

Applying Multihazard Risk Assessment to Support Spatial Planning in Accordance with the Sendai Framework: Insights from Practice

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Abstract

Disaster risk is increasingly influenced by the combined effects of natural hazards, urbanization, and socio-economic development, requiring integrated approaches to risk assessment and management. This paper presents a multihazard assessment framework designed to support spatial planning in the Republic of North Macedonia, with particular emphasis on seismic risk as a dominant hazard. The proposed methodology is based on the integration of hazard data for earthquakes, floods, landslides, wildfires, and erosion within a Geographic Information System (GIS) environment. Individual hazard maps are standardized and combined into a multihazard map, enabling the identification of areas exposed to multiple hazards. While the analysis primarily focuses on the hazard component, exposure and vulnerability are considered qualitatively within the spatial planning context. The results highlight significant spatial variability of hazard exposure and reveal areas where multiple hazards overlap, increasing the potential for complex risk scenarios. The study demonstrates that the integration of multihazard assessments into spatial planning provides a valuable basis for risk-informed decision-making, land-use regulation, and infrastructure development. A particular focus is given to seismic risk management, reflecting the country's historical experience and existing scientific capacity. A synthesized SWOT analysis identifies key strengths, including established research institutions and long-term seismic monitoring, as well as critical weaknesses such as outdated regulations and limited implementation of modern design standards. Based on these findings, a structured working plan is proposed, including modernization of monitoring systems, development of national risk assessment methodologies, and implementation of mitigation and retrofitting strategies in accordance with Eurocode 8. The study concludes that effective disaster risk reduction requires the integration of multihazard risk assessment with spatial planning and policy frameworks. The proposed approach provides a practical tool for enhancing resilience and supports the development of future national spatial strategies aligned with international frameworks such as the Sendai Framework for Disaster Risk Reduction 2015–2030.

Keywords: spatial planning, multihazard, risk, hazard, vulnerability

1- INTRODUCTION

Disaster-related losses are increasing globally, with significant consequences for human life, infrastructure, and economic development. Over the past decades, disasters have affected hundreds of millions of people annually, driven by a combination of factors such as climate change, rapid and often unplanned urbanization, environmental degradation, population growth, and increasing exposure of assets in hazard-prone areas [1]. These trends highlight the growing need for comprehensive and forward-looking approaches to disaster risk management that integrate scientific knowledge, policy frameworks, and spatial planning practices.

At the international level, the United Nations Office for Disaster Risk Reduction plays a central role in coordinating disaster risk reduction efforts [2], [3]. The adoption of the Sendai Framework for Disaster Risk Reduction 2015–2030 [4] marked a significant shift toward a more holistic understanding of risk, emphasizing not only hazard assessment but also the roles of exposure and vulnerability. The framework defines four priorities for action: (i) understanding disaster risk; (ii) strengthening disaster risk governance; (iii) investing in disaster risk reduction for resilience; and (iv) enhancing disaster preparedness for effective response and recovery, including the “Build Back Better” principle.

A key aspect of the Sendai Framework is the recognition of **spatial and urban planning as essential tools for disaster risk reduction**. The integration of hazard and risk assessments into land-use policies, zoning

regulations, and development planning enables more resilient spatial development and reduces long-term exposure and vulnerability. In particular, the enforcement of building codes and the incorporation of risk-informed planning principles are critical for minimizing disaster impacts.

Within this context, the Spatial Plan represents the primary strategic instrument for guiding national development, defining land use, infrastructure development, and environmental protection over long-term planning horizons [5]. However, in many countries, including the Republic of North Macedonia, disaster risk considerations have not been fully integrated into spatial planning processes. In the previous Spatial Plan (2000–2020), attention to hazards was limited and primarily focused on selected risks, without a comprehensive multihazard perspective.

This paper addresses this gap by proposing a **multihazard assessment approach to support spatial planning**, with the aim of improving the integration of disaster risk reduction into national development strategies.

2- DISASTER RISK AND SPATIAL PLANNING IN THE REPUBLIC OF NORTH MACEDONIA

The Republic of North Macedonia is exposed to a wide spectrum of natural and human-induced hazards, including earthquakes, floods, landslides, droughts, erosion, wildfires, snow-related hazards, and technological accidents. These hazards can cause significant damage to the built environment, critical infrastructure, natural resources, and human lives, particularly in areas with high exposure and vulnerability.

In this context, **hazard** is defined as a potentially damaging physical event or human activity, while **risk** is understood as the result of the interaction between hazard, exposure, and vulnerability. Vulnerability reflects the susceptibility of individuals, communities, and systems to adverse impacts, influenced by physical, social, economic, and environmental factors [6], [7]. Exposure refers to the presence of people, infrastructure, and assets in areas that may be affected by hazards. Together, these components determine the level of potential damage and losses [8], [9].

The national disaster risk management system in North Macedonia is based on a legal and institutional framework that includes key institutions such as the Crisis Management Center and the Protection and Rescue Directorate. These institutions are responsible for monitoring hazards, coordinating response activities, and implementing risk reduction measures. In recent years, efforts have been made to modernize risk assessment approaches through the use of geographic information systems (GIS), spatial data platforms, and improved analytical tools.

In preparation of the new Spatial Plan with a planning horizon up to 2040 [10], [11], a comprehensive study was developed to assess the full range of natural and technological hazards and their associated risks. This study represents a significant step toward integrating disaster risk reduction into spatial planning. It includes detailed analyses of natural conditions (geological, tectonic, hydrological, and climatic), as well as socio-economic factors that influence exposure and vulnerability.

A key component of the study is the **identification and spatial analysis of multiple hazards**, including earthquakes, floods, landslides, erosion, and wildfires. These analyses are supported by thematic maps and GIS-based tools, enabling the visualization of hazard distribution and the identification of high-risk areas. In addition, the study evaluates the existing institutional framework and identifies strengths and weaknesses through a SWOT analysis.

Particular attention is given to the increasing complexity of disaster risk due to global trends such as climate change, migration, urbanization, and environmental degradation. These factors not only increase hazard intensity and frequency but also amplify vulnerability and exposure.

Based on these analyses, the study defines strategic objectives and measures aimed at reducing disaster risk through prevention, protection, preparedness, and response. The integration of **multihazard assessment into spatial planning** is identified as a key priority, providing a foundation for more resilient development and improved decision-making at national and local levels.

3- METHODOLOGY FOR MULTHAZARD APPROACH

This study applies a multihazard assessment approach to support spatial planning in the Republic of North Macedonia, aligned with the principles of the Sendai Framework for Disaster Risk Reduction (2015–2030). The methodology integrates hazard assessment, spatial analysis, and data harmonization within a Geographic Information System (GIS) environment, enabling the spatial identification of areas exposed to multiple hazards. The risk assessment is based on the widely accepted concept:

Risk = Hazard × Exposure × Vulnerability

The present study primarily focuses on the **hazard component**, while exposure and vulnerability are considered qualitatively through spatial interpretation and planning context.

The methodological workflow consists of the following steps:

1. Collection and preprocessing of spatial and statistical data
2. Development of individual hazard maps
3. Integration of hazards into a multihazard map
4. Interpretation for spatial planning purposes

Data were collected from multiple national and institutional sources, including: Seismological and geological data, Hydrological and meteorological records, Historical disaster databases (wildfires, erosion) and Spatial datasets (topography, land use, administrative boundaries) All datasets were processed and harmonized within a **GIS environment**, ensuring consistent spatial resolution and coordinate systems.

The analysis includes the following natural hazards:

- **Flood Hazard:** Flood hazard maps are developed based on **maximum water levels**, derived from hydrological analyses and historical flood records (Figure 1).
- **Landslide Hazard:** Landslide susceptibility is assessed considering geological, topographical, and seismic factors, including the influence of seismic loading for the same return period 475 years, (Figure 2).
- **Wildfire Hazard:** Wildfire hazard is represented using the **total number of recorded open-air fires per municipality (2005–2023)**, providing a spatial distribution of fire-prone areas (Figure 3).
- **Erosion:** Erosion hazard is based on **registered erosion processes**, reflecting long-term land degradation patterns (Figure 4).
- **Earthquake Hazard :** Seismic hazard is represented using a **return period of 475 years**, corresponding to a 10% probability of exceedance in 50 years, consistent with European design standards [12] . Ground acceleration values are used as the primary indicator (Figure 5).

The multihazard map is developed by combining individual hazard layers using a GIS-based overlay approach (Figure 6) Each spatial unit is assigned a cumulative hazard level based on the number and intensity of overlapping hazards. The multihazard approach enables the identification of:

- Areas with overlapping hazards
- Areas with increased potential for cascading or compound disaster effects

This provides a more comprehensive understanding of spatial risk patterns compared to single-hazard analyses.

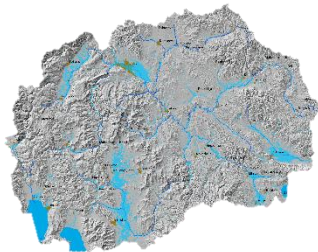


Figure 1- Flood For Maximum Water Levels Hazards [11]

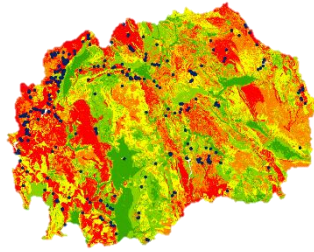


Figure 2-Landslides For A Seismic Return Period Of 475 Years [11]



Figure 3- Total Number Of Open-Air Fires By Municipalities (2005–2023) [11]

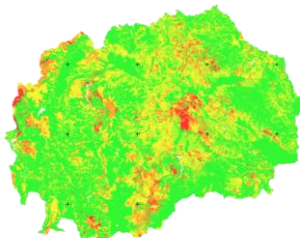


Figure 4-Map Of Registered Erosion [11]

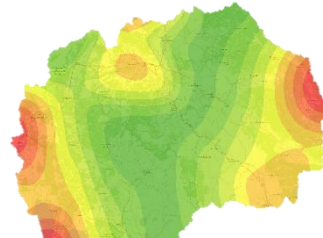


Figure 5- Earthquake For A Seismic Return Period Of 475 Years [11]

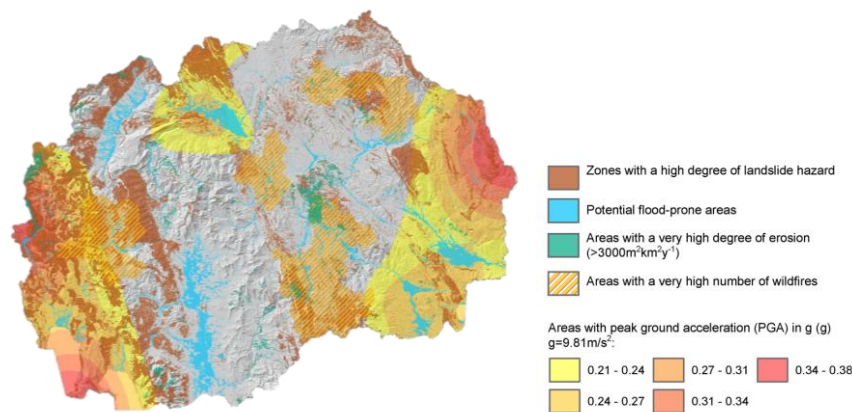


Figure 6-Multihazard map [11]

The resulting multihazard map is interpreted in the context of spatial planning, with the aim of: identifying high-risk zones, supporting land-use regulation, guiding infrastructure development and enhancing disaster resilience. The results provide a basis for integrating disaster risk reduction into national and local spatial planning strategies.

4- CONCEPT FOR IMPROVING THE CAPACITY OF THE DISASTER RISK REDUCTION SYSTEM IN REPUBLIC OF NORTH MACEDONIA

During the implementation of the Spatial Plan (2000–2020), the Republic of North Macedonia followed global developments in disaster risk reduction, including alignment with frameworks promoted by the United Nations Office for Disaster Risk Reduction. A national legal and institutional framework has been established, primarily through the Law on Crisis Management and the Law on Protection and Rescue, supported by key institutions such as the Crisis Management Center and the Protection and Rescue Directorate.

Despite this progress, the analysis reveals several important challenges. Risk assessment methodologies are unevenly developed across hazard types, with more advanced approaches for seismic risk compared to other hazards such as drought and erosion. In addition, **limited data availability, insufficient technological infrastructure, and weak inter-institutional coordination** constrain effective risk assessment and decision-making. The lack of a comprehensive national disaster risk reduction strategy aligned with the Sendai Framework further highlights the need for systemic improvements.

This concept is developed based on an assessment of the current system and its alignment with international frameworks, including the Sendai Framework for Disaster Risk Reduction (2015–2030), the Sustainable Development Goals, and European Union policies.

4-1- VISION

Reduction of disaster risk and promotion of a culture of resilience through improved knowledge of hazards and of the physical, social, economic, and environmental vulnerabilities faced by the country. This includes understanding how hazards and vulnerabilities evolve in the short and long term and undertaking activities based on such knowledge.

4-2- GOALS

In order to achieve the above-defined vision, four goals and objectives have been established. The specific objectives are aligned with the Sendai Framework for Disaster Risk Reduction 2015–2030. The principles of this framework have been adopted to ensure that the national strategy of the Republic of North Macedonia for reducing the consequences of natural disasters and technological accidents is aligned with global developments in this important policy area and contributes to international efforts aimed at achieving sustainable development.

Goal 1: Understanding Disaster Risk - Disaster risk management should be based on a comprehensive understanding of disaster risk in all its dimensions, including hazard characteristics, vulnerability and capacity, exposure of people and assets, and environmental conditions.

Objectives	SO11	Collection, analysis, management, and use of relevant data and information on all types of hazards and enabling their use by different categories of users.
	SO12	Strengthening technical and scientific capacities for consolidating existing knowledge and for developing and applying modern methodologies and models for assessing vulnerability, exposure, and disaster risk.
	SO13	Identification and periodic updating of risks from all types of hazards and presentation of this information through risk maps disseminated to decision-makers and the wider public using geographic information systems.
	SO14	Promotion and improvement of dialogue and cooperation between the scientific community, relevant stakeholders, and policy-makers in order to strengthen the science-policy interface in disaster risk management.
	SO15	Strengthening scientific research on disaster risk reduction through coordination of existing international research networks with the support of the United Nations Office for Disaster Risk Reduction.

Goal 2: Strengthening disaster risk governance to manage disaster risk- Disaster risk management at national, regional, and local levels is essential for ensuring coordinated and coherent disaster risk reduction across sectors and between national and local governance frameworks.

Objectives	SO21	Revision and improved alignment of national and local regulations and public policies to clearly define the roles and responsibilities of public and private sector actors and integrate disaster risk reduction activities across all sectors.
	SO22	Adoption and implementation of national and local strategies and plans for disaster risk reduction with defined objectives, indicators, and timelines aimed at preventing hazards, reducing existing risks, and strengthening economic, social, health, and environmental resilience.
	SO23	Establishment and strengthening of coordination platforms composed of relevant stakeholders at national and local levels, including national and local platforms for disaster risk reduction, and designation of a national focal institution for implementing the Sendai Framework.

Goal 3: Investing in disaster reduction for resilience - Public and private investments in disaster prevention and risk reduction through structural and non-structural measures are essential for improving the resilience of communities, infrastructure, and the environment.

Objectives	SO31	Ensuring the proper construction of buildings capable of withstanding different hazards through appropriate design regulations and material standards, reconstruction and retrofitting of existing structures, and fostering a culture of maintenance.
	SO32	Ensuring the proper construction of buildings capable of withstanding different hazards through appropriate design regulations and material standards, reconstruction and retrofitting of existing structures, and fostering a culture of maintenance.
	SO33	Increasing public and private investments in disaster resilience, particularly through structural and non-structural measures aimed at reducing risks in critical infrastructure such as schools, hospitals, and transport systems.

Goal 4: Enhancing disaster preparedness for effective response - Experience demonstrates that disaster preparedness must be strengthened to ensure effective response and recovery. Recovery, rehabilitation, and reconstruction phases should be planned in advance and should provide opportunities to “build back better” by integrating disaster risk reduction measures.

Objectives	SO41	Investment in multi-sectoral forecasting and early-warning systems, communication mechanisms during disasters, and hazard monitoring systems.
	SO42	Establishment of centres for public awareness-raising and storage of necessary materials for rescue and assistance operations, as well as training of professional and volunteer responders.
	SO43	Promotion of resilience of new and existing critical infrastructure, including water supply, transport, telecommunications, education, and health facilities.
	SO44	Development of coordinated regional approaches and operational mechanisms for rapid and effective disaster response when national capacities are exceeded.

4-3- IMPLEMENTATION STAGES AND MONITORING INDICATORS

The implementation of the proposed framework is monitored through a set of indicators aligned with the defined goals. Given the varying levels of data availability and methodological development across hazards, the indicators include both qualitative and quantitative measures.

- For **Goal 1 – Understanding Disaster Risk**, indicators focus on modernization of equipment for monitoring relevant information (I11), establishment or improvement of a platform for data collection (I12), development of scientifically based methodologies for determining hazard, vulnerability, exposure, and risk (I13) and development of up-to-date hazard and risk maps (I14).
- For **Goal 2 – Strengthening Risk Governance**, the emphasis is on introduction or improvement of regulations for different types of disasters and accidents (I21) and enhancement of human resource and institutional capacities for disaster management (I22).
- For **Goal 3 – Investing in Risk Reduction**, indicators address development of national, regional, and local strategies for reducing different types of risks (I31), inspection and control of existing building stock and infrastructure (I32) and application of modern technologies and skills to increase the resilience of buildings, infrastructure, and industrial facilities (I33).
- For **Goal 4 – Enhancing Preparedness**, indicators focus on establishment or improvement of a national platform for raising knowledge and awareness of different types of disasters and accidents (I41), establishment or improvement of monitoring and early-warning systems for different types of disasters and accidents (I42) and development of plans for effective disaster response (I43).

These indicators provide a structured basis for monitoring progress and supporting risk-informed spatial planning.

5- SEISMIC RISK MANAGEMENT IN REPUBLIC OF NORTH MACEDONIA

Seismic risk represents one of the most critical natural hazards in the Republic of North Macedonia, due to the country's tectonic setting and historical earthquake activity. The 1963 Skopje earthquake remains a defining event that has significantly influenced the development of earthquake engineering, seismic design practices, and institutional capacities in the country.

This section presents a focused assessment of the current state of seismic risk management through a synthesized SWOT analysis, followed by a proposed working plan for its improvement, aligned with the previously defined strategic goals.

5-1- SYNTHESIZED SWOT ANALYSIS – SEISMIC RISK MANAGEMENT IN THE REPUBLIC OF NORTH MACEDONIA

The analysis shows that the Republic of North Macedonia has a strong institutional and scientific basis for seismic risk management, largely developed after the 1963 Skopje Earthquake. Long-term seismic monitoring, supported by national networks and data, together with key institutions such as Institute of Earthquake Engineering and Engineering Seismology and the Ss. Cyril and Methodius University in Skopje, provides a solid foundation for research, education, and practice. Existing regulations and crisis management frameworks further strengthen the system.

However, important weaknesses remain, including outdated monitoring infrastructure, limited technological upgrades, and obsolete seismic design regulations (dating from 1981), with delayed implementation of Eurocode 8. Public awareness is low, and local authorities often lack technical capacity, while building owners show limited engagement in risk reduction measures.

Significant opportunities exist for improvement through modernization of the monitoring network, development of national risk assessment methodologies, and implementation of building inspection and retrofitting programs. Financial incentives and improved coordination among stakeholders could further enhance mitigation efforts.

Key threats include weak enforcement of regulations, limited financial resources, low political prioritization, shortage of trained professionals, and legislative gaps—particularly regarding critical infrastructure.

Overall, despite strong scientific and institutional capacity, effective seismic risk management requires modernization, regulatory updates, capacity building, increased public awareness, and sustained financial and political support.

5-2- WORKING PLAN FOR IMPROVEMENT

The proposed working plan (Table 1) outlines a set of prioritized actions aimed at strengthening seismic risk management in the Republic of North Macedonia. It integrates institutional, regulatory, scientific, and technical measures.

Table 1- Working plan

	Goal	Objective	Description of the task	Time frame	Indicator
Task 1 Modernization of the seismological observatory and network	G.1	O.11, O.12	Expansion and modernization of the seismological network, increase the scientific staff (number of tenure positions).	5 years	I11, I22
Task 2 Modernization of the seismological service law	G.2	O.21	Harmonization of regulation with European ones	2 years	I21
Task 3 Development of a national methodology and analytical tools for the assessment of seismic risk.	G.1	O.12, O.14, O.15	Funding of a national scientific research project aimed at developing a national methodology for seismic risk assessment aligned with European and global practices.	2 years	I13
Task 4 Defining seismic risk at national/ regional/local level	G.1	O.12, O.13	Based on the assessed seismic risk, a national strategy and corresponding risk reduction measures should be developed, involving the scientific and professional community and drawing on international experience.	3 years	I14
Task 5 Development of a national strategy and measures for seismic risk mitigation	G.3	O.31, O.32	Based on the assessed seismic risk, and with the participation of the scientific and professional community as well as the use of international experience, a strategy should be prepared and risk mitigation measures developed at the national level.	2 years	I31
Task 6 Definition of Local Strategies and Measures for Seismic Risk Mitigation	G.3	O.31, O.32	Based on the national strategy, measures should be developed for seismic risk mitigation at the local level for regions with seismic hazard greater than 0.15 g .	3 years	I31
Task 7 Inspections of Critical Infrastructure Facilities and Identification of Structural and Non-Structural Retrofit Measures	G.3	O.32	For all critical infrastructure facilities located in areas with seismic hazard greater than $a_g=0.15g$, It is necessary to carry out structural seismic analyses in accordance with the provisions of EC8 and, where necessary, define the required strengthening and retrofitting measures. Priority should be given to schools and hospitals.	10 years	I32, I33
Task 8 National Platform for Enhancing Knowledge and Practices in Regions with Seismic Risk and Communication with the Public in the Event of an Earthquake	G.4	O.42	Establishment of a national digital platform to raise awareness of earthquake risk, provide knowledge on how to act during an earthquake, and facilitate communication with the public in the event of a disaster.	2 years	I41, I42

6- DISCUSSION

Despite the existence of a solid institutional and scientific foundation for disaster risk management in the Republic of North Macedonia, several critical gaps continue to limit its overall effectiveness. One of the key challenges identified in the analysis is the uneven development of methodologies across different hazard types. While seismic risk assessment is relatively well advanced, methodologies for other hazards—such as drought, erosion, and sedimentation—remain insufficiently developed and lack standardization, hindering the adoption of a comprehensive multihazard approach.

Another significant limitation lies in the weak integration of risk assessment into spatial planning processes. Although hazard-related data and assessments are available, they are not systematically incorporated into land-use planning, zoning regulations, or development control practices. As a result, the potential of these assessments to reduce exposure and vulnerability is not fully realized. This issue is further compounded by the outdated state of monitoring systems and technological infrastructure, particularly in the case of the seismological network, which requires modernization and expansion to ensure the availability of reliable, high-resolution data.

Data-related challenges represent a major constraint in advancing multihazard risk assessment. Historical records of disaster events are often incomplete, fragmented, and inconsistently maintained across institutions. The absence of standardized methodologies, harmonized data formats, and high-resolution spatial datasets, combined with the lack of a centralized and publicly accessible national risk database, significantly affects the accuracy, comparability, and usability of risk assessments. These limitations are particularly critical when attempting to integrate multiple hazards into a unified analytical framework.

Institutional capacity and coordination also play a decisive role in shaping the effectiveness of disaster risk management. The analysis indicates insufficient coordination among key institutions, including the Crisis Management Center and the Protection and Rescue Directorate, as well as limited collaboration between the scientific community and policy-makers. In addition, local governments often lack the technical expertise and resources required to implement risk-informed planning and mitigation measures. Financial constraints further exacerbate these challenges, limiting the scope and continuity of risk reduction initiatives. Clearer delineation of roles and responsibilities, along with improved mechanisms for data sharing and inter-institutional communication, remains necessary.

Finally, public awareness and stakeholder engagement are relatively low, which reduces the effectiveness of risk reduction efforts, particularly in areas such as seismic strengthening of existing buildings. Addressing these challenges requires a coordinated and systematic approach, including the development of standardized methodologies for all relevant hazards, the establishment of a centralized national risk database, strengthening institutional capacities and coordination mechanisms, alignment with European regulatory frameworks, and the integration of multihazard risk assessment into spatial planning policies and practices. Such measures are essential for enhancing national resilience and ensuring a more effective and comprehensive approach to disaster risk management.

7- CONCLUSION

This study presents a **multihazard assessment framework** designed to support spatial planning in the Republic of North Macedonia, in alignment with the principles of the Sendai Framework for Disaster Risk Reduction (2015–2030). By integrating multiple hazard types: earthquakes, floods, landslides, wildfires, and erosion—into a unified spatial analysis, the research demonstrates the importance of a comprehensive approach to understanding and managing disaster risk.

The results highlight that, while significant progress has been made in developing institutional structures and hazard-specific knowledge, **substantial gaps remain** in the areas of methodological consistency, data availability, and practical implementation. In particular, the lack of standardized approaches across hazards, limited integration of risk information into spatial planning, and insufficient coordination among institutions reduce the overall effectiveness of the disaster risk management system.

The multihazard mapping approach developed in this study provides a **valuable tool for identifying areas of overlapping risk**, thereby supporting more informed decision-making in land-use planning and infrastructure development. It also emphasizes the need to move from hazard-based assessments toward **risk-informed planning practices**, where exposure and vulnerability are systematically considered.

Overall, the study contributes to bridging the gap between scientific risk assessment and practical spatial planning, offering a pathway toward **increased resilience and sustainable development** in hazard-prone regions.

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