Post-Mining Multi-Hazards evaluation for land-planning

PoMHaz

WP5: Application on real case studies

D17: Deliverable 5.2 - Geological and environmental data in accordance of GIS and DSS tools of the selected case studies sites

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Acronyms

DMT	DMT-Gruppe (Deutsche Montan Technologie)
DSS	Decision Support System
GIG-PIB	Główny Instytut Górnictwa – Państwowy Instytut Badawczy
GIS	Geographic Information System
POMHAZ	Post-Mining Multi-Hazards evaluation for land-planning
RFCS	Research Fund for Coal and Steel
SRK	Spółka Restrukturyzacji Kopalń
THGA	Technische Hochschule Georg Agricola
WP	Work Package

1. Executive Summary

This deliverable is part of the POMHAZ project, Post-Mining Multi-Hazards evaluation for land-planning. The main objective of POMHAZ is to identify the interaction between the post-mining hazards for coalmines in Europe and to develop tools for facilitate the management of the post-mining hazards in coal region.

In the POMHAZ project, the present deliverable is part of the WP5 that is dedicated to the application of the tools (DSS and GIS) on European real case studies to test and validate the methodology and the tools (DSS and GIS).
The main goal of WP5 was to validate the usability of the GIS and Decision Support System (DSS) tools developed for multi-hazard risk assessment and management across diverse real-world case studies. Therefore, Deliverable 5.2 is directly related to Task 5.2 "GIS and DSS implementation on real case studies". This deliverable focuses on geological and environmental data in accordance with GIS and DSS tools of the selected case studies site; each site presenting different geological, technical, and historical conditions, enabling evaluation of the flexibility and adaptability of the tools.

Sosnowiec Case Study

In Sosnowiec, a well-studied former mining area, individual hazards such as flooding and subsidence were first mapped and later combined into a comprehensive multi-hazard risk map. The tool effectively visualized the risks, particularly in the most exposed urban areas, providing support for local spatial planning and decision-making. The results confirmed the tool's accuracy and relevance in this environment.

Piekary Śląskie Case Study

A similar approach was applied to Piekary Śląskie. The multi-hazard map revealed serious risks from both subsidence and hydrological disturbances. A notable example was a floodplain formed due to historical mining activities (coal, zinc, and lead), which created a closed basin susceptible to periodic flooding. This situation had a significant impact on residents and land usability.
To address this, a large hydrotechnical investment (2020–2024) was undertaken by SRK S.A. in cooperation with the city authorities. The project included the construction of ditches, a retention reservoir, a pumping station, and pipelines, successfully mitigating the flooding risks. This real-life case clearly demonstrated the DSS tool's ability to identify and assess complex hazard interactions.

Wałbrzych Case Study

In Wałbrzych, the focus was on radon emission risks and discontinuous ground deformations. A smaller section of the city was analysed, and risk maps were generated using the DSS tool. These were then compared with existing data and limited field measurements. Although field measurements were constrained, the findings validated the DSS tool's estimations. The results showed that overlapping risks of radon and ground instability can be significant, underlining the importance of integrated risk assessment.
Due to the diversity of locations in terms of geology, history and mining methods (ore and hard coal) as well as natural and socio-economic conditions, the collection of data for the GIS DSS tool, often required formatting and adaptation in accordance with specific requirements.

2. Background

Deliverable D5.2, entitled "Geological and environmental data in accordance of GIS and DSS tools of the selected tools of the selected case studies site", refers to WP5 application of project's developed tools and methods on existing post-mining areas.

The general objective of WP5 was to validate the usability of the tool (DSS and GIS) developed in the previous tasks for multi-hazards management on real case studies.

In the POMHAZ project, the present deliverable D17 is the part of the WP5 that is dedicated to validate the usability of the tools developed for multi-hazard risk assessment and management across diverse real-world case studies. Each site presented different geological, technical, and historical conditions, enabling evaluation of the flexibility and adaptability of the tools. As part of this deliverable, the partners were required to identify, collect, and critically evaluate geological, geotechnical, and environmental datasets from available national and institutional sources. This process involved assessing the completeness, quality, and interoperability of existing data and selecting those most suitable for integration into the advanced software GIS/DSS environment. The resulting harmonised datasets formed the foundation for the model's development and for further analytical and visualisation functions, ensuring that the tool could effectively support spatial planning and risk assessment in post-mining areas.

The challenge of partners was to collect geological and environmental data in specific accordance.

In the case of Poland, the task described in this Deliverable was particularly challenging due to the fact that there are no national databases containing unified data. The data sources contained information of varying quality, often old, mining maps from the last century. The preparation of appropriate data sets allowed them to be used in GIS DSS, and then to verify the usefulness of this tool in the conditions of Polish post-mining areas.

3. Introduction

The aim of Work Package WP5 was to validate on real case studies the usability of the GIG DSS tools, developed for multi-hazards management. Every site has its own specific requirements and characteristics. The diversity of test sites allowed us to verify the flexibility of the tools and their suitability for various geological, technical and historical conditions (in terms of how long the exploitation lasted and how long ago it ended).

4. Data collection

4.1. Mining and geological data

The DSS system was developed by the German project partner Technische Hochschule Georg Agricola (DMT-THGA). In order to create the system, it had to be 'fed' with information characterizing individual testing locations. It was necessary to create a database of available data determining hazards in selected cities in mining areas. Polish project's partner GIG-PIB was responsible for collecting data and creating databases, according to the guidelines and common agreements with the partner THGA. The general information about each location was collected, such as: geology, topography, hydrology because it has a direct impact on hazards and risks. An important factor shaping the development of hazards is the described history of exploitation – past mining methods, methods of mine closure, and the time that has passed since the closure of the mining facilities. The actions that have been taken systematically, regulated by legal regulations or recommended instructions, aimed at monitoring adverse phenomena was analysed as well.

The data collected and prepared according to the requirements were presented in form of different maps and visualisations. The data was prepared in the form of a QGIS project, containing vector data layers in *.shp format. The databases covered the following issues:

- Seam maps,
- Shafts, shafts and headings connected to the Surface
- Seams,
- Shallow mining,
- Protective pillars,
- Waste dumps and Settling ponds,
- Deformation and Faults,
- Adits,
- Occurences/outcrops of various geological formations,
- Depressions from the beginning to 1996,
- Subsidences 1946 to 1996,
- Age-related subsidences,
- Reservoirs - extent of underground water bodies,
- Overflow lands - areas of projected potential flooding,
- Study areas - area of possible anomalous radon and other gases concentration.

The collected and formatted data and information concerning the hazards identified in the cities enabled the creation of risk maps for individual hazards. The Sosnowiec area is the best known because we were able to gather the most up-to-date data and information.

4.2. Environmental data

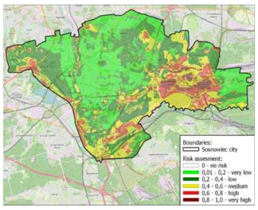
One of the stages of the DSS tool is to assess the vulnerability of the areas under study. Environmental conditions have a significant impact on the quality of life of residents and the value of post-mining areas. A set of environmental data was prepared for each location, as presented in the Table 1. In addition to geological, mining and environmental data, socio-economic information was collected, as described in another section of the reports.

Table 1: The set of environmental data

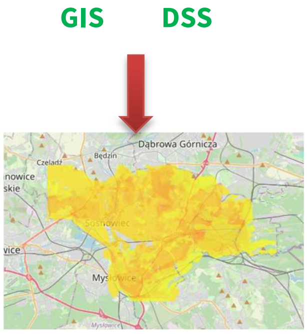
PIEKARY ŚLĄSKIE SITE		
Land use		km²
	total area	40
green areas	forests	3,03
	woodland	1,53
	groves	0,35
cultivated areaa	allotments gardens	1,07
	plantations	0,02
	orchards	0,02
uncultivated areas		0,05
waste damps	municipal, industrial waste	0,004
excavations and landfills	excavations	1,77
	landfills	0,06
rivers, streams etc.	total lenght (km)	7,73
WAŁBRZYCH SITE		
Land use		km²
	total area	85
	forests	29,6
green areas	woodland	1,17
	groves	0,83
	allotments gardens	4,6
cultivated areaa	plantations	0,01
	orchards	0,25
uncultivated areas		0,69
	municipal, industrial waste	0,427
excavations and landfills	excavations	0,08
	landfills	0,19
rivers, streams etc.	total lenght (km)	97,2
SOSNOWIEC SITE		
Land use		km²
	total area	91
	forests	18,46
green areas	woodland	7,6
	groves	6,3
	allotments gardens	4,1
cultivated areaa	plantations	0,2
	orchards	0,2
uncultivated areas		0,52
waste damps	municipal waste	0,2
	industrial waste	0,1
excavations and landfills	excavations	1,77
	landfills	0,06
rivers, streams etc.	total lenght (km)	37,4

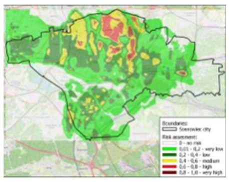
5. GIS and DSS implementation on real case studies.

As part of the implementation of the tool, the effects of its use were checked in locations previously identified by GIG-PIB. Before the tool became available for use, individual hazards were analysed. Maps were created for each of them. When implementing the tool, the effects of assessing and visualising individual hazards were compared with visualisations (maps) of multiple hazards (Figure 1).



Hydrological disturbances risk map (GIG)





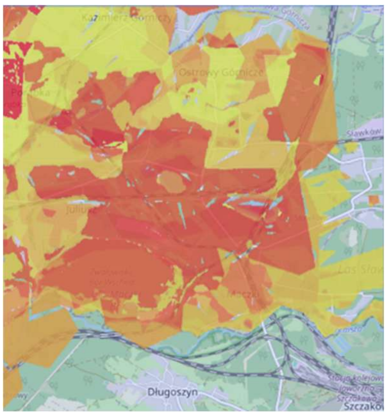
Vertical deformation – subsidence risk map (GIG)

Figure 1: Multi-risks map in well recognised site – case Sosnowiec.

The multi-risk visualisation clearly shows the potential hazards of the city. It confirms that the implementation of this tool module in Sosnowiec will meet the project's objective, which is to support local stakeholders in their decision-making, particularly with regard to spatial development.

In the next step we produced the risk map for the most exposed to hazards area of Sosnowiec. The results are presented on Figure 2 confirmed our earlier conclusions and estimates in a location that is well known in terms of mining and geological conditions.

The risk map for chosen area in Sosnowiec



Percentage of risk in chosen area

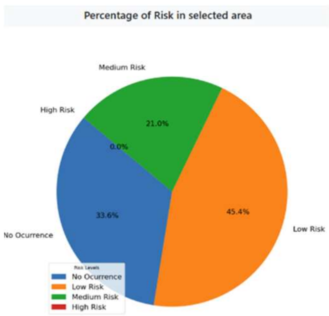
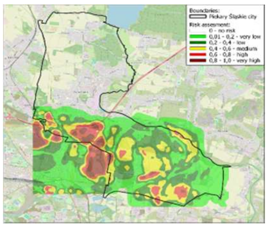


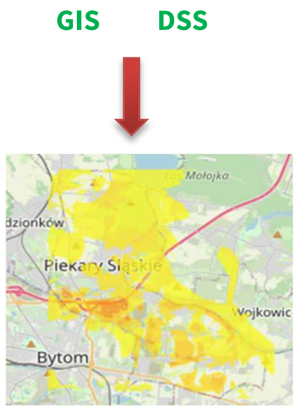
Figure 2: GIS DSS tool Multi-Hazard risk map for selected area of the site Sosnowiec – well recognised in field

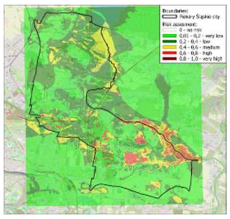
A similar approach was taken at the selected area in Piekary Śląskie.

Well-known hazards were analysed on the basis of available geological, mining and environmental data: hydrological hazards – flooding and subsidence. The generated („produced") by the DSS tool multi-hazard visualisation accurately reflects the situation in the analysed section of the city (Figure 3).



Hydrological disturbances risk map (GIG)

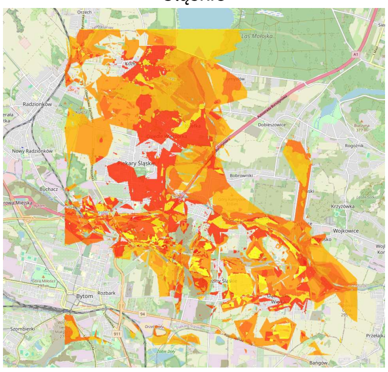




Vertical deformation – subsidence risk map (GIG)

Figure 3: Multi-risk map in well recognised site Piekary Śląskie case.

The risk map for chosen area in Piekary Śląskie



Percentage of risk in chosen area

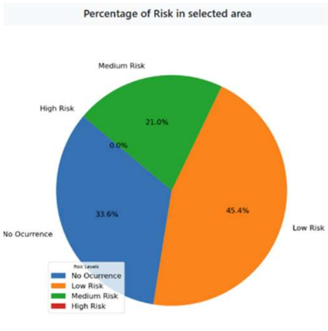
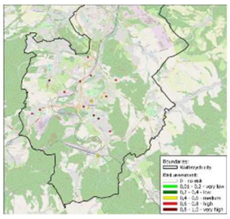


Figure 4: GIS DSS tool Multi-Hazard risk map for selected area of the site Piekary Śląskie – well recognised in field

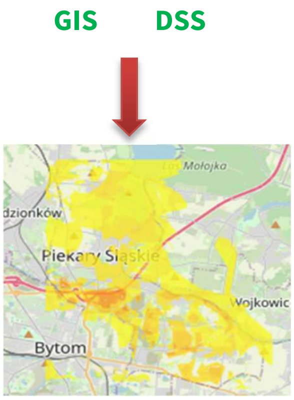
In Wałbrzych, the radiation hazard – radon emissions – and the hazard of discontinuous deformations were analysed. As in previous cases, a limited area of the city was selected. The results of the DSS tool were evaluated using our knowledge based on:

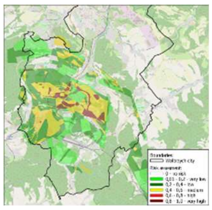
- radon risk assessment using the 'radon tool';
- existing data on discontinuous deformations.

Figure 5 shows the results of the comparison.



Radon emission risk map (GIG)

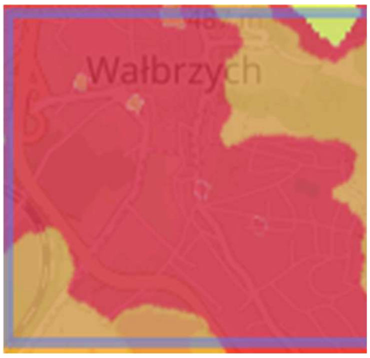




Discontinuous defermations risk map (GIG)

Figure 5: Multi-risks map in well recognised site -Wałbrzych case.

The risk map for chosen area in Wałbrzych



Percentage of risk in chosen area

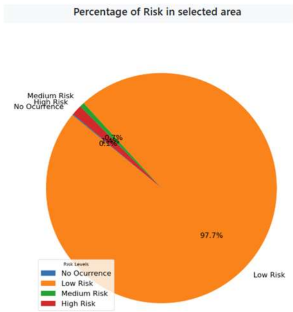


Figure 6: GIS DSS tool Multi-Hazard risk map for selected area of the site Wałbrzych – well recognised in field.

Radon concentration measurements were taken in buildings in the indicated area of the city. Unfortunately, for logistical reasons, their number was very limited. Nevertheless, the actual results confirmed the theoretical estimates. As a result, the DSS tool estimates indicating that the multiple risk resulting from the co-occurrence of radon emissions and discontinuous deformations may be even high were confirmed.

6. Multi-hazards and their effects on post-mining areas – case studies

6.1 Hydrological disturbances

The multi-hazard visualisation shows the hazards of each of the case studies. In the case of Piekary Śląskie, floodplains are particularly troublesome. In the part of the city marked in red on the multi-risk map (Figure 3, above), a floodplain has actually formed. In Piekary Śląskie, the risks caused by subsidence pose a threat of the formation of drainage basins and floodplains. Such phenomena are a serious problem, especially in parts of the city where subsidence, resulting from centuries of shallow and deep mining, reached several to several dozen metres.

Below is presented an example of actual problems that occurred in the discussed area of Piekary Śląskie.

In the analysed area, located within the territory of two cities: Piekary Śląskie and Bytom, a closed basin was created. The basin was created as a result of the negative effects of hard coal – deep level, zinc and lead ore mining. The area was characterised by severe waterlogging and was exposed to periodic flooding by rainwater (Figure 7,Figure 8). The effects of flooding cause serious problems for residents and local authorities. They threaten buildings and render areas unusable for development, plants cultivation or recreation.

Figure 7: Floodplain in Piekary Śląskie.

Figure 8: Floodplain in Piekary Śląskie – damages to the environment.

Therefore, it was decided to build a drainage system for the entire basin area.

Investment aimed at eliminating the damage caused by drainage and protecting the property against flooding by rainwater. The investment was carried out by SRK S.A., in collaboration of the city of Piekary Śląskie, which also covered part of the costs of its implementation. Duration of the entire investment: 2020–2024.

As part of the project, drainage was carried out for a closed basin created as a result of the negative effects of hard coal, zinc and lead ore mining. The closed basin covers a catchment area of 157.60 ha. Water from the basin catchment area is drained through a system of ditches to a buffer retention reservoir, where it is temporarily stored and discharged through a gravity pipeline to the pumping station's equalisation reservoir and then pumped to the Szarlejka river watercourse. Temporary storage of excess rainwater in reservoirs effectively reduces the risk of flooding caused by short-term torrential rains, known as flash floods. SRK SA and the city undertook the construction of a drainage system for a closed basin. Ditches, a retention reservoir, a dock inlet, a water pumping station, and a gravity and pressure pipeline were built in the city of Piekary Śląskie. Pictures below show the successive stages of hydrotechnical works (Figure 9-12).

Figure 9: Construction of the hydrotechnical system.

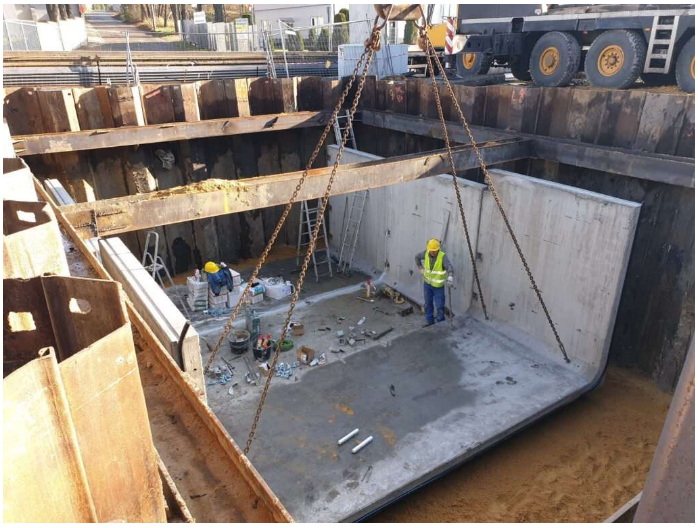


Figure 10: Construction of the hydrotechnical system – the next stage.

Figure 11: The effect of the work undertaken.

Figure 12: The effect of the work undertaken: waters are pumped to Szarlejka river.

The above example shows that the DSS tool effectively identifies the risk of occurrence and intensity of multiple hazards.

6.2. Impact of mine closure method on surface water quality

The method adopted for the closure of hard coal mines has a fundamental influence on the water balance and on the quality of both surface water and groundwater. In practice, two main approaches are applied:

- mine closure with continued dewatering,
- mine closure through flooding of mine workings (either complete or partial).

Each of these options entails different environmental consequences.

1. Closure with continued dewatering – In this case, mine water continues to be pumped from the workings and discharged into surface watercourses. This allows for maintaining

a relatively stable groundwater table within the rock mass and prevents the uncontrolled outflow of mineralized waters to the surface. However, such a method of closure results in a permanent impact of discharges on rivers and streams, particularly in terms of:

- increased salinity (Na^{+}, Cl^{-}, SO_4^{2-}),
- increased concentrations of iron, manganese, and heavy metals,
- changes of pH and reduced dissolved oxygen content.

These discharges often lead to local degradation of surface water quality, especially during low-flow periods. In some cases, processes of iron and manganese oxide precipitation are observed in riverbeds, disturbing the functioning of aquatic ecosystems. Nevertheless, in deep mine dewatering systems of abandoned mines (submersible systems), chemical stratification of mine waters is often observed, where water of poorer quality ("heavier," more mineralized) occupies deeper parts of the workings, while the upper levels are characterized by better quality parameters. Consequently, the waters discharged to the surface may exhibit relatively good quality and, under certain conditions, may not pose a significant burden to surface water environments. An example is the Saturn pumping station (Sosnowiec/Piekary Śląskie area), where millions of cubic meters of water are pumped annually with parameters comparable to drinking water.
However, prolonged pumping from deeper parts of the workings may lead to preferential removal of higher-quality water, resulting in a gradual deterioration of the physicochemical parameters of the water remaining within the system. Over time, this can cause more mineralized waters to be abstracted and subsequently discharged into surface water bodies.

2. Mine Closure through Flooding of Workings – When dewatering pumps are switched off, a gradual rise in the groundwater table begins. In the initial phase, the dominant processes involve the saturation of the rock mass, accompanied by the reactivation of mineral compounds (sulfides, carbonates, clay minerals). As a result of the oxidation of pyrite and marcasite, acid mine drainage (AMD) is generated, characterized by high concentrations of sulfate ions, iron, and manganese, as well as smaller amounts of heavy metals.

   If carbonate minerals (such as calcite and dolomite) are present in the deposit, a neutralization process may occur, which can mitigate acidity but simultaneously increase water hardness and the concentrations of Ca^{2+} and HCO_3^{-} ions.
   From the perspective of risks to surface and groundwater quality, the hydraulic connection between the Carboniferous and Quaternary aquifers is of key importance. The risk of contamination of Quaternary and surface waters mainly arises in two situations:

   - when hydrostatic pressure in the Carboniferous strata exceeds that in the overlying aquifers, causing upward migration of mineralized waters (particularly within fault and fracture zones);
   - when the mine water table reaches the ground surface, leading to the formation of ponds or natural discharges that may flow toward surface watercourses.

   In such cases, the mixing of waters with differing chemical compositions occurs, resulting in a local increase in salinity and ionic load in surface waters.

Consequently, both continued dewatering and mine flooding constitute potential sources of pressure on the aquatic environment, differing in the nature and dynamics of their impacts. From the standpoint of water protection, the most favorable approach is controlled, staged flooding, accompanied by systematic monitoring of water level changes and chemical composition, and by ensuring safe discharge pathways for mine waters.

Forecasting and Indication of Areas Prone to Surface Waterlogging after Mine Closure
Hydrogeological and Geomechanical Conditions

The occurrence of surface waterlogging in post-mining areas is a direct consequence of the rising groundwater levels following the shutdown of mine dewatering systems. Its manifestation depends on the geological structure, hydrodynamic conditions within the rock mass, and the extent to which the environment has been altered by mining activities.

In the conditions of the Upper Silesian Coal Basin (USCB), the following factors are of key importance:

- Lithology and permeability of overburden formations, which determine the potential for water filtration from Carboniferous aquifers toward shallower groundwater horizons;
- Distribution of surface deformations and subsidence basins, which may serve as local accumulation zones for precipitation and groundwater, as well as their spatial relationship to surface watercourses and the groundwater table;
- Degree of documentation and technical condition of former shafts, boreholes, and workings, which often act as preferential filtration pathways between aquifers;
- Existence of hydraulic connections between neighboring mines, influencing the spatial extent of groundwater rebound during the mine flooding process.

Methodology for Forecasting Areas Prone to Waterlogging

Forecasting areas at risk of surface waterlogging requires an integrated approach that combines the analysis of geological, hydrodynamic, and morphometric data with spatial modeling. In practice, a combination of three complementary methods is most commonly applied:

a) Morphometric and geomorphological analysis, based on elevation data (DEM, DTM), which enables the identification of terrain depressions that may function as potential closed or poorly drained basins.
b) Hydrogeological analysis, which includes:
    - determination of the groundwater table level in mine workings, based on monitoring data or numerical modeling results, including forecasts;
    - interpolation of piezometric contours (hydroisohypses) and assessment of groundwater flow directions;
    - comparison of hydraulic pressures between the Carboniferous and Quaternary aquifers.
c) Spatial modeling within a GIS environment, involving the superposition of informational layers such as terrain morphology, lithology, location of mine workings, boundaries of mining fields, and the hydrographic network.

As a result of such analyses, areas are delineated where the mine water table is or is expected to be located within the near-surface zone—that is, where there is a high probability of groundwater emergence at the surface under conditions of intense precipitation, natural groundwater fluctuations, or capillary rise. These areas also include zones where uncontrolled or unforeseen further groundwater rebound may occur due to disturbances in the established hydrodynamic regime, for example, as a result of deep building foundations or other anthropogenic intrusions.

Characteristics of Areas Prone to Waterlogging – Examples from Research Sites

- Wałbrzych – The historic coal mines in this region are located in the valleys of streams such as the Pełcznica and Szczawnik. The area is characterized by the high permeability of Carboniferous rocks and the presence of numerous fractures. The mine flooding process has been completed, and mine water is currently discharged by gravity through drainage adits. These waters are no longer subject to further rebound. A characteristic phenomenon in the region, however, is the occurrence of local ponds and periodic waterlogging, mainly after heavy rainfall events, especially within former mining subsidence zones.

- Sosnowiec – In this city, the mine flooding process is still ongoing. For instance, in one of the mines, the water level has risen by more than 6 meters over the past three months, currently reaching a depth of about 250 m b.g.l., while in other mines the level differs—by as much as 100 m higher. It is currently difficult to predict the ultimate rebound level, as there is no established long-term dewatering strategy for the northern part of the Upper Silesian Coal Basin. The final approach adopted will determine the safety of the surface, particularly regarding the risk of pond formation and local flooding. Even now, certain areas of Sosnowiec experience local and periodic waterlogging, caused partly by disturbances in the surface and groundwater drainage systems resulting from post-mining waste heaps and spoil tips.

- Piekary Śląskie – All mines in this area have been closed, and some are currently undergoing flooding. The process is limited by the extent of hydraulic connections with neighboring mines, meaning that the area is indirectly drained by nearby pumping stations. The highest risk of waterlogging occurs in the central and southern parts of the city, where coal as well as zinc and lead ores were formerly mined. As a result, extensive closed depressions have developed, including one exceeding 150 hectares in surface area. These zones have long experienced flooding problems after heavy rainfall, although the situation has recently improved due to the construction of a large pumping station system designed to protect urbanized areas from inundation.

Methods for Reducing Waterlogging Risk in Post-Mining Areas

In the process of mine closure and flooding of workings, one of the key environmental challenges is reducing the risk of surface waterlogging and pond formation. This phenomenon results from the restoration of hydrodynamic equilibrium after dewatering cessation, as well as from changes in the structure of the rock mass and land morphology caused by mining operations. Depending on local conditions — geological structure, method of mine closure, overburden characteristics, and surface morphology — effective risk mitigation requires the application of different methods or their combinations, including technical, hydrological, and reclamation measures.

a) Controlled flooding and maintaining water levels at a safe elevation

The fundamental method of mitigating post-mining water hazards is controlled flooding, involving the gradual filling of mine workings with water while continuously monitoring the groundwater table. Maintaining water at a predetermined safe elevation prevents both excessive rebound and uncontrolled outflows to the surface. In technical practice, controlled flooding includes measurements of water levels in boreholes and piezometers, with emergency pumping initiated if necessary.

b) Local dewatering through wells, drains, and drainage ditches

In areas where surface waterlogging mainly results from shallow (Quaternary) groundwater, local lowering of the water table can be effective. This is achieved through dewatering wells, ditches, or drainage systems that discharge excess water into surface watercourses or enable its reuse (e.g., for drinking or utility purposes, depending on quality). Such measures are particularly useful in urban and industrial areas, where local depressions have formed due to mining subsidence. The main advantage of this method is its precise, localized operation and the ability to control groundwater levels in urbanized zones. However, it requires regular maintenance, as blocked drains may lead to renewed water accumulation.

c) Hydrotechnical structures and drainage systems

Where surface water accumulates in post-mining depressions or subsidence basins, hydrotechnical measures are implemented to enable its discharge into natural watercourses. This typically involves constructing a network of ditches, drains, collectors, or pipelines to ensure safe outflow of water from ponds to receiving streams. If gravity drainage is not feasible, pumping systems are installed. The gravity flow from ponds to rivers is designed to minimize erosion, often incorporating sedimentation tanks and separators to reduce pollutant loads.

d) Reclamation and leveling of subsidence depressions

In areas where surface deformation has led to the formation of closed, poorly drained basins, an effective mitigation approach is technical reclamation — filling depressions with materials (e.g., post-mining waste) or leveling the terrain to restore natural surface runoff. These activities are often combined with biological reclamation (afforestation, deep-rooted vegetation), which promotes slope stability and reduces erosion. The advantages of this method include its long-term effectiveness and improvement of landscape and aesthetic values.

e) Discharge of surface waters from ponds into mine workings (drainage system)

In certain post-mining regions, it is possible to use mine workings as receivers of excess surface water. This applies to cases where surface ponds were not formed by mine flooding, and the mine water table is or will be maintained at a safe depth through pumping or gravitational drainage to adjacent mines. This method involves drilling drainage boreholes or infiltration pipelines that direct water from ponds or surface depressions into underground workings. Such a solution requires a comprehensive hydrogeological assessment, including evaluation of the potential impact of surface water on mine water quality, as well as economic feasibility analysis.

The comparison of methods for reducing waterlogging risk presented in the table in Appendix 1 has been developed based on general knowledge of mine hydrogeology, mine closure practices, and logical reasoning regarding the technical and environmental implications of each approach.

6.3. Hazard of ionising radiation emission – radon problems in analysed case studies

During the project, our knowledge of the overall actual conditions, the needs of cities, and the possibilities for implementing the GIS DSS tool grew. We identified the need to change the ranking of hazards to cities. We understood that Polish cities, selected for the study, had equally extensive needs, regarding post-mining hazards. However, each city has different conditions and a different level of awareness of the situation.

For example, in the initial stages of analysing and identifying hazards, we assumed that Wałbrzych might be at risk of increased emissions of radon and other gases. The existing database of results did not allow us to confirm this assumption. Therefore, we performed a series of in situ measurements, presented below.

6.3.1. Results of *in situ* measurements – Wałbrzych site.

Elevated concentrations of methane, CO_2 and radon were measured in the 'Lisia Sztolnia' excavation and in the exhaust air from the shafts. High concentrations of radon have been measured in areas such as shafts and adit outlets – up to 1335 Bq/m^3. Measurements of radon concentrations in residential buildings were also taken. The measured concentrations ranged from about 20 to about 120 Bq/m^3. In no case did radon concentrations exceed the recommended value, 300 Bq/m^3. No elevated gas concentrations were measured in the basements of residential buildings either (Figure 13, Figure 14).

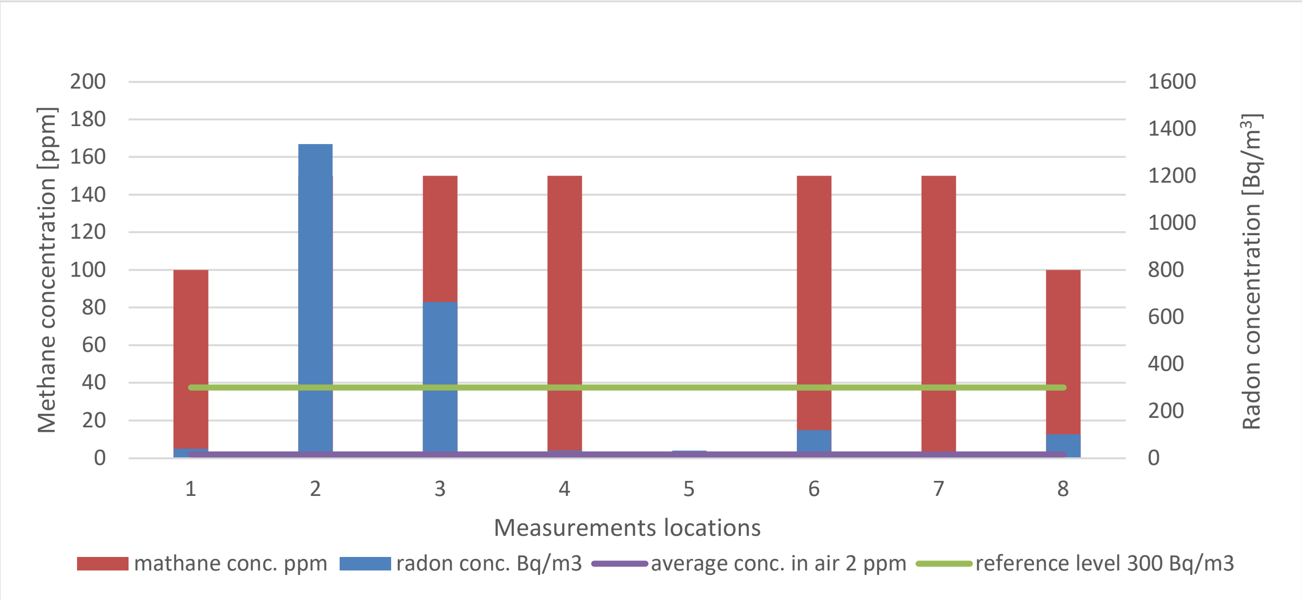


Figure 13: Results of mesurements of radon and methane in post mining instalations (outlets of shafts and adit) in Wałbrzych.

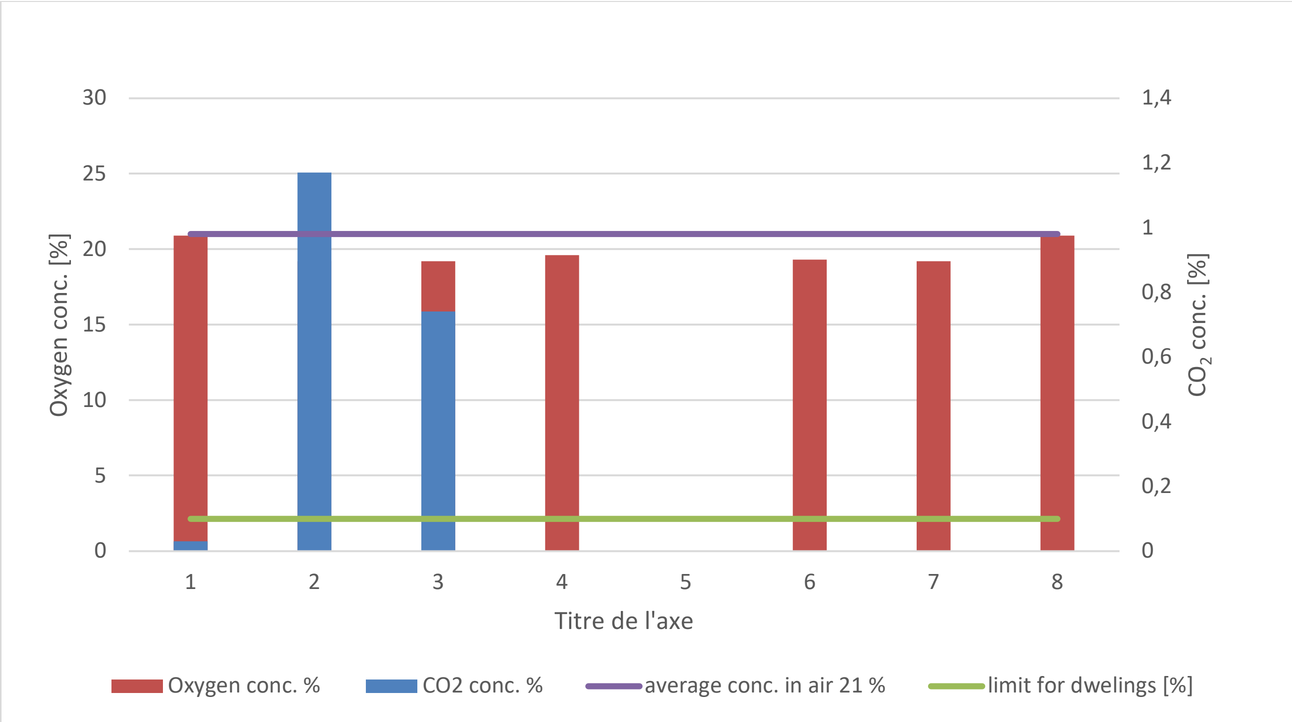


Figure 14: Results of mesurements of oxygen and CO² in post mining instalations (outlets of shafts and adit in Wałbrzych

Elevated concentrations of these gases were not measured in open spaces or in areas of shallow mining, surface discontinuities and porphyry outcrops. Concentration of methane measured in open air above the shaft didn't exceed 1,9 ppm, which means that it does not pose any risk to residents (general population) (Figure 13).

Figure 15: Location of measurement points of methane

A series of geodetic measurements of vertical surface displacements were carried out at points of the geodetic network established in 1925 (Figure 16). A slight uplift of the surface was observed

(Figure 17). However, the existing depressions, created during the operation of the Wałbrzych mines and after their liquidation, continue to create conditions for the formation of floodplains, especially after heavy rainfall.

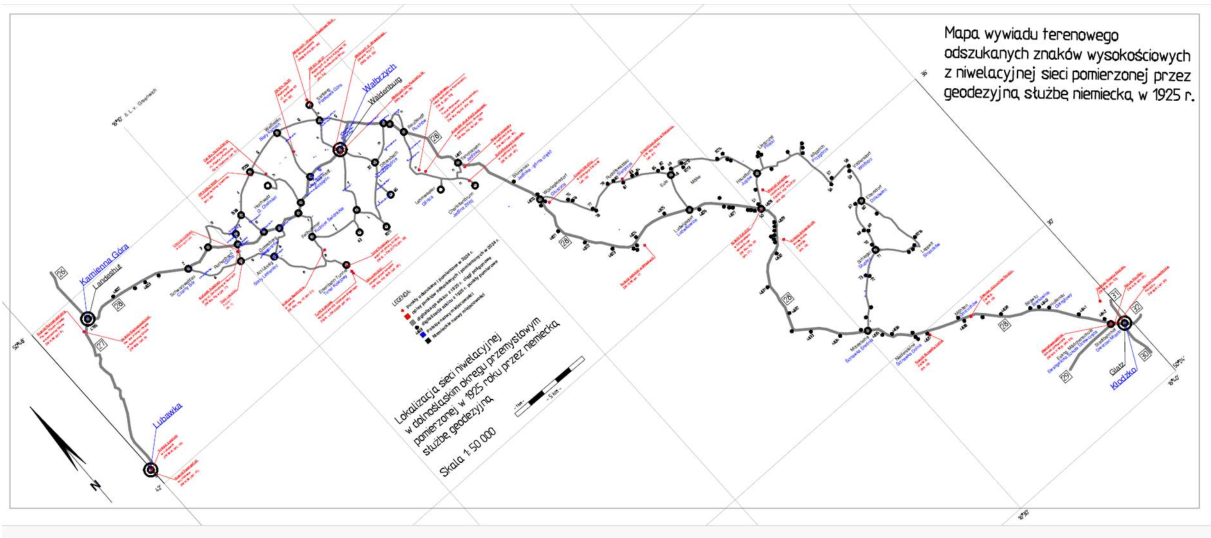


Figure 16: Wałbrzych case: the map of elevation marks from the levelling grid measured by the German surveying service in 1925, repeated in 2024

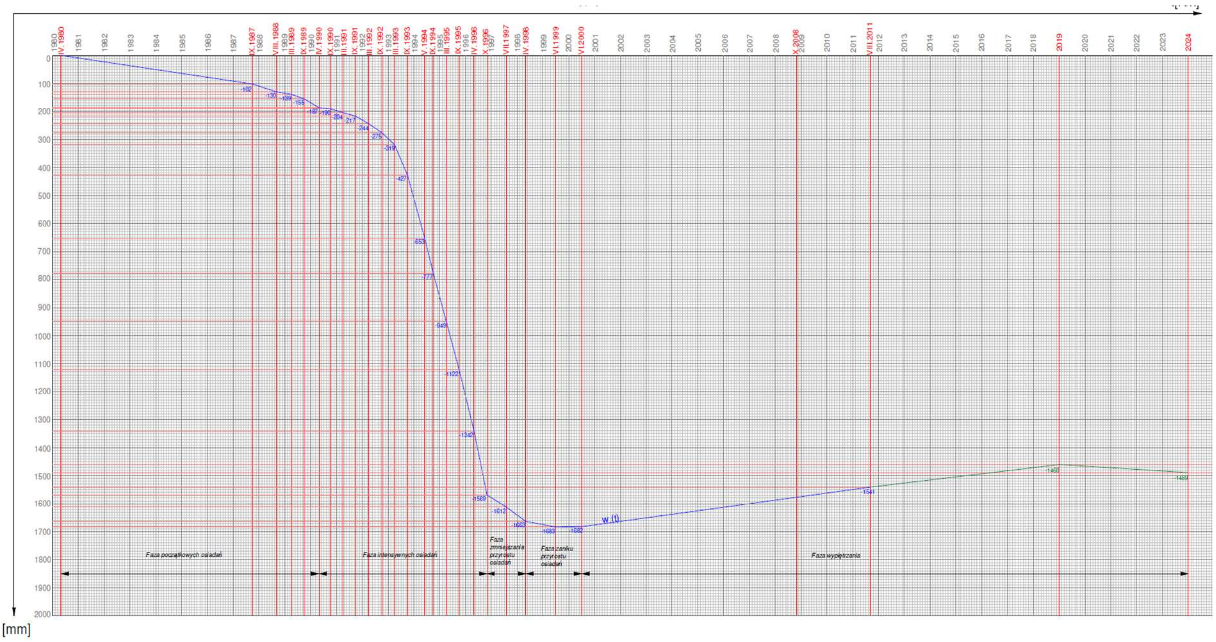


Figure 17: The vertical surface displacement- results of current measurements, as a continuation of measurements taken during mine closures

Conclusions from in situ measurements showed that today's focus should be on hydrological disturbances and mining induced floods. The risk of increased gas emissions is lower than expected and limited to inaccessible areas such as shafts and adits. Which indicates the actual requirements of end-users/stakeholders.

6.3.2. Radon in situ – Piekary Śląskie and Sosnowiec case studies

The radon hazard is best recognised in Piekary Śląskie, as relatively systematic measurements have been carried out there for many years. In 34 public buildings, a repeat measurement campaign was carried out as part of the PoMHaz project. The Figure 18 shows the radon concentrations in buildings measured over three years. In most buildings, radon concentrations are increasing, despite the fact that no mining activity has been carried out since 2021.

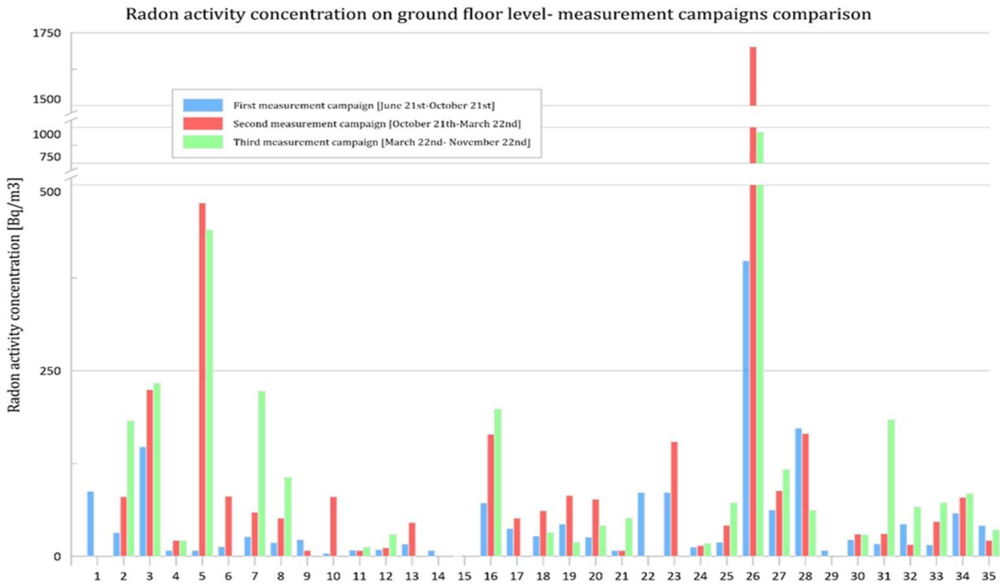


Figure 18: Radon activity concentration on ground level – measurements campaigns comparison

Using the 'radon tool', we made a theoretical estimate of the city's radon potential. The result showed that there is a probability that a certain number (percentage) of buildings may have elevated radon concentrations. Measurements were carried out in a number of schools selected by the city. The obtained results suggest that the potential risk of exposure of residents to increased radon concentrations in buildings may pose the problem for the city. Measurements taken in school buildings confirmed the conclusions of theoretical estimates.

Radon *in situ* – Sosnowiec

Theoretical estimates of radon risk have shown that there are so-called 'radon-prone' locations. Therefore, measurements were also taken in this city in school buildings indicated by the city authorities. In order to obtain reliable information with less uncertainty, both in Piekary and Sossnowiec, the measurements were long-term - 6 months. The Figure 19 shows the results of radon concentration measurements in basements and on the ground floors of schools. Most (except for two) of the results on the ground floors exceed the average value for Upper Silesia, i.e. 47 Bq/m^3. In basements, concentrations exceed the reference value of 300 Bq/m^3 in several cases. It was found that buildings with high concentrations were built in areas of former shallow mining. For this reason, the significance of this threat has been increased.

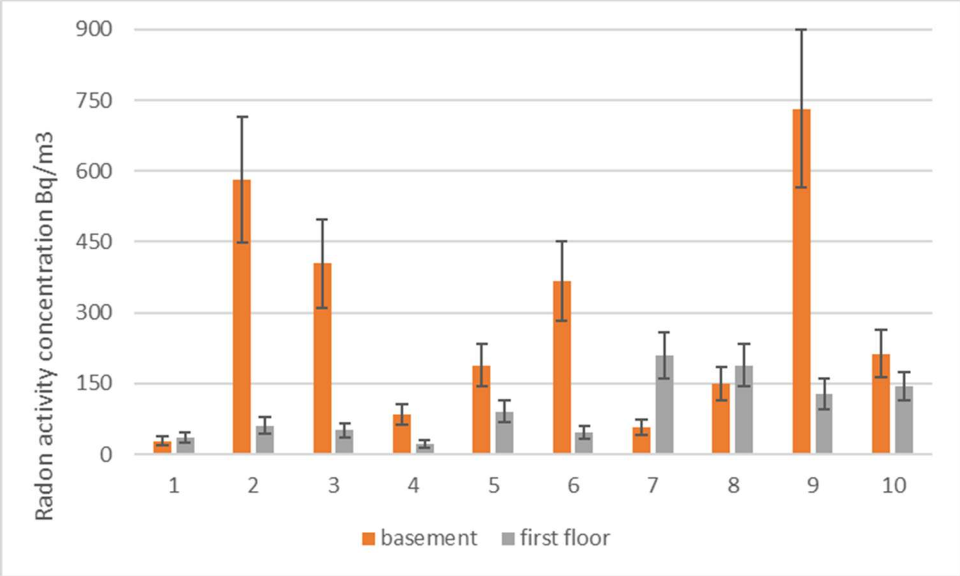


Figure 19: Radon activity concentrations in buildings in Sosnowiec

6.4. Proposal to identify 'radon prone areas' in the analysed post-mining towns.

While carrying out the project tasks, the risk of increased radon emissions was analysed in case studies, among other things. The work was carried out in three stages. The first stage consisted of reviewing archival data, if available in the GIG-PIB database. Most of the measurement results in buildings, carried out at various times from the 1990s to 2022, concerned the city of Piekary Śląskie. In Sosnowiec, measurements were carried out in a few buildings. We had the least measurement data in Wałbrzych. In the database from Piekary Śląskie, the analyses of geological structure and mining activity carried out so far, allowed us to formulate general observations and conclusions, which provided the basis for planning activities in this project.

The most important conclusions from previous studies confirm that the main source of radon in buildings are the surface layers beneath and in the immediate vicinity. Radon migration is facilitated by the presence of cracks, cavities and fractures. The routes of entry into buildings are ventilation ducts, technical ducts, and cracks and damage to the structure of buildings. The impact of mining activities on increased radon migration was analysed. According to the information obtained from mining specialists, at present, after coal mines are closed down, the effects of mining on surface deformation, are of a residual nature. However, the disintegration and changes in the strata, caused by centuries of mining activities are irreversible. Physical and chemical processes occurring in the subsurface layer and at deeper levels may influence the migration of fluids. The dynamics of gas migration is determined by many factors and processes, directly or indirectly related to the effects of underground mining:

- surface erosion, causing the disintegration of rock material, usually reaches 15 metres. In specific cases, the erosion takes place at much greater depths, even up to 100 m;
- as a result of stresses caused by mining activities, some of the tectonic faults are rejuvenated and sometimes reopened, clogged faults are usually accompanied by a zone of contemporary cracks, creating the pathways for gas migration;
- post-mining areas are often drained, the groundwater level is lowered, which enables the easier migration of fluids;

- deep mining exploitation may cause surface discontinuities driving excavation in the vicinity of a fault zone even at a depth of 800 m may result in surface damages.

In the second stage of radon analyses, taking into account the above observations and conclusions, radon risk areas were identified using an algorithm developed as part of the implementation of the task T3.2. The algorithm takes into account information on:

concentration of radon in soil gas
- Based in measurements in situ, or
- Estimated on the basis of literature data concerning permeability of different strata,

the geological structure of the study site
- Thickness of Quaternary deposits,
- Lithology of Neogen deposits,
- Lithology of Triassic and Carboniferous,

description of the mining situation
- Depth of the exploitation,
- Method of exploitation,
- Thickness of extracted beds,
- Numer of exploited coal beds,
- Number of shafts, and other drill holes and other mining excavations connected to the surface,

and environmental/ technological criterion
- Suitability of land for development (Categories of damages).

The results of the theoretical analysis provided the basis for identifying areas where elevated radon concentrations may occur in buildings, i.e. so-called ‘radon prone areas’.

The final stage of the analysis of increased radon emissions was the verification of theoretical estimates by performing a series of measurements in buildings in 3 cities. The verification indicated the need for minor adjustments relating to the rank and weight of some of the factors taken into account in the Radon Tool. However, in general, the in situ measurements confirmed the conclusions of previous studies and estimates using the Radon Tool algorithm.

Figures 20-22 show radon risk maps based on the results of the study.

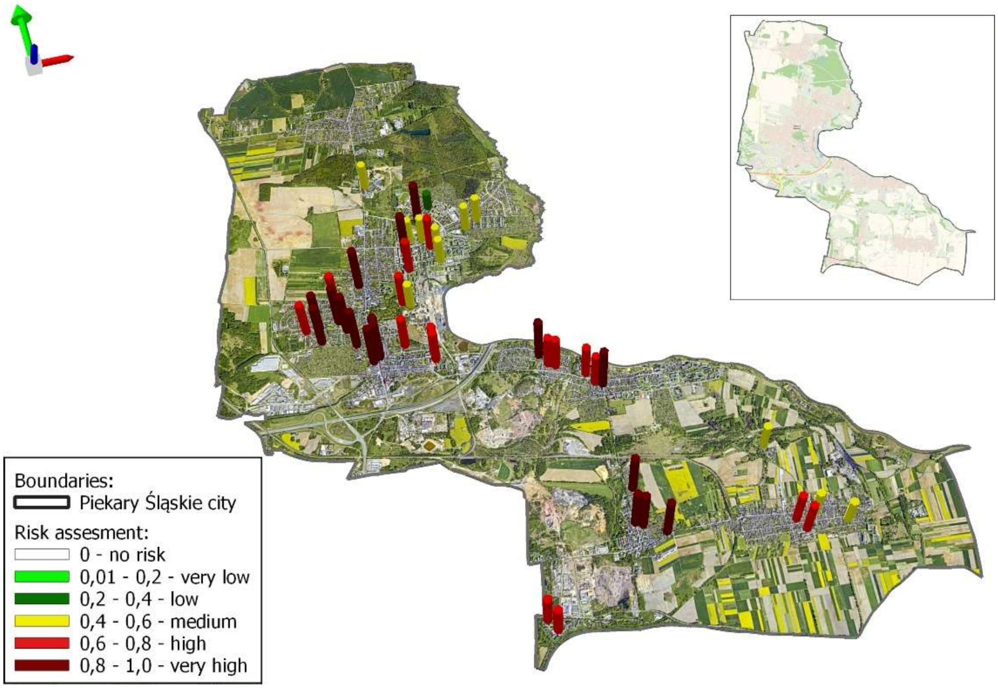


Figure 20: The map of radon risk in Piekary Śląskie

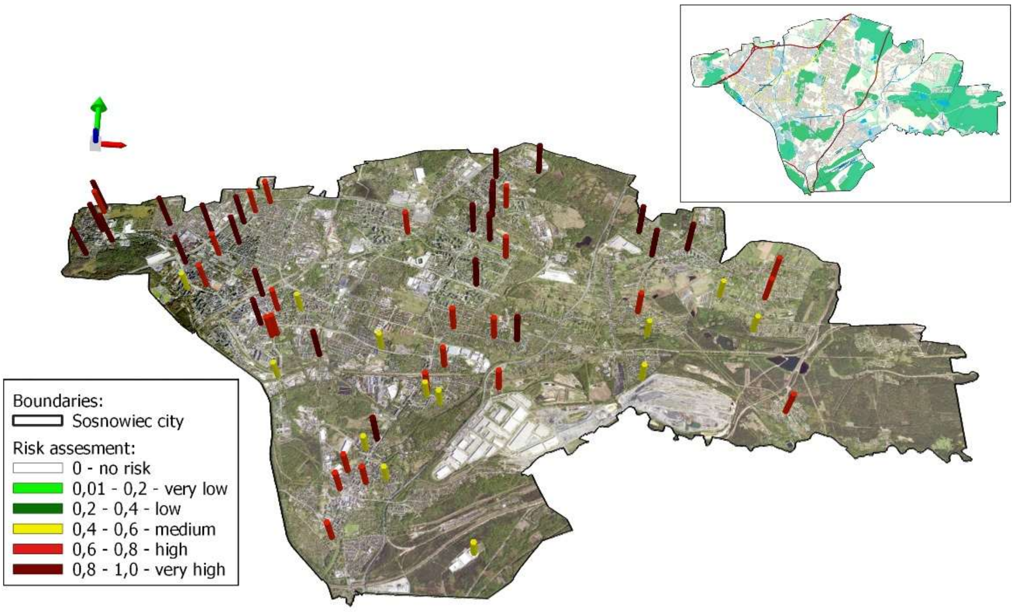


Figure 21: The map of radon risk in Sosnowiec

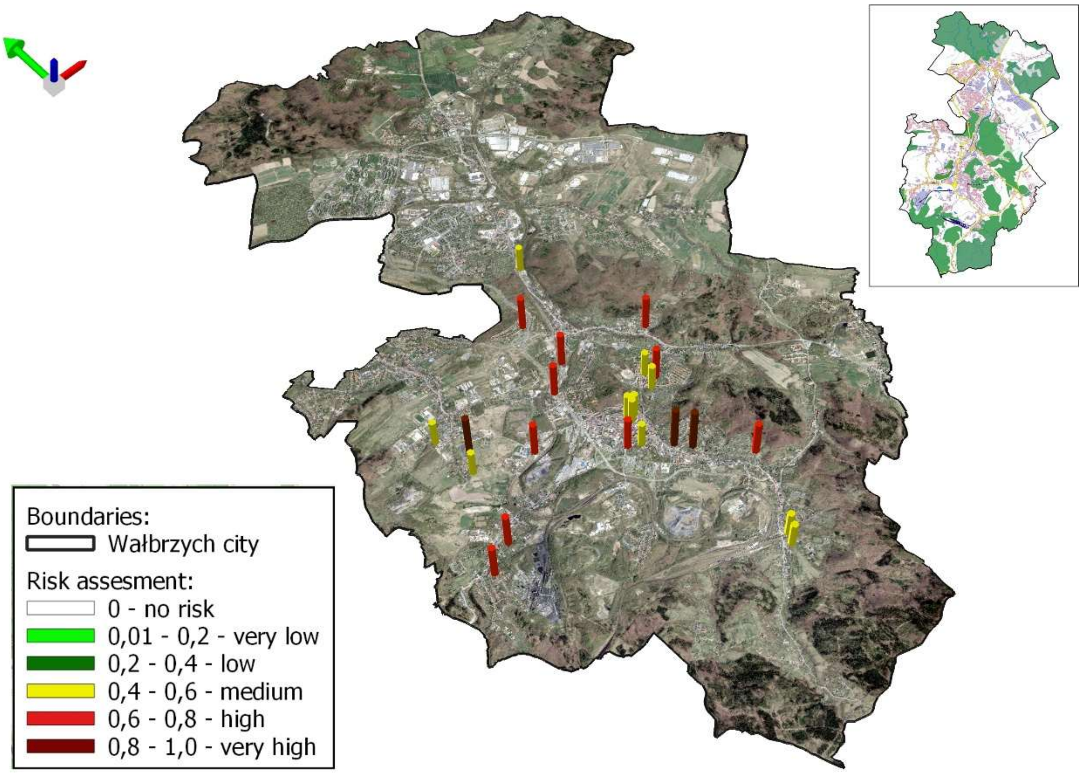


Figure 22: The map of radon risk in Wałbrzych

The indicated 'radon prone areas' coincide with areas where the structure of the overburden and near-surface rocks favours gas migration. That is, if there are pathways in the form of voids, fractures and loosening of the rock mass. In the case of Piekary Śląskie and Sosnowiec, these are areas where the Quaternary overburden is reduced. Carbonate Triassic rocks form outcrops on the surface. An additional factor is the fracturing and loosening of rocks, which is particularly intense in areas of shallow and then deep mining, and the resulting surface subsidence (Figures 23-24).

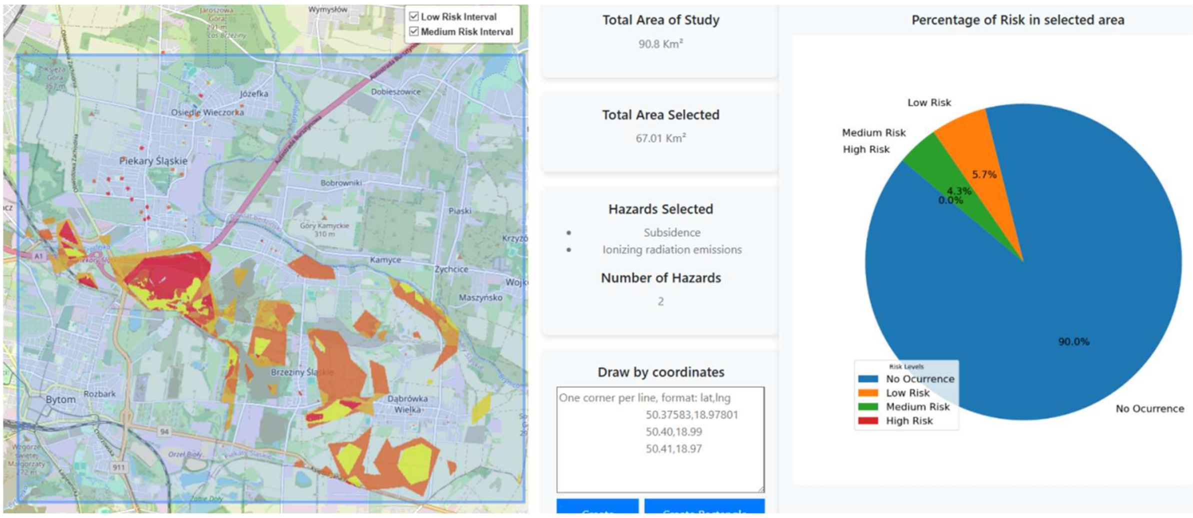


Figure 23: Piekary Śl. Subsidence + radon – percentage of area at risk

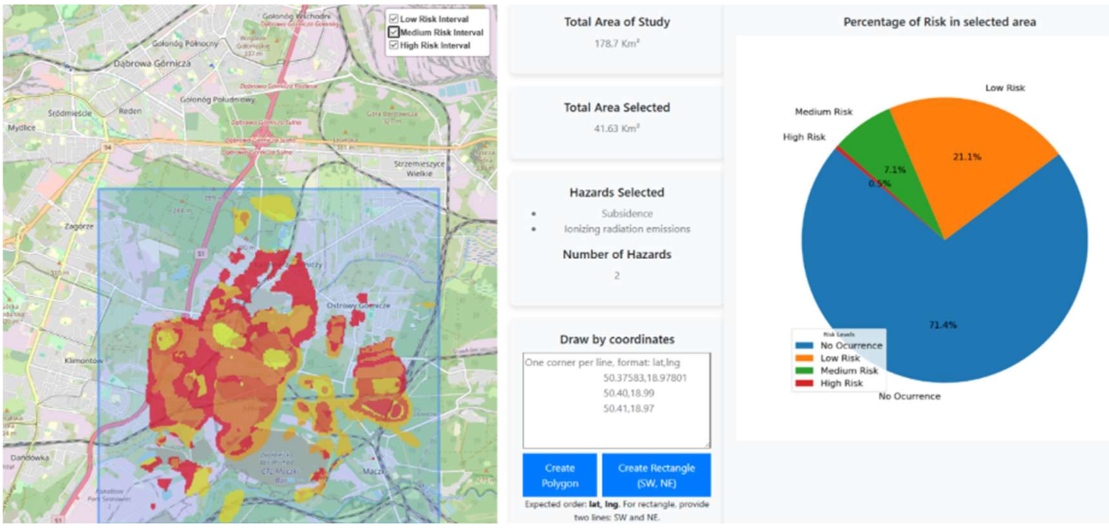


Figure 24: Subsidence + radon – percentage of area at risk

In Wałbrzych, the effect of facilitated gas migration is enhanced by the presence of numerous excavations connected to the surface. These include hundreds of shafts and small shafts, outcrops, and so-called ‘poor shafts’.

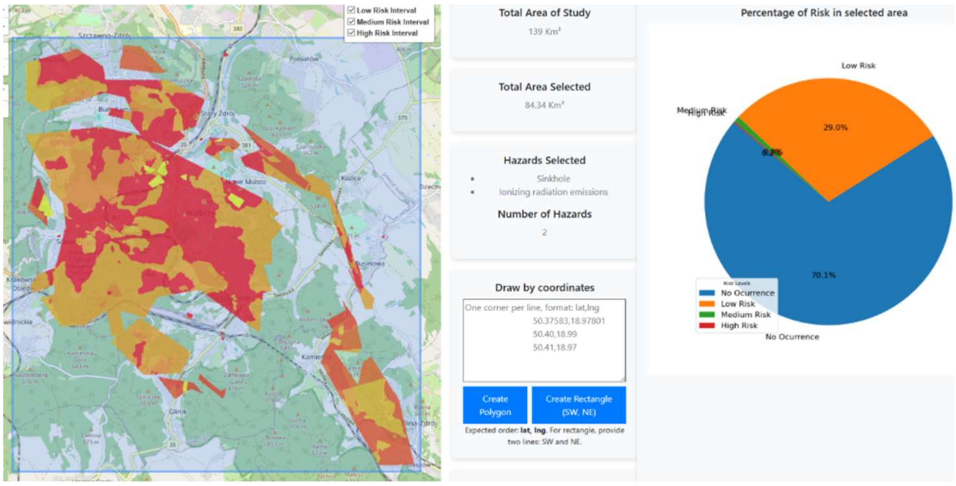
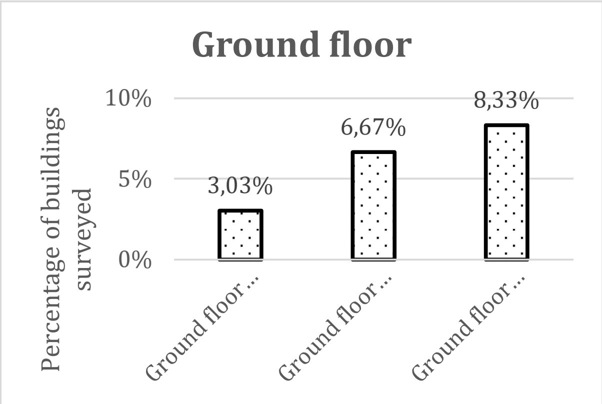


Figure 25: Wałbrzych, radon+ sinkholes+percentage

However, measurements taken in Wałbrzych did not confirm the correlation between the presence of methane, CO2 and radon. Theoretically, the phenomenon of gas co-transport is entirely possible. The stress state of the rock mass, altered as a result of mining exploitation, can cause the loosening and disintegration of rocks. This is the reason for the release and migration not only of methane, but probably also of radon. However, the research conducted as part of the project did not provide grounds for confirming this hypothesis.

Research conducted in previous years within the boundaries of the GZW allowed for an estimate of the number of buildings in which radon concentrations are elevated, it is above the level 300 Bq/m^3, can be expected at around 2%. Theoretical estimates and in situ measurements carried out as part of the project confirm this estimate. In particular, measurements in Piekary Śląskie, where measurement campaigns were repeated at different times, show that elevated radon concentrations occur in specific parts of the city in 3 - 8% of buildings (Figure 26). In basements the number of buildings at risk of radon exposure is greater: from about 6% up to 17%. Elevated radon concentration in ground floor generally do not pose a hazard to residents. However, it is an indicator of potential risk in the event of building damages and the formation of gas migration pathways, such as leaks and cracks in foundations and walls. A few percent of buildings at risk of radon exposure seems insignificant, but considering the population density in Upper Silesia and other mining and post-mining areas, it can be assumed that several hundred thousand residents may be exposed to elevated radon concentrations.



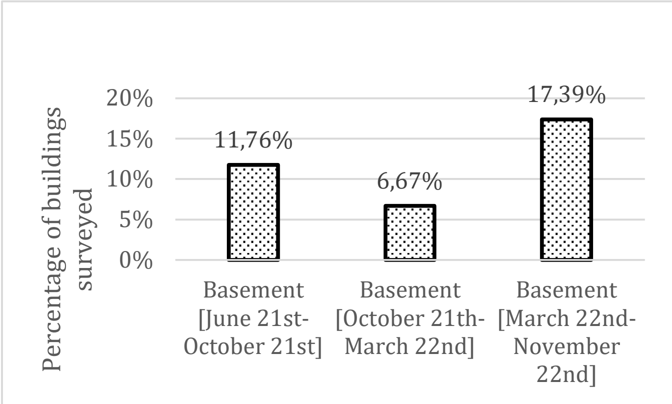


Figure 26: Percentage of buildings with elevated (above 300 Bq/m^3) radon concentration on ground floors and in the basements – the example of one investigated site

7. Impact of multi-hazards on surface infrastructure – damage to buildings

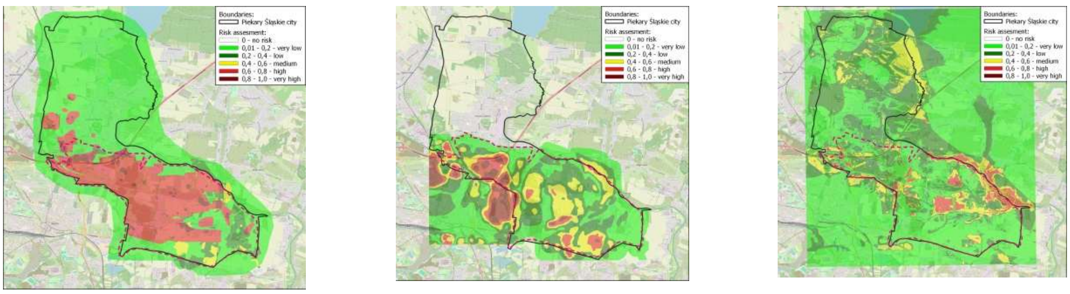
In post-mining areas, the destruction of buildings is a significant problem, especially in areas of shallow exploitation. This is caused by the effects of mining, particularly subsidence. The susceptibility of buildings to damage depends not only on their location in a subsidence basin, but also on their technical condition. The end of mining operations under the city reduces the rate and number of repeated damage to buildings. Not all buildings are equally exposed to damages: older ones, closer to mining fronts – more; new ones, well-founded – less.

Current data show that after the end of mining operations, the number of buildings requiring renovation does not exceed a few per cent of the housing stock in cities (Table 2). It should be noted that during the period of intensive coal mining, damage to building structures was a much more frequent phenomenon. Numerous buildings were demolished, while others were renovated several times.

Table 2: Buildings damages due to mining – assessment

Site	Estimated percentage of buildings experiencing minor mining damage (e.g. cracks, minor deformations)	Estimated percentage of buildings with more serious structural damage
Piekary Śląskie	1-3 %	less than 1 %
Sosnowiec	2-5 %	About 1 %
Wałbrzych	4-7 %	1 - 2 %

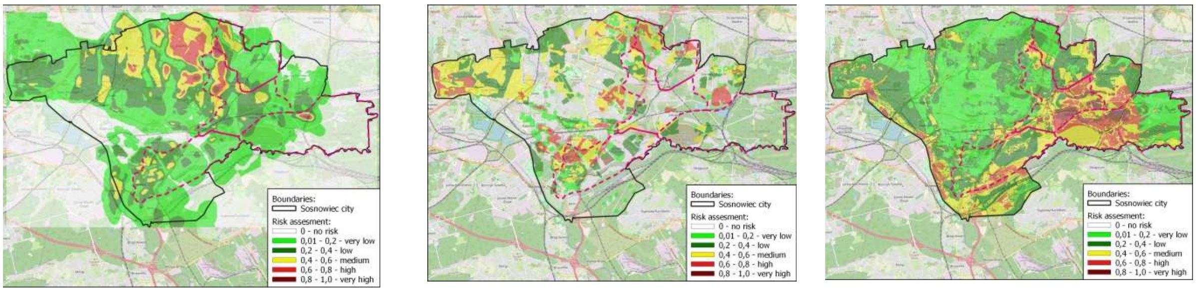
Figure 27-29 show the location of the districts with the highest number of damaged buildings on maps of individual risks.



a. subsidence b. sinkholes c. floodplains

Figure 27: Piekary Śląskie, area with the highest number of buildings damaged by post-mining hazards

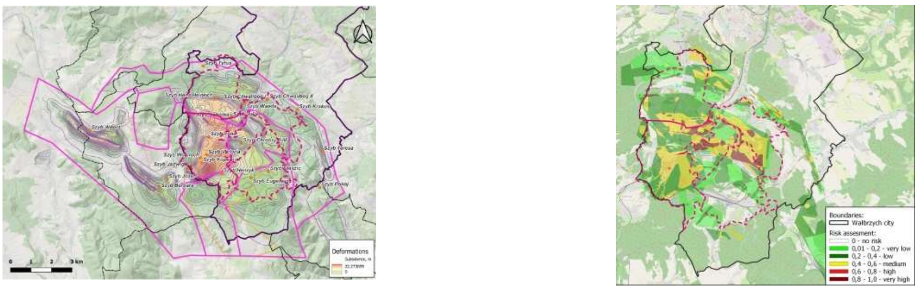
In Piekary Śląskie, the suitability of land for development, and thus the susceptibility of buildings to damage, is influenced by various phenomena related to the mining of zinc and lead ores as well as hard coal. The reduction in the suitability of land for development was influenced, among other things, by the occurrence of mining waste embankments. Over the centuries, mining in the area of the city has contributed to changes in the landform. These changes occur in large numbers in the central part of the city and in the south-eastern part. In addition, in the same areas, there were significant surface deformations associated with the exploitation of zinc and lead ores and gallium, as well as iron, and then deeper hard coal (Figure 27a). In the same areas, discontinuous deformations such as pits, crevices and fissures often formed (Figure 27b). Floodplains form in subsidence areas, further altering the technical parameters of the soil and damaging building foundations (Figure 27c). All these hazards affected and continue to affect the technical condition of the buildings.



a. subsidence b. sinkholes c. floodplains

Figure 28: Sosnowiec, area with the highest number of buildings damaged by post-mining hazards

In Sosnowiec, the construction conditions of grounds are in numerous parts of the city, unfavorable. Poor conditions or conditions that exclude the possibility of foundations of buildings are largely caused by the occurrence of mining waste embankments. The exploitation of coal as in Piekary Śląskie caused continuous and discontinuous deformations of the surface of the city (Figure 28a, 28b). The subsidence basins reach a depth of up to several meters. The basins are often filled with floodplains (Figure 28c). The occurrence of post-mining hazards, further exacerbated by the poor condition of soils and land, affects the technical condition of buildings, necessitating repairs and, in extreme cases, demolition.



a. subsidence b. sinkholes

Figure 29: Wałbrzych, area with the highest number of buildings damaged by post-mining hazards

The interactions between mining hazards and the destruction of urban building resources are evident. In Wałbrzych, which is particularly vulnerable to the effects of many years of mining, a number of buildings had to be, or will probably have to be, demolished. Others required and still require renovation. However, it should be remembered that a large percentage of the city's buildings date from before the war and before 1945, which increases their vulnerability to damage. Many post-mining buildings and old tenement houses are in poor technical condition, not only due to the effects of mining activity, but also due to their age.

8. Impact of multi–hazards on surface - suitability of land for development, land classification

Due to the fact that post-mining areas are subject to severe deformation, specialists in the fields of construction, mining and surface protection have been working for years on a method of categorising post-mining areas, taking into account the type and intensity of deformation and its effects. The aim of these activities was to support decision-makers in planning the development of mining towns and municipalities. Knowledge about areas within the city limits where construction development is unfavourable or even dangerous allows for the avoidance of damage repair costs and, in extreme cases, significant material losses and reduced well-being of individual residents.

The classification of post-mining areas in relation to the degree of post-exploitation transformation is given in Table 3. The Table presents the classification developed by geologists and geophysicists, included in the methodological guide entitled "Principles of documenting geological and engineering conditions for the purposes of mine decommissioning" (Methodological Guide, 2009). Table 3 presents the categories of post-mining area of liquidated mines due to restrictions on their use for construction purposes.

Table 3: Categories of post-mining area of liquidated mines due to restrictions on their use for construction purposes (Methodological Guide, 2009)

<table>
<tr><th>Categories</th><th>Post-mining transformation degree</th><th>Restrictions on construction use</th><th colspan="2">Hazards</th><th>Comments</th></tr>
<tr><td>1</td><td>2</td><td>3</td><td colspan="2">4</td><td>5</td></tr>
<tr><td>A</td><td>Slightly transformed</td><td>Useful area (in the presence of load-bearing soils and the water table below 2 m)</td><td colspan="2">Practically do not occur</td><td>To exclude minor damage to finishing and architectural elements it is recommended to consider the need for reinforcement of the building structure</td></tr>
<tr><td>B_1</td><td rowspan="5">Transformed</td><td rowspan="5">Conditionally useful area</td><td colspan="2">Continuous deformations at subsidence that do not cause flooding</td><td>It can be classified as category A after 5 years from the end of mining operations</td></tr>
<tr><td rowspan="3">B_2</td><td rowspan="3">Discontinuous deformations with a degree of hazard</td><td>low $B_{2,1}$ [1)]</td><td rowspan="3">In the case of shallow underground mining of minerals and borehole sulphur mining and the presence of shafts posing hazards classified as $B_{2.1}$, $B_{2.2}$, it is possible to prepare the area for development by backfilling voids or using special foundation methods of buildings.
In areas with a $B_{2.3}$ risk level, depending on the risk analysis, they should be considered as classified as category C</td></tr>
<tr><td>medium $B_{2,2}$ [2)]</td></tr>
<tr><td>high $B_{2,3}$ [3)]</td></tr>
<tr><td>B_3</td><td colspan="2">Gas</td><td>Temporary hazards</td></tr>
<tr><td>C</td><td>Strongly transformed</td><td>Useless area</td><td colspan="2">Floodplains and flooding, areas at risk of landslides and large-area sinkholes (including, for example, safety zones designated around unabandoned shafts)</td><td>It is recommended to exclude from the development the areas of unabandoned shafts, borehole mines, protective strips of open-pit excavations, areas of heaps, external and internal dumps and protective zones around them.
Use of land for purposes other than construction (green areas, recreational areas, etc.).</td></tr>
</table>

There are three degrees of risk to the post-mining area by discontinuous deformations:

- low $B_{2,1}$ [1)]
- medium $B_{2,2}$ [2)]
- high $B_{2,3}$ [3)],

[1)] Provided that all of the following conditions are met:

- lack of sinkholes,
- lack of suffusion phenomena,
- vertical and inclined excavations having connections to a surface with a known method of decommissioning,
- thickness of concise roof rocks, at least five times the height of the mining workings.

[2] If one of the following conditions occurs:

- there are sinkholes with a diameter below 3 m,
- there are thresholds,
- there are cracks,
- there are shafts with an unknown method of liquidation,
- thickness of concise roof rocks less than five times and greater than three times the height of mining workings,
- horizontal and inclined excavations with an unknown method of liquidation.

[3]) If one of the following conditions occurs:

- there are sinkholes with a diameter of more than 3 m,
- there are thresholds,
- there are cracks,
- suffusion phenomena occur,
- thickness of concise roof rocks less than three times the height of mining workings,
- there are "poor shafts" (bootleg mining),
- there are fire phenomena in areas of shallow coal mining,
- intense paraseismic phenomena occur.

In the comments to the categories presented in Table 3, it should be noted that in the case of land use for construction purposes, the method of development must take into account the type of hazard and the type of possible post-exploitation surface deformations, which is of particular importance for category B2.

The basic methods and classifications presented for assessing the suitability of land after mining operations have ended, known as post-mining land for development, should be treated as a framework indicating the general idea and course of action for classifying post-mining land for development. It is obvious that individual mining enterprises and/or communes have their own distinct character and then the presented solutions must be adapted to the existing conditions.

However, it should be noted that the classification of individual areas into categories of suitability for development is subject to change, caused, for example, by:

- closure of individual mines – changes and limitations in the impact of coal mining,
- controlled liquidation of mining excavations connected to the surface,
- reclamation of subsidence basins,
- hydrotechnical investments undertaken to restore natural water flows.

An analysis of the hazards affecting the condition of post-mining areas allows for the creation of maps showing the suitability of land for development. The analysis covers the archival resources of the Coal Mining Authority (WUG), coal companies, proprietary data, and publicly available geological and geotechnical maps, e.g. resources of the Polish Geological Institute (PIG-PIB). Experts, analysing all available data, make an assessment which, as emphasised above, is subject to change as mining operations are modified or ended and as a result of measures taken to eliminate some of the effects of mining.

The results of the above analyses are presented in the form of maps containing categories of suitability of land for development after the end of mining activity. The examples of such maps for Polish sites are presented below. Examples of mining maps, or maps prepared for mines, which form the basis for estimating the category of a given area designated for development, were also shown – see Figures 30 - 35.

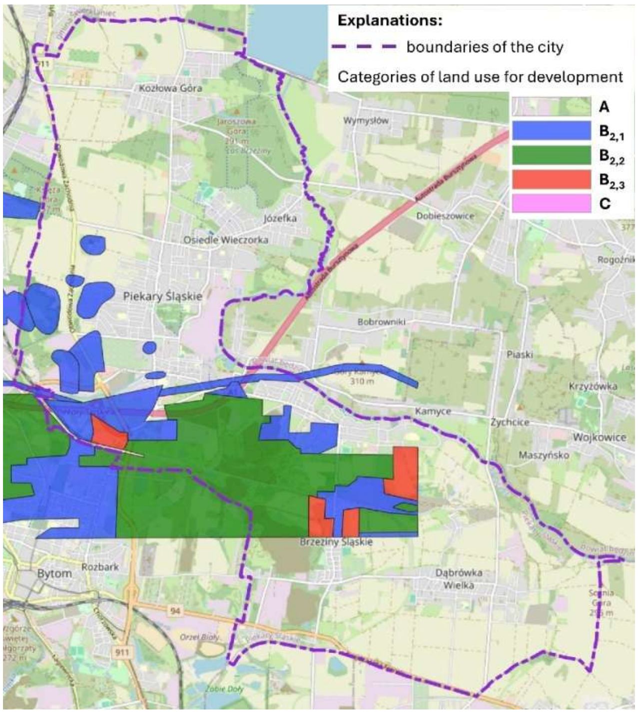


Figure 30: Ilustrative map of land suitability for development - Piekary Śląskie

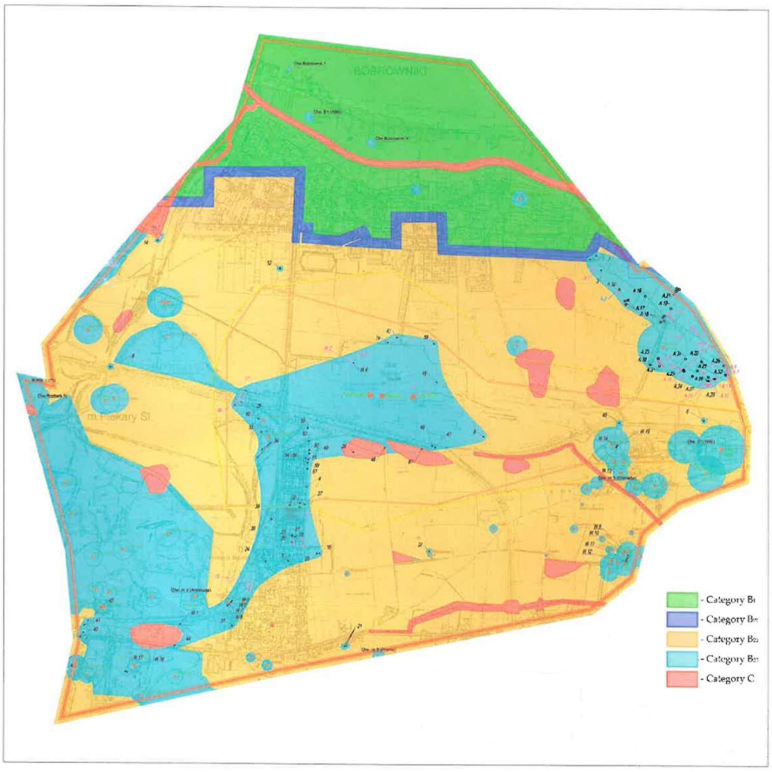


Figure 31: Example of a mining map of land suitability categories for development Piekary Mine (based on a study by MIDACH for the Bobrek-Piekary Coal Mine, Piekary Division)

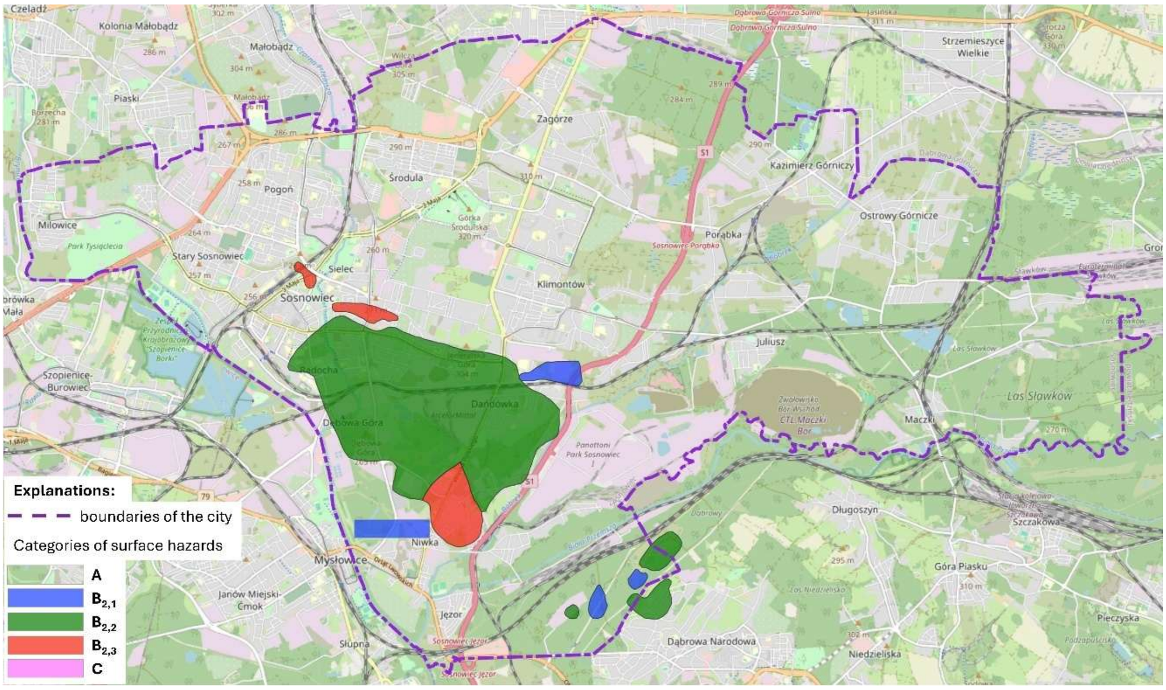


Figure 32: Ilustrative map of land suitability for development – Sosnowiec (base: Kotyrba et al. archival study)

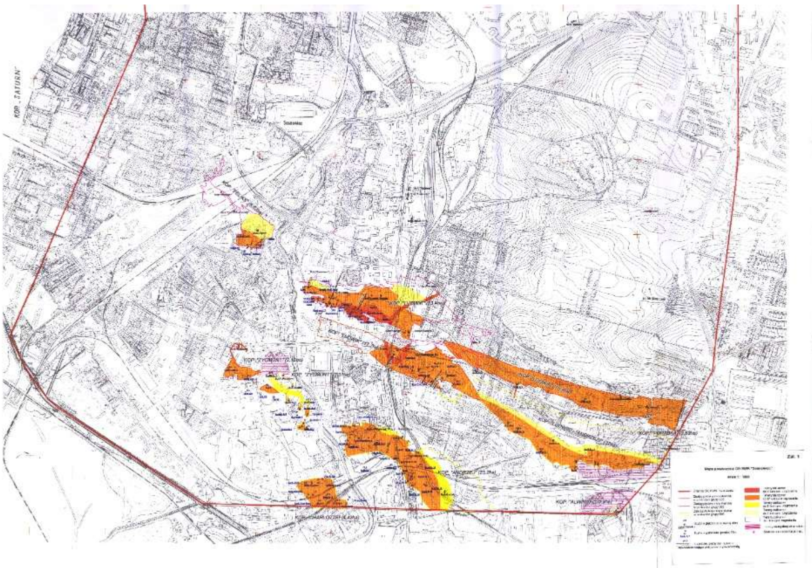


Figure 33: Example of a mining map of land suitability categories for development within the borders of Sosnowiec coal Mine (WUG: archive materials)

The map shown in Figure 33 indicates that in this case, the basis for classifying areas as suitable for development was an analysis of the extent of shallow mining in individual coal seam groups. A different scale than the recommended one was adopted.

The categories adopted by mines correspond to the following categories:

Coal mine category	Recommended category
V	C
IV	$B_{2,3}$
III	$B_{2,2}$
II	$B_{2,1}$
I	A

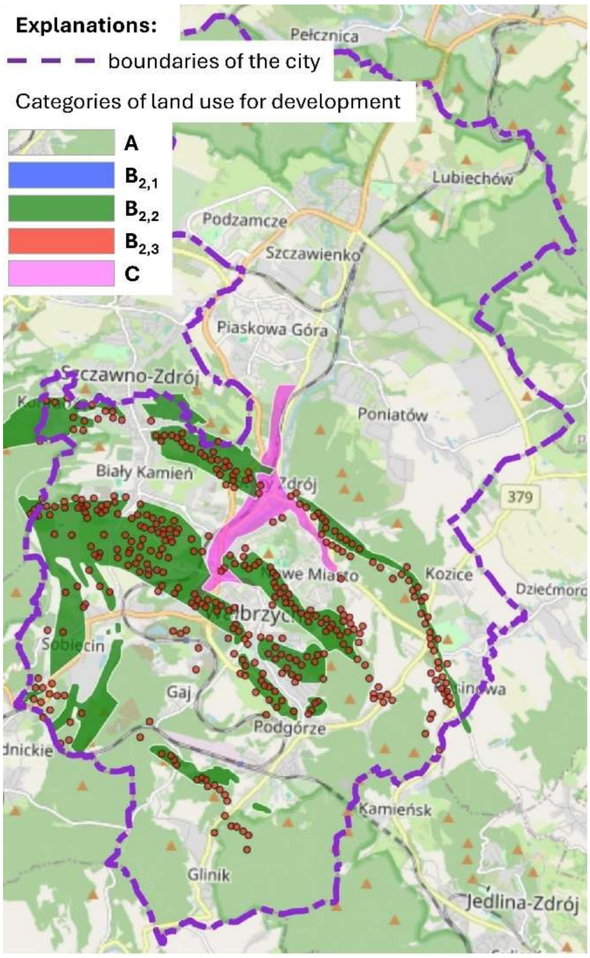


Figure 34: Ilustrative map of land suitability for development – Wałbrzych (based on Kowalski 2000)

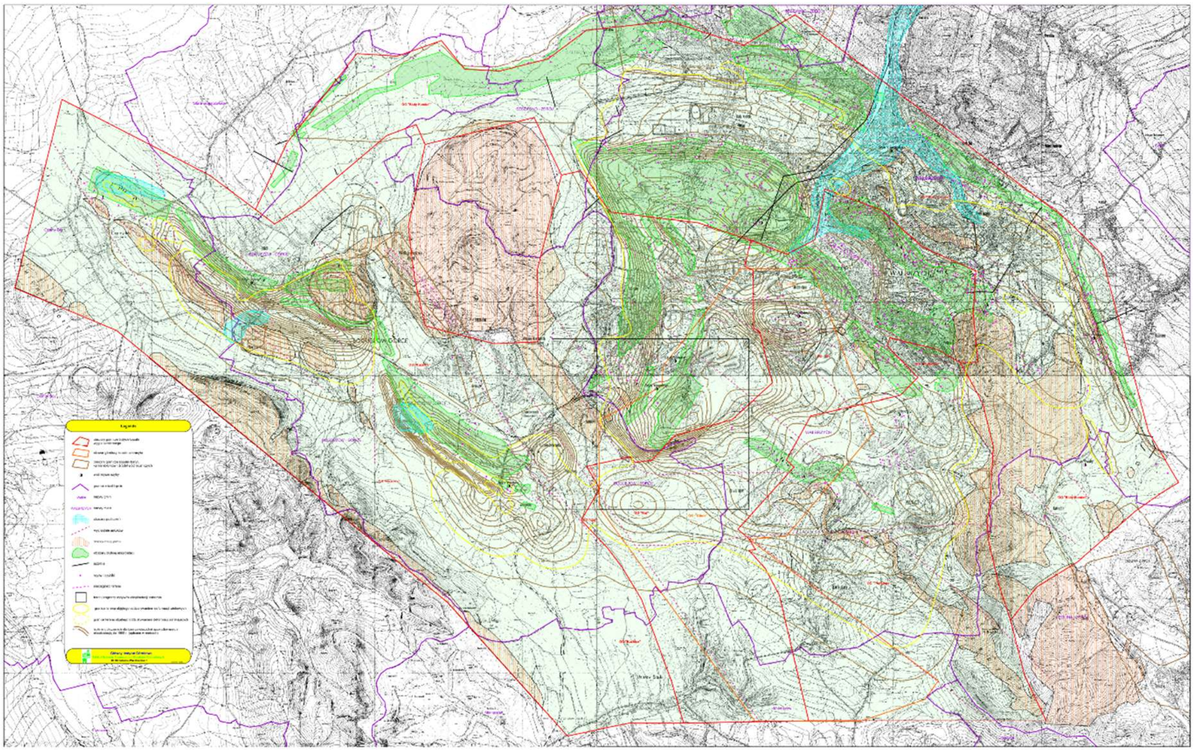


Figure 35: Example of a municipality map of hazards (determining land use) occuring within the borders of Wałbrzych (GIG-PIB archival data base)

Map legend:
flooded areas – blue grid
fault outcrops – red dotted line
porphyry intrusion areas – yellow vertical stripes
shallow mining areas – green chessboard pattern

The example of Wałbrzych shows how various factors and threats were taken into account when assessing the impact on the area and restrictions on the city's development. In many cases, mines and coal companies decided to link the categorisation of areas to a specific, predominant threat. In other cases, a larger number of threats relevant to a given area were analysed. However, it is important to be aware that the categorisation of suitability for development changes over time. After the closure of successive mines, various types of activities are undertaken to restore the value of post-mining areas. Thanks to these activities, successive fragments of the areas allow for the development and construction not only of service facilities (warehouses, offices, large-area shops), but also for residential construction.

On the other hand, the GIS DSS tool is an invaluable aid for quickly analysing the co-occurrence of interactions between hazards, assessing risks, visualising various scenarios and suggesting actions that cities or coal companies should take. Of course, this requires data to be supplemented and updated. This segment of activity is particularly important in Poland, where mines were closed at different times, with some still in operation. The mitigation of the adverse effects of mining is therefore proceeding at various time scales in different cities or even districts of mining towns.

9. Assessment of the practical application of the GIS DSS system, using databases that can be collected.

The Decision Support System (DSS) developed within the project enabled the integration and visualization of spatial data related to the risk of various post-mining hazards, including surface inundation, ground surface deformations, and elevated radon emissions. The system's structure is based on a set of interactive thematic layers that represent the spatial variability of hazard susceptibility and intensity indicators. This approach made it possible to analyze not only individual phenomena but also their co-occurrence and potential interactions in a multi-hazard context.

The data used in the system originated from studies prepared by individual project partners within the earlier project stages (WP2 and WP3), as well as from national and local sources, including geological, hydrogeological, and geodetic data provided by GIG-PIB. For the Polish case, the integrated datasets included raster-based risk index maps for hazards such as sinkholes, ground surface deformation, inundations (water impoundments), and radon emissions. Additionally, the system allowed for the inclusion of information on infrastructure, land use, and socio-economic factors (so-called elements at risk), enabling a more comprehensive assessment of the potential impacts of adverse events.

The DSS was tested during workshops involving project partners and external stakeholders, including end users from local government and administrative units. Test exercises were conducted, among others, for the city of Sosnowiec, which constituted one of the three Polish case studies (alongside Piekary Śląskie and Wałbrzych). During the tests, participants analyzed sample multi-risk scenarios against the background of land-use changes.

The test results confirmed that the developed DSS can serve as an effective tool supporting risk assessment processes in post-mining areas. Workshop participants positively evaluated the system's user interface clarity and its ability to provide quick access to information on local hazard levels. At the same time, they pointed out the need for further system development, particularly toward implementing mechanisms for dynamic data updates and an interpretative module enabling automatic classification of risk levels.

It was also emphasized that the current DSS version is a research prototype, primarily developed to verify the multi-hazard risk assessment methodology and to test the feasibility of integrating data from diverse geographical and mining environments. Nevertheless, the experience gained during the project and workshop activities demonstrated that, once refined, the system could become a valuable support tool for local authorities, spatial planning services, and crisis management agencies in assessing the risk of post-mining phenomena under real field conditions.

10. Summary

Deliverable D17 of the POMHAZ project (Post-Mining Multi-Hazards Evaluation for Land-Planning) focuses on validating the usability of the GIS and DSS tools developed for assessing and managing multiple post-mining hazards across selected European case studies. The main goal of this work was to test the applicability, flexibility, and adaptability of the system under different geological, technical, and historical conditions found in former coal mining regions.

The Polish partner GIG-PIB was responsible for collecting and preparing geological, mining, environmental, and socio-economic data for three representative test sites: Sosnowiec, Piekary Śląskie, and Wałbrzych. This process included the compilation of archival maps, mine closure records, deformation data, and environmental information into harmonised GIS datasets. These datasets formed the foundation for multi-hazard modelling and visualisation in the DSS environment. Data covered such elements as mine shafts, shallow workings, waste dumps, subsidence, hydrological networks, and potential gas emissions zones.

In Sosnowiec, a well-documented area, the tool effectively demonstrated its ability to visualise multiple hazards, confirming its usefulness for spatial planning and urban risk management. In Piekary Śląskie, the DSS identified zones prone to flooding and land subsidence due to historical deep and shallow mining, correlating strongly with real floodplain occurrences. The city's hydrotechnical investment (2020–2024) to drain a 157.6 ha basin confirmed the accuracy of the tool's predictions. In Wałbrzych, the analysis combined radon emission risk with discontinuous deformation data. The DSS results were verified with field measurements, showing strong consistency between predicted and observed hazard levels.

Overall, the implementation demonstrated that the DSS tool allows for an integrated and spatially detailed assessment of multi-hazard interactions in post-mining regions. It supports decision-makers in prioritising mitigation actions, planning redevelopment, and preventing environmental and structural damage. The work also highlighted challenges in data harmonisation—especially in Poland, where national mining and geological databases are fragmented and vary in quality—but confirmed that once harmonised, these datasets provide a solid basis for effective, evidence-based land-use planning.

In carrying out the discussed task (Task 5.2) of the project, in situ measurements of selected factors (gas emissions, including radioactive radon, and vertical surface deformation) were performed in selected locations in order to verify the state of knowledge. A method for identifying 'radon prone areas' was proposed. In addition, the current state of knowledge on the impact of ground deformation on building damage was presented. With regard to water hazards, an analysis of the impact of mine closure methods on groundwater quality was presented.

Overall, WP5 confirmed that the POMHAZ GIS/DSS tools are effective instruments for multi-hazard risk assessment, providing a scientific basis for sustainable land-use decisions in post-mining regions. Their use will enable to enhance cooperation between scientists, municipalities, and industry, helping to mitigate long-term environmental and structural risks in former mining cities.

11. References

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What is PoMHaz?

The goal of PoMHaz is to improve methodological and practical knowledge for the assessment and management of multi-hazards, at the scale of a coal mining basin, through the active and continuous engagement of key stakeholders involved in or affected by post-mining activities.

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Further information can be found under https://www.pomhaz-rfcs.eu.

For feedback on the PoMHaz project or the published deliverables, please contact contact@pomhaz-rfcs.eu.

The PoMHaz Consortium

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