Guidelines for the assessment and monitoring of seismic hazards in coal mining areas

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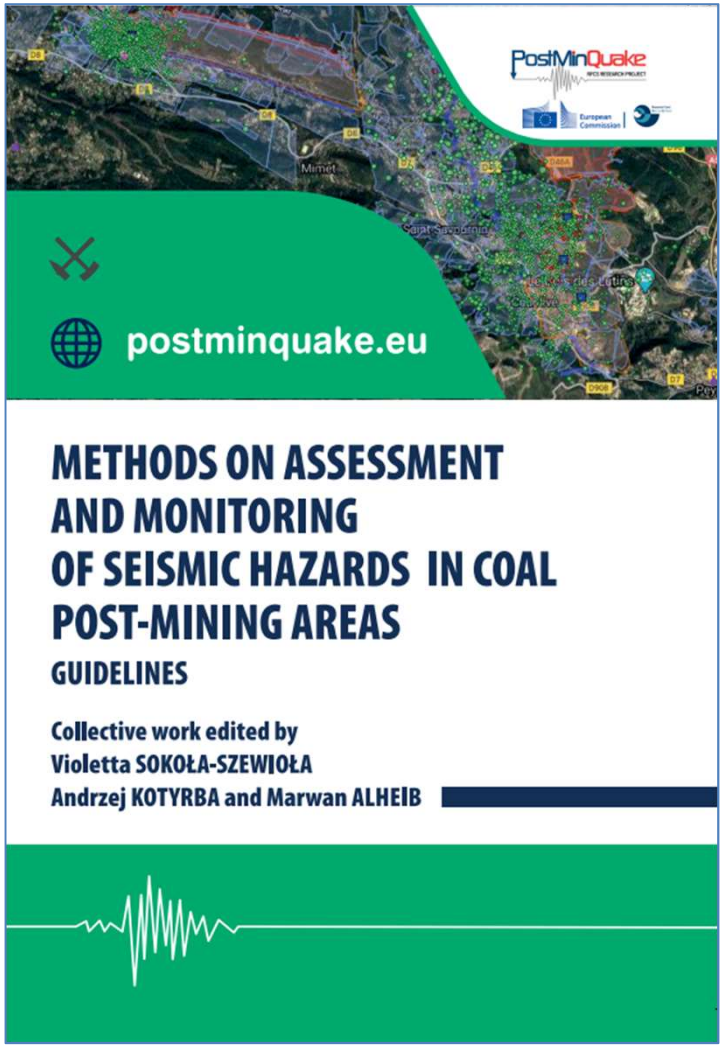
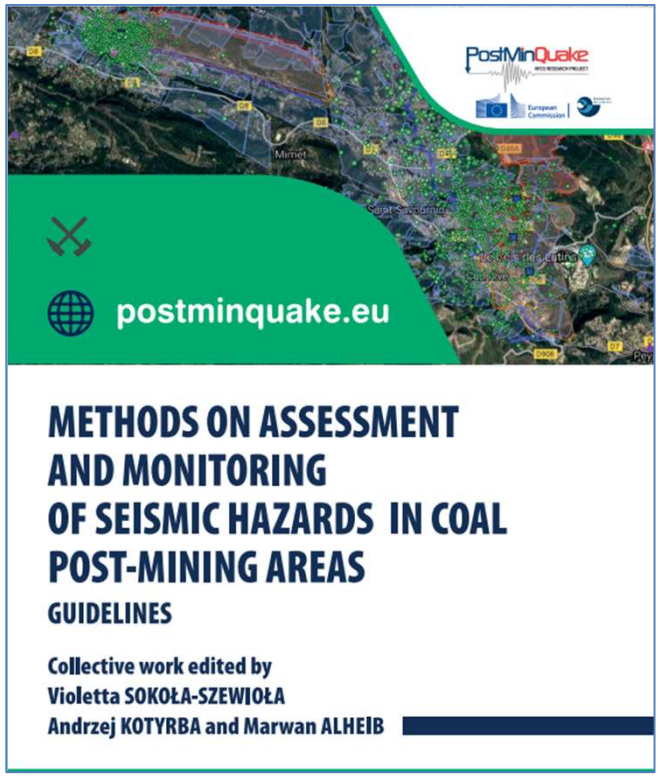


- Based on the results obtained from the implementation of the various tasks in the project as planned, guidelines were developed as an implementation of the deliverable 7.2 entitled “A comprehensive book (transnational guidelines) on a method on assessment and monitoring of seismic hazard in post mining areas.”
- The guidelines were published, in August 2023 by the Silesian University of Technology Publishing House in the form of a book entitled:

METHODS ON ASSESSMENT AND MONITORING OF SEISMIC HAZARDS IN COAL POST- MINING AREAS

GUIDELINES



The guidelines are mainly addressed to mining consultants, potential investors and decision making bodies in post-mining areas, including authorities responsible for managing closed mines, in particular the ones which are undergoing the flooding procces.

Representatives of the following project partners participated in the development of the guidelines: BRGM, DIAMO, GIG, Green Gas DPB, GFZ, IGN, INERIS, SUT, THGA.

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Content summary

- The book contains guidelines on the assessment methods and monitoring of seismic hazards in the areas of decommissioned and flooded deep coal mines in Europe and in the world with the aim of ensuring public safety in post-mining areas.
- The successive chapters present methods and basic recommendations in the process of their implementation.
- In each of the chapters describing the methodology for implementing the assessment and monitoring of seismic hazards, a brief theoretical introduction is included to allow a proper understanding of the content presented in the chapter with references to studies where the interested party will find more information beyond what is necessary for these guidelines.

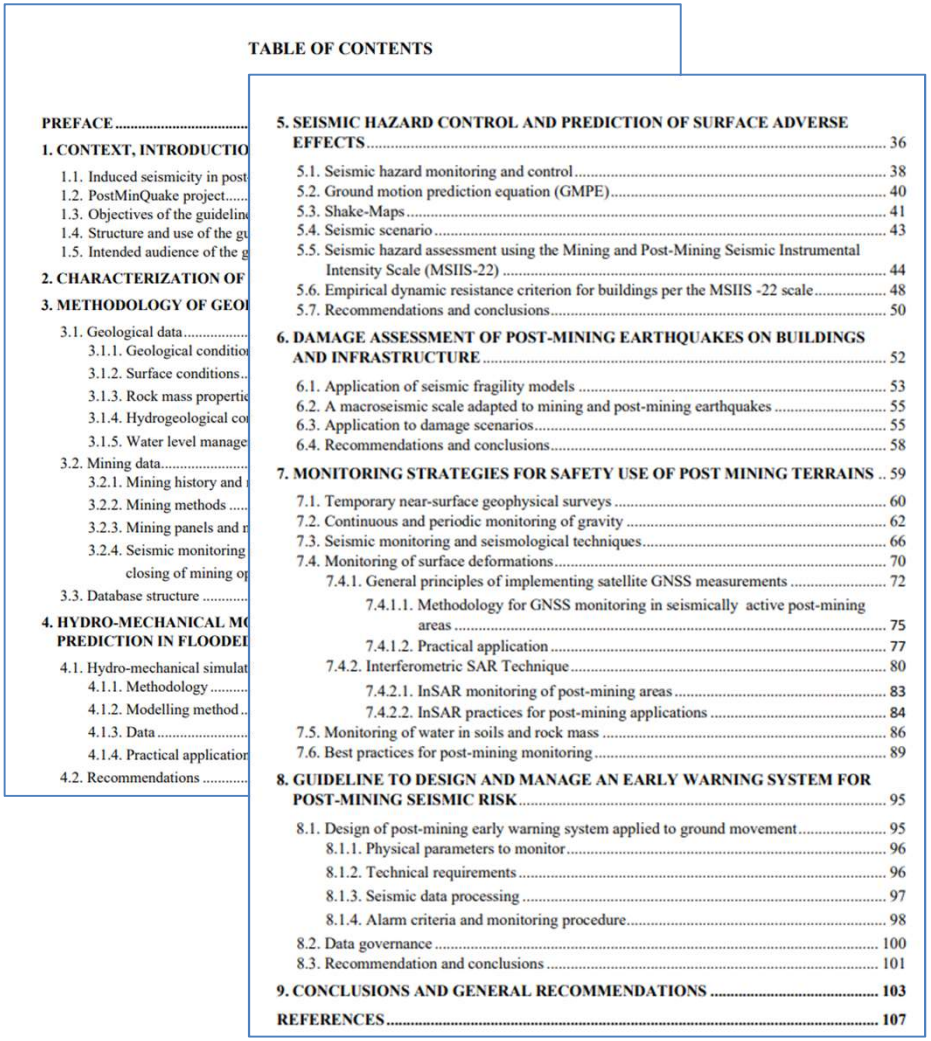
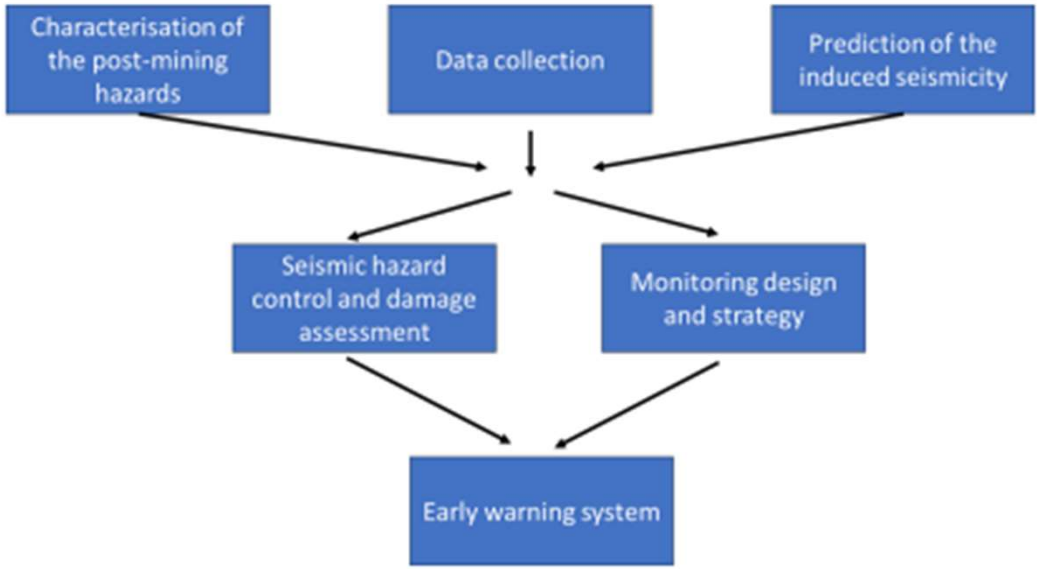


TABLE OF CONTENTS

The book includes a foreword, 9 chapters and a list of references.

Chapter 1
CONTEXT, INTRODUCTION, AND OBJECTIVES OF THE GUIDELINES

- The chapter includes: basic information on post-mining seismicity, explains the basic terms used in the book, provides basic information on the PostMinQuake project, presents the main objectives of the guidelines, their structure and how to use them, and identifies the target audience.



Methodology for assessment and monitoring of seismic hazard in coal post-mining areas (source: Method on assessment and monitoring, ed. by Sokoła-Szewioła V., Kotyrba A., Alheib M, ., 2023)

Chapter 2
CHARACTERIZATION OF POST-MINING HAZARDS

- The chapter presents the main post-mining hazards that may occur after mine closure of underground mines.

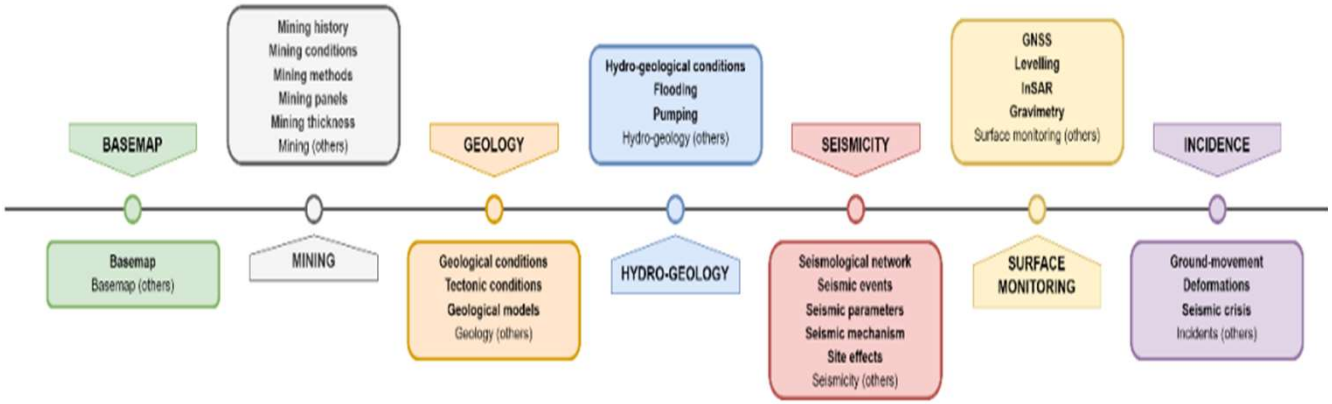
	Name
Ground	Subsidence/Uplift
	Sinkholes
	Induced seismicity
Water	Modification of outlet flow
	Appearance of humid zones or polder areas
	Modification of river flows
Gas	Outflow of mine gas

(source: Method on assessment and monitoring, ed. by Sokoła-Szewioła V., Kotyrba A., Alheib M., 2023)

Chapter 3
METHODOLOGY OF GEOLOGY AND MINING DATA COLLECTION

The chapter:

- presents the scope of geological and water level management data, mining and seismic monitoring data, and **recommended database structure for data storage,**
- gives the importance and significance of collected data for assessing the rock mass, the mine conditions including the process of flooding and induced seismicity related to post-mining phase.



Proposed database structure
(source: Method on assessment and monitoring, ed. by Sokoła-Szewioła V., Kotyrba A., Alheib M., 2023)

IT solutions dependent on user requirements.

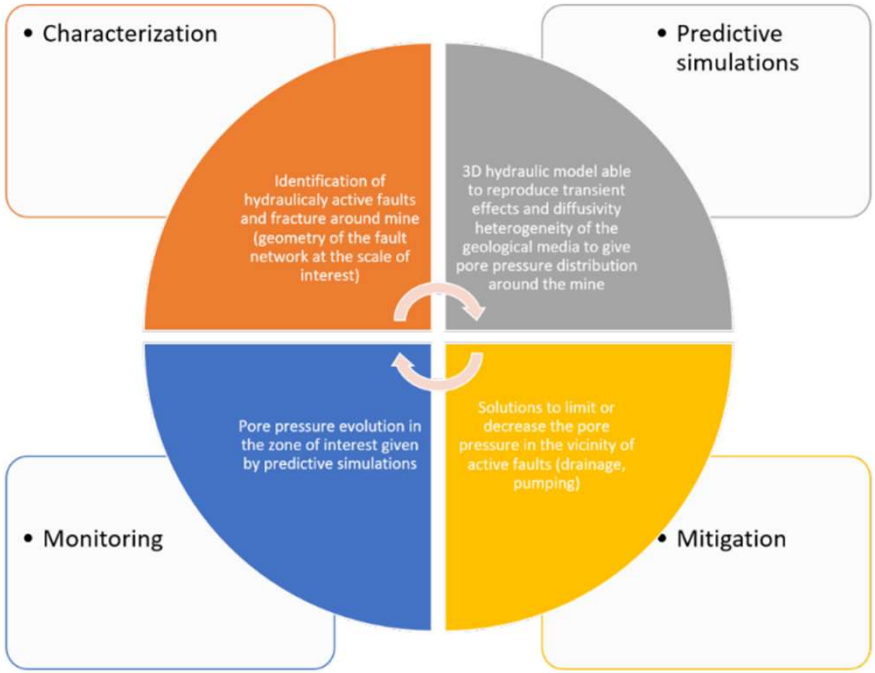
Chapter 4
HYDRO-MECHANICAL MODELLING AS A TOOL FOR SEISMICITY PREDICTION IN FLOODED COAL MINES

The chapter:

- presents the usefulness of numerical modelling to predict the induced seismicity related to the post-mining and the flooding of the underground structures.
- includes a description of the modelling methods that can be used and the range of data needed to carry them out.

The generic recommendations established to better predict seismicity related to loading state of existing/assumed faults near mines and its variation due to hydraulic changes because of flooding and water level fluctuations are presented.

The simulations have been realised with Itasca codes (Finite Differences with Flac3D, and Discrete Elements with 3DEC), but any hydro-mechanical code with the same or other numerical methods can be used.



Proposed recommendations derived from hydro-mechanical simulations of water level variation impact on post-mining seismicity associated with fault zones surrounding mine galleries. (source: Method on assessment and monitoring, ed. by Sokoła-Szewioła V. Kotyrba A., Alheib M., 2023)

Chapter 5
SEISMIC HAZARD CONTROL AND PREDICTION OF SURFACE ADVERSE EFFECTS

The chapter concerns issues regarding the harmfulness of the impact of ground vibrations caused by post-mining earthquakes on buildings and people .

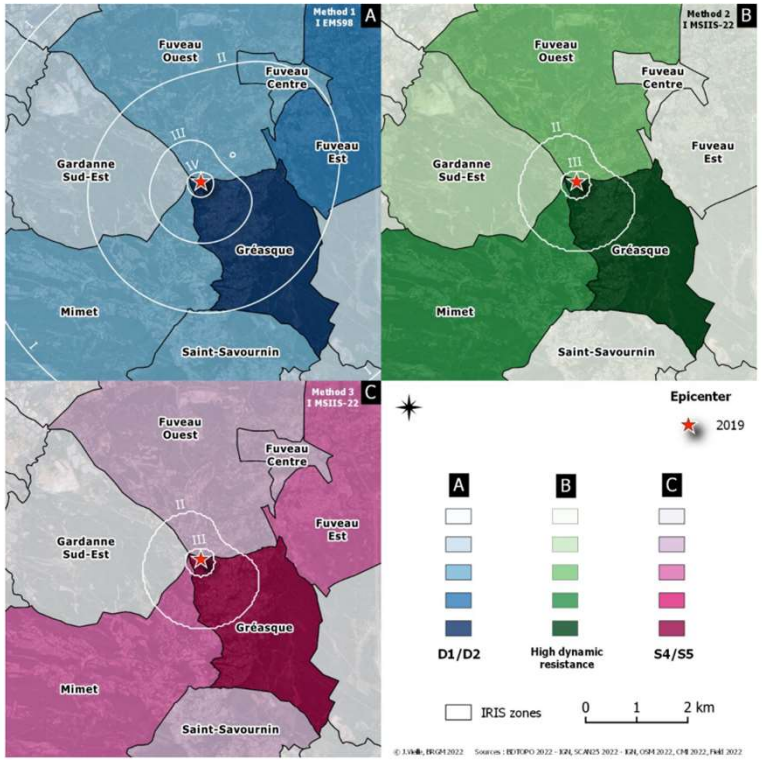
- The seismic hazard control, seismic monitoring, ground motion prediction equation, earthquake maps, seismic scenario, and MSIIS-22 instrumental intensity scale adapted to post-mining earthquakes are presented.

MSIIS-22 Degrees of seismic instrumental intensity I_{MSIIS}	Vibration velocity (mm/s)		Perceived shaking	The potential damage to buildings	Degrees of the harmfulness of vibrations in buildings S
	short time duration impact (t≤1.5 s)	long-time duration impact (t>1.5s)			
I	<1	<1	Not felt or very weak felt	none	S_1
II	1-5	1-5	weakly felt or felt indoors	none	S_2
III	5 - 20	5 - 10	Felt indoors by many people, and outdoors by few. The dishes rattle, and the hanging objects begin to swing.	none	S_3

Short form of the Mining and Post-Mining Instrumental Intensity Scale MSIIS-22 (A fragment of the scale),
(source: Method on assessment and monitoring, ed. by Sokoła-Szewioła V., Kotyrba A., Alheib M., 2023)

Chapter 6
DAMAGE ASSESSMENT OF POST-MINING EARTHQUAKES ON BUILDINGS AND INFRASTRUCTURE

- The chapter presents the classical approach used for natural seismicity (European Macroseismic Scale - EMS-98) and that developed for induced seismicity (MSIIS-22) to assess damage to existing buildings due to post-mining induced seismicity.



Damage scenario results of the April 19th 2019, post-mining earthquake (Mw 1,7) using method A (based on EMS-98 intensity), methods B and C (based on MSIIS-22 intensity), (source: Method on assessment and monitoring, ed. by Sokoła-Szewioła V., Kotyrba A., Alheib M., 2023)

Chapter 7
MONITORING STRATEGIES FOR SAFETY USE OF POST- MINING TERRAINS

The chapter concerns multi-disciplinary monitoring in post-mining areas, especially during the period of mine flooding that includes:

- temporary near-surface geophysical measurements,
- continuous and periodic gravity monitoring,
- seismic monitoring,
- surface deformation monitoring,
- monitoring of water in deep and shallow parts of the rock mass.

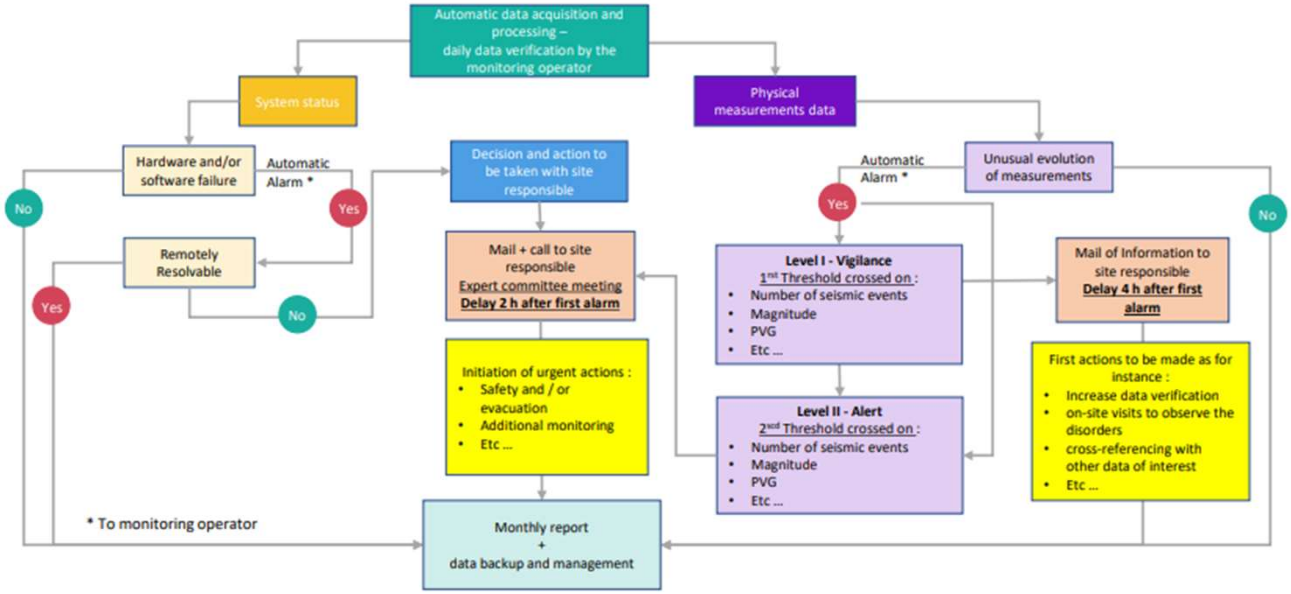
For each of the scopes of monitoring, detailed recommendations were formulated for application.

Near-surface geophysics	Surveys	Perform temporary geophysical surveys to characterise fissuring processes in faulting zones; long term observations of deformation processes is
Gravity	Monitoring	Continuous and periodic gravity measurement is useful to monitor regions prone to post-mining seismogenesis: those with potential void collapsing,
Seismicity	Monitoring	Post-mining seismicity poses a hazard comparable to mining seismicity and should be accurately monitored.
Deformation	GNSS	Include continuous surface deformation monitoring system based on high-frequency satellite observations from multiple GNSS, using as many satellites as
Hydrological	Water level	Automated monitoring systems are recommended, ensuring real-time data. The sensing probes should be located in abandoned shafts or geological boreholes.
	Water origin	In mines where coal-bearing formations are covered with younger sediments, it is recommended to monitor water in each stratigraphic series.

Recommendations for post-mining monitoring (Fragments of the table containing the recommendations, source: Method on assessment and monitoring, ed. by Sokoła-Szewioła V., Kotyrba A., Alheib M., 2023)

Chapter 8
GUIDELINE TO DESIGN AND MANAGE AN EARLY WARNING SYSTEM FOR POST-MINING SEISMIC RISK

- The chapter contains guidelines for the development of an automatic early warning system for rock mass movements caused by post-mining earthquakes and for reporting on the harmfulness of their impact on buildings.



Example of monitoring logigram,
(source: Method on assessment and monitoring, ed. by Sokoła-Szewioła V., Kotyrba A., Alheib M., 2023)

Chapter 9
CONCLUSIONS AND GENERAL RECOMMENDATIONS

The chapter presents important, conclusions, on the content of the guidelines and general recommendations for the application of the guidelines.

Obligatory and recommended monitoring program in coal mines in the process of flooding
(+ indicates the need to use a monitoring method)

No.	Monitoring method	Water level in rock - mass at depth ≤100m -Case 1-	Water level in rock-mass at depth>100m -Case 2-
		Obligatory	Recommended
1	Regional seismological continuous observations	+	+
2	Local seismological continuous observations	+	
3	Continuous water level observations in stratigraphic series in depth range from surface to the point of deepest shaft in a mine	+	
4	Temporary water level observations in stratigraphic series in depth range from surface to the point of deepest shaft in a mine		+
5	InSAR	+	+
6	GNSS		+
7	Continuous gravity observations		+
8	Periodic gravity surveys in areas of shallow room and pillar mining	+	

(source: Method on assessment and monitoring, ed. by Sokoła-Szewioła V., Kotyrba A., Alheib M., 2023)

Chapter 9
CONCLUSIONS AND GENERAL RECOMMENDATIONS
cont.

Additional general recommendations

Monitoring	Period
Hydro- mechanical model of the rock mass should be used to assess the impact of the flooding process and water table fluctuations on the triggering of seismic activity.	The mine decommissioning plan should provide the hydro-mechanical model. The model should be updated throughout the period of mine flooding on an ongoing basis.
The assessment of the impact of post-mining earthquake vibrations on buildings, the perceptibility of vibrations to people, and the assessment of the safety of transmission of dynamic impacts through buildings and the assessment of damage to facilities.	On an ongoing basis, based on seismic monitoring data and data on the technical condition of facilities, throughout the period of mine flooding.
Early warning system.	The system should be developed before the mine flooding process begins. The system should operate on an ongoing basis, especially during the period of mine flooding.

(source: Method on assessment and monitoring, ed. by Sokoła-Szewioła V., Kotyrba A., Alheib M., 2023)

CONTACTS

If you need more detailed information on any of the subjects discussed in the book, we recommend that you contact the responsible corresponding authors .

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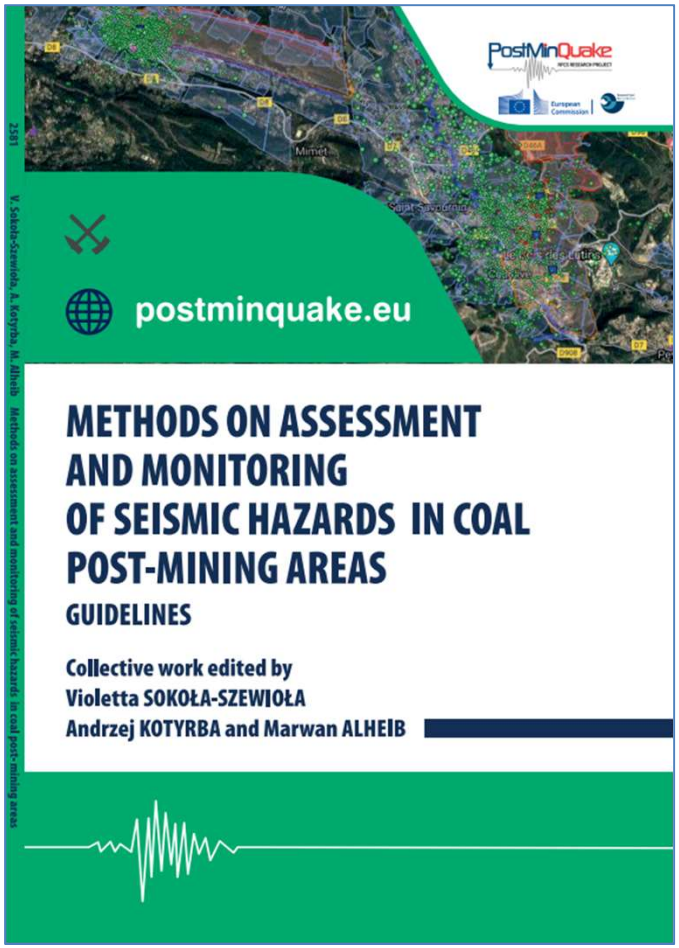

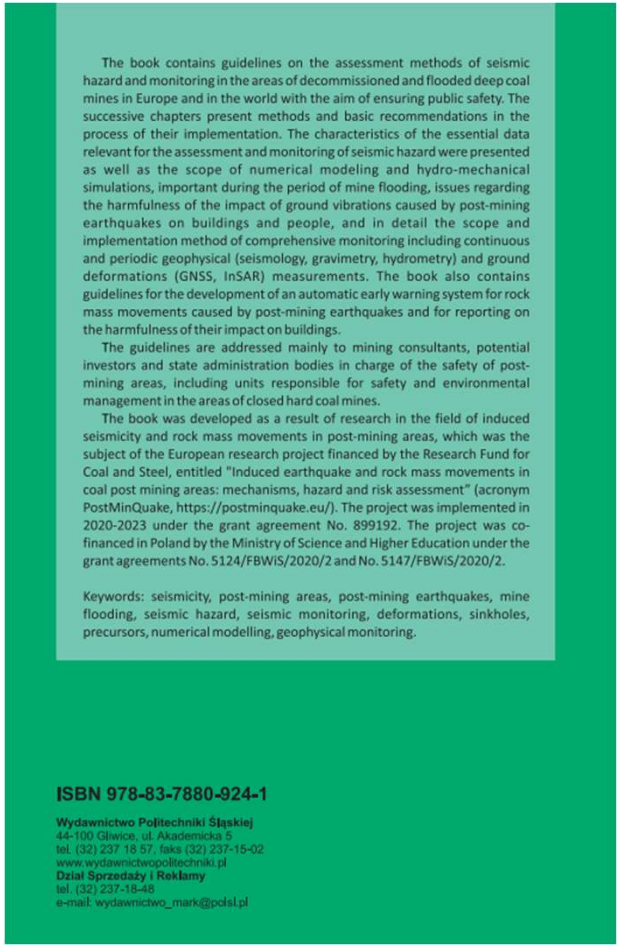
The book contains guidelines on the assessment methods of seismic hazard and monitoring in the areas of decommissioned and flooded deep coal mines in Europe and in the world with the aim of ensuring public safety. The successive chapters present methods and basic recommendations in the process of their implementation. The characteristics of the essential data relevant for the assessment and monitoring of seismic hazard were presented as well as the scope of numerical modeling and hydro-mechanical simulations, important during the period of mine flooding, issues regarding the harmfulness of the impact of ground vibrations caused by post-mining earthquakes on buildings and people, and in detail the scope and implementation method of comprehensive monitoring including continuous and periodic geophysical (seismology, gravimetry, hydrometry) and ground deformations (GNSS, InSAR) measurements. The book also contains guidelines for the development of an automatic early warning system for rock mass movements caused by post-mining earthquakes and for reporting on the harmfulness of their impact on buildings.

The guidelines are addressed mainly to mining consultants, potential investors and state administration bodies in charge of the safety of post-mining areas, including units responsible for safety and environmental management in the areas of closed hard coal mines.

The book was developed as a result of research in the field of induced seismicity and rock mass movements in post-mining areas, which was the subject of the European research project financed by the Research Fund for Coal and Steel, entitled "Induced earthquake and rock mass movements in coal post mining areas: mechanisms, hazard and risk assessment" (acronym PostMinQuake, https://postminquake.eu/). The project was implemented in 2020-2023 under the grant agreement No. 899192. The project was co-financed in Poland by the Ministry of Science and Higher Education under the grant agreements No. 5124/FBWiS/2020/2 and No. 5147/FBWiS/2020/2.

Keywords: seismicity, post-mining areas, post-mining earthquakes, mine flooding, seismic hazard, seismic monitoring, deformations, sinkholes, precursors, numerical modelling, geophysical monitoring.

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Thank you

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