanding of processes and systems. Today, innumerable methods are available for observing mining facilities and operations as well as the environmental impact of those. Their efficiency has to be tested and developed further time and again. New methods have to be assessed for their applicability in (post-)mining. At the moment, this requirement holds especially true for the enormous potential that satellite-supported earth observation encompasses.

As initial examinations have shown, the data available from the Copernicus Programme can be put to value: the monitoring of ground movements caused by landslides, sinkholes, subsidence or fluctuations of (mine) water levels is almost ready for practical use. Changes in the depth to water tables and their impact on vegetation can also be observed and interpreted.

What needs to be done now is to purposefully bundle the numerous monitoring measures regarding the individual issues to be tackled and to combine those measures with the anthropogenic expertise: that is exactly what our innovative approach will focus on.

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