# Different monitoring techniques relative to mining hazards and their interactions

*Task 1.2. DMT-THGA*
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## 1 Introduction

DMT-THGA was tasked with compiling data on various monitoring techniques related to coal and post-mining hazards and differentiating them based on their application to terrestrial and remote sensing methods such as UAV and satellite data. The objective was to analyze their effectiveness in monitoring different hazards and their interactions. This analysis has to include the requirements and conditions of applicability, the strengths and weaknesses of each technology, cost and benefits.

## 2 Monitoring techniques related to (post) mining hazards

Regarding the classification, evaluation and use of a wide range of monitoring techniques for active and abandoned mining, various projects have been carried out at the Research Center of Post-Mining in recent years [1]. The results were also presented in a "3D monitoring cube" showing the relationships between mining elements, monitoring methods and parameters (Figure 1) [2].

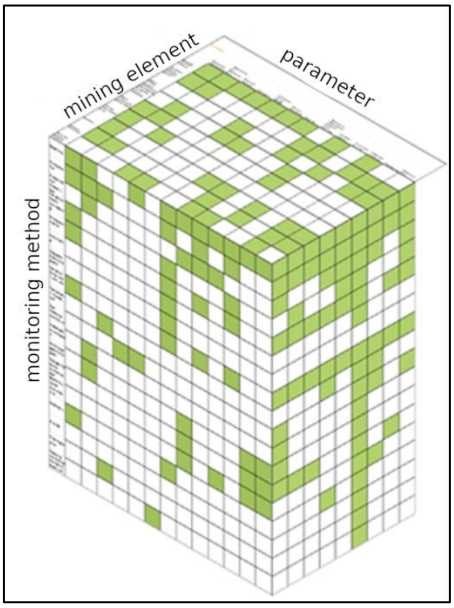


*Figure 1: Sample presentation of the monitoring cube for abandoned mines [2]. Green = correlation, white = no correlation.*

In a further step, the Research Center of Post-Mining is currently conducting research to additionally divide these methods into active and passive monitoring [3]. The data presented here for PoMHaz Task 1.2 condenses these different research results and has been adapted to the risks identified in Task 1.1.

## 2.1 Terrestrial Methods

Over the last centuries, many different terrestrial methods have been developed and used to monitor the hazards of mining operations [4]. This lists shows examples of these methods still used in today's mining and post-mining environment:

- Ground-Based Surveys:
    - Traditional surveying techniques involving the use of instruments such as total stations, GNSS rovers and levels.
- Geotechnical Monitoring
    - Installation of instruments like inclinometers, piezometers, extensometers and strain gauges.
- Hydrological and geochemical Monitoring:
    - Discharge volume measurements, permeability measurements, water chemistry analysis and multi-parameter probes.
- Seismic Monitoring:
    - Seismometers and accelerometers.

## 2.2 Remote Sensing Methods

In order to complement the above-mentioned measurements, which can usually only be used at specific points and not over a larger area, many remote sensing methods are also used today in the field of active and post-mining. The application of modern remote sensing methods has proved very successful when it comes to meeting the necessary requirements for such a geomonitoring regime in terms of spatial and temporal coverage.

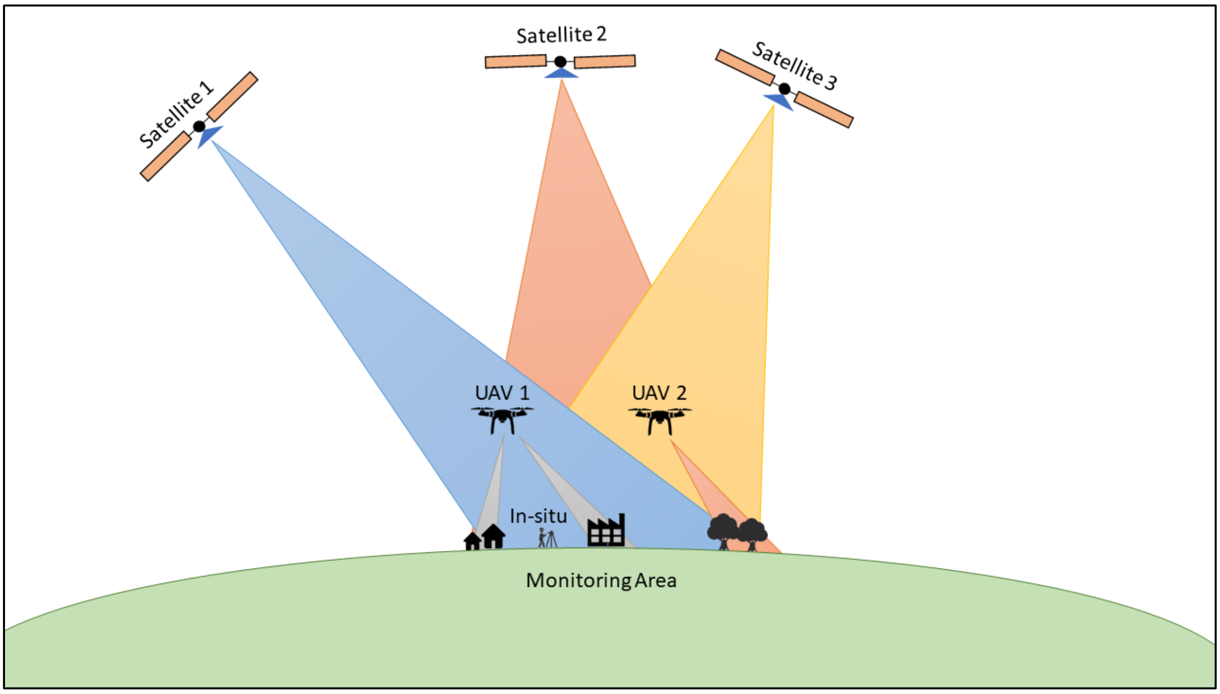


*Figure 2: Multilevel geomonitoring using different remote sensing platforms and terrestrial methods [6].*

The freely available data from various European and American satellite missions have significant potential to offer. These temporally high but spatially low-resolution data can be supplemented, for example, by the cost-effective use of drones, which can cover smaller areas but at very high resolution [5] [6]. The sensors of the platforms are so similar that the data can complement and mutually validate each other through their high-precision georeferencing (Figure 2) [7].

The list of remote sensing methods is split into platforms and sensors [8]. In principle, the same type of sensor, e.g. a multispectral camera, can be used on different platforms, thus balancing spatial and temporal advantages and disadvantages (Figure 3) [9].

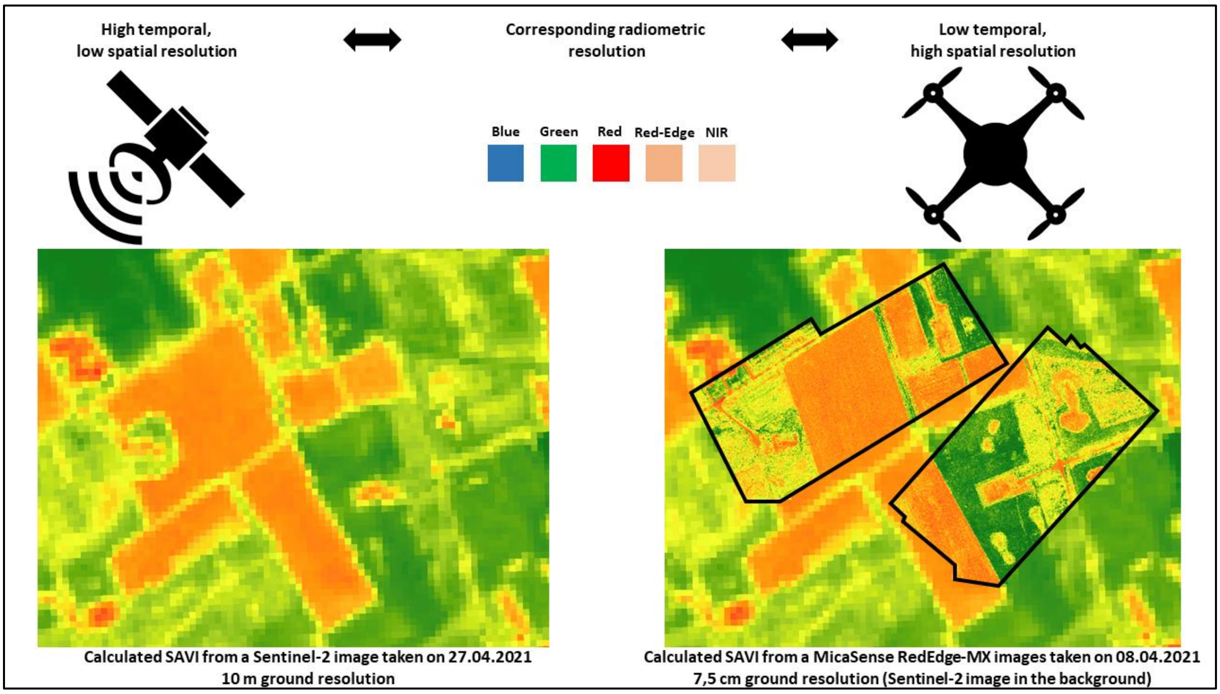


*Figure 3: Comparison and combination of spatial, temporal and spectral resolutions from Sentinel-2 satellite data and a UAV-based MicaSense RedEdge-MX camera using a Soil-Adjusted Vegetation Index (SAVI) [9].*

- Remote sensing platforms
  - Satellites
  - Aircrafts
  - Helicopters
  - Unmanned Aerial Vehicles (UAV)
  - Mobile Mapping Systems (Cars, trains, backpacks, handhelds, apps, …)
- Remote Sensing sensors
  - Active sensors
    - LiDAR and Laser
    - Radar
    - Electromagnetic Sensors
    - Ultrasound
  - Passive sensors
    - RGB cameras
    - Thermal Infrared cameras
    - Multispectral cameras
    - Hyperspectral cameras
    - Magnetometer
    - Gravimetric sensors
    - Gamma spectroscopes

Various monitoring methods can be derived from the combination of platform and sensor (or even sensor combination), which would go beyond the scope here. Not all sensor types are being used for mining hazard monitoring yet, therefore the assignment of sensors/platform combinations as monitoring techniques for mining hazards will be limited to those currently in use. The development of completely new monitoring methods based on the available data sources is not part of the PoMHaz project.

# 3 Allocation and assessment of hazards and monitoring techniques

Based on the hazards identified in Task 1.1 and the available terrestrial and remote sensing methods, these were mapped to each other and analyzed in terms of their requirements, strengths and weaknesses, costs, and benefits.

This analysis is basically a multi-dimensional problem, where first the platforms and sensors are assigned to the monitoring methods and then these are assigned to the respective mining hazards [2] [6]. For the sake of clarity, the results are presented here in abbreviated form in Appendix 1.

# 4 Conclusion

The monitoring methods presented here can be used to varying degrees for the different post-mining hazards. The efficiency, effectiveness and costs depend significantly on the type and size of the respective hazard. Overall, however, it can be stated that no sensor or monitoring method can be used alone without restrictions. Comprehensive risk management can only be successful through their combination, whereby the weaknesses of one method are balanced by the strengths of the other.

Further analyses within the project have to show their suitability for multi-hazard analyses, the combinability of the different methods as well as the integration into the Decision Support System (DSS) and the Geoinformation System (GIS).

# 5 References


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[9] B. Bernsdorf, J. Tiganj und B. Haske, „Geomonitoring as an instrument to accompany structural changes in post-mining areas,“ in *Managing the Change: Tasks of Post-Mining in Ukraine*, Bochum, 2023, pp. 92-117.

| | Name of hazard | Mine type (surface/underground/waste embankments/pit lake) | Monitoring Methods | Strength | Weaknesses | Costs |
|---|---|---|---|---|---|---|
| GROUND MOVEMENT | Subsidence | underground | Ground-Based Surveys<br>Interferometric synthetic aperture radar (InSAR) | High spatial resolution<br>High temporal and vertical resolution, wide area coverage | Low temporal resolution, low area coverage, large personnel expenditure<br>Low horizontal resolution | High (personnel and equipment)<br>Low (Sentinel-1) to high (Commercial satellite data) |
| | Settlement | underground/surface/waste embankment | Ground-Based Surveys<br>Geotechnical Monitoring<br>Interferometric synthetic aperture radar (InSAR) | High spatial resolution<br>High temporal and vertical resolution, wide area coverage | Low temporal resolution for Surveys, low area coverage for geotechnical monitoring, large personnel expenditure<br>Low horizontal resolution | High (personnel and equipment)<br>Low (Sentinel-1) to high (Commercial satellite data) |
| | Slope movement (slope stability)<br>- (Generalized scale- level of whole excavation) | surface | Ground-Based Surveys<br>Geotechnical Monitoring<br>Interferometric synthetic aperture radar (InSAR)<br>UAV-Monitoring (RGB) | High spatial resolution<br>High temporal and vertical resolution, wide area coverage (InSAR)<br>High spatial resolution (UAV) | Low temporal resolution for Surveys, low area coverage for geotechnical monitoring, large personnel expenditure<br>Low horizontal resolution (Satellite)<br>Low temporal resolution (UAV) | High (personnel and equipment)<br>Low (Sentinel-1) to high (Commercial satellite data)<br>Medium (UAV and sensor) |
| | Slope movement (slope stability)<br>- (Local scale- level of bench) | surface/waste embankment | Ground-Based Surveys<br>Geotechnical Monitoring<br>Interferometric synthetic aperture radar (InSAR)<br>UAV-Monitoring (RGB) | High spatial resolution<br>High temporal and vertical resolution, wide area coverage (InSAR)<br>High spatial resolution (UAV) | Low temporal resolution for Surveys, low area coverage for geotechnical monitoring, large personnel expenditure<br>Low horizontal resolution (Satellite)<br>Low temporal resolution (UAV) | High (personnel and equipment)<br>Low (Sentinel-1) to high (Commercial satellite data)<br>Medium (UAV and sensor) |
| | Rock falls | underground/surface | Ground-Based Surveys<br>Geotechnical Monitoring<br>Interferometric synthetic aperture radar (InSAR)<br>UAV-Monitoring (RGB) | High spatial resolution<br>High temporal and vertical resolution, wide area coverage (InSAR)<br>High spatial resolution (UAV) | Low temporal resolution for Surveys, low area coverage for geotechnical monitoring, large personnel expenditure<br>Low horizontal resolution (Satellite)<br>Low temporal resolution (UAV) | High (personnel and equipment)<br>Low (Sentinel-1) to high (Commercial satellite data)<br>Medium (UAV and sensor) |
| | Induced seismicity | underground/surface | Seismic Monitoring | High spatial and temporal resolution | High number of sensors, availability of digital high resolution time/depth-model required | High (personnel and equipment) |
| | Sinkhole | underground | Ground-Based Surveys<br>Geotechnical Monitoring<br>Interferometric synthetic aperture radar (InSAR)<br>UAV-Monitoring (RGB) | High spatial resolution<br>High temporal and vertical resolution, wide area coverage (InSAR)<br>High spatial resolution (UAV) | Low temporal resolution for Surveys, low area coverage for geotechnical monitoring, large personnel expenditure<br>Low horizontal resolution (Satellite)<br>Low temporal resolution (UAV) | High (personnel and equipment)<br>Low (Sentinel-1) to high (Commercial satellite data)<br>Medium (UAV and sensor) |

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|---|---|---|---|---|---|---|
| | **Crevice** | underground | **Ground-Based Surveys**<br>**Interferometric synthetic aperture radar (InSAR)**<br>**Optical Monitoring (Satellite/Aircraft)** | **High spatial resolution**<br>**High temporal and vertical resolution, wide area coverage (InSAR)**<br>**Wide area coverage (Satellite), medium resolution (Aircraft)** | **Low temporal resolution, low area coverage, large personnel expenditure**<br>**Low horizontal resolution (Satellite)**<br>**Low temporal resolution (Aircraft)** | **High (personnel and equipment)**<br>**Low (Sentinel-1) to high (Commercial satellite data)**<br>**Low to high (Free or commercial aircraft data)** |
| **ENVIRONMENTAL POLLUTION** | **Environmental water pollution** | surface/pit lake/underground | **Hydrological and geochemical Monitoring**<br>**Vegetation Monitoring (Satellite)**<br>**Hyperspectral Imaging (UAV/Satellite)** | **High accuracy in the determination and quantity of pollutants**<br>**Fast detection of vegetation changes**<br>**Possible determination and quantity of pollutants** | **Low temporal resolution, low area coverage, large personnel expenditure**<br>**Low horizontal resolution, only detection of secondary effects**<br>**Low temporal resolution (UAV), low spatial resolution (Satellite)** | **High (personnel and equipment)**<br>**High (commercial use of hyperspectral satellite data)**<br>**High (UAV and hyperspectral sensor)** |
| | **Environmental pollution from spoils** | surface/underground | **Hydrological and geochemical Monitoring**<br>**Vegetation Monitoring (Satellite)**<br>**Hyperspectral Imaging (UAV/Satellite)** | **High accuracy in the determination and quantity of pollutants**<br>**Fast detection of vegetation changes**<br>**Possible determination and quantity of pollutants** | **Low temporal resolution, low area coverage, large personnel expenditure**<br>**Low horizontal resolution, only detection of secondary effects**<br>**Low temporal resolution (UAV), low spatial resolution (Satellite)** | **High (personnel and equipment)**<br>**High (commercial use of hyperspectral satellite data)**<br>**High (UAV and hyperspectral sensor)** |
| | **Environmental pollution from tailings dams** | waste embankment | **Ground-Based Surveys**<br>**Geotechnical Monitoring**<br>**Interferometric synthetic aperture radar (InSAR)**<br>**UAV-Monitoring (RGB)** | **High spatial resolution**<br>**High temporal and vertical resolution, wide area coverage (InSAR)**<br>**High spatial resolution (UAV)** | **Low temporal resolution for Surveys, low area coverage for geotechnical monitoring, large personnel expenditure**<br>**Low horizontal resolution (Satellite)**<br>**Low temporal resolution (UAV)** | **High (personnel and equipment)**<br>**Low (Sentinel-1) to high (Commercial satellite data)**<br>**Medium (UAV and sensor)** |
| **GICAL ISSUES/ WATER DISTURBANCES** | **Hydrological disturbances, mining induced floods** | pit lake | **Hydrological and geochemical Monitoring**<br>**Radar (Satellite)**<br>**Vegetation Monitoring (Satellite)** | **High accuracy in hydrological factors**<br>**Fast detection of water areas**<br>**Detection of effects of the water on the vegetation** | **Low temporal resolution, low area coverage, large personnel expenditure**<br>**Low horizontal resolution, only detection of secondary effects**<br>**Low temporal resolution (UAV), low spatial resolution (Satellite)** | **High (personnel and equipment)**<br>**High (commercial use of hyperspectral satellite data)**<br>**High (UAV and hyperspectral sensor)** |
| | **Hydrological disturbances, mining induced floods** | surface | **Hydrological and geochemical Monitoring**<br>**Radar (Satellite)**<br>**Vegetation Monitoring (Satellite)** | **High accuracy in hydrological factors**<br>**Fast detection of water areas**<br>**Detection of effects of the water on the vegetation** | **Low temporal resolution, low area coverage, large personnel expenditure**<br>**Low horizontal resolution, only detection of secondary effects**<br>**Low temporal resolution (UAV), low spatial resolution (Satellite)** | **High (personnel and equipment)**<br>**High (commercial use of hyperspectral satellite data)**<br>**High (UAV and hyperspectral sensor)** |

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|---|---|---|---|---|---|---|
| HYDROLO | Hydrological disturbances, mining induced floods | underground | Ground-Based Surveys<br>Hydrological and geochemical Monitoring<br>Interferometric synthetic aperture radar (InSAR) | High spatial resolution in detection of uplifts<br>High accuracy in hydrological factors<br>High temporal and vertical resolution, wide area coverage, detection of uplifts | Low temporal resolution, low area coverage, large personnel expenditure<br>Low horizontal resolution | High (personnel and equipment)<br>Low (Sentinel-1) to high (Commercial satellite data) |
| GAS/ FIRE | Ionizing radiation emissions | underground/surface | Hydrological and geochemical Monitoring<br>Gas detection (UAV/Helicopter) | High accuracy<br>High area coverage | Low area coverage, large personnel expenditure<br>Low accuracy, small volumes might not be detected | Medium (personnel and equipment)<br>Medium (UAV) to High (Helicopter) |
| | Gas emissions linked to mining | underground | Hydrological and geochemical Monitoring<br>Gas detection (UAV/Helicopter) | High accuracy<br>High area coverage | Low area coverage, large personnel expenditure<br>Low accuracy, small volumes might not be detected | Medium (personnel and equipment)<br>Medium (UAV) to High (Helicopter) |
| | Combustion and overheating of mine waste | waste embankment | Ground-Based Surveys<br>Thermal-Infrared Measurements (UAV/Satellite) | High accuracy<br>High accuracy, high area coverage | Low area coverage, large personnel expenditure<br>Dependent on environmental and weather conditions, low spatial resolution for satellite data | Medium (personnel and equipment)<br>Low (Landsat) to Medium (UAV) |