Post-Mining Multi-Hazards evaluation for land-planning

PoMHaz

WP4: GIS development tools
D14 - Deliverable 4.3: GIS-based python toolbox for the implementation of the post-mining hazards

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Content

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Acronyms

API	Application Programming Interface
CLI	Command-Line Interfaces
CPU	Central Processing Unit CPU
CSS	Cascading Style Sheets
DSS	Decision Support System
GIS	Geographic Information System
GPU	Graphics Processing Unit
GUI	Graphical user Interface
HDD	Hard Disk Drives
KML	Keyhole Markup Language
MCDA	Multi-Criteria Decision Analysis
NAS	Network-Attached Storage
RDBMS	Relational Database Management System
RFCS	Research Fund for Coal and Steel
SAN	Storage Area Network
SDSS	Spatial Decision Support System
TUBAF	Technical University of Bergakademie Freiberg
UPS	Uninterruptible Power Supplies
VR	Virtual Reality
WFS	Web Feature Service
WMS	Web Map Service

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.

Deliverable 4.3, titled "GIS-based Python Toolbox for the Implementation of Post-mining Hazards," is a critical component of the POMHAZ project and is documented as a technical report related to Task 4.3 “GIS and DSS Development and Advanced data visualization”. Implementation in the context of this report means how to integrate post-mining hazards assessed during previous steps in the GIS-based toolbox.

This deliverable aims to create a sophisticated system that integrates a Decision Support System (DSS), a comprehensive database, and a knowledge base within a GIS environment. Its primary goal is to equip stakeholders with powerful tools to predict and assess various post-mining hazards. These hazards are of particular concern in regions affected by abandoned mines, where the interaction of multiple risk factors poses significant threats to both the environment and human safety.

The objectives of Deliverable 4.3 are multifaceted. First, it seeks to develop a Python-based GIS toolbox that automates complex GIS analyses, simplifying the often-arduous process of hazard implementation. This toolbox is designed not only to analyze individual hazards but also to account for the interactions between multiple hazards, making it a highly adaptable and comprehensive solution. The use of open-source tools such as QGIS, along with libraries like OpenLayers and Leaflet, enhances the toolbox's capabilities and accessibility. By incorporating the DSS into this system, the toolbox goes beyond simple data analysis; it provides decision-makers actionable insights, allowing them to take proactive measures in mitigating risks. The toolbox is further tailored with visualization tools that transform raw data into intuitive graphical representations, making it easier for non-technical users to understand the risks and take appropriate actions.

The significance of this deliverable within the POMHAZ project cannot be overstated. By addressing multi-hazard scenarios, it helps predict potential threats that are often interconnected, such as soil erosion, subsidence, water contamination, and methane emissions, which are common in post-mining areas. Deliverable 4.3 equips stakeholders, ranging from local governments to mining companies and environmental agencies, with the tools they need to make data-driven decisions. It bridges the gap between data collection and action, ensuring that stakeholders can efficiently assess hazards and implement timely solutions to protect both human health and the environment.

Key Outcomes: Integration of the DSS, Database, and Knowledge Base

One of the most important achievements of Deliverable 4.3 is the seamless integration of the DSS, database, and knowledge base into a single GIS-based platform. The DSS is essential for transforming raw data into meaningful insights, helping decision-makers evaluate different hazard-risk scenarios and predict the outcomes of various risk mitigation strategies. The

integration of the DSS into the GIS toolbox means that users are not just analyzing data in isolation; they are evaluating how multiple hazards interact and impact each other, leading to more comprehensive risk assessments.

The database plays a crucial role by providing a central repository for all the information needed for hazard assessment. This database includes environmental data, historical mining records, satellite imagery, sensor inputs, and real-time monitoring data. The ability to standardize, validate, and integrate diverse datasets ensures that the hazard assessments are both accurate and reliable. Furthermore, the database's integration with the DSS allows for real-time decision-making, enabling stakeholders to react promptly to evolving risks.

The knowledge base is another key component that ensures the system is informed by best practices and scientific research. It provides context and depth to the hazard analysis, ensuring that the system is not merely processing data, but is doing so based on established methodologies and expert knowledge. This integration of knowledge into the GIS toolbox ensures that the decisions made using the DSS are well-founded and scientifically robust.

Benefits to Stakeholders in Hazard Implementation and Decision-making

Deliverable 4.3 provides numerous benefits to stakeholders, particularly in the area of hazard implementation and decision-making. The GIS toolbox, now equipped with a fully functional DSS**,** allows stakeholders to predict post-mining hazards with a high degree of accuracy. The system can handle complex multi-hazard scenarios, providing users with the ability to assess how different hazards, such as subsidence, flooding, and gas emissions, might interact and exacerbate each other. This multi-dimensional approach gives decision-makers a clearer picture of the risks they are dealing with and allows them to craft more effective mitigation strategies.

In terms of decision-making, the integration of the DSS enables stakeholders to make more informed and proactive decisions. For example, mining companies can use the system to monitor abandoned mine sites in real time, identifying potential occurrence of hazards before they become critical issues. Local governments and environmental agencies can use the GIS toolbox to assess the environmental impact of these hazards, enabling them to allocate resources more effectively for disaster preparedness and response. The toolbox's visualization capabilities, built using open-source libraries like OpenLayers and Leaflet, also make it an excellent communication tool. Stakeholders can generate easy-to-understand visual representations of complex data, helping non-experts understand the risks and support decision-making processes at all levels.

Furthermore, the flexibility of the Python-based GIS toolbox allows for easy adaptation and customization. Stakeholders can tailor the system to their specific needs, adding or modifying hazard assessment tools as required. This flexibility ensures that the system remains useful and relevant as new hazards emerge or as new data becomes available. The system's modular design, leveraging open-source technologies, also makes it easy to maintain and update, ensuring that it remains a valuable tool for years to come.

In conclusion, Deliverable 4.3 has successfully developed a GIS-based Python toolbox that integrates a DSS, database, and knowledge base to provide a powerful tool for multi-hazard assessment and decision-making**.** The significance of this deliverable lies in its ability to empower stakeholders with the data, tools, and insights they need to effectively manage post-mining hazards, ensuring the safety of communities and the protection of the environment. With this system in place, the POMHAZ project takes a major step forward in addressing the challenges posed by post-mining environments and ensuring a safer, more sustainable future for affected regions.

1. Introduction

The assessment and management of hazards in post-mining areas are critical for ensuring the safety of communities and the protection of the environment. Abandoned mines pose a complex array of risks, including soil erosion, subsidence, water contamination, and the release of harmful gases, such as methane. The WP2 discussed the assessment of the post-mining hazards and the methods and tool to assess their potential interactions. These hazards can have far-reaching implications for both human health and ecological systems, necessitating robust methodologies for their assessment and mitigation. As the world increasingly shifts towards sustainable practices, it becomes imperative to develop tools that enable stakeholders to predict and manage these hazards effectively. Understanding these dynamics is essential for preventing catastrophic events and ensuring sustainable land use in regions affected by mining activities.

In the POMHAZ project, the present deliverable is part of the WP4 that is dedicated to the development of a Post-Mining Risk Information System. This WP supports planning and decision-making and provides information to a broad range of stakeholders. Deliverable 4.3 is linked to other deliverables such as Deliverable 3.3 which has layed the groundwork by developing a Decision Support System (DSS) and documenting its application for hazard assessment. Deliverable 3.3 focuses on the conceptualization and implementation of a tool that integrates data analysis and visualization to guide stakeholders in making informed decisions about post-mining hazards. Building on this, Deliverable 4.2 has expanded the system by implementing the necessary interfaces, database structures, and a DSS toolbox. It ensures seamless data integration and user-friendly access to spatial and hazard data through web-based and desktop interfaces, forming the backbone for hazard analysis.

Complementing these, the present Deliverable 4.3 develops a GIS-based Python toolbox tailored for predicting post-mining hazards, using the systems and data established in D4.2 and methodologies outlined in D3.3. This toolbox focuses on advanced analysis and modelling capabilities, integrating seamlessly with the DSS to enhance predictive functionalities. In other words, the three deliverables are deeply interconnected: D3.3 defines the decision-making framework, D4.2 implements the foundational systems to operationalize the DSS, and D4.3 extends these capabilities to include sophisticated hazard prediction tools. Together, they form a cohesive ecosystem for assessing and managing post-mining risks.

Deliverable 4.3 of the POMHAZ project, titled "GIS-based Python Toolbox for the Implementation of Post-mining Hazards," aims to address these challenges by integrating a sophisticated Decision Support System (DSS), a comprehensive database, and a knowledge base within a unified GIS environment. The primary objective of this deliverable is to empower stakeholders—including local governments, mining companies, and environmental agencies—with advanced tools for hazard assessment, thereby enhancing their decision-making capabilities in the face of multifaceted risks associated with post-mining landscapes.

To achieve these objectives, Deliverable 4.3 focuses on the development of a Python-based GIS toolbox that automates complex GIS analyses and provides a series of decision-making tools tailored for assessing various types of post-mining hazards. This toolbox (Figure 1) will incorporate advanced algorithms and models to evaluate not only individual hazards but also the interactions among multiple hazards, making it particularly suitable for conducting multi-hazard assessments. The integration of spatial analysis capabilities with hazard modelling techniques allows stakeholders to visualize potential risks and assess their cumulative impacts effectively. The open-source nature of the toolbox facilitates accessibility and collaboration, enabling users to customize and extend the functionalities as needed.

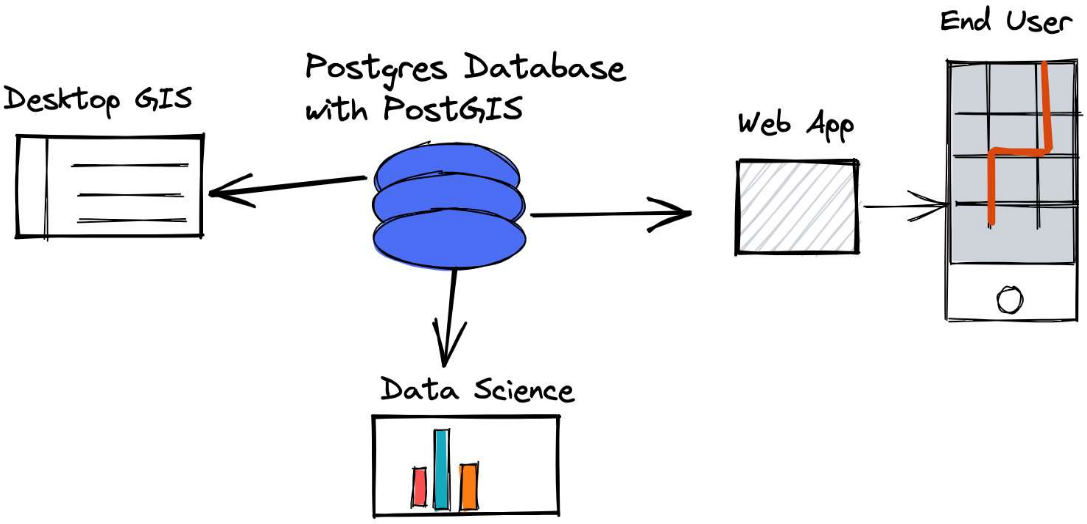

Figure 1. Toolbox structure and design

The Technical University of Bergakademie Freiberg (TUBAF) plays a pivotal role in leading Deliverable 4.3, bringing together a team of experts in geoinformatics, environmental science, and data analysis to drive its development.

Working closely with all partners, TUBAF aims to ensure that the toolbox is comprehensive, effective, and user-friendly. Each partner brings unique expertise: CERTH provides advanced methodologies for data integration and analysis, while DMT-THGA offers practical insights into decision support frameworks for hazard management, and Ineris makes available crucial guidance on environmental risk assessments and regulatory frameworks.

Together, these partners are dedicated to conducting thorough research and implementing the tasks outlined in Work Package 4 (WP 4). This collaborative approach not only enhances the technical robustness of Deliverable 4.3 but also ensures that it meets the diverse needs of stakeholders involved in post-mining hazard assessment and management. By combining their resources and knowledge, the partners are committed to creating a powerful resource that not only addresses immediate hazard assessment needs but also fosters sustainable practices in post-mining management for years to come.

In summary, Deliverable 4.3 represents a significant step forward in the POMHAZ project, providing an innovative, Python-based GIS toolbox (Figure 1) that integrates a DSS, database, and knowledge base for effective multi-hazard assessment and decision-making. The commitment to open-source development, combined with the collaborative efforts of TUBAF, CERTH, DMT-THGA, and Ineris, ensures that this deliverable will serve as a vital tool for stakeholders in navigating the complexities of hazard assessment and management in post-mining landscapes.

2. Hazards Assessment and Implementation

This section outlines the development of the hazard component within the GIS-based Python toolbox. The aim is to integrate various methodologies, data sources, and computational techniques to accurately predict and integrate hazards associated with post-mining areas into the DSS. The following subsections provide a detailed description of the framework, methods, and GIS features used to implement the hazard assessment system.

2.1 Framework Overview

In the context of the POMHAZ project, the assessment and management of hazards in post-mining areas encompass three main categories: natural, post-mining, and technological hazards. These hazards stem from post-mining environmental changes, including altered water conditions, ground movement, fires, explosions, and the release of gases after mining operations cease. Post-mining areas with complex infrastructure, such as old mining sites, are particularly vulnerable to concurrent hazards, often referred to as 'multi-hazard' phenomena. Analyzing these multi-hazard scenarios presents unique challenges, as the diverse range of hazards requires more comprehensive assessments compared to single-hazard evaluations.

Due to the interactivity between natural, post-mining, and technological hazards, multi-hazard analysis is limited in post-mining contexts, with research focusing primarily on the interaction between natural and technological hazards (NaTech) (Gill and Malamud, 2014). Deliverable 4.3 addresses these complexities through the development of a GIS-based Python toolbox tailored for hazard assessment in post-mining regions. This toolbox integrates data sources across hazard categories to streamline multi-hazard analysis, providing stakeholders enhanced visualization and analytical capabilities to identify, assess, and mitigate risks in post-mining landscapes. The POMHAZ toolbox framework aims to establish a robust platform for comprehensive hazard assessment, aligning with the project's goal of informed decision-making and proactive risk management.

2.2 Multi Hazards Methods Development

Multi-hazard scenarios involve the sequential occurrence of different hazards, posing significant assessment challenges in post-mining areas due to the complex interactions among these hazards.

Three categories of methodologies are commonly employed to assess hazard interactions and calculate the Multi-hazard Index: qualitative, semi-quantitative, and quantitative.

The project partners determined that using semi-quantitative methods was the only feasible approach for the project's multi-hazard and multi-risk methodology. This decision was influenced by several factors. First, the limited data and available methods for modelling interactions between different hazards make semi-quantitative methods preferable to quantitative ones. Additionally, semi-quantitative approaches demand fewer data sources, streamlining data collection and advancing project efforts. Lastly, these methods are more user-friendly, easier to communicate, and simpler to understand, enabling comprehensive inclusion of hazard interconnections within guidelines.

The Integrated Methods section is pivotal to the overall goal of the POMHAZ project, which aims to develop a comprehensive hazard system for post-mining areas. This system will integrate multiple methodologies, leveraging diverse datasets and computational tools to deliver reliable forecasts of hazards.

The primary outcome of our conducted research is to compute and rank the selected multi-hazard scenarios according to their Multi-hazard Index (MHI), which measures their intensity. In subsequent works of WP3, the MHI of each scenario will be related to the area's vulnerability and the exposed elements at risk such as buildings, infrastructures, etc. This correlation facilitates the quantification of associated risks for each scenario, enabling a proper ranking to identify the most catastrophic scenarios within the study area.

The multi-hazard risk assessment detailed in this section follows seven key methodological steps. Each step has been thoroughly examined, discussed, and presented to project partners. Some steps are already complete, while others are still underway, pending the completion of Deliverable D3.1 (Methodological Guidelines for Risk Management). Figure 2 presents the structure of the main steps, which are elaborated in the following sections.

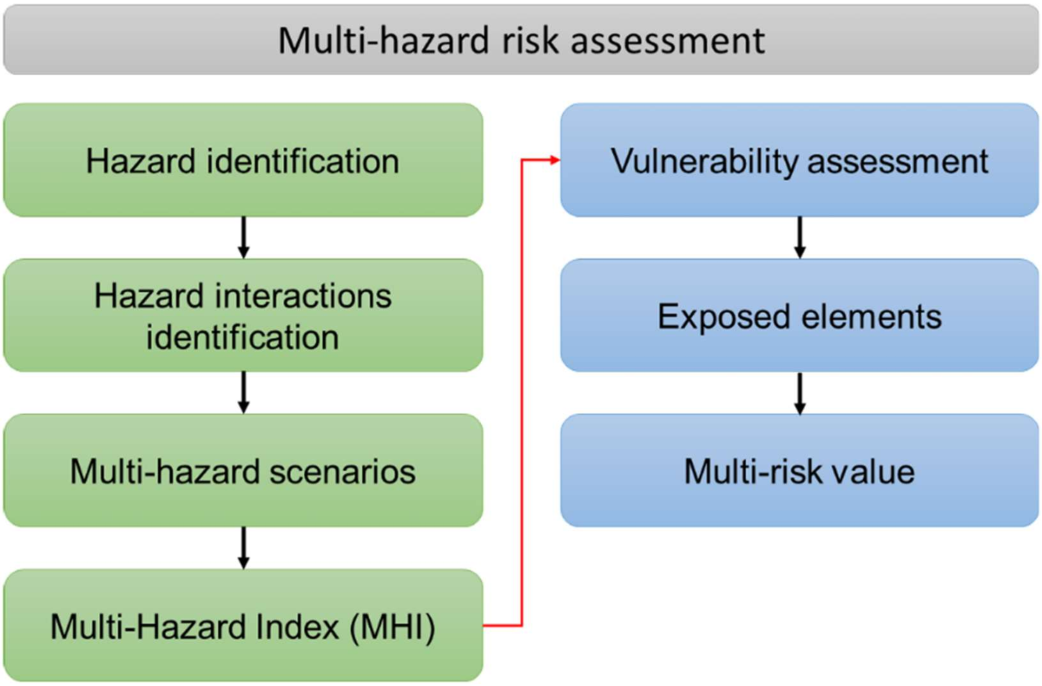

Figure 2. Methodological framework of the multi-hazard risk assessment, green boxes represent the hazard analysis and blue boxes represent the risk assessment (source: D2.3)

Figure 2 presents the methodological framework to assess the multi-hazard risks for the POMHAZ project. This methodology is mainly based on using interaction matrices developed in Task 2.3.

2.3 Implementation of specific hazards

The project develops multi-hazard scenarios using interaction matrices generated in Task 2.3. These structured scenarios provide a basis for assessing multi-risk levels in post-mining areas. By calculating the Multi-Hazard Index (MHI), the intensity of each scenario can be quantified, allowing for ranking according to potential impact. In subsequent stages, each scenario's MHI will be correlated with vulnerability factors and the exposed elements within the study area to identify the most severe scenarios. This analysis will support decision-makers in implementing effective risk reduction and management strategies in post-mining regions.

For the POMHAZ project, a semi-quantitative approach for Multi-hazard analysis has been selected by the partners due to its flexibility and compatibility with limited data, especially in post-mining areas. Semi-quantitative methods balance computational analysis with expert judgment, requiring fewer data sources than quantitative methods and allowing for more accessible communication among stakeholders.

In the context of Deliverable 4.3 in the POMHAZ project, the database was meticulously designed and integrated within the GIS-based python toolbox to facilitate the application and visualization of hazard-specific data layers for post-mining risk assessment. This integration enables the database to support real-time decision-making processes within the DSS framework by allowing seamless access to essential data directly within the GIS environment.

To enhance the functionality and precision of the GIS-toolbox, additional shapefile (SHP) layers were created, capturing a range of hazard-related spatial data, such as subsidence zones, contaminated water bodies, erosion-prone areas, and methane leakage sites. Each SHP file was structured to align with national standards and incorporates attributes crucial for hazard classification, including intensity levels, spatial extent, historical data, and vulnerability indices.

During the database's implementation, feedback was collected from partners, who highlighted specific national standards and data requirements. This feedback led to further refinements, ensuring that the database and its SHP layers were adaptable to regional needs while maintaining data consistency. The database was subsequently validated for integration into the GIS-toolbox, with each SHP file formatted for optimal compatibility, supporting efficient mapping, querying, and analysis.

Furthermore, a PDF technical report was created to accompany the Excel knowledge database, providing in-depth documentation on data sources, processing methods, and usage guidelines for each SHP file and database component. Both the Excel database (Figure 3) and the supplementary report can be accessed on the project website, ensuring transparency and accessibility for project partners and stakeholders:

- https://www.pomhaz-rfcs.eu/sites/default/files/medias/D6-WP2-D2.1-CERTH_final_annex.xlsx

- https://www.pomhaz-rfcs.eu/sites/default/files/medias/D6-WP2-D2.1-CERTH_v2.pdf

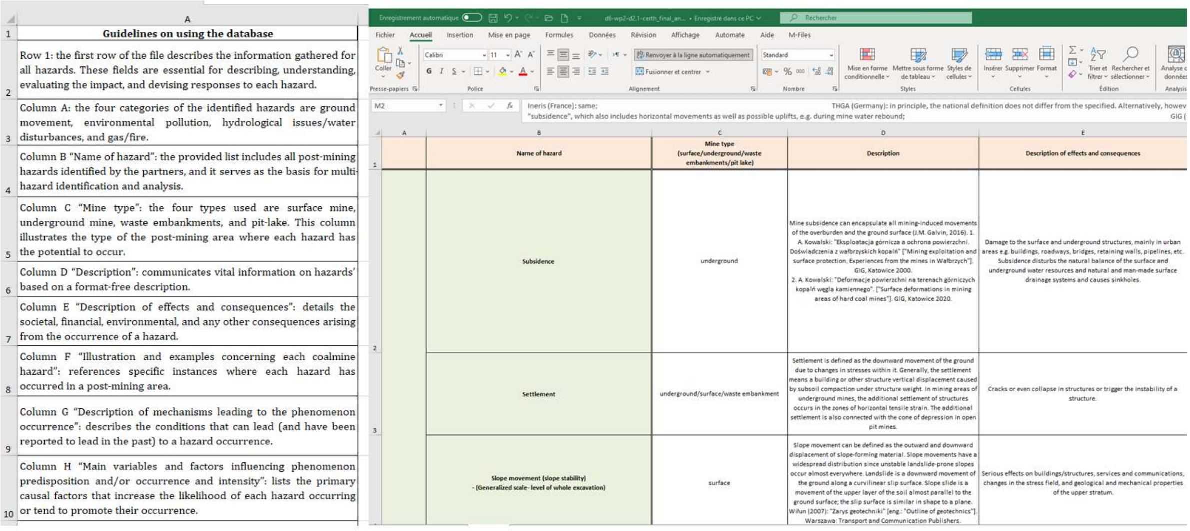

Figure 3. Presentation of the database of the post-mining hazards, Task 2.1, Deliverable D2.1

As described in the next chapter, the aforementioned database was integrated into the DSS, utilizing inputs from previous work packages and tasks, including hazard polygons for various regions created by relevant experts (T5.1) as well as the system's designated outputs (such as risk maps and decision-support variables). Building on these components, a complex workflow was developed, incorporating semi-quantitative algorithms to calculate Multi-risk, based on the factors "Multi-hazard" and "vulnerability".

3. GIS Development and Knowledge base integration

3.1 GIS development

For Deliverable 4.3, GIS-based Python Toolbox development and integrations within the POMHAZ project, are essential to ensure that the toolbox meets the project's objectives of accuracy, scalability, and usability. The GIS-based Python toolbox is designed not only to enable precise assessments of post-mining hazards but also to integrate smoothly with the broader GIS ecosystem and the Decision Support System (DSS) that POMHAZ aims to establish.

The toolbox should support a multi-functional DSS framework capable of addressing the full spectrum of needs for effective risk management in post-mining regions. Within the DSS, this GIS-based toolbox will allow:

1. Data Integration: The toolbox must facilitate seamless integration of diverse data sources, including spatial data, historical mining records, environmental variables, and live sensor data from ground-based and satellite sources. The use of standardized formats and consistent data management processes within the GIS environment will ensure that data from different sources can be harmonized, stored, and retrieved with ease.
2. Risk and Multi-Hazard Assessment: One of the primary functions of the GIS toolbox is to conduct complex risk and multi-hazard assessments. Leveraging the input from previous work packages, including hazard polygons, vulnerability data, and exposure metrics, the toolbox should employ semi-quantitative algorithms to evaluate risks based on the intersection of multi-hazard data and regional vulnerability. This will involve calculating Multi-risk indices to aid in prioritizing and managing the hazards most likely to impact the study area.
3. Reporting Capabilities: To support informed decision-making, the toolbox should generate detailed, customizable reports. This includes visualizations such as risk maps, trend analyses, and statistical summaries, which will be instrumental in presenting the findings of hazard assessments clearly and comprehensively to stakeholders.
4. User Interface and Decision Tools: The toolbox will include an intuitive user interface that allows stakeholders to access, analyze, and interpret hazard data within the DSS. This interface should offer interactive mapping features, query tools, and visualization options, enabling users to explore different hazard scenarios. Additionally, decision-support tools will provide recommendations based on user-defined criteria and thresholds, helping stakeholders to identify areas of critical concern and guiding their risk mitigation efforts.

The GIS-based Python toolbox, therefore, is designed to be a core component of the POMHAZ DSS, (Figure 4) providing a flexible and user-centred environment that enables data-driven decision-making. By supporting data integration, risk assessment, hazard reporting, and decision support, the Decision Support System aims to strengthen the capabilities of stakeholders in managing post-mining risks effectively and sustainably.

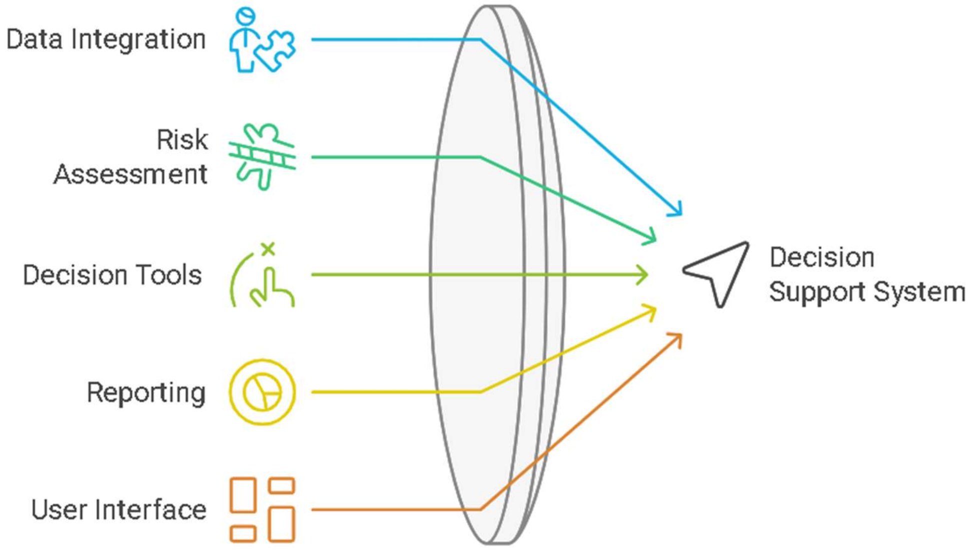

Figure 4. Features for Decision Support System

The GIS-based Python Toolbox for the POMHAZ project integrates a comprehensive suite of features and functionalities within the Decision Support System (DSS), detailed in Figure 5. This figure illustrates the core functionalities and specifications that enhance the toolbox's capabilities in managing and assessing post-mining hazards. Key functionalities include:

- **Data Integration and Management**: The GIS toolbox efficiently integrates and manages a wide array of datasets, including topographical, geological, hydrological, socioeconomic, and remote sensing data, such as Land Use/Land Cover (LULC) and digital elevation models derived from satellite imagery. It provides robust handling, standardization, and reclassification of diverse vector and raster formats to ensure data compatibility and ease of analysis.
- **Risk Assessment and Analysis**: Designed to support comprehensive risk assessments, the toolbox employs multi-criteria analysis methods, such as the Analytical Hierarchy Process (AHP), to evaluate risks associated with post-mining, natural, and technical hazards. It also allows for the modelling and simulation of multiple hazard scenarios, assessing their potential impacts to aid in proactive risk management.
- **Decision Support Tools**: The DSS includes powerful decision-making tools, such as scenario analysis, decision trees, and cost-benefit analysis modules, helping stakeholders to explore and evaluate different management options. Advanced visualization tools allow complex data to be represented in formats accessible to technical and non-technical audiences alike.
- **Reporting and Documentation**: The toolbox automates report generation, including analysis results, decision records, and methodological descriptions, which ensures transparency and thorough documentation. These reporting features support decision-makers by providing detailed insights and traceable records for each analysis.
- **User Interface and Accessibility**: With an intuitive and user-friendly interface, the GIS toolbox is accessible to stakeholders with varied technical backgrounds. This interface simplifies access to the DSS's capabilities and enables users to interact seamlessly with complex hazard data and assessment results.

- **Customization and Scalability**: The toolbox is designed for customization to meet the specific needs of project partners and regions, allowing users to adapt the DSS to different geographical scales, from site-specific to broader regional analyses. Its scalable design ensures it can accommodate various levels of data granularity.
- **Interoperability and Compatibility**: To ensure smooth integration into existing workflows, the toolbox is compatible with widely-used GIS platforms and data formats. This interoperability fosters collaboration and data sharing among project partners, facilitating consistent data use across platforms.
- **Reliability and Accuracy**: The GIS toolbox offers high reliability and precision in data processing and analysis, supported by robust error-checking and validation mechanisms. This ensures that all analytical outputs are credible and trustworthy.
- **Security and Data Privacy**: Strong security protocols protect sensitive information within the DSS, including role-based access controls and adherence to data privacy regulations, particularly when dealing with sensitive urban and property-related data.
- **Local and Regional Specificities**: The DSS incorporates unique local and regional factors in risk assessments, acknowledging each area’s distinctive characteristics and mining history. This ensures that assessments are contextually relevant and sensitive to the specific needs of each region.

Together, these features position the GIS-based Python toolbox as a versatile and powerful tool for integrating hazard data, conducting multi-hazard assessments, and supporting informed decision-making within the POMHAZ project. Figure 5 provides a visual overview of these capabilities, highlighting how each element aligns with the project’s overarching goals.

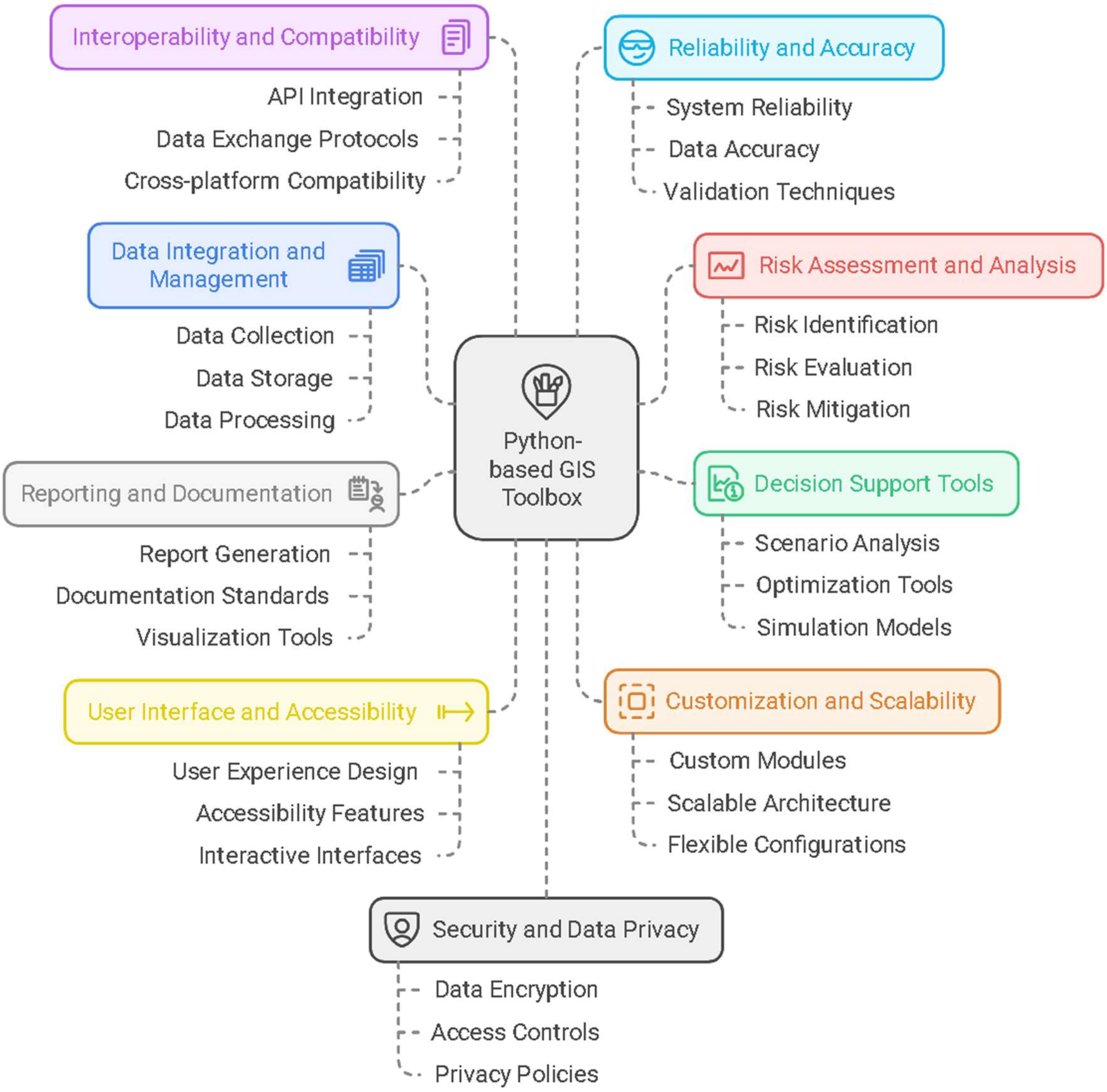

Figure 5. Functionalities and specification of the Python GIS-toolbox

3.2 Knowledge Base Integration

The knowledge base (Figure 3) is a central component of the POMHAZ GIS Toolbox, offering a shared resource for documenting post-mining hazard occurrences across various coal mining communities. As illustrated in Figure 5 this GIS Toolbox encompasses features and specifications that integrate the knowledge base seamlessly, enhancing data-driven hazard management.

Content of the Knowledge Database: The database provides extensive information on surface mines, underground mines, waste embankments, and pit lakes. Designed for open access, it is shared across coal mining communities and stakeholders in France, Greece, Germany, and Poland. Key data elements include:

- **Hazard Identification**: Lists each known hazard, along with a detailed description of its effects and consequences. This section also contains illustrations and examples, ensuring comprehensive understanding of each hazard type within the GIS Toolbox.

- **Mechanism Analysis**: Describes the physical and chemical mechanisms behind each phenomenon, covering variables that influence hazard intensity, probability, occurrence, velocity, and monitoring requirements.
- **Categorization and Grouping**: In response to feedback from Ineris, hazards were categorized into four main families for clarity: (1) Ground movement, (2) Environmental pollution, (3) Hydrological issues, and (4) Gas/fire hazards. Each hazard is further categorized based on the type of mine (surface, underground, pit lake, or waste embankment) to facilitate targeted hazard management and monitoring strategies.

Development Process and Database Structure: In December 2022, partners collectively discussed the structure of the knowledge database. To ensure accessibility and ease of use, a Microsoft Excel spreadsheet was chosen as the final format (Figure 3). This structure aligns with the project's goals of creating a universally accessible tool that facilitates integration into the GIS Toolbox. A technical report embedded as a supplementary sheet within the Excel file provides guidelines on using and interpreting the data, enhancing usability and transparency for project partners and stakeholders (see 3.3).

Integration with the GIS Toolbox: Within the GIS Toolbox, the knowledge database serves as a foundational layer for hazard data visualization, modelling, and analysis. The structured hazard data supports the toolbox's advanced functionalities, including:

- **Data Integration and Management**: Allows seamless integration of hazard data with other GIS layers, enabling comprehensive analyses that account for topographical, geological, hydrological, and remote sensing data. Data homogenization and reclassification processes standardize the data for use in multi-criteria risk assessment.
- **Risk Assessment and Analysis**: The database enables sophisticated multi-criteria risk assessments, drawing on various factors that influence hazard occurrence, intensity, and impacts. The database content directly supports the creation of multi-risk models, quantifying hazards by combining data on exposure, vulnerability, and potential consequences.
- **User-Friendly Decision Support**: The database's structured and accessible design supports decision-making processes through the DSS, with features like automated reporting, visualized data outputs, and scenario analysis tools tailored to inform stakeholders of risk levels and mitigation options in post-mining areas.

Through continuous feedback and collaborative revisions, the knowledge database now provides a comprehensive resource that addresses the specific post-mining hazards across participating regions. By integrating this rich repository of hazard information with the GIS Toolbox, POMHAZ equips stakeholders with the data and tools needed for informed, proactive risk management and hazard mitigation.

4. Structure of the Python-based GIS Toolbox with DSS

The implementation of a Python-based GIS toolbox, integrated with a Decision Support System (DSS), involves a systematic approach utilizing PostgreSQL and its PostGIS extension within QGIS. This process is structured into several key steps:

Setting Up PostgreSQL with PostGIS: The first step involves installing PostgreSQL and the PostGIS extension, which is crucial for supporting geographic objects. Once installed, a new database is created specifically for GIS data. The PostGIS extension is activated within this database by executing the SQL command CREATE EXTENSION postgis. This setup establishes a spatial database framework for the subsequent integration of GIS data.

Importing Spatial Data into PostgreSQL: After configuring the database, the next phase entails connecting QGIS to PostgreSQL. This is accomplished by utilizing the "DB Manager" plugin, where users can establish a new connection by entering their PostgreSQL credentials. With the connection established, spatial data such as shapefiles and GeoJSON can be imported into the PostgreSQL database. The "Import Layer" function in the DB Manager facilitates the uploading of these data layers as new tables within the database.

Styling and Preparing Data in QGIS: Once the spatial data is imported, it can be styled and prepared for visualization. In QGIS, users can apply various styling options, including colour gradients, labels, and other symbology to enhance the visual representation of the data. After styling, it is essential to save the QGIS project to retain the layer configurations and styles, which can be further exported for web mapping.

Exporting to Web Map using QGIS2Web: The next step is to utilize the QGIS2Web plugin, which must be installed via the QGIS Plugin Manager. This tool enables the export of the QGIS project as a web map. Users can configure export settings, selecting Leaflet as the web mapping library, choosing specific layers for export, and customizing interactivity options such as pop-ups and styling. By executing the export command, an HTML, JavaScript, and CSS file structure is generated, facilitating the creation of a Leaflet-based web application.

Integrating with Leaflet: Finally, the exported files from QGIS2Web are deployed in a web server environment. Leaflet then renders the map using the provided GeoJSON or TopoJSON data. Further customization of the JavaScript code is possible, allowing adjustments to map behaviour and the inclusion of additional controls and pop-ups, ultimately enhancing the user experience and functionality of the web-based GIS toolbox.

The Decision Support System (DSS) has multiple points of contact and active interfaces with other parts of the project, making it a central component. Data for the decision-making process is sourced from various channels, including the graphical user interface (GUI, e.g. weights for the MHI calculation), GIS (e.g. hazard maps), knowledge database (e.g. information on hazards or process documentation), model database (e.g. models for calculating risk classes), and open data sources (e.g. elevation models, if not otherwise available). There will also be interfaces in the opposite direction. The DSS output will be presented to the user through the GUI in different formats such as maps, reports, and diagrams. Additionally, the analysis results will be written back to the corresponding databases, enabling an iterative process with modified parameters.

In summary, this structured approach described in Figure 6 not only establishes a robust database system for GIS data management but also facilitates the creation of interactive web maps, empowering users to effectively analyse and visualize spatial information within the context of a Decision Support System.

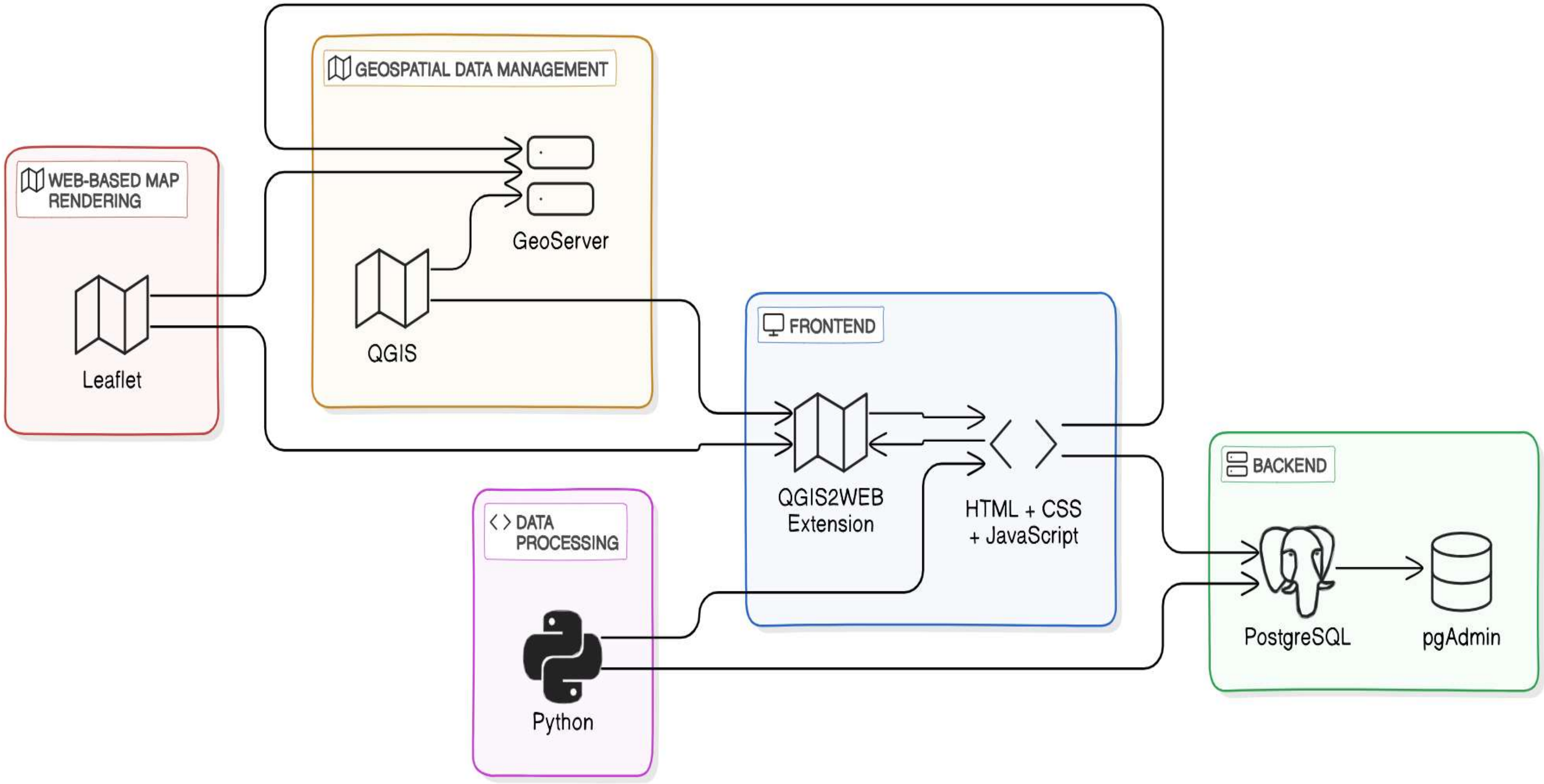

Figure 6. Diagram of Components involved in Interface and GIS Database Development

4.1 Basic Functionalities and Administrative Tools

The desktop application serves as the primary platform for visualizing and analyzing spatial data associated with post-mining hazards. Built on open-source Python libraries, such as QGIS, GDAL, and GeoPandas, this GIS application provides essential functionalities to meet the POMHAZ project's goal of conducting effective hazard assessment and multi-risk analysis in abandoned mining areas. Its spatial data management capabilities allow for seamless integration, visualization, and editing of vector and raster data, which is essential for mapping geological, hydrological, and environmental factors. The application supports a range of datasets critical to post-mining hazards, including topographical maps, satellite-based land cover layers, and hazard-specific data, enabling comprehensive spatial analysis.

To further support its spatial data management, the application offers robust administrative tools for handling user access, data inputs, and regular updates. These administrative tools ensure data security and integrity, allowing for efficient data organization and management within the GIS desktop environment. The application's role-based user access management feature assigns permissions according to specific user roles—data viewer, editor, or project administrator—ensuring that only authorized personnel can modify sensitive data, thereby preventing accidental alterations. Tailoring access to specific datasets enhances data security, particularly for proprietary hazard information or restricted environmental assessments.

Additionally, administrative tools facilitate streamlined data input and updates, maintaining consistent accuracy in spatial datasets essential for hazard analysis. Regular updates are managed within a structured administrative interface, ensuring that the application remains current and all data processes are logged for transparency. These functionalities provide the backbone of the POMHAZ project's GIS platform, enabling stakeholders to conduct controlled, reliable, and collaborative hazard assessment, ultimately supporting the mitigation of post-mining risks in coal mining regions.

4.2 DSS-based Python Script Library for Hazard Analysis

The DSS-based Python script library for hazard analysis in the POMHAZ project is specifically crafted to automate complex GIS analyses for effective hazard assessment and decision-making. These Python scripts leverage a range of libraries, such as GeoPandas, GDAL, and Scipy, to conduct in-depth spatial analyses of post-mining hazards, including ground stability, hydrological issues, and environmental contamination. Designed to integrate directly with the Decision Support System (DSS), each script automates essential GIS workflows, enabling real-time analysis of multi-hazard data. This automation provides a standardized method for processing large datasets, reducing manual intervention, and ensuring consistent analysis across different hazard types and geographical areas.

Moreover, the scripts are tailored to support the decision-making process by generating actionable insights based on DSS logic, offering tools like risk scoring, multi-criteria analysis, and scenario-based simulations. By simplifying complex data interactions, these tools allow stakeholders to evaluate hazard impacts quickly, assess vulnerability levels, and prioritize mitigation actions. The Python script library not only enriches the DSS by adding analytical depth but also streamlines the interpretation of results, ensuring that critical information on post-mining hazards is readily accessible to decision-makers. This integration ultimately enhances the POMHAZ project's mission to support safe and sustainable land use in former mining areas.

4.3 Visualization Component for Stakeholders

The visualization component of the POMHAZ GIS toolbox provides a customizable, intuitive way to display hazard data tailored specifically to diverse stakeholder needs. Designed with both technical and non-technical users in mind, this component converts complex datasets into clear visual outputs, using interactive maps, and layered views to represent various hazard types and intensities. Stakeholders, from local authorities to environmental specialists, can explore data through user-friendly tools that highlight crucial insights, such as areas of high-risk land instability. These visualizations ensure accessibility and understanding, regardless of technical expertise.

To further enhance decision-making, the visualization component integrates real-time outputs from the Decision Support System (DSS). This integration overlays actionable recommendations directly onto maps (see deliverable 3.3), providing stakeholders with instant feedback on hazard assessments and risk prioritization. The DSS-based visualizations allow users to quickly evaluate different scenarios, consider mitigation measures, and communicate findings effectively. This seamless alignment of analysis with practical recommendations is essential for informed decision-making in post-mining areas, supporting the POMHAZ project's goal to ensure both safety and sustainability.

5. Conclusion

The present deliverable marks a significant milestone in the POMHAZ project, highlighting the successful integration of a comprehensive GIS toolbox, Decision Support System (DSS), and a robust knowledge database to facilitate post-mining multi-hazard analysis and multi-risk assessment. Key achievements include the development of Python-based tools for spatial data management, hazard evaluation, and user-specific visualization components. These functionalities provide a flexible, secure, and efficient platform for stakeholders to analyze, interpret, and make informed decisions based on complex post-mining hazard data. The integration of multi-layered data within the GIS environment, combined with DSS-driven logic, has created an advanced hazard analysis framework that sets the foundation for ongoing project activities.

Throughout this report, various challenges emerged, primarily related to harmonizing data from multiple sources and ensuring compatibility with existing GIS standards. The project team addressed these issues by standardizing data inputs, developing custom scripts for data homogenization, and incorporating robust administrative tools for secure data handling. Furthermore, the design of intuitive visualization features allows both technical and non-technical users to access insights, while the role-based access system ensures data security and relevance to each user group.

Moving forward, the project aims to expand on this foundation by developing advanced web-based and virtual reality applications to improve user engagement and accessibility. Future improvements will focus on refining user interfaces and further enhancing DSS capabilities to better support multi-hazard analysis. By incorporating these future enhancements, the POMHAZ project will continue to evolve as a vital resource for risk management in post-mining areas across Europe.

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.

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