



SIRIMA

SINKHOLE HAZARD AND RISK MANAGEMENT IN POST MINING AREAS
RFCS PROJECT NO 101157400



Co-funded by
the European Union

Deliverable D.2.1

Shallow coal mining in Europe

WP2. Data bases creation and advanced analysis

Responsible Partner: Główny Instytut Górnictwa – Państwowy Instytut Badawczy, Poland

Contributing Partners:

1. Bureau de recherches géologiques et minière – BRGM, France
2. DMT-Gesellschaft für Lehre und Bildung mbH - THGA, Germany
3. Systra Subterra Ingenieria SL, Spain
4. GEODERIS, France

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August 2025



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1. Introduction

Document Overview

The SIRIMA: *Sinkhole Hazard and Risk Management in Post-Mining Areas* project is carried out with co-financing from the Research Fund for Coal and Steel of the European Union as the action RFCS-2023-01-RPJ Coal Research Projects under Grant Agreement No. 101157400.

This document entitled “Shallow coal mining in Europe”, represents the deliverable for Task 2.1 and is denoted as D.2.1. The purpose is to present an information on the acquired data, its processing and integration for the needs of the interactive map of shallow coal deposits in the areas of abandoned mines on the SIRIMA project website. Due to the complexity of the issues for the entire European Union, limitations in access to materials, the analysed data are limited to the Partner countries participating in the project implementation: France, Germany, Poland and Spain. The study is based on the following sections:

- Introduction
- General description of sinkholes hazard in areas of abandoned mines (Section 2)
- Processing information about shallow exploitation areas by project partner countries (Section 3)
- Creation of an integrated map as part of the SIRIMA project website (Section 4)
- Conclusions (Section 5).

Contributing Partners

The SIRIMA Project Consortium consists of seven Partners and one Associated Partner. The Table 1 below, presents the Consortium participants along with the contact details of the persons responsible for the implementation of the SIRIMA project in their home institutions:

Table 1 Contact list of persons responsible for the implementation of the SIRIMA project at the Consortium Partners

Partner	Full Name	Contact Person	Contact Email
GIG-PIB	Główny Instytut Górnictwa - Państwowy Instytut Badawczy	Sławomir Siwek	ssiwek@gig.eu
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General Information about Project

The SIRIMA project focuses on increasing knowledge and experience related to the threats of post-mining areas in EU Member States. The main objective of the project is to reduce the occurrence of uncontrolled and unexpected movements of the Earth's surface in the areas of abandoned shallow coal mines. These movements, apart from subsidence related to the conducted mining or movements resulting from the impact of mining tremors, can also take the form of uplifts caused by the lifting of the groundwater table in the rock mass and sudden - discontinuous deformations of the ground surface, i.e. sinkholes. The sinkhole hazard is the main type of hazard affecting coal regions in transition. It is due to existence of shallow mining workings and the resulting risk of damage to the buildings, infrastructure or threat to people living in in post-mining areas.



Figure 1 Graphical presentation of the Partners in the SIRIMA project.

2. General description of sinkholes hazard in areas of abandoned hard coal mines.

The management of post-mining areas in the European Union countries is an important issue for safety and economic reasons. The adopted European Green Deal policy will, over the next 20-30 years, intensify problems resulting from the closure of hard coal mines. One of the greatest challenges associated with the decommissioning of underground mining operations is changing or limiting the drainage of the rock mass where mining operations were conducted. This has both environmental and economic implications. In the face of ongoing climate change, it is crucial to restore the original groundwater resources in such areas to restore natural streams and reservoirs, as well as to restore their usability for residents of post-mining regions. From an economic perspective, maintaining a costly drainage system is a significant financial burden and involves the use of significant amounts of energy (e.g., for operating submersible pumps). However, uncontrolled and unprotected flooding of the decommissioned mine area can lead to new threats to the surface, such as flooding, and, in the case of shallow mining operations, the risk of discontinuous and sudden surface deformations – sinkholes (Whittaker and Reddish, 1989).

Hard coal mining has played a pivotal role in Europe's industrial development. Shallow mining, which is defined as mining to a depth of 80-100 m below ground level (bgl) (Kotyrba, 2005, Kotyrba et al., 2006, Didier et al., 2008), has been carried out in most European countries over time. However, in many countries, hard coal mining was limited due to scarce resources (Italy, Slovenia, Slovakia, Ireland, Hungary, Romania, Bulgaria, Portugal, Croatia). The situation is different in countries such as Poland, Germany, France, the Czech Republic, the United Kingdom currently outside the EU), as well as Belgium and Spain. In these countries, hard coal deposits are much larger and have been (France, Germany, Belgium, Spain, the United Kingdom) or still are (Poland, the Czech Republic) subject to mining.

Industrial mining and its documentation have been conducted from the beginning of the Industrial Revolution in the 17th century to the present day. During this time, hard coal was extracted from successively deeper coal seams. Initially, coal was mined through small open pits. Later, as resources were exploited, underground mining was introduced. Access to the shallowest hard coal seams was possible through shallow shafts, descending galleries and mining galleries located at shallow depths. Over time, mining began at increasingly deeper layers, and the shallowest seams and access to them were abandoned or closed.

Mining techniques used in underground hard coal mining did not differ significantly between countries, especially since, for example, Polish mining developed using the knowledge of German and French miners brought by mining entrepreneurs to Polish coalfields (Jaros 1972). The first step was always to excavate galleries to explore and access the deposit. These galleries were excavated in the direction of the deposit. In the next stage, coal was extracted from sections (mining fields) marked by galleries using various techniques that

changed with the development of mining knowledge. A common feature of this mining was that after extracting coal from a given section of the deposit, the support elements suitable for further exploitation were removed, which had a great technical and economic justification.

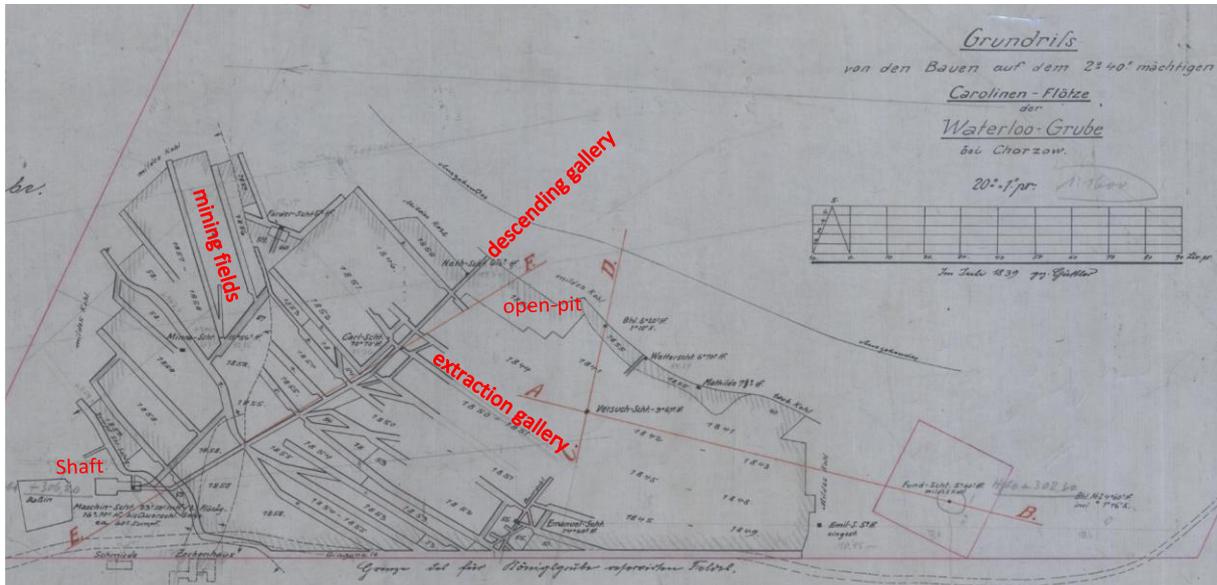


Figure 2 An example of the mining excavations on an old exploitation map. Waterloo abandoned hard coal mine in Katowice, Poland

This action led to the roof breaking and the collapse of rocks in the mined-out part of the deposit. This process was uncontrolled, leaving significant voids in the subsoil. Moreover, the main haul roads were often left intact for indefinite future use. Even during the mining of shallow coal seams, the removal of support and the collapse of workings caused sinkholes to form on the surface. In many cases, these processes were not documented, and the deformations were filled with waste rock. Some workings (especially shafts) were closed by backfilling, partially secured or left unsecured. Over time, a large part of them self-liquidated. This type of mining activity left significant voids in the ground (empty mine galleries, spaces left after coal was extracted). Such mining operations left significant voids in the subsoil (empty galleries, spaces left over from coal extraction). Their persistence in the subsoil depended on many factors, including the type of rock surrounding the void, particularly the overburden and its susceptibility to cracking and deformation, water inflow, drainage, deeper mining, and access to atmospheric air. Under favourable conditions, some of the voids filled with a mixture of gases or liquids, reached a state of temporary equilibrium and remain in the ground to this day.

In the current situation, with the depletion of deep-sea hard coal deposits, increasing natural hazards (temperature, pressure, gas hazards), high costs of hard coal extraction from such deposits, and changes in the European Union's energy policy (Green Deal), efforts to cease mining are accelerating. The consequence of these actions is the commencement of the process of complete mine closure and their impact on the natural environment. A key element

of this process is the pursuit of ceasing rock mass drainage. This is driven both by the high costs of maintaining a permanent water drainage system and the need to restore natural groundwater resources. This is particularly important in the current period of climate change. However, rising groundwater levels disrupt the existing temporary equilibrium between the rock mass and the post-mining voids in areas of shallow hard coal mining. This causes a gradual migration of groundwater towards the surface. This process leads to the emergence of sinkhole hazards in post-mining areas.

The SIRIMA project's T2.1 task – Database of shallow coal mining exploitation in abandoned mines in the partner's countries – focuses on collecting, standardizing, and presenting information on shallow mining exploitation areas in the project partner countries (Germany, France, Poland, Spain). The specific objectives related to the implementation of this task are as follows:

- collection of data and metadata,
- identification of post-mining areas with sinkhole hazard due to shallow mine workings,
- presentation of results in the form of an interactive map provided via the publicly accessible website.

The action undertaken through the adopted objectives aims to inform numerous consumers, residents, and businesses operating in European Union countries, where their regions may face threats resulting from historical shallow hard coal mining. These threats are related to: the above-mentioned ground surface movements (particularly sinkholes but also subsidence or uplift); hydrogeological changes (floods and flooding); soil, water, and air pollution; thermal disturbances in the ground and gas emissions from low-temperature coal oxidation or combustion (Didier 2009).

Information on the data collected, processed and provided by the project partners to GIG-PIB for the purposes of visualization on the website is presented in the next chapter (3) divided by country.

Despite the completion of this document, the project partners will continue to work on expanding the database. It should be noted that the underlying idea behind this work is to create a unified map of shallow mining areas of hard coal deposits for the entire European Union. To this end, funding sources for such work will be sought, as well as opportunities to engage teams from other countries.

The information generated as part of the implementation of task T.2.1 is made available via the SIRIMA project website (<https://sirima.gig.eu/>)

3. Processing information about shallow exploitation areas

As a consequence of mining exploitation in post mining areas surface deformations may occur, especially in places where mine extraction was conducted on a low depths. Potential surface hazards determine the safety for civil and building engineering. The main goal of the T2.1 in the project is to record on present cartographical maps the areas of old shallow coal exploitation. In agreement with partners, the value of 80 m below ground level was adopted as the boundary of shallow exploitation areas.

The basic materials for presenting the scope of shallow coal mining and the location of workings providing access to coal deposits were mining maps of liquidated mines.

The SIRIMA project web portal has a modular structure. It was first launched in April 2025 as a beta version. The DIGITAL DATABASE module contains the "Integrated map of shallow coal mining in Partner's countries" built on the basis of data documenting mining activities such as:

- boundaries of mining areas of liquidated coal mines,
- boundaries of areas of shallow (up to 80 m below ground level) exploitation of this raw material.

In the task T2.1 in the project, the aim is to digitize areas covered by shallow coal exploitation and make this information available in the public space in the form of an internet website. To construct the digital map of shallow mining extent polygons marking places where coal was selected from seams in the depth range of 0-80 m below the surface was needed. In order to achieve those purpose we need two maps superimposed on each other:

- a archival seam map from a given mine (or a few mines) with marked zones of extracted coal,
- a hypsometric map of the ground surface above extracted parts of the coal seams.

The work carried out within the SIRIMA project concerns 4 European Union countries: France, Germany, Poland and Spain. Below the information on the acquisition and processing of information on areas of shallow mining of hard coal deposits in those countries is presented.

3.1. France

In France, coal mining has historically been of great economic importance, particularly in the regions of Nord-Pas-de-Calais, Lorraine, Massif Central and Provence. Among the extraction methods, surface or open pit mines are distinguished by their ability to extract coal located relatively close to the surface. Shallower underground mine workings require significant technical means to stabilize the walls and manage groundwater.

Today, French coal activity has stopped, but with the cessation of drainage and pumping of mine water, the flooding of former superficial mine workings may constitute a risk of sinkhole causing danger for the populations.

The constitution of a database and an associated GIS grouping together the most superficial mining works on the national territory allows for a better assessment of the sinkhole hazard and the associated risk. This part specifies the constitution of the database and the associated GIS on the French territory and the selection of relevant data in order to satisfy the needs of the SIRIMA project.

Method

An extract from the GEODERIS BDSTM database, which contains coal mining sites and claims recorded in France, was provided to BRGM for processing. Since this database is the result of a compilation of several non-harmonized studies and projects, it was necessary to clean and select the mining sites according to the criteria established by the leader of Task 2.1 of WP2 of the SIRIMA project, namely: taking into account only coal mine workings and considering only shallow mining operations ranging from 0 to 80 meters in depth (including workings where part of the mine is deeper than 80 meters, as long as another part is shallower than 80 meters). The adopted methodology is as follows:

Step 1: Understanding the BDSTM

An extract of coal mining titles (administrative right-of-way granting the right to explore and exploit the concessioned substance), exploitation rights-of-way (surface projection of underground workings with positional uncertainty), and underground mine workings (digitized from mine plans) was provided by GEODERIS. These GIS data are in the form of polygons, lines, or points. Initially, it was necessary to understand and interpret the different fields provided in each GIS layer. Exchanges between BRGM and GEODERIS in April and May 2025 helped clarify these aspects. Some examples of objects such as coal mining claims, coal mining right-of-way and underground coal mine workings are showed on Figure 3.

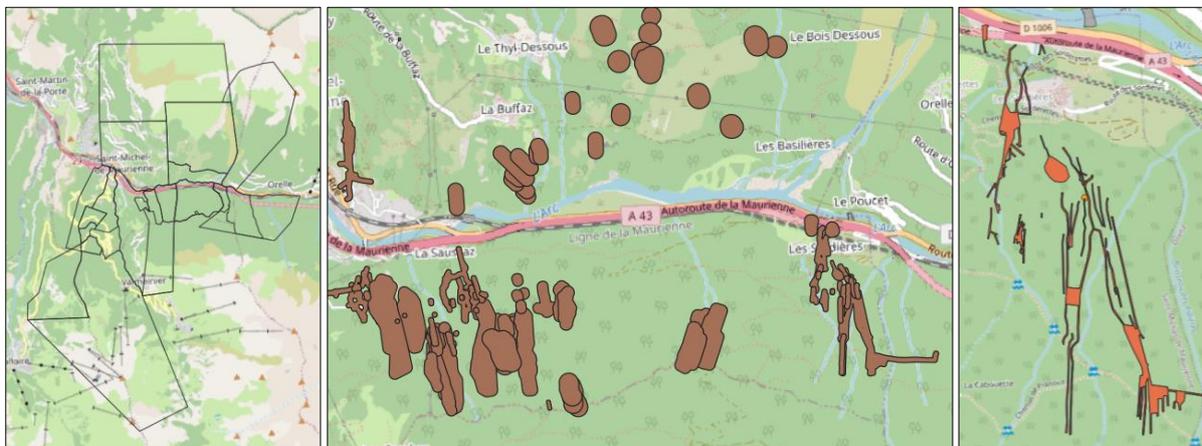


Figure 3 Example of coal mining claims (left), coal mining right-of-way (middle) and underground coal mine workings (right) from the BDSTM before cleaning, processing and selection.

Step 2: Database cleaning

Following discussions with GEODERIS, based on the “name” field, the following mine workings (very small or unnecessary elements for characterizing mining rights-of-way) were removed:

- Assemblies
- Outcrops
- Shafts
- Galleries
- Inclines
- Excavations
- Extractions
- Veins
- Gallery entries / gallery bodies
- Indices
- Uncertainties
- Scrapings
- Bridges
- Trenches
- Fissures

Step 3: Data selection methodology

A methodology was agreed upon with the GIG-PIB (Central Mining Institute – Polish National Research Institute) and GEODERIS to adapt the data for integration into the SIRIMA project website and meet partner expectations.

All coal mining claims were retained for integration into the project. No further work was necessary on this GIS layer as it was already clear and well-organized.

The main work focused on the coal mining right-of-way, using the associated mine workings and particularly the fields “depth” and “cover”. These fields, although not always informed, indicate the mine's depth range. A predefined selection based on specific criteria made it possible to consider the mining rights-of-way relevant to the project's needs and the categories established with the GIG-PIB.

The selection was as follows:

1. Known depth:

- **Underground coal mining rights-of-way strictly between 0 and 80 meters depth:**

Selection of mine workings where the “depth” or “cover” fields confirmed that operations were strictly between 0 and 80 meters. Once selected, the associated exploitation right-of-ways fully intersected by these workings were also selected for inclusion in the SIRIMA database.

- **Underground coal mining rights-of-way where part lies between 0 and 80 meters and the rest deeper:**

Selection of mine workings with “depth” or “cover” confirming operations between 0 and 80 meters. Associated rights-of-way partially intersected by these workings were included in the database.

Also selected were mine workings with “depth” or “cover” showing that at least part of the workings was within the 0–80 m range. The associated rights-of-way were then included.

2. Unknown depth :

In the native GEODERIS BDSTM database, the GIS layer “Localized Collapse Hazard” was created based on underground workings located less than 50 meters deep. A collapse hazard implies that the mine workings are necessarily located at depths below 50 meters. This allowed for the selection of exploitation rights-of-way containing underground coal workings with no recorded depth but intersecting the collapse hazard layer—thus assumed to be within 0 to 50 meters depth.

- **Underground coal mining rights-of-way strictly between 0 and 50 meters depth:**

Selection of mine workings entirely intersecting the “Localized Collapse Hazard” layer. The associated exploitation rights-of-way fully covered by this layer were included in the SIRIMA database (**Błąd! Nie można odnaleźć źródła odwołania.**).

- **Underground coal mining rights-of-way partly between 0 and 50 meters depth and partly deeper:**

Selection of mine workings entirely intersecting the “Localized Collapse Hazard” layer. If they only partially intersected the right-of-way, the entire right-of-way was still included.

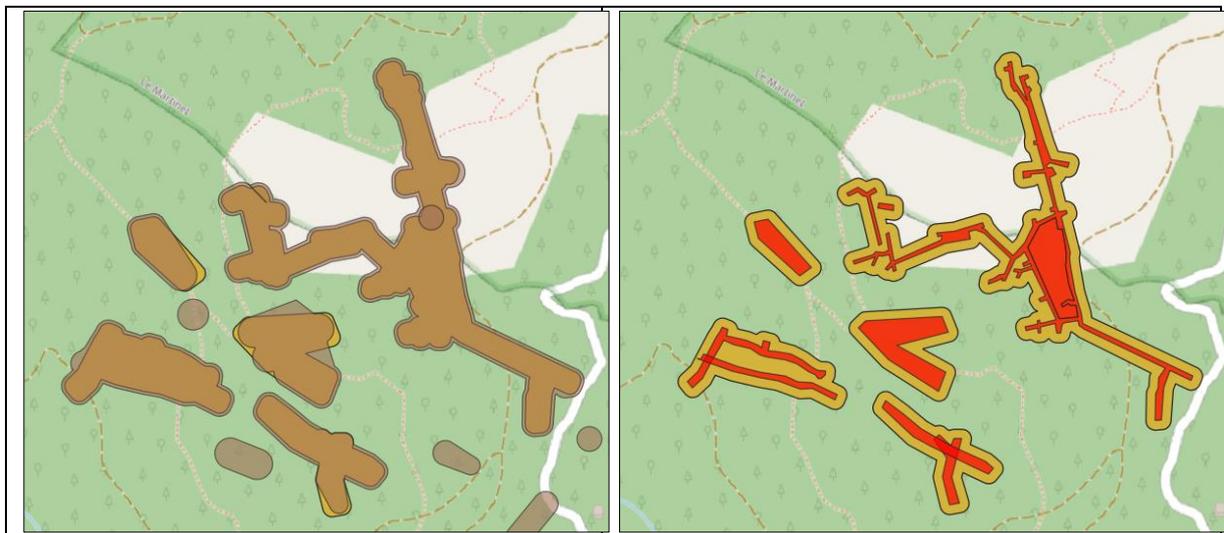


Figure 4 Full coverage of the “Localized collapse hazard” layer in grey over the yellow mining right-of-way (left) and full coverage of the mining workings in red over the yellow mining right-of-way (right).

Step 4: Formatting adjustments : Aggregation and Merging of Overlapping Footprints

Once the four mining footprint layers were created, overlapping areas were merged to simplify the resulting geometries.

Due to the need to limit the number of geographic coordinates used to describe each polygon for data transfer and integration into the GIS interface, mining right-of-way with complex geometries, including galleries or access tunnels, were simplified as much as possible while maintaining their overall shape.

Further simplifications may be required if some polygons still contain too many coordinates for integration into the SIRIMA project website.

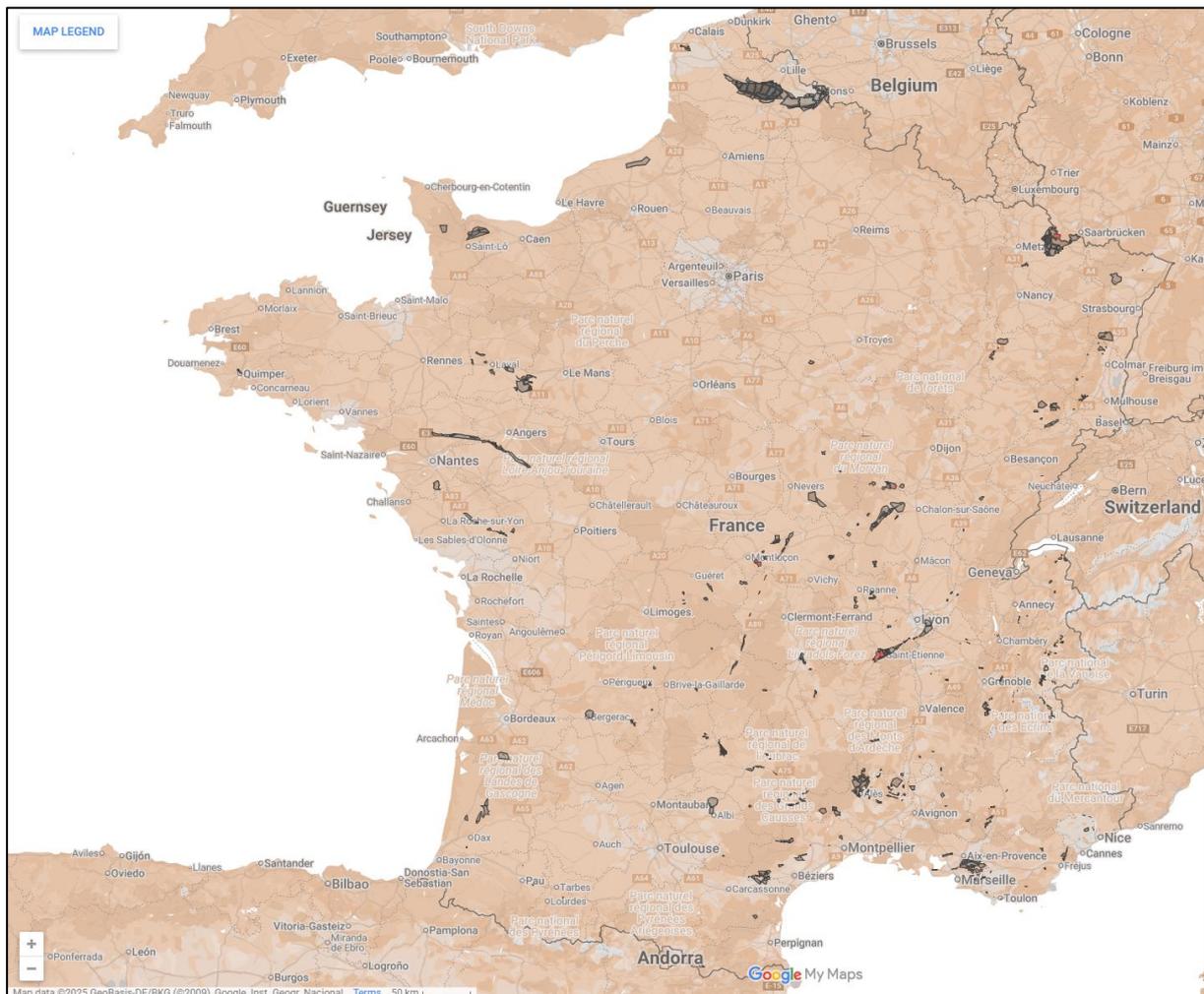


Figure 5 Final results of SIRIMA Integrated Map of Shallow Exploitation – France.
Integrated Map screenshot, source: <https://sirima.gig.eu/integrated-map/>. In black – Mining Areas, in red (80 bgl) and orange (50 m bgl) – shallow exploitation zones.

Final Data:

- 979 Licensed Coal Mining Areas
- 79 areas of shallow coal mining 0-50 m bgl (associated with localized collapse hazard zone by BRGM)

- 132 areas of shallow coal mining 0-80 m bgl (directly from GEODERIS database)
- 211 areas of shallow coal mining up to 80 m bgl (0-50m + 0-80m)

3.2. Germany

Introduction

The Ruhr mining area, renowned for its long-standing industrial heritage, has a mining history that dates back to the Roman period or even earlier. Mining activities in the region have primarily focused on resources such as ore, hard coal, lignite, and salt, along with other materials like clay, sand, and slate.

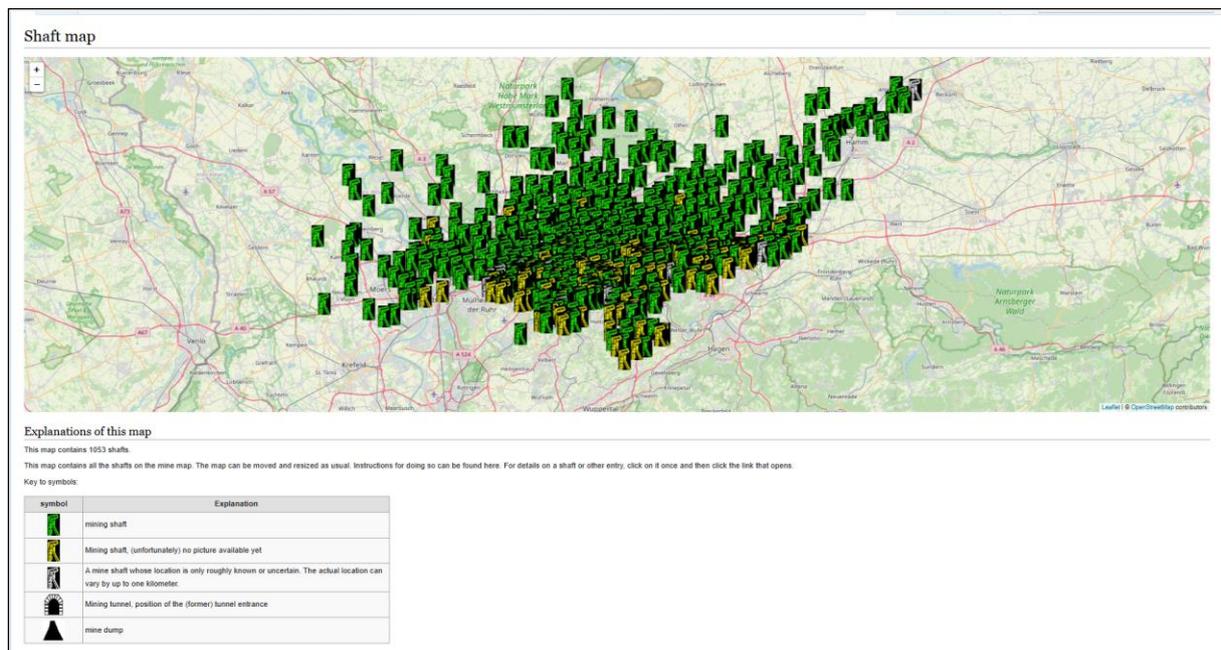


Figure 6 Shaft map in Ruhr mining area (Zechenkarte, 2025).

Due to the intensity and duration of these operations, post-mining risks particularly the formation of sinkholes resulting from shallow coal seam exploitation, remain a significant concern. A critical first step in analysing these risks is the systematic collection of relevant data and information. This dissemination presents the methodology used to obtain and process data related to shallow coal seams in the Ruhr mining area.

Data storage of mines and shallow coal seams in Ruhr mining area

Hard coal mining activities in Ruhr mining area was started quite early. In the 13th century, hard coal was already being mined in numerous places in the southern area of today's Ruhr area, from Mülheim an der Ruhr to the area of Unna, usually in simple grave holes (pings) (Hüske, 2006). Large-scale coal seam maps were produced by mine surveyors Johann Friedrich Niemeyer (1759–1814) and Johann Ehrenfried Honigmann (1775–1855), laying the foundation for early spatial documentation of shallow coal seam distribution in the Ruhr area.

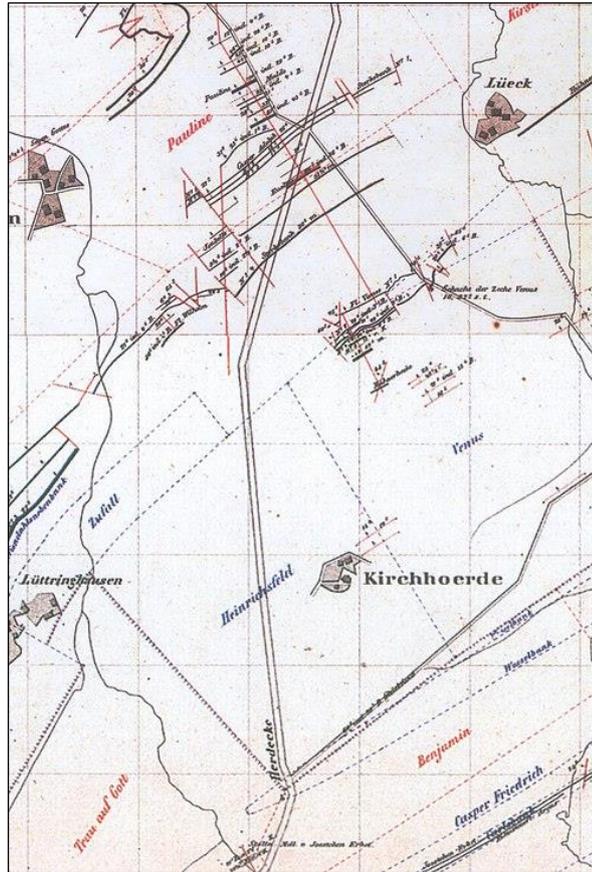


Figure 7 Coal fields, seams und tunnels in Kirchhörde around 1868 (Kapp, 1868).

From Figure 7, the data mainly includes floor plans accompanied by depth values and directional information. To identify areas of shallow coal seam exploitation, the approach involves integrating data on coal seam locations with records of officially permitted mining areas. This combination enables a more accurate delineation of zones affected by historical shallow mining activities.

Methodology

To support the development of a comprehensive database on shallow coal mining areas in the Ruhr mining region, a structured data acquisition process was implemented. The georeferencing of all spatial data was carried out using the following reference systems:

- Location: ETRS89/UTM32 (EPSG 25832)
- Height: DHHN2016 (EPSG 7837)

The data was collected from *OpenGeodata.NRW* as the selection of „Bergbauberechtigungen für die Aufsuchung und Gewinnung von Bodenschätzen in NRW“ (Information und Technik Nordrhein-Westfalen) translated to „Permitted mining data for the

exploration and extraction of mineral resources”. The data contains mining permits with information on field names, field sizes, natural resources, type of permits, legal owner, etc.

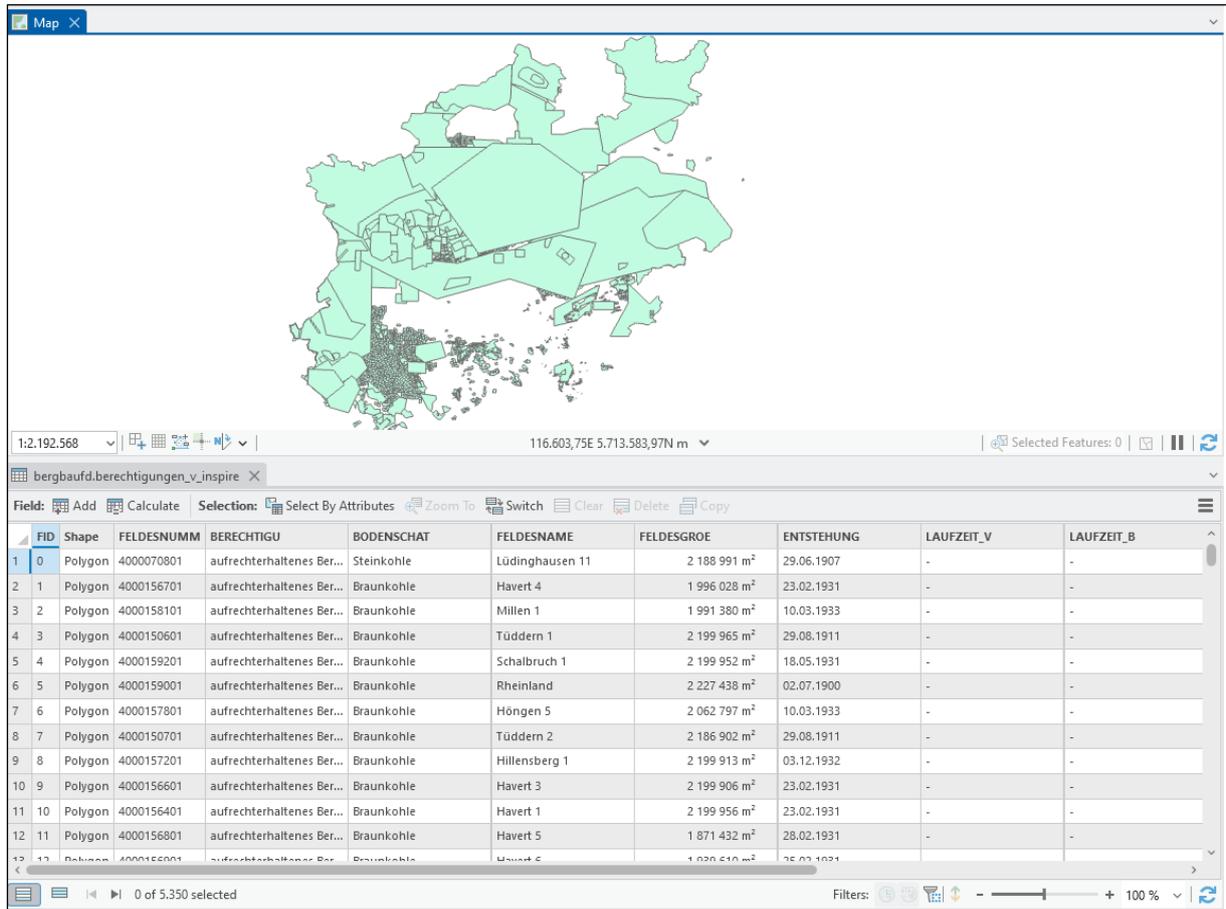


Figure 8 Permitted mining data for the exploration and extraction of mineral resources with geometrical and attribute table information.

To align with the intended purpose of the data, the selection was limited to „Steinkohle”, corresponding to „hard coal”.

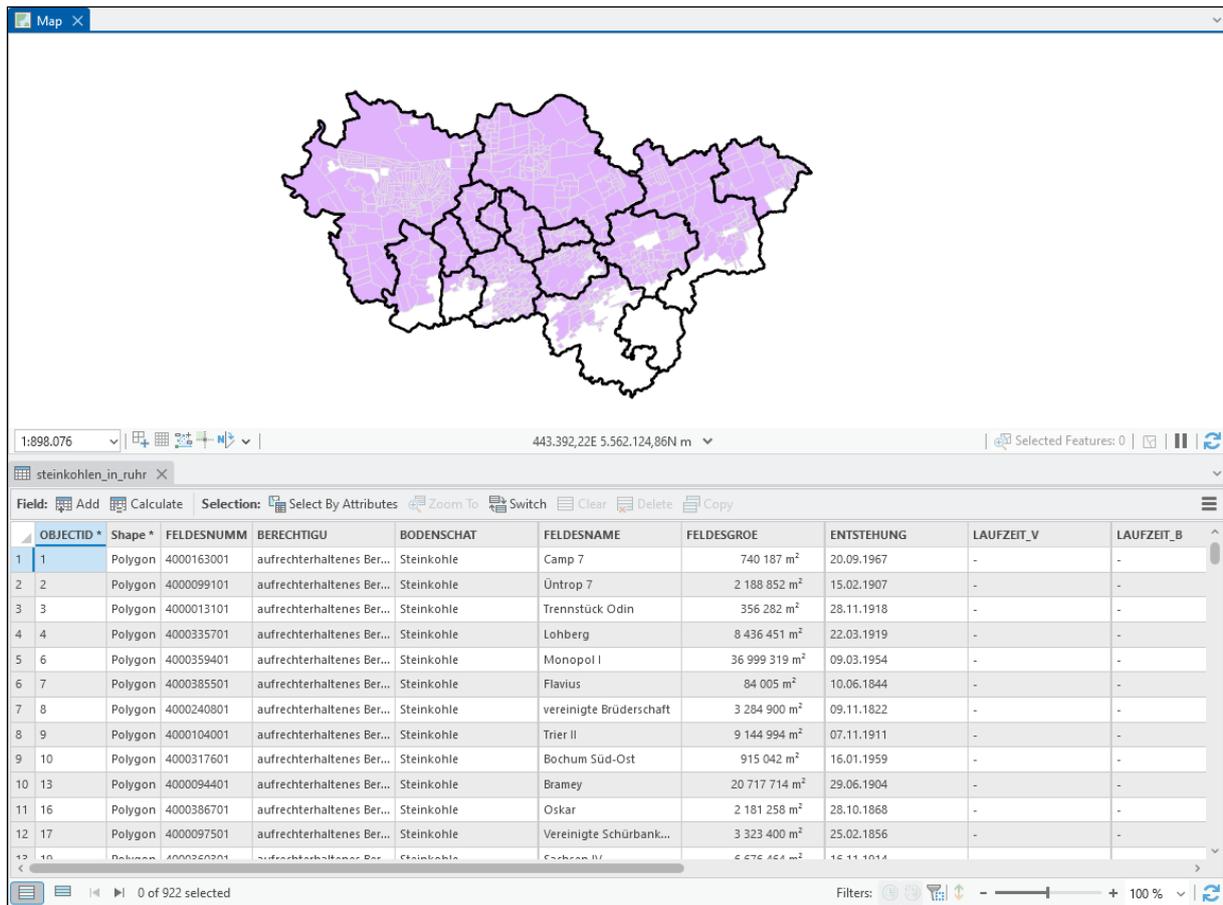


Figure 9 Permitted hard coal mining data for the exploration and extraction of mineral resources with geometrical and attribute table information in Ruhr mining area.

The dataset used was obtained from Geologischer Dienst NRW, Geologische Karte des Rheinisch-Westfälischen Steinkolengebietes 1:10 000 – Geological maps of hard coal areas in Rhein-Westfallen (Geologischer Dienst NRW). The data which are involve in this topic are:

- Blattschnitt – Cross section
- Flöz – Coal seams
- Gestein – Rock type
- Karbontiefe – Depth of coal seams
- Sandstein – Type of sandstones
- Tektonik – Types of tectonic

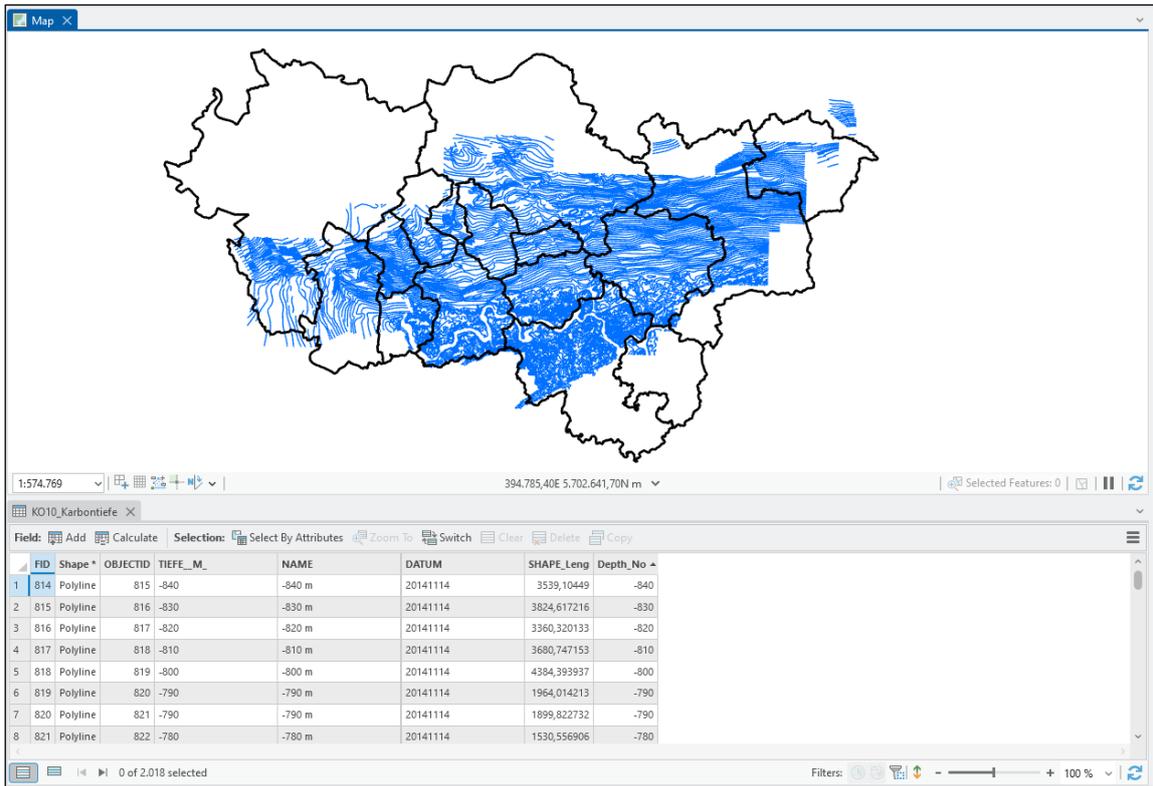


Figure 10 Depth of coal seams (Karbondiefe) data in Ruhr mining area with the value compared to sea level.

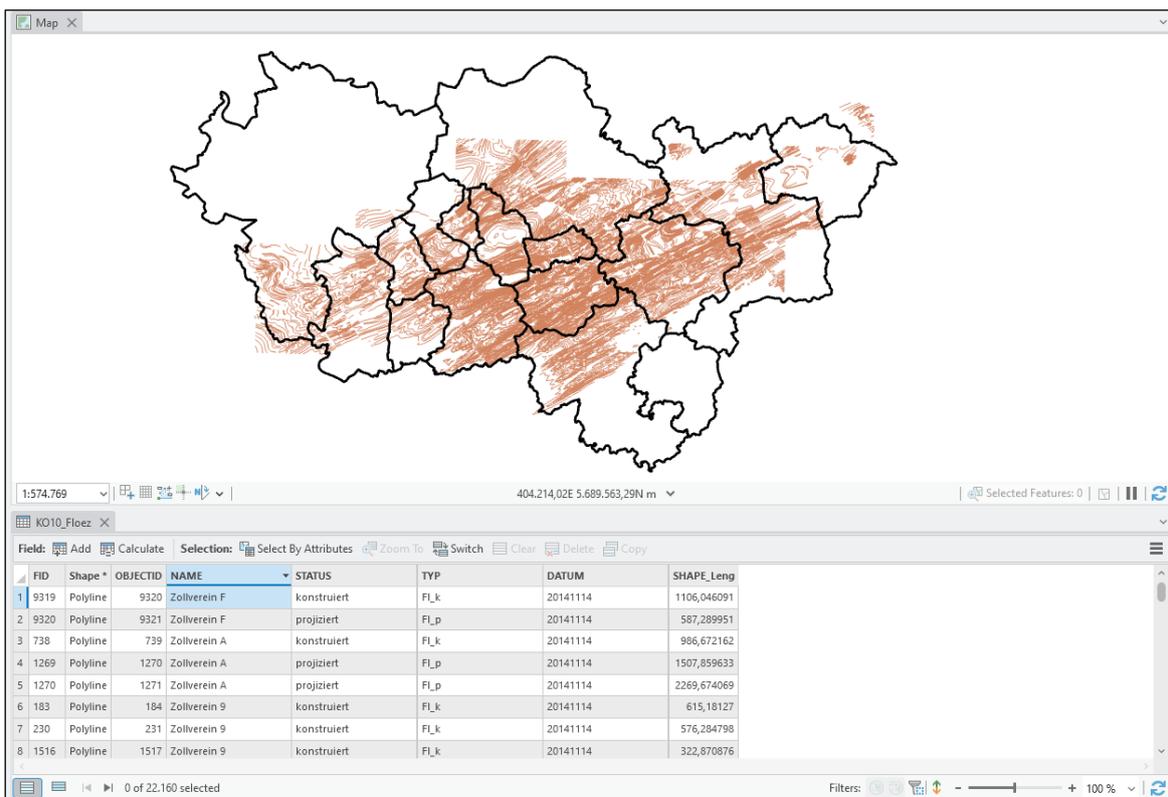


Figure 11 Coal seams (Flöz) data in Ruhr mining area.

Digital Terrain Model (DTM) in Ruhr mining area

DTM is collected from Geoportal.nrw (Geschäftsstelle des IMA GDI Nordrhein-Westfalen) with the title Dgiales Geländemodell (DGM) – Digital Terrain Model.

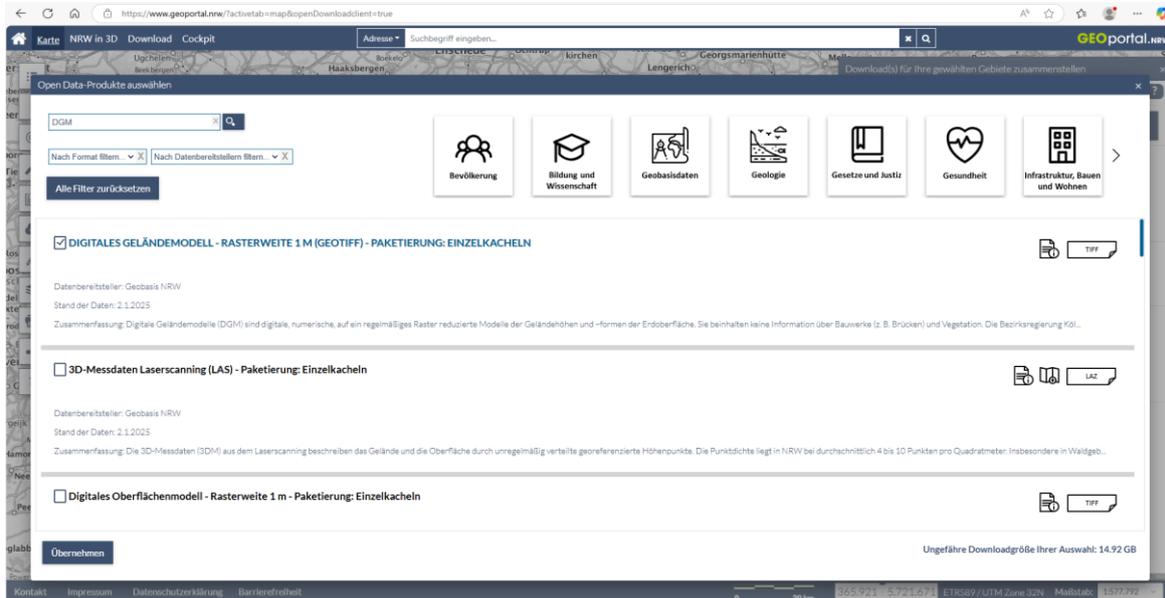


Figure 12 DTM raster is collected from Geoportal.nrw.

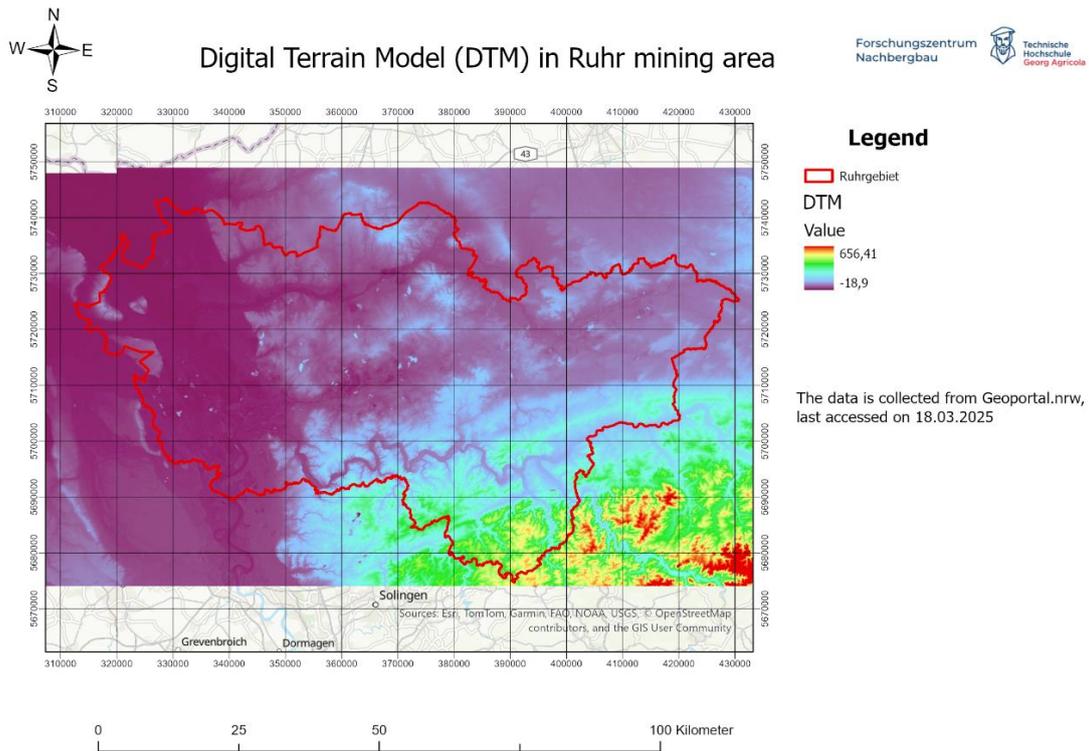


Figure 13 DTM raster in Ruhr mining area.

The DTM raster with resolutions:

- Grid width: 1 meter
- Grid points are positioned at 0.5 m intervals (center of each cell)
- Data format: GeoTIFF
- Pixel depth: 32-bit

Data processing

The extraction of coal seams located at depths of up to 80 meters below ground level is based on analysis using a Digital Terrain Model (DTM). This is followed by the selection of validated coal seam data within officially licensed mining areas to ensure reliability and regulatory compliance.

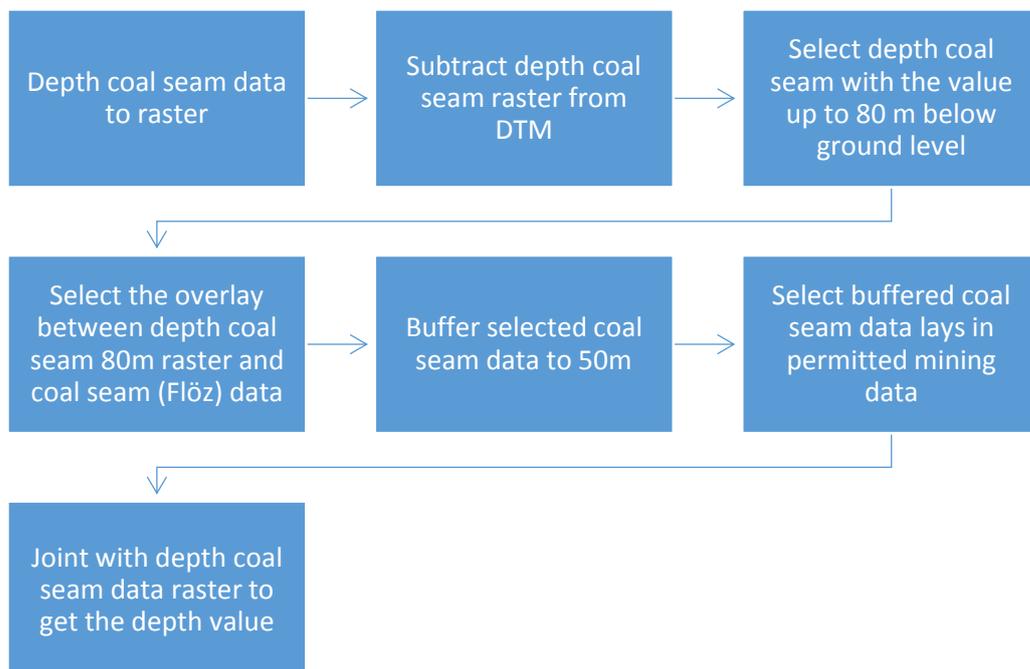


Figure 14 An overview of the workflow for shallow coal seams in Ruhr mining area.

To identify shallow coal seam exploitation zones (up to 80 meters below ground level), a multi-step geospatial data processing workflow was applied, as illustrated in Figure 14. The process is described below:

1. Rasterization of Coal Seam Data: The depth values of coal seams (Karbontiefe) were converted into a raster format to enable spatial analysis and computation.
2. Depth Calculation Using DTM: The coal seam depth raster was subtracted from the Digital Terrain Model (DTM) to derive the depth of coal seams below ground level.
3. Selection of Shallow Coal Seams: From the resulting raster, coal seams located at depths of up to 80 meters below the surface were selected for further analysis.

4. Overlay with Seam (Flöz) Data: The 80-meter coal seam depth raster was overlaid with coal seam geometry data (Flöz) to refine the spatial extent of potential shallow seams.
5. Buffering and Spatial Constraint Application: The selected coal seam (Flöz) areas were buffered by 50 meters to account for spatial uncertainty and operational context. Then, only those buffered areas that intersect with officially permitted mining zones were preserved.
6. Depth Attribution: Finally, the filtered coal seam areas were joined with the original coal seam depth raster to assign precise depth values to each identified zone.

This processing chain ensures that only shallow, geologically validated, and legally permissible coal seam exploitation areas are identified for further analysis or visualization.

Contribution

After identifying shallow coal seam areas that meet the required standards, the corresponding spatial coordinates were exported for further display on the project website and for use in subsequent analyses.

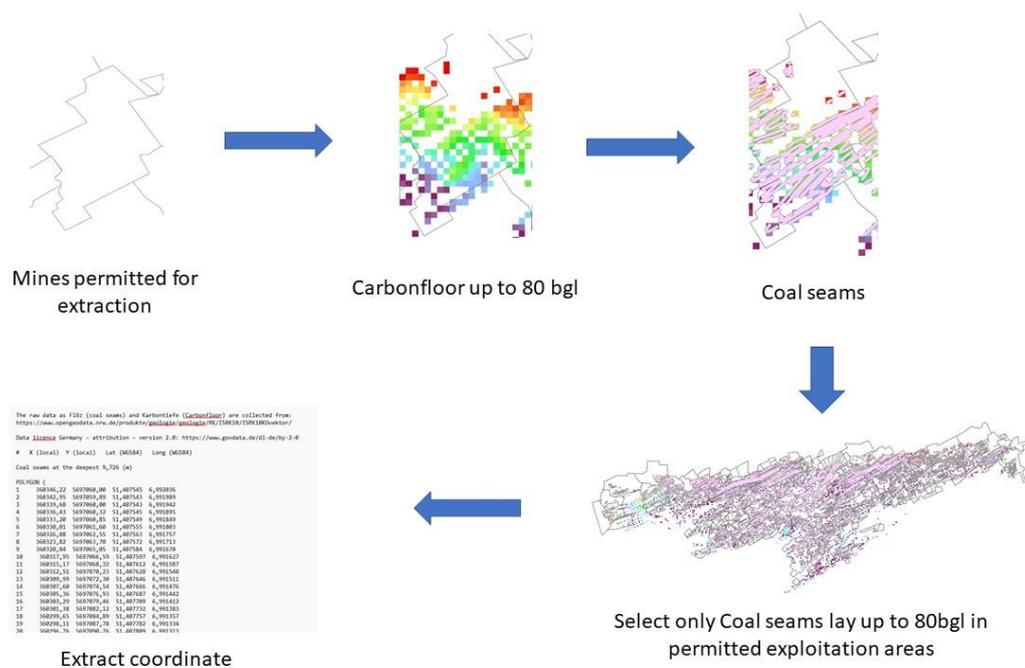


Figure 15 An overview of data processing to obtain shallow coal seam data in Ruhr mining area.

Conclusion

Sinkholes represent one of the significant post-mining risks, particularly in areas where shallow coal seam exploitation has taken place. Collecting and processing relevant spatial data is essential for improving the understanding of these risks and enabling further analysis. Although historical maps may lack detailed or complete information, the integration of modern digital geospatial data provides a valuable means to access, interpret, and visualize

shallow coal seam conditions. This approach supports more informed decision-making in post-mining land management and risk mitigation.

Although it is not the primary study case in the SIRIMA project, the collection and analysis of data from this region will provide valuable insights, particularly regarding sinkhole hazards, benefiting Ruhr mining area as well.

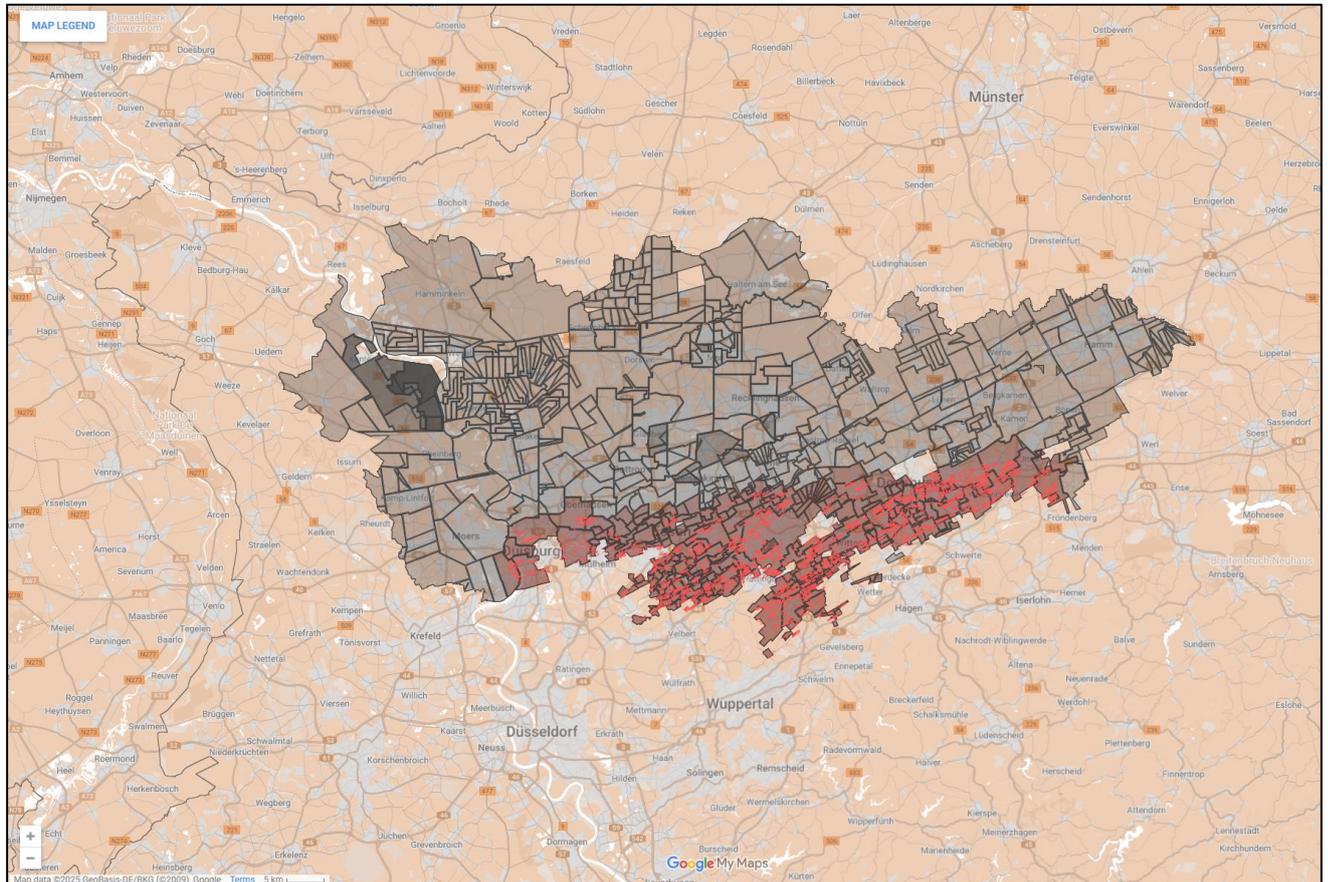


Figure 16 Final results of SIRIMA Integrated Map of Shallow Exploitation for region of Ruhr mining area - Germany. Integrated Map screenshot, source: <https://sirima.qiq.eu/integrated-map/>. In black – Mining Areas, in red – shallow exploitation zones (80 bgl).

Final Data:

- 981 Licensed Coal Mining Areas,
- 328 Mining Areas of Mines conducting shallow mining of coal,
- 1507 areas of shallow coal mining up to 80 m bgl.

3.3. Poland

Chronologically, mining activity in the area of the present-day Silesian Voivodeship in Poland began as early as in 12th century with the extraction of zinc-lead ores, among which larger concentrations of iron and silver were found locally. The beginnings of hard coal mining in the Polish part of the Upper Silesian Coal Basin date back to the 18th century. This

exploitation has not been documented in principle. On contemporary mining maps, areas of such activity are sometimes marked and described as opencast or bootleg mining.

Regardless of the timing of mining operations, the exploitation of individual raw materials began in areas of shallow deposits. Such areas were places of surface outcrops of ore mineralization zones and coal seams, or areas where they were covered only with thin Quaternary sediments of fluvial-glacial origin or by weathering products of roof-level stratigraphically older rocks (dolomites, limestones, sandstones, claystones, and shales). Such geological conditions for metal ores exist in the area between Tarnowskie Góry and Chrzanów, and for hard coal in the area between Zabrze and Trzebinia, and Dąbrowa Górnicza and Siersza. Shallow mining of metallic raw materials and hard coal using the pillar-and-room method was conducted in the present-day Silesian Voivodeship both historically and after World War II. There are known regions where longwall caving mining was conducted at shallow depths in the 1950s and 1960s. Similar situations exist in some ore mines operating under pillar-and-room mining systems today.

The so called shallow exploitation of hard coal, covering the depth range from 0 to 80 m below ground level within the Upper Silesian Coal Basin concentrates mainly near it's northern border. The areas of coal extraction from those depths runs from the city of Zabrze through Bytom, Ruda Śląska, Chorzów, Siemianowice Śląskie, Katowice, Czeladź, Sosnowiec, Mysłowice, Jaworzno to Trzebinia. Parallel to this zone but a little further north - at the very border of the USCB, shallow exploitation took place in the area of the cities of Grodziec, Łągisza, Będzin, Dąbrowa Górnicza i Kazimierz Górniczy. The main source for documenting the shallow exploitation of coal in Poland are the seam and workings maps.

In Task 2.1 GIG-PIB team have concentrated on archival coal seam maps from the coal mines with marked extracted parts of exploitation fields for different seams, on different depths but only to 80 m below ground level. Comparing exploited parts of the seams with the elevation of the terrain surface the documenting team indicated only those parts of the exploited seams which are not deeper than 80 m bgl.

Below more detailed description of the actions taken basing on the example of the "Grodziec" coal mine operating in Będzin is given.

The mine operating in the Będzin district called "Grodziec" was conducting mining of hard coal deposits between 1899 and 1998. Mine liquidation was performed in the years 1999-2011. Formerly old mines of "Barbara", "Maria" ("Grodziec I"), "Bory" were operating in this area in the years 1823–1917.

In the geological structure of the mining area Quaternary, Triassic and Carboniferous deposits are involved. The rock mass is characterized by quite complex tectonics. Carboniferous deposits generally fall towards SW. They are cut by four main faults with the stratigraphic throw of over 150 m:

- Wojkowicko-Będziński Fault extending NW- SE and dividing the Mining Area into the north and south regions. The amplitude of throw changes from about 30 m (NW part)

up to 200 m (SE part). Layers throw have SW direction. North of the fault the subsurface group of deposits consist of Quaternary and Carboniferous strata. In the south direction deposits of the Triassic or Quaternary and Triassic strata are present,

- Grodziecki Fault with the N-S strike drops layers towards W. Amplitude of throw is approximately 250 m,
- Przełajka Fault with N-S strike drops layers also towards W. Amplitude of throw is about 180 m,
- Antoni Fault with W-E strike is located in the northern part of the “Grodzic” Mining Area. Layers are thrown in the S direction. Amplitude of throw probably reaches 200-250 m.

Those four main faults were the cause for dividing the coal deposits in mining parts which correspond to natural tectonic blocks. Depth of coal deposits in individual batches depends on their location in relation to tectonic dislocations.

The main faults are accompanied by significant number of faults with smaller throws.

In the “Grodzic” Mining Area and north of it (previous mines) the following seams were exploited: 501, 504, 510, 615, 616, 620, 621,622, 805, 816, 833 at a depths from 0 to about 300 m. The thickness of the seams and coal exploitation varies from approx. 1.5 m to 9 m in seam 510.

Sinkhole threat exists on the surface in the areas where the coal was extracted in the depth ranging from 0 to 80 m. Such exploitation was carried out in seams 805, 816, 833 (Gruszowskie layers), 615, 616, 620, 621, 622 (Porebskie layers) and 501, 504, 510 (Siodłowe layers) in the area - north of the Będziński Fault. The threat is highest in the area of shallow exploitation of seam 510 due to the significant thickness of the coal seam taken.

In Figure 17 a schematic example showing the idea of digitizing areas of shallow exploitation conducted by “Grodzic” Coal Mine from seams no 501, 504, 510 is presented.

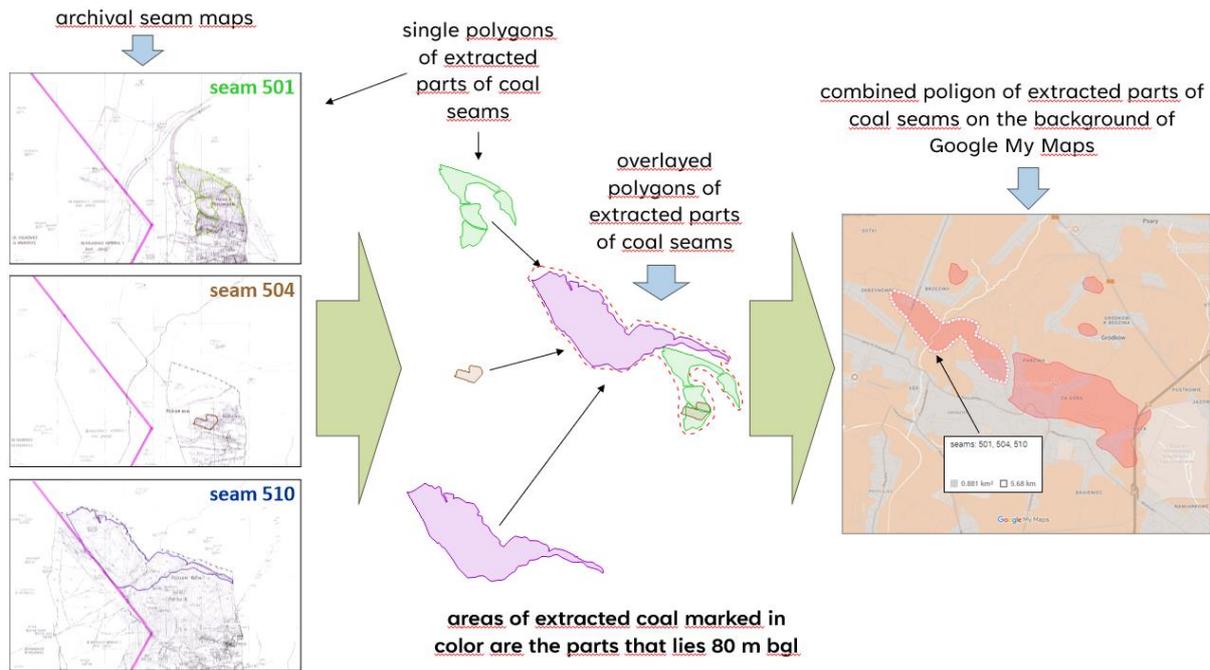


Figure 17 Steps taken to digitize the information on shallow mining operations in the seams of 500 group in "Grodzic" Mining Area.

On the left side of the Figure one can see archival maps of different coal seams (501, 504, 510) of "Grodzic" mine. The first step of digitization of shallow mining areas was the identification of the exploited parts of seams that lie in the depth interval 0-80 m. It was conducted by verification the exploitation depth with the terrain elevation from hypsometric map. The next step was contouring those parts of given seam, overlaying them and joining in one larger polygon (middle of the Figure). In the process of constructing the Integrated Map [...] the polygons obtained for different seams during the digitization of exploited parts were combined into one larger polygon in a given area. The summed up polygon superimposed on a contemporary situational map of the terrain surface, as it appears on SIRIMA Website is presented in the Figure 17 on the right.

The above example was one of many such polygons in the Upper Silesian Coal Basin region. The GIG-PIB team repeated the presented methodology several times for all shallow coal seams within the Mining Areas of all coal mines in the region. Finally on SIRIMA Web site in the Integrated Map [...] the summarised polygons (in red) along with the Mining Plant Areas (in black) are presented as shown in Figure 18. GIG-PIB team has documented in total: 51 Licensed Coal Mining Areas and 141 areas of shallow coal mining down to 80 m bgl in the manner described in this section.

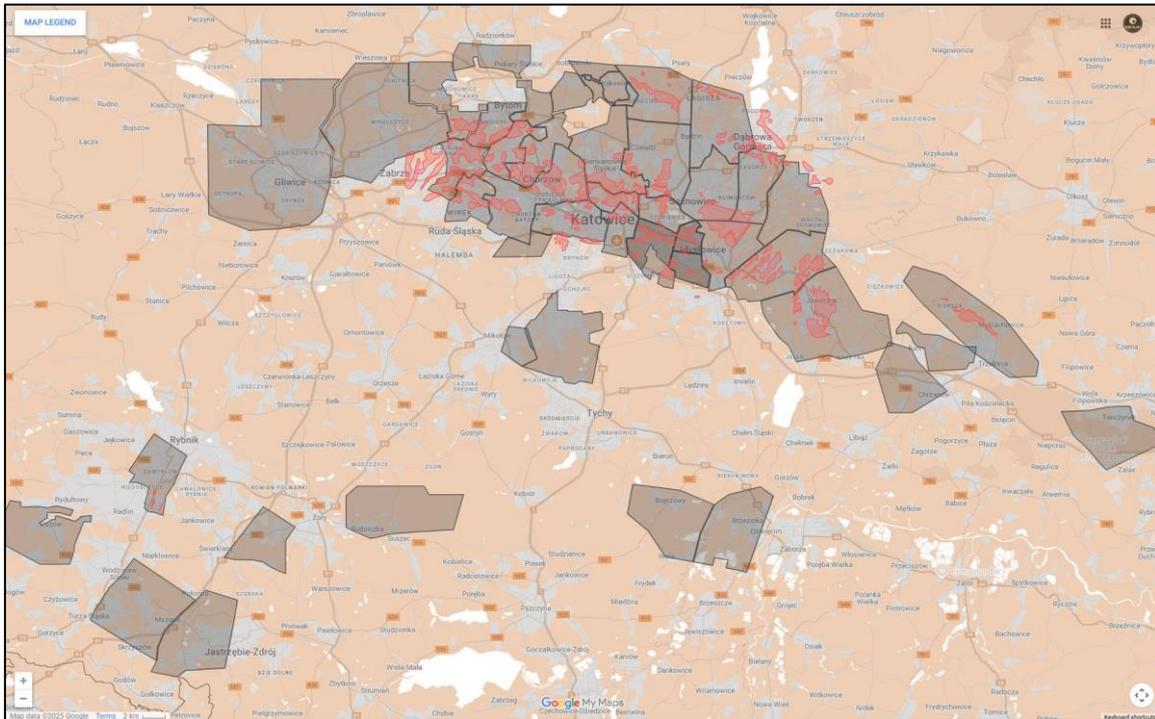


Figure 18 Final results of SIRIMA Integrated Map of Shallow Exploitation for region of USC B - Poland. Integrated Map screenshot, source: <https://sirima.gig.eu/integrated-map/>. In black – Mining Areas, in red – shallow exploitation zones (80 bgl).

Final Data:

- 51 Licensed Coal Mining Areas
- 141 areas of shallow coal mining up to 80 m bgl

3.4. Spain

In Spain, coal mining has followed a pattern determined by the depth at which coal seams are found and the economic viability of extraction methods. Coal mines located at depths between 0 and 150/200 meters below sea level are generally not exploited through underground mining but rather through open-pit methods. This is due to several technical and economic reasons.

The open-pit method is preferred for coal seams located at shallower depths because it is more economical and safer compared to underground mining. Open-pit extraction allows for the removal of large amounts of overburden to expose and extract the coal more efficiently. Additionally, this method reduces the risks associated with underground mining, such as collapses and ventilation problems.

When coal seams are found at depths greater than 150/200 meters, underground mining becomes the most viable option. At these depths, the amount of overburden that would need to be removed for open-pit mining would be too large, making the process economically unfeasible. Underground mining allows access to these deep seams without the need to remove large volumes of earth and rock.

The absence of coal mines exploited through underground mining at depths between 0 and 150/200 meters in Spain is due to the efficiency and economic viability of the open-pit method for these depths. Only when coal seams are found at greater depths is underground mining considered a practical option.

In Spain, a coal mine is considered shallow if it has a depth of less than 200 meters. In the Central Asturian Basin, the largest coal basin in Spain, the deepest shafts range from 700-900 meters (Maria Luisa Shaft , Sotón Shaft). In the Nalón Basin, depths reach 600-800 meters. In the Leonese Basin, shaft depths range from 300 to 700 meters. The coal basin in northern Palencia reaches 600 meters in depth.

Regarding the shallower coal basins in Spain, due to the arrangement of exploitable coal layers, we have Teruel coal basin where lignite is extracted between 160/180-400 meters.

The Guadiato Basin, with shaft depths operating from 50 to 500 meters, there are a large number of shafts with different depths. In general, underground mines in the Guadiato Basin have reached depths between 300 and 500 meters.

The Norte Shaft in Puertollano reaches a depth of 205 meters, and Santa María shaft reached 178 meters.

Mining in the Guadiato Basin region, in the province of Córdoba, has been historically significant. One of the notable geological formations in this area is the Azuaga Formation, located at a depth of approximately 300 meters. Confianza Shaft, located in Espiel, was situated in the northeastern area of the mining concession, at an elevation of 506 meters above sea level, and reached a depth of 51.36 meters. This shaft is an example of shallow mining operations in the region.

Espiel Shaft consisted of three levels, located at depths of 120, 185, and 250 meters, reflecting the complexity and depth of mining operations in this area. María Shaft, on the other hand, had levels at 120, 195, 270, and 345 meters deep, showing the capacity of mining infrastructures to reach coal seams at different depths.

In Belmez, several historical shafts, with century-old headframes, served coal operations with diameters of four meters and varying depths. In the region, there are several mining shafts of varying depths. Arcadio Shaft has a depth of 80 m, while Padre Murillo Shaft reaches 260 m. The Santa Isabel Shaft extends to 181 m, and the Aurora Shaft is 201 m deep. Franco Shaft has a depth of 179 m. The Belmez Shaft reaches 325 m, making it one of the deepest in the area. Lucas Mallada Shaft has a depth of 78 m, and Neptuno Shaft reaches 89 m. Finally, Terrible-No.4 Shaft located in the urban area of Peñarroya-Pueblonuevo to the south, has a depth of 100 m.

These shafts reflect the rich mining history of the region and the diversity of depths at which coal has been extracted in the Guadiato Basin. In the Valdeinfierno Basin, the Maestro Shaft stands out, reaching a depth of 160 meters. The San Francisco Shaft, with a level at 22 meters deep, was strategically connected to the 60th floor of the Maestro Shaft through an inclined chimney at 33 meters deep.

In the northern Teruel Basin, known for the towns of Ariño and Andorra, are the Innominada mine, which reached up to 500 meters, and La Oportuna mine up to 640 meters. The Pilar Shaft, in Escucha, reached 380 meters. In the Teruel basin, there are several mining shafts in different locations. In Andorra, San Juan Shaft extends to 386 m. In Utrillas, the Santa Bárbara Shaft has a depth of 160 m, with three loading levels at 60, 105 and 150 m.

Another of the shallower coal basins in Spain is the Mequinenza Basin, located in the Ebro Geological Depression. The lignite levels are situated in the Mequinenza Formation at 100-150 m deep and are subhorizontal. The erosion caused by the rivers in the basin has created a series of ravines from which coal can normally be accessed through horizontal galleries and without shafts, as both in dip and direction, the stratigraphy is practically horizontal with a slight inclination of barely 3% with specific areas of a maximum of 5%.

In León basin, there are several important mining shafts in different locations. In Palencia, Calero Shaft reaches a depth of 342 m. In Fabero, Julia Shaft goes down to a depth of 275 m. In Sabero, Herrera I Shaft has five floors of 30 m each, reaching a total depth of 160 m, while Herrera II Shaft, located in Sotillos de Sabero, goes down to 512 m. Finally, in Barruelo de Santullán, the Peragido Shaft reaches a depth of 600 m.

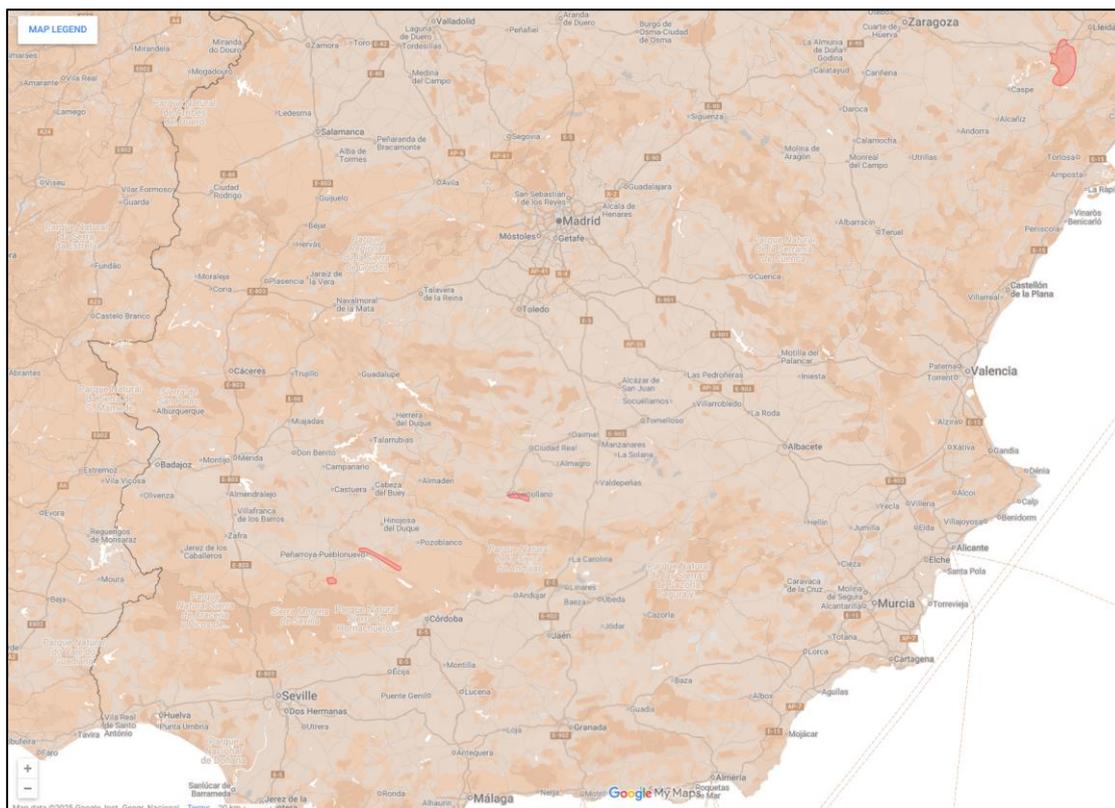


Figure 19 Final results of SIRIMA Integrated Map of Shallow Exploitation for region of Teruel Basin - Spain. Integrated Map screenshot, source: <https://sirima.giq.eu/integrated-map/>. In red – shallow exploitation zones (80 bgl).

Final Data:

- 5 areas of shallow coal mining up to 200 m bgl.

4. Creation of an integrated map

All Partners prepared and provided to the GIG-PIB team responsible for this task data on shallow mining (in SIRIMA *shallow* means mine workings down to 80 m below ground level) of hard coal deposits in the areas of abandoned mines in their countries, which they obtained basing on their own resources, archives functioning in their countries or other publicly available collections. The prepared data primary include the data files containing fields of exploitation with a description. Each field of exploitation includes one number, geodetic coordinates in the local geodetic system, coordinates converted to the universal WGS84 geographic coordinate system, as well as information on the name of the mine, the name or number of the coal deposit, its refinement (designation of the coal seam or other). This data were processed and adapted for presentation on a publicly available, free map based on the service My Maps provided by Google Maps.

The data for shallow coal mining areas were put together into an Integrated Map of Shallow Coal Mining in Partner's Countries which is now available publicly on the SIRIMA Website under the link: <https://sirima.gig.eu/integrated-map/>.



Figure 20 Web Integrated map of shallow coal mining in Europe – in general.

Both, shallow coal mining areas and abandoned Mining Areas, GIG-PIB team received from the partners in local coordinates as well as in the format of web map with WGS84 coordinates. Those last are formatted in closed areas named POLYGONS or MULTIPOLYGONS enclosed in ASCII text format files. POLYGON ((L₁ B₁, L₂ B₂, ..., L_n B_n)) is a function of L which is the latitude and B - the longitude, both given in geographical degrees. Below are examples (Figure 20) of text

files containing an area of shallow mining exploitation for the purposes of Task 2.1 both in local coordinates system (a) and in WGS84 (b).

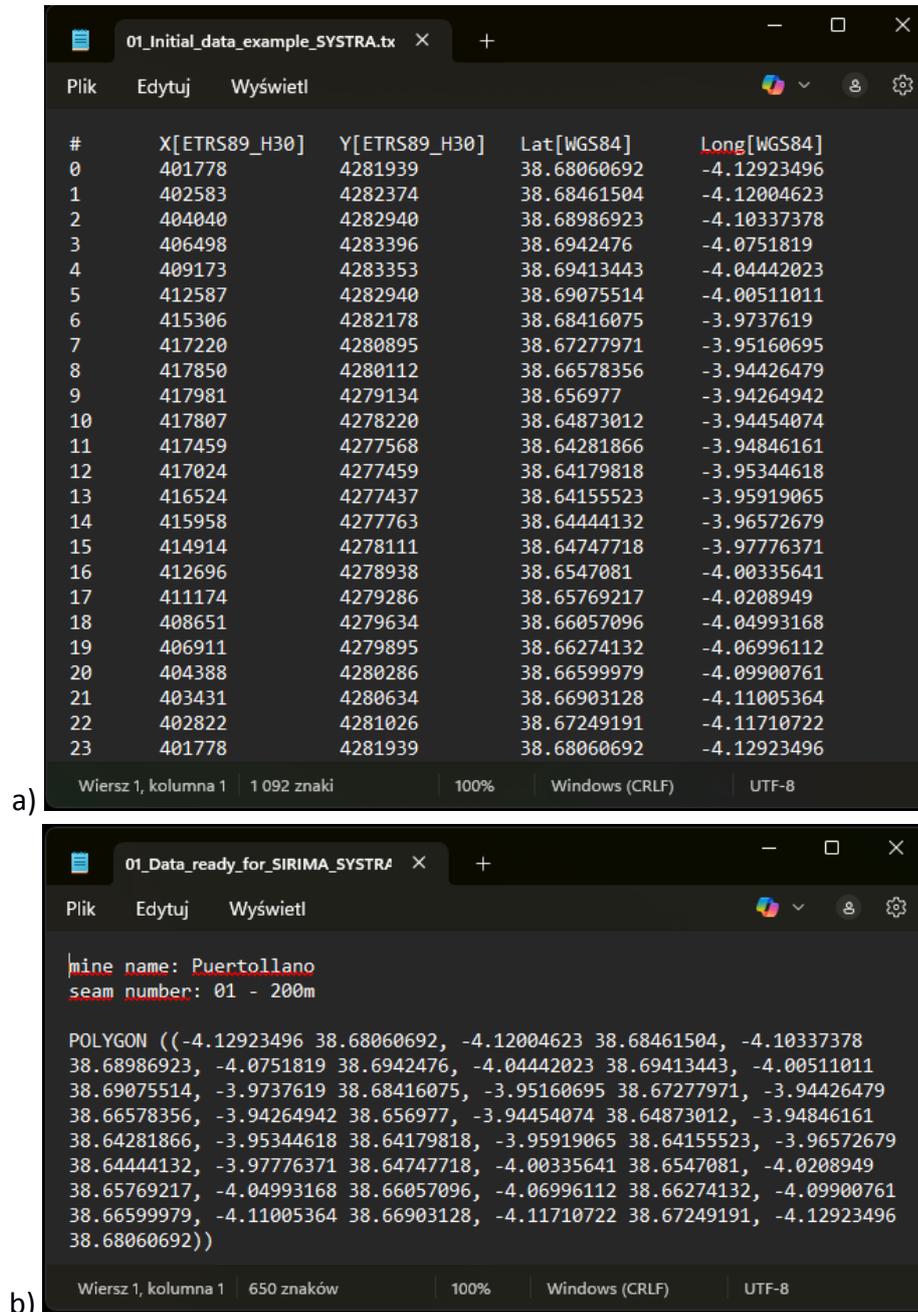


Figure 21 Example of an area of shallow mining exploitation for the purposes of task 2.1. a) – local coordinates system, b) – WGS84.

Having data on the coal Mining Areas of mines and areas of shallow coal exploitation carried out in the partner countries, GIG-PIB proceeded to create an Integrated Map of Shallow Coal Mining in Europe.

The Integrated Map of Shallow Coal Mining in Europe

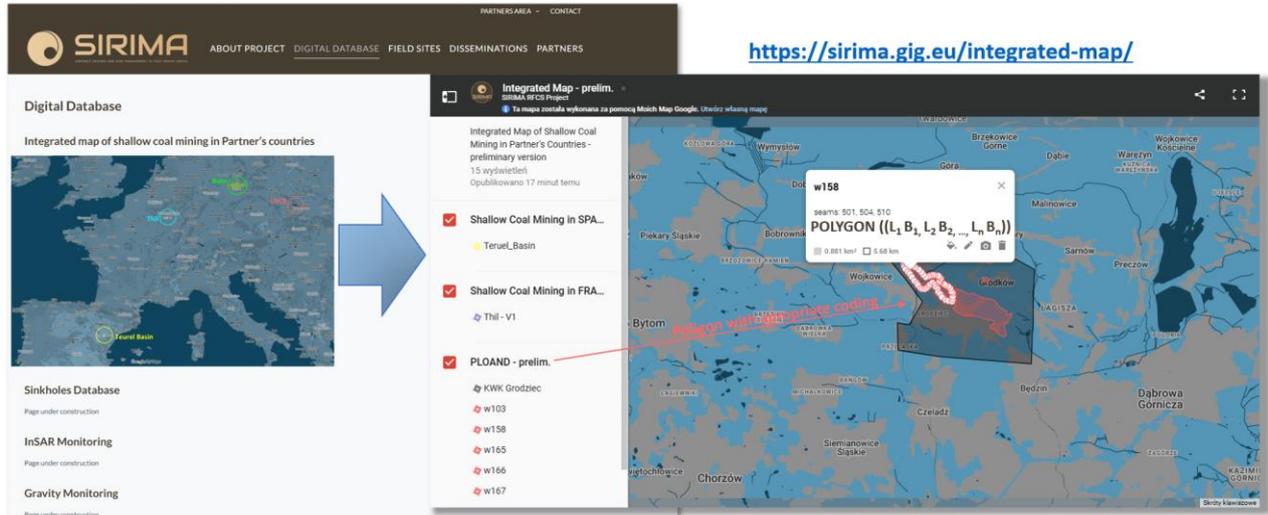


Figure 22 Web Database of shallow coal mining in Europe. On the right side - zoom for Poland.

Basing on the collected data sets, the website presenting the areas of shallow mining and the resulting sinkholes at the European Union level was created but as mentioned in Section 1 - the scope of information is limited to the countries from which the project partners come from.

The deliverable of the Task 2.1 - database that is presented in the form of a map with public access via the project website - is now available to various actors and users of the coal region and will remain accessible in the future.

The Integrated Map of Shallow Coal Mining in Partner's Countries consist of:

- shallow coal mining areas in the form of polygons (up to 80 m bgl),
- Mining Areas of abandoned mines in the partner's countries,
- situation map background based on Google Maps with the possibility to choose one of 9 types of basemaps: Map, Satellite, Terrain, Light Political, Mono City, Simple Atlas, Light Landmass, Dark Landmass, Whitewater. Currently the Dark Landmass/Whitewater are the default ones depending on what content is presented.

In Figure 23 the final view of Web Database of shallow coal mining in Europe is presented. 'Whitewater' base map styling with country names and borders is used as a base map for clarity. Because of the fact that presented content of Task 2.1 is incomparably smaller in size compared to the size of the continent; the content in Figure 23 is not fully legible. This figure is for illustrative purposes only, and details can be viewed on the task results page at the link: <https://sirima.gig.eu/integrated-map/>.



Figure 23 Web Database of shallow coal mining in Europe. 'Whitewater' base map styling with country names and borders. In black – Mining Areas, in red – shallow exploitation zones (80 bgl).

5. Conclusions

The information provided on SIRIMA Website within the Integrated Map may be used for the illustrative quantification and assessment of the threat of surface deformations.

1. Deliverable D2.1 presents the creation of a publicly accessible interactive map of shallow coal mining exploitation areas in abandoned mines across four European countries: France, Germany, Poland, and Spain. This map is hosted on the SIRIMA project website in the section DIGITAL DATABASE\ Integrated map of shallow coal mining in Partner's countries – Figure 23 (<https://sirima.gig.eu/integrated-map/>).
2. Integrated Map [...] aims to support risk management related to sinkholes and surface deformations.
3. The map serves as a tool for risk assessment and public awareness. It indicates areas susceptible to post-mining hazards associated with shallow mining operations, in particular sinkholes.
4. This project forms the basis of a European database on shallow coal mining areas.

Acknowledgments

The authors warmly thank GEODERIS, as associated partner, particularly Thierry DELAUNAY, Monique TERRIER and Pascal BIGARRE, for providing an extract from the BDSTM database, which lists the coal mining sites and mining titles (or claims) registered in France as part of Task 2.1, contributing to this deliverable, as part of Task 2.1.

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