Comprehensive Analysis of the Use of Web-GIS for Natural Hazard Management: A Systematic Review

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Systematic Review

Comprehensive Analysis of the Use of Web-GIS for Natural Hazard Management: A Systematic Review

Muhammad Daud, Francesca Maria Ugliotti * and Anna Osello

Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, 10129 Turin, Italy; muhammad.daud@polito.it (M.D.); anna.osello@polito.it (A.O.)
* Correspondence: francesca.ugliotti@polito.it; Tel.: +39-349-407-3861

Abstract: This systematic review aims to synthesise Web-GIS evidence for managing natural hazards to share state-of-the-art practices and policies. A comprehensive search in SCOPUS, among other databases, identified 1775 articles published between 2014 and 2023. Following a selection process based on the PRISMA model, 65 articles met the inclusion criteria. The analysis revealed a growing trend over the past decade, with most research concentrated in the last three years. Eight crucial subtopics within the Web-GIS domain have emerged: Integrated Spatial Analysis and Modelling, Technologies and Infrastructure, Visualisation and User Interface Design, Decision Support Systems, Real-time Monitoring and Early Warning, Disaster Recovery and Resilience, Citizen and Social Media Integration, and Multi-Stakeholder Collaboration. A substantial contribution of the literature has been identified in Decision Support Systems and Integrated Spatial Analysis, reflecting their vital role in strategising and predicting hazard impacts. Furthermore, a geographical distribution analysis revealed significant Web-GIS applications in countries like Italy and China, alongside a deficit in low- and middle-income countries. It also highlights potential gaps in hazard studies, including the need to prioritise heatwave management in the face of climate change. This research calls for policymakers and practitioners to leverage evidence-informed decision making and foster community collaboration for enhanced natural disaster resilience.

Keywords: Web-GIS; digital twin; natural hazards; risk management; engagement; awareness; decision support system; real-time monitoring; resilience; collaboration

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1. Introduction

According to the United Nations Office for Disaster Risk Reduction (UNDRR), disasters are reversing global development at unprecedented rates; therefore, urgent actions are needed to build resilience to withstand and respond to shock in every decision we make [1]. Anthropogenic and natural pressures in the context of climate change strain our planet, communities, and prosperity, hindering the achievement of the significant Sustainable Development Goals of the 2030 Agenda [2]. The Global Assessment Report on Disaster Risk Reduction (GAR) 2023 presents a new analysis mapping hazards and disasters, showing a dramatic rise with knock-on effects on global food security, employment, and education [3].

Natural hazards encompass various naturally occurring events, ranging from earthquakes and hurricanes to floods and wildfires, each capable of inflicting significant harm upon human life, property, and the environment [4]. Large disasters cause extensive damages and numerous fatalities [5,6]. However, their impact extends beyond immediate devastation, often resulting in the displacement of populations, the destruction of infrastructure, and enduring socio-economic and environmental repercussions [4]. Climate change further exacerbates the impacts of natural hazards, emphasising the need for effective disaster management strategies [7–9]. Central to this endeavour is a comprehensive understanding of the type and severity (i.e., frequency, magnitude, and ramifications) of such events, levels of exposure, and social and economic vulnerabilities in affected areas, facilitating strategies to mitigate their effects and bolstering community resilience [6,10,11]. Past experiences with natural disasters tend to increase people's perception of risk and preparedness, although these effects may sometimes be short-lived [12]. Until the mid-1990s, systematic information about the occurrence of small- and medium-impact disasters and disaggregated data about the effects of large-scale disasters were not available in most countries in the world [13]. In 1994, a group of researchers from Latin America devised DesInventar, a conceptual and methodological tool for generating National Disaster Inventories and building databases of damage, loss, and general effects of disasters [13].

Recognising the gravity of natural hazards is imperative in prioritising effective hazard management and disaster preparedness initiatives [10]. According to the Sendai Framework of 2015, clear targets and priorities for action were outlined to prevent new and reduce existing disaster risks, including (i) the need for improved understanding of disaster risk in all its dimensions of exposure, vulnerability, and hazard characteristics; (ii) the strengthening of disaster risk governance, including national platforms; and (iii) accountability for disaster risk management; preparedness to "Build Back Better"; recognition of stakeholders and their roles; mobilisation of risk-sensitive investment to avoid the creation of new risk; resilience of health infrastructure, cultural heritage and work-places; strengthening of international cooperation and global partnership, and risk-informed donor policies and programs, including financial support and loans from international financial institutions [14].

By recognising the crucial nature of the subject, several projects at the international level are helping to define a consistent thread of research. These include the multi-risk science for resilient communities under a changing climate (RETURN) Italian project [15], funded under the National Recovery and Resilience Plan (NRRP), which promotes participation in strategic European and global value chains. It aims to apply and exploit technology to help strengthen critical competencies, technology and knowledge base transfer, and governance in disaster risk management involving public administrations, stakeholders, and private companies. In addition, studies on continuity and the change of risk management policies are traced by systematically analysing the interaction between discursive, institutional, and contextual factors [16].

Over the years, natural hazard management has evolved, leading to a departure from traditional static approaches in favour of dynamic data integration enabled by the implementation of real-time monitoring systems. Nowadays, the Digital Twin (DT) paradigm [17] is the most promising, although it is still far away. It provides a digital replica of an asset or environment interconnected with the physical one according to four levels depending on their relationship with the physical asset's life cycle and their dependency on the DTs' operators [18]. DT can continuously interact and exchange big data to perform cutting-edge simulations to advance disaster resilience by empowering decision makers to glean actionable insights into natural hazards, fostering proactive mitigation strategies and facilitating stakeholder collaboration for swift responses to evolving scenarios. In this context, Geographic Information System (GIS) and Building Information Modelling (BIM) systems at the territorial and building levels, respectively, are the reference graphical databases that can be exploited for this purpose.

Central to effective natural hazard management is the availability of accurate and timely data about hazard occurrence, characteristics, and impacts. Such data underpin risk assessment, disaster preparedness, and response planning efforts, serving as the cornerstone for evidence-based decision making to minimise adverse outcomes [19]. Indeed, GIS occupies a central role in this data ecosystem, integrating spatial and non-spatial information to facilitate the analysis and visualisation of natural hazard-related data [20]. Through the synthesis of maps, satellite imagery, and other datasets, GIS empowers stakeholders across research, policy, and emergency response domains to identify high-risk areas [21], assess vulnerabilities, and optimise resource allocation and evacuation routes, thereby enhancing overall preparedness and resilience in the face of natural hazards [22–25].

The abundance of available data, also due to the rapid technological advancement of recent years, has further transformed the landscape of natural hazard management by introducing the idea of a centralised repository. WebGIS, also known as Web GIS or Web-GIS, is a modern approach that leverages the power of the internet to deliver GIS data, maps, and analysis tools through web-based platforms. The evolution in data delivery and analysis [26] has significantly impacted natural hazard management, providing real-time hazard monitoring and interactive mapping tools for visualisation and facilitating information sharing and stakeholder collaboration for rapid decision making [27]. Furthermore, the collaborative nature of Web-GIS promotes inter-agency cooperation, leading to more effective disaster response and recovery efforts [28]. Web-GIS has been instrumental in various contexts, such as road network risk assessment [28], disaster monitoring in urban areas [29], and seismic risk evaluation [30,31]. Integrating Web-GIS with real-time data sources enables near-instantaneous disaster evaluation and integration with emergency management systems [27,32].

Consequently, Figure 1 illustrates a notable increase in interest in Web-GIS, as shown by the solid line representing Google Trends [33] web search data for the past six months. The dotted line projects this trend into the future, suggesting continued growth in interest. This upward trend reflects the growing attention and awareness surrounding this subject in the context of natural hazard management, identifying a potential shift toward adopting and using Web-GIS as a pivotal tool for assessing resilience dimensions in an integrated manner. This systematic review makes it crucial to consider the implications behind this broad-based focus and appreciate its potential impact on the international panorama.

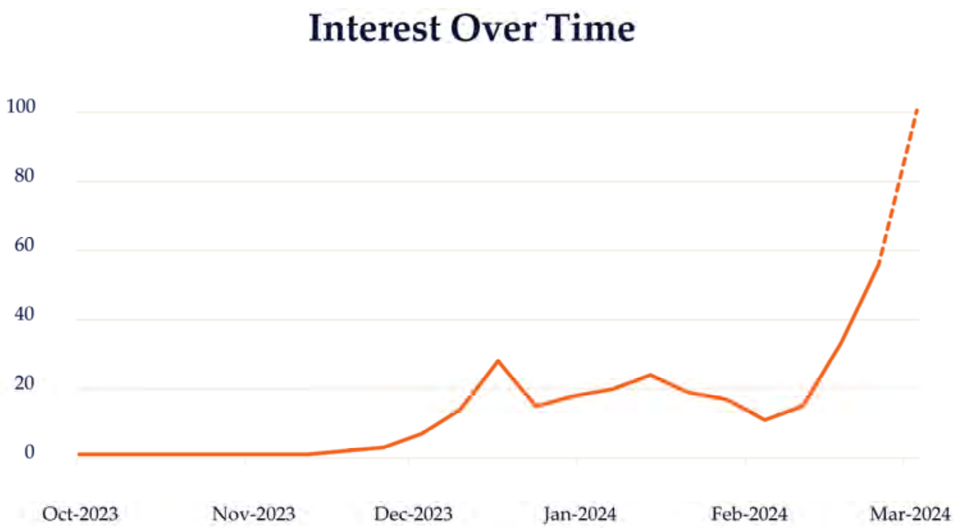

Figure 1. Web-GIS topic interest over time.

Over the past decade, numerous comprehensive reviews have explored the realm of Web-GIS, examining its applications in diverse domains such as public health surveillance systems [34], infrastructure planning and development [35], and irrigation water management [36]. This research has highlighted the versatility and potential of Web-GIS in enhancing decision-making processes, promoting public engagement, and optimising resource utilisation. While early insights into Web-GIS applications for natural resource management have been foundational [37], it is imperative to acknowledge the swift evolution of Web-GIS technology. Consequently, a cautious approach is necessary when extrapolating these insights to contemporary natural hazard management practices. Despite the extensive investigation in other areas, Web-GIS's precise role and contributions in natural hazard management remain relatively uncharted territory, highlighting the exigency for further exploration into its potential to enhance preparedness, response, and recovery efforts amidst natural disasters. Conducting a comprehensive analysis can identify research gaps and propose innovative approaches for leveraging Web-GIS in this context.

This systematic review comprehensively analyses the integration of Web-GIS in natural hazard management across eight distinct thematic areas. These include Integrated Spatial Analysis and Modelling; Technologies and Infrastructure; Visualisation and User Interface Design; Decision Support Systems; Real-time Monitoring and Early Warning; Disaster Recovery and Resilience; Citizen and Social Media Integration; and Multi-Stakeholder Collaboration, Information Sharing, and Policy. Through this examination, this review aims to uncover challenges, opportunities, and best practices associated with employing Web-GIS across these diverse domains to mitigate natural hazards effectively. Moreover, it offers insights into the potential barriers and limitations that need to be addressed to maximise the utility of Web-GIS in effectively addressing natural hazards.

2. Review Methodology

The search strategy utilised the bibliographic databases Scopus, Web of Science, and Google Scholar to ensure comprehensive coverage of the relevant literature. The inclusion criteria applied to titles and abstracts involved selecting articles published between January 2014 and December 2023, written in English, and appearing in peer-reviewed journals. The search was refined to focus on three distinct domains: Web, Geographic Information Systems, and Hazards. Table 1 outlines the specific search queries for each domain, ensuring a comprehensive exploration of relevant topics.

Table 1. Domains and relevant keywords for search queries.

Research Domains		
Domain 1	**Domain 2**	**Domain 3**
Web	Geographic Information Systems	Hazards
Search Period 2014–2023		
Search Queries		
TITLE-ABS-KEY	AND TITLE-ABS-KEY	AND TITLE-ABS-KEY
"web GIS" OR *web-GIS* OR *webgis** OR *"internet GIS"* OR *"web mapping"* OR *"web visualisation"* OR *"web portal"* OR *"web tool"* OR *"web technology"* OR *"online platforms"* OR *"online tool"* OR *"online mapping"* OR *"geoportal"* OR *"mapping tool"* OR *"visualisation tool"* OR *"interactive mapping"* OR *"geospatial visualisation"* OR *e-learning*	*gis** *"geographic information science"* *"geospatial analysis"* *"spatial analysis"* *"remote sensing"* *geoinformatics* *geodatabase*	*hazard** *disaster** *risk** *mitigation** *assessment**

The results from Scopus indicated a notable increase in publications post 2020, highlighting a growing interest in the intersection of Web-GIS and hazard management, as shown in Figure 2.

Further analysis shown in Figure 3 revealed that research in this field spans various subject areas, with Earth and Planetary Sciences, Environmental Sciences, and Social Sciences comprising significant portions of the literature. This interdisciplinary approach underscores the complex nature of natural hazard management and the diverse perspectives required for practical solutions.

Figure 2. Documents by year.

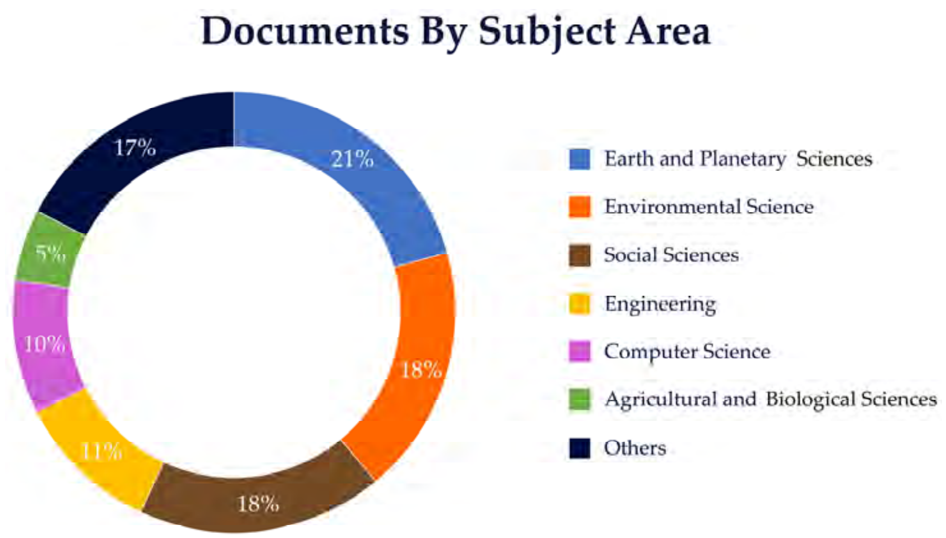

Figure 3. Documents by subject area.

Process of Screening

In the framework of the search, a total of 1775 records were identified from the selected databases. Automatic screening processes were then applied to remove duplicates, excluding 295 records. The subsequent screening steps involved assessing the relevance of titles and abstracts, which led to removing an additional 109 records about subject areas outside the study's scope. Furthermore, records outside the specified publication period were excluded (536 records), along with those not meeting criteria related to document type, language, and keywords (424 records), leading to only 411 records (Table A1 in Appendix A). Finally, manual screening was conducted on the remaining records, thoroughly assessing full-text articles. This process excluded articles based on various criteria, including irrelevant titles and abstracts, the lack of a central idea related to the topic, and an insufficient citation impact over the years. Following the complete screening process outlined in Figure 4 based on the PRISMA model [38] (Supplementary Materials), 65 articles were selected for review. The final selection criteria included only articles directly contributing to understanding Web-GIS applications in hazard management.

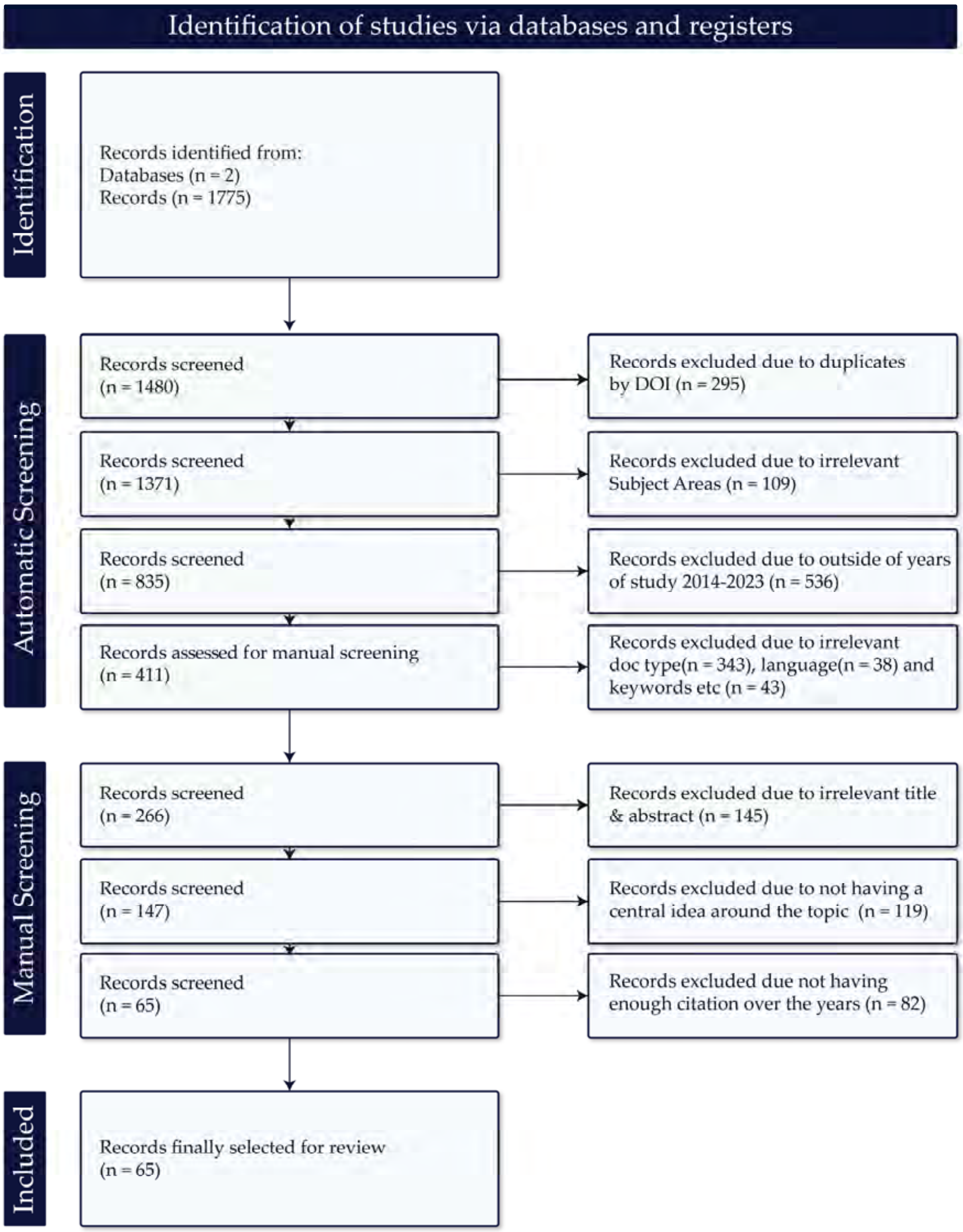

Figure 4. Overview of inclusion and exclusion criteria based on the PRISMA model.

The selected articles were further analysed using Social Network Analysis (SNA) to identify clusters of keywords and themes. Figure 5 presents an SNA plot illustrating the relationships between keywords, facilitating the identification of subtopics for exploration. This visual representation aids in organising the literature into cohesive strands, guiding the systematic review process and enabling a comprehensive analysis of the current state of research in Web-GIS for natural hazard management.

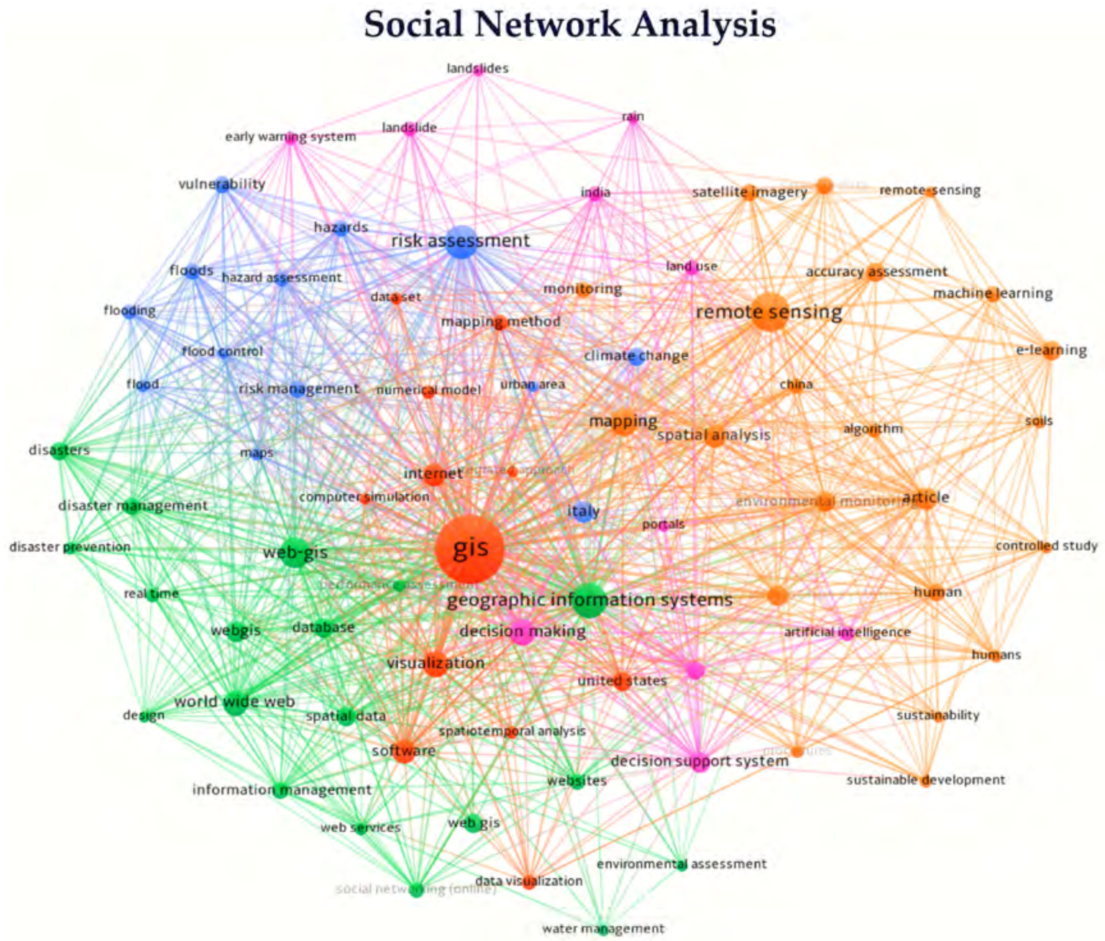

Figure 5. SNA plot of the keywords.

3. Results

The systematic literature review identified a total of 65 papers from different parts of the world outlining various distinct research strands regarding the use of Web-GIS in natural hazards management.

3.1. Geographic and Hazard Application Distribution

Understanding the spatial and thematic patterns of research is essential for identifying regions and hazards that require particular attention.

Figure 6 portrays the geographic distribution of studies included in the literature review, using a colour gradient to indicate the intensity of research activity across different countries. Italy is the most studied country, with 16 cases documented. This high research concentration can be attributed to Italy's geographical complexity and vulnerability to diverse natural hazards, including seismic events, floods and landslides, and volcanic eruptions. The country's geological diversity and densely populated urban areas make it a focal point for hazard research and mitigation efforts. The RETURN research project is currently underway precisely about these issues. It has been allocated significant resources and has an extended partnership to strengthen research chains on environmental, natural, and Man-made hazards nationally and to promote their participation in strategic European and global value chains [15].

China, with seven documented cases, follows closely behind Italy. Its vast territory encompasses various climatic and geological conditions, contributing to its susceptibility to natural hazards such as floods, earthquakes, and landslides. The country's significant research activity reflects its ongoing efforts to develop effective strategies for hazard monitoring, early warning, and disaster management.

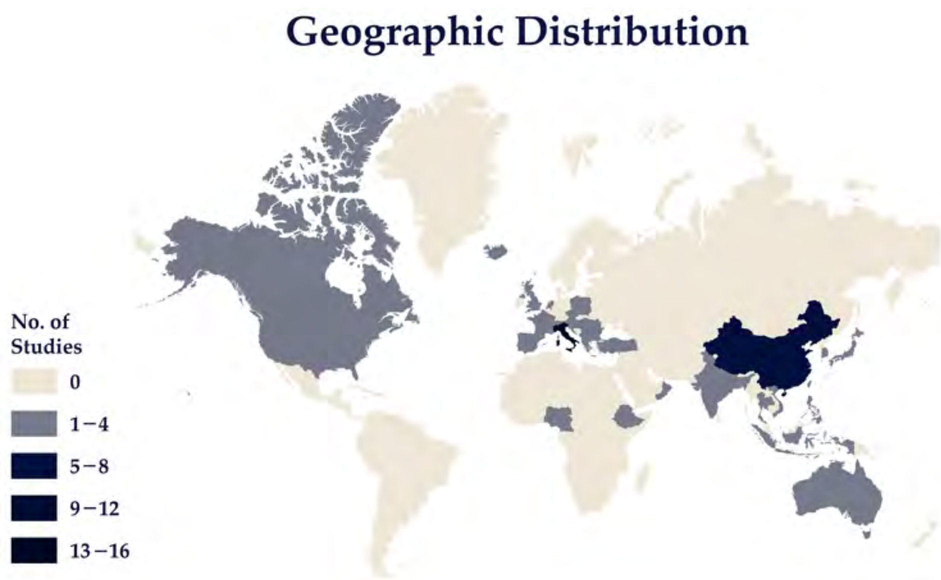

Figure 6. Geographic distribution.

Other countries with notable research contributions include Austria, France, India, Nepal, Portugal, and Greece, each with four documented cases. These countries represent diverse geographic regions and hazard profiles, highlighting the global relevance of natural hazard management research.

Figure 7 presents the distribution of hazard occurrences studied in the selected literature, providing insights into the types of hazards researchers have focused on. Floods emerge as the most extensively studied hazard, with 24 occurrences documented across the papers. Floods pose significant threats to communities, infrastructure, and ecosystems, making them a primary research focus in natural hazard management.

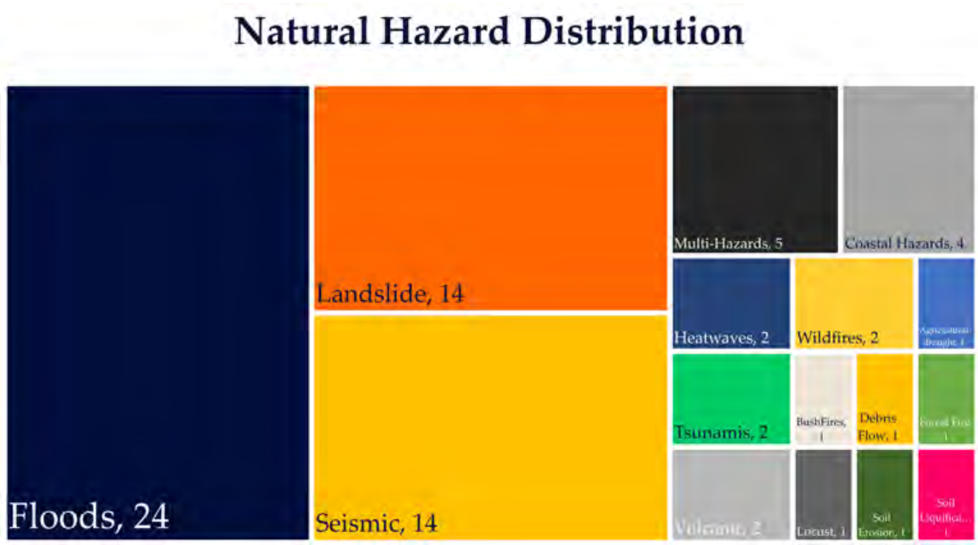

Figure 7. Hazard-type distribution over selected papers.

The literature also prominently features landslides and seismic events, with 14 occurrences each. Landslides, triggered by heavy rainfall, slope instability, and human activities, are widespread hazards with severe consequences for human settlements and transportation networks. Seismic events, including earthquakes and associated phenomena such as tsunamis, represent another critical area of research due to their devastating impact on communities and infrastructure.

Coastal hazards, multi-hazards, and heatwaves are notable subjects of study, with four, five, and two occurrences, respectively. Coastal hazards, including storm surges, erosion, and sea-level rise, are of increasing concern due to climate change [7–9] and coastal development. Multi-hazard approaches are essential for understanding the complex interactions between hazard types and developing comprehensive risk reduction strategies. Heatwaves, exacerbated by climate change, pose significant health risks and challenges for urban resilience and adaptation.

The detailed geographic and hazard distribution analysis in the selected literature provides valuable insights for researchers, policymakers, and practitioners involved in natural hazard management. Stakeholders can prioritise resources and interventions to address the most pressing challenges and vulnerabilities by identifying regions and hazards with significant research activity. Additionally, understanding the distribution allows for identifying gaps and opportunities for future studies to advance the field of natural hazard management further.

3.2. Characterisation of the Selected Papers

The selected 65 papers have been characterised according to their contribution concerning subtopics. These groupings were derived from the SNA plots (Figure 5) and encompassed various aspects of technology, analysis, and applications. The identified subtopics listed below provide a comprehensive framework for exploring the different facets of Web-GIS, guiding the subsequent analysis of the selected literature.

- Integrated Spatial Analysis and Modelling;
- Technologies and Infrastructure;
- Visualisation and User Interface Design;
- Decision Support System;
- Real-time Monitoring and Early Warning;
- Disaster Recovery and Resilience;
- Citizen and Social Media Integration;
- Multi-Stakeholder Collaboration.

Figure 8 illustrates the distribution of papers across these subtopics, highlighting the varying degrees of emphasis within the literature. Notably, specific subtopics received significant contributions, indicating their prominence in the field. For instance, papers focusing on Decision Support Systems (61 papers) and Integrated Spatial Analysis and Modelling (55 papers) were particularly abundant, reflecting their importance in facilitating informed decision making and modelling hazard risks. Another question to note is the confluence between some of the subtopics analysed. As Figure 8 also emphasises, some themes in the selected papers recur in a pair. This fact is most evident for Real-time Monitoring and Early Warning compared with Decision Support Systems and Technologies and Infrastructures compared with Visualisation and User Interface Design subtopics. These groups have many aspects in common and could be evaluated as subsets of each other; however, they are kept separate precisely to stress specific aspects considered crucial. In the following detailed description of individual subtopics, these confluences are recalled.

Given the considerable volume of papers addressing individual subtopics, the ensuing sections of the literature review are focused solely on articles deemed pivotal to the subject matter or those offering unique insights, thereby avoiding redundancy. This strategic approach ensures that the review remains focused and concise, allowing for a thorough examination of the most significant developments and findings according to the different dimensions of Web-GIS. Additionally, the citation network graph by Litmaps [39] (Figure 9) provides insights into the connectivity and impact of the selected 65 papers. The graph illustrates the interconnections among these papers, highlighting the degree of citation and influence they have garnered over the years. The network structure indicates a robust exchange of ideas and knowledge within the research community, underscoring the quality and relevance of the selected literature.

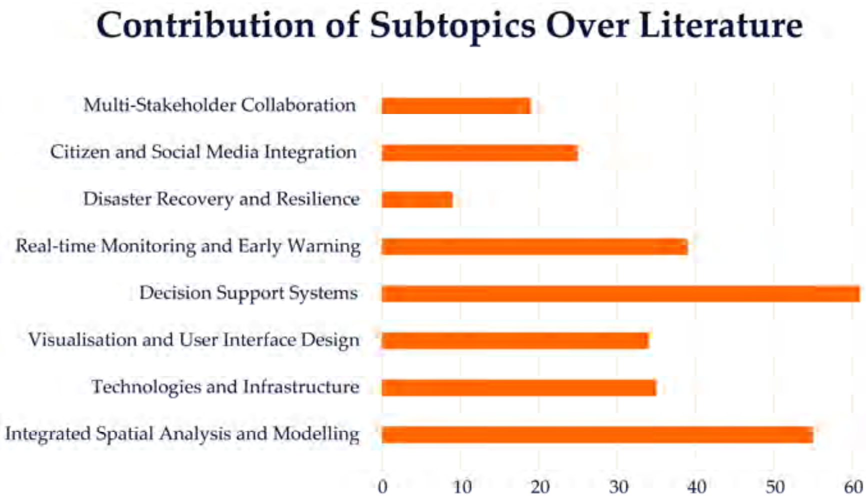

Figure 8. Contribution of literature over subtopics.

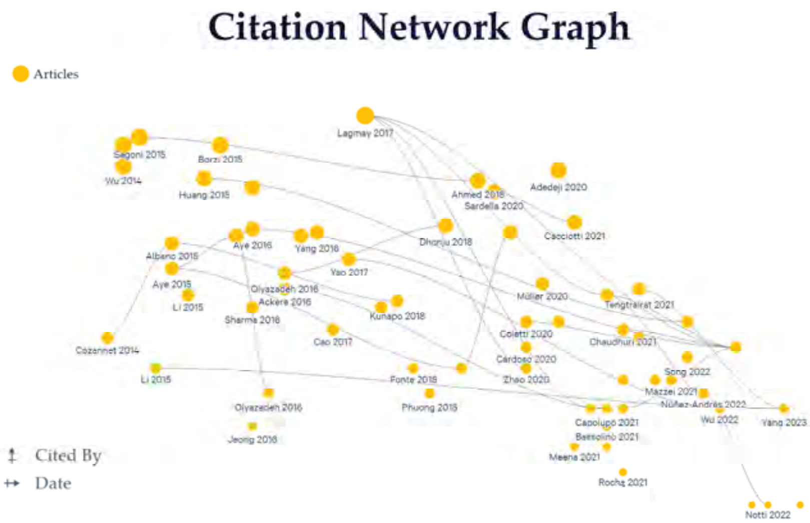

Figure 9. Citation network graph.

3.3. *Exploration of the Subtopics*

This section provides a comprehensive understanding of the subtopics that have emerged from this research.

3.3.1. Integrated Spatial Analysis and Modelling

Integrated Spatial Analysis and Modelling within the domain of Web-GIS for natural hazard management embodies an advanced approach to utilising geospatial data and computational techniques. This interdisciplinary field merges principles from geoinformatics, environmental science, and computer science to thoroughly analyse and model various natural hazards. By integrating spatial data with sophisticated modelling algorithms, decision makers gain the ability to assess risks, devise emergency responses, and implement effective mitigation strategies.

The literature offers a comprehensive insight across diverse domains, including landslides, floods, seismic events, and wildfires. Beginning with landslide prediction and monitoring, studies have employed diverse methodologies such as Wireless Sensor Networks [40], machine learning algorithms [41], and geospatial databases [42] to enhance the accuracy of risk assessments. Notably, the ROOMA application [43] integrates ground-truthing with Web-GIS, significantly improving landslide hazard risk modelling.

Similarly, integrated spatial analysis techniques have proven instrumental in addressing seismic hazard and flood risk assessment. Fragility curves evaluate the seismic vulnerability of bridges, enabling the modelling of damage and collapse scenarios [44]. Additionally, integrating satellite data and Light Detection And Ranging (LiDAR) technology has contributed significantly to community preparedness and disaster risk reduction efforts by accurately mapping flood hazards [45,46]. Advancements in fire hazard analysis include systems developed for wildfire risk modelling [47] and forest fire danger assessment [48], highlighting the importance of integrating spatial data analysis with environmental factors for precise risk assessment.

Integrating spatial analysis and hazard risk modelling in urban areas is pivotal for addressing many challenges in densely populated environments. Urban flood risk management remains a critical focus, with efforts such as coupled storm water modelling and estuarine hydrodynamics [49] and developing Web-GIS-based flood risk modelling frameworks [50]. Similarly, from microclimatic simulations [51] to heatwave risk assessment [52], integrating spatial data with advanced modelling techniques is essential for effective urban climate adaptation planning and bolstering urban resilience.

Integrating remote sensing with machine learning techniques has been employed to monitor natural hazards in coastal areas [53]. Platforms like the MOSAIC [54] utilise predictive models such as SCHISM and XBeach to interpret local coastal hazards effectively. Additionally, modelling soil erosion in catchments showcases the potential of these technologies in enhancing soil-related hazard risk assessments [55]. Frameworks integrating Web-GIS with hydrodynamic models for flood risk assessment [56], along with tools like GIS WATER for urban drainage system management and the EPA's Storm Water Management Model [57], underscore the growing importance of spatial analysis within Web-GIS platforms for comprehensive hazard risk management strategies.

As we move ahead, analysis and modelling technologies are advancing rapidly. This includes the integration of transfer learning algorithms and advanced spatial data techniques. These advancements are expected to play a crucial role at a much higher level in safeguarding communities and environments from the devastating impact of natural hazards.

3.3.2. Technologies and Infrastructure

Web-GIS technologies encompass the tools, frameworks, and protocols used to create and operate web-based geographic information systems tailored to manage the GIS data online. These are pivotal in natural hazard management, integrating GIS with the web for real-time data visualisation and analysis. The recent literature delineates three types: open, closed, and prototype systems. Open-source solutions offer flexibility and community-driven development but may require technical expertise, a potential consideration compared to the streamlined support offered by closed-source platforms. Closed-source platforms provide advanced features and support but come with licensing costs and limited cross-platform interoperability. Prototypes showcase innovation but may lack scalability. When considering long-term deployment, a comparison with more mature technologies may be necessary. Balancing cost and functionality is crucial when choosing between these options.

Regarding the predominantly used technology, researchers have employed open-source technologies like Leaflet and Mapbox, which are maintained as open-source for interactive mapping and online map publishing, emphasise flexibility [27,58,59], though their effective deployment may require specialised technical expertise or resources to handle large-scale data. PostgreSQL/PostGIS stands out for its role in spatial data storage [54,56,60–62], contributing to platforms such as READY [63] and SAMCO [9] for flood resilience and hazard assessment. Open Street Maps have been utilised [64] as well as OpenLayers [65,66] alongside Ol3-Cesium for dynamic 2D/3D visualisations, enhancing flood risk visualisation [65], though potential data quality limitations or inconsistencies must be considered, particularly in areas with limited contributor coverage. GeoServer plays a vital role as web server infrastructure in disaster impact assessment [9,55,60,66–68].

The literature also highlights the application of various other open-source technologies, such as MySQL with Vue.js for real-time earthquake monitoring [27] and innovative 3D GIS research [69]. Additionally, tools like QGIS, GeoDjango, and Django contribute to specialised platforms for flood risk assessment [70], cultural heritage preservation [56], and landslide management [54]. Similarly, the implementation of the QGIS platform with linear regression, Artificial Neural Networks, and bidirectional LSTM machine learning [42] gives an advanced approach to integrate open-source tech.

On the other hand, closed-source platforms like ESRI's ArcGIS [71,72] find applications, offering advanced features, but their adoption may face institutional barriers such as licensing costs and a potential need for specialised training. Similarly, closed-source API integration is emphasised, explicitly mentioning ESRI's ArcGIS API for JavaScript and ArcGIS Online for developing web hazard maps [71]. Microsoft integration is evident in the Integrated Climate Adaptation Model, utilising Microsoft's Internet Information Services and ArcGIS Server [52].

Prototyping is a significant theme, with the introduction of a prototype Web-based simulation framework for tsunami modelling [73]. The Da.D.O. Web-GIS platform, designed to store, catalogue, and share data from large post-earthquake damage campaigns in Italy, is discussed [74]. On the other hand, VHASS is an online tool that provides hazard assessment and risk mitigation tools for Quaternary volcanoes worldwide [75]. Other specific examples include QuickDeform [49], a Web-GIS platform that introduces interactive mapping and real-time earthquake monitoring, utilising previously discussed open-source technologies such as Leaflet, Django, and MySQL. Similarly, the ECLiq platform [62] employs an Apache Tomcat server on Linux and the PostgreSQL database with PostGIS for spatial processing.

In the 3D data domain, the integration of 3D visualisation technologies is exemplified by the introduction of EqMap3D [76] and the presentation of a Web-GIS system for landslide disaster response with real-time 3D visualisation using vue.js, Cesium API, and WebGL technology [69].

As per recent trends, Android applications contribute to disaster management, as demonstrated by the ROOMA Android application [43], which utilises Leaflet, Cordova/PhoneGap, and PostgreSQL with PostGIS. Social media integration is evident in the Web-GIS-based platform [77], which aggregates real-time georeferenced data from social networks. Disaster impact assessment is a recurring theme, with the integration of open-source tools [68] and the introduction of the RiverCure Portal, a Web-GIS platform for data management and analysis in flood risk assessment [56]. Additionally, cloud-based platforms are emerging as potent solutions [55], with studies introducing Cyber-Flood for flood disaster management [45] and utilising cloud computing in AEGIS for fire management [47].

The distribution of technology utilisation across various hazard management scenarios is evident in several studies. These studies encompass shoreline change analysis [61], volcanic hazard assessment [75], and flood risk assessment in Quebec using ArcGIS StoryMaps [78]. Addressing climate change risk visualisation for cultural heritage sites, a Web-GIS tool powered by open-source applications is introduced [58]. Disaster response benefits from seismic analysis and 3D rendering technologies, as seen in using tools like OpenSees and Three.js [79]. Platforms like WebFRIS [80] prioritise user accessibility through their infrastructure for flood risk management. Similarly, open-source GIS technologies play a pivotal role in landslide management, as demonstrated by the conceptual framework for NELIS [81]. Additionally, cross-platform data sharing and integration are showcased by combining QGIS with a web-based GIS application for flood risk assessment [70].

Looking forward, the future of Web-GIS technologies for natural hazard management involves improving interoperability among various platforms and utilising advancements in computational capabilities. Interoperability between open, closed, prototype, and cloud-based systems will promote seamless data exchange and collaboration, enabling stakeholders to leverage the strengths of each technology. As computational power continues to increase, more robust infrastructure will emerge that is capable of hosting and managing vast amounts of data with greater efficiency and scalability. Additionally, to ensure the widespread and successful adoption of these technologies, it will be crucial to address implementation challenges such as technical constraints, data accessibility issues, and institutional barriers.

3.3.3. Visualisation and User Interface Design

Effective visualisation and user interface design are imperative in natural hazard management, enabling stakeholders to efficiently comprehend and mitigate environmental risks. Through intuitive interfaces, complex geospatial data on hazards such as floods, earthquakes, wildfires, and hurricanes can be accessed and analysed swiftly, facilitating informed decision making. For instance, interactive maps overlaying floodplain data with infrastructure locations aid in identifying at-risk areas for evacuation planning, while real-time seismic activity visualisations assist in issuing timely warnings. Web-GIS further revolutionises this field by seamlessly integrating geospatial data with web-based interfaces, enhancing accessibility, interactivity, and collaboration. Citizens can track wildfires and receive evacuation alerts through user-friendly web interfaces, while data sharing among multiple agencies is streamlined, improving coordination during emergencies. This synergy between visualisation, user interface design, and Web-GIS not only enhances situational awareness but also empowers communities to proactively mitigate and respond to natural hazards effectively.

Leveraging animated time series simulation data [64,73] enables users to grasp the evolving dynamics of hazards such as floods [82], empowering them to make timely and informed decisions. Moreover, integrating 3D visualisation techniques immerses users in lifelike representations of geological phenomena, facilitating more profound understanding and enhancing situational awareness [27,65,76,79,83]. Similarly, effective visualisation by creating 3D models for non-expert consultation enhances public engagement and comprehension [67]. The Volcanic Hazards Assessment Support [75] System ensures a user-friendly Web-GIS interface design for visualising simulation results. In contrast, the efficiency of the Web-GIS interface in displaying and analysing earthquake hazard data is underscored in another study [72].

Symbolic representations and colour coding provide intuitive means of conveying complex information, accommodating diverse user preferences and cognitive styles [27,52,62,66,70,84]. UI/UX design principles emphasise user interaction and accessibility, prioritising user-centric approaches [42,50,62,80,85]. These approaches focus on understanding user needs and workflows to create interfaces that seamlessly integrate into their decision-making processes. The READY platform [62] prioritises efficient visualisation and user interface design, implementing "experimental graphic semiology" principles. Its design features include a centralised map, a sizable legend on the right, and additional information at the bottom for user accessibility. This design approach facilitates non-technical users in rapidly creating customised flood awareness and resilience maps [8].

The ease of navigation and intuitive controls, as emphasised by studies [47,53,60,86,87], ensure that users can traverse through vast datasets and perform tasks with minimal cognitive load, including [53] where using a progressive web application for data visualisation and user engagement is beneficial. Advocating for accessibility ensures that users of varying technical proficiency can effectively engage with the system [71,88–90]. Personalised risk perception [64,78,79,88] empowers users to make informed decisions aligned with their unique circumstances. Critiquing traditional text- and verbal-based public warnings, advocates emphasise the need for improved user interfaces to facilitate personalised risk perception and decision making during crises [88]. It specifically addresses the design of public warning maps and the need for improved user interfaces to facilitate personalised risk perception and decision making.

In educational contexts, integrating web-based hazard maps offers interactive learning experiences that transcend the limitations of traditional paper maps [71]. By engaging high school students with dynamic web maps, educators can foster a greater understanding of disaster risk areas and mitigation strategies, thereby cultivating a new generation of informed citizens equipped to navigate natural hazard scenarios with resilience and confidence.

Furthermore, incorporating community engagement features [52,58,78] promotes collaboration and knowledge sharing among diverse stakeholders. These platforms democratise the hazard management process by providing avenues for public input and feedback, ensuring that community voices are heard and local knowledge is leveraged to inform decision making.

In the quest for advancing natural hazard management, the evolution of Visualisation and User Interface Design holds promising avenues, with emerging technologies such as Virtual Reality (VR), Augmented Reality (AR), and the Metaverse poised to redefine the landscape. Incorporating VR and AR into Web-GIS platforms could offer immersive experiences, allowing stakeholders to explore hazard scenarios in realistic environments. By getting into VR headsets, emergency responders could simulate evacuation routes or assess infrastructure vulnerabilities, while AR overlays on mobile devices could provide on-the-ground insights during crises. Moreover, integrating Metaverse concepts into Web-GIS can create persistent, interconnected virtual environments where real-time hazard data are seamlessly visualised and collaboratively analysed by users across geographical boundaries.

3.3.4. Decision Support Systems

Decision Support Systems (DSSs) integrated with Web-GIS are vital for natural hazard management. They combine geospatial data, analytical tools, and user-friendly interfaces to help stakeholders assess risks, plan responses, and allocate resources effectively. Real-time information, historical data, and predictive modelling empower decision makers, ultimately saving lives and minimising disaster impacts. However, to ensure success, these systems must address challenges in data interoperability, system compatibility, and scalability for seamless integration.

To further enhance decision making, DSSs leverage cutting-edge technologies to forecast and monitor various hazards, ranging from landslides and seismic events to debris flows [40,44,87]. By providing real-time alerts and enabling swift civil protection responses, they serve as linchpins in bolstering community resilience against the ravages of natural disasters. Illustrating the effective use of DSSs during seismic events [44] provides the development of a Web-GIS platform for the seismic risk assessment of bridges. This platform offers capabilities such as real-time damage scenarios, seismic risk maps, and network analysis, guiding decisions effectively.

Operational Early Warning Systems, integral components of proactive risk mitigation strategies, utilise advanced data analytics to issue timely alerts based on space–time rainfall patterns [63,91]. Enriching the decision-making landscape during crisis situations, Interactive Decision-Making Platforms foster collaborative engagement among stakeholders and experts [82,92].

The practical impact of DSSs is vividly illustrated through tangible examples in real-world scenarios. In northeastern Italy, a prototype web-GIS tool [82] significantly aids risk analysis in the Fella River basin, thereby enhancing the decision-making process regarding risk management strategies. Similarly, in Taiwan, the "Portrait-based Disaster Alerting System" [40] seamlessly integrates Web-GIS and sensor technology to monitor landslide hazards effectively for local authorities. Moreover, Italian Civil Protection leverages a Web-GIS platform [44] for seismic vulnerability assessment, enabling prompt and accurate damage assessments. In another context, the participative decision support platform [93] implemented in Italy's Malborghetto Valbruna municipality enhances stakeholder coordination in areas prone to flash floods and landslides. Preliminary feedback underscores its role in fostering collaboration among various risk management institutions by integrating stakeholders' local knowledge into decision-making processes. Additionally, the eForestFire system [59] deployed in India achieves remarkable success, reducing reported forest fire cases by 31%, thus highlighting its effectiveness in resource allocation and early warning. Similarly, collaborative frameworks for hazard management underscore the critical role of stakeholder engagement and iterative evaluation in shaping adaptive disaster response strategies [64,85].

Integrating DSS with Web-GIS technology assumes paramount importance in enhancing risk awareness and fostering community engagement, especially in the face of floods [46] and seismic events [94]. Employing sophisticated modelling techniques, Seismic Risk Assessment and Mitigation frameworks gauge seismic vulnerabilities and inform proactive hazard management measures [74,75]. Climate Risk Management approaches also leverage GIS platforms to evaluate vulnerabilities and devise targeted protective strategies for vulnerable cultural heritage sites [58].

Forest fire danger assessment systems, powered by diverse datasets, deliver comprehensive evaluations of fire risks, empowering stakeholders in forest fire prevention and response efforts [48]. Semantic Technologies for Risk Assessment augment decision-making capabilities by providing nuanced insights into urban risks and vulnerabilities [95]. Real-time reporting and visualisation tools enable strategic resource allocation and predictive modelling, optimising response efficiency in dynamic hazard scenarios [59].

Facilitating swift decision making and effective emergency response, Rapid Response Systems furnish timely and accurate information during seismic events and coastal hazards [27,31]. Flood risk management strategies leverage Web-GIS DSS to communicate flood risks effectively and guide decision making at various administrative levels [57,80]. Presenting a web-based DSS for urban flooding mitigation [57,80] utilises GIS WATER and EPA's SWMM for detailed case studies. Additionally, MOSAIC [54], a Web-GIS-based DSS for coastal hazard prediction, is introduced. This system integrates real-time monitoring data and predictive numerical models, employing tools such as the OPENCoastS forecast service with SCHISM and XBeach models.

Similarly, the Soil Erosion Assessment framework [55] utilises GIS-based DSSs to predict soil loss and prioritise conservation measures in vulnerable watershed areas. Lastly, 3D Spatial Analysis for Emergency Response systems enhances situational awareness and response capabilities during crises, embodying the synergy between technology and resilience in hazard management [69].

In conclusion, DSSs integrated with Web-GIS are invaluable tools for natural hazard management. They empower decision makers with forecasting capabilities, real-time monitoring, and collaborative platforms, aiding in proactive risk mitigation and effective response. To maximise their potential, addressing data interoperability, system compatibility, and scalability remains crucial. By focusing on these aspects, the capabilities of Web-GIS DSSs can be further enhanced, strengthening resilience against natural disasters.

3.3.5. Real-Time Monitoring and Early Warning

Real-time monitoring is paramount in natural hazards as it provides timely insights into evolving environmental conditions, enabling proactive responses to mitigate potential risks. While valuable, traditional GIS often needs help keeping pace with the dynamic nature of real-time data, underscoring the need for more agile solutions and entering Web-GIS. This transformative approach bridges this gap by seamlessly integrating diverse data sources, sometimes facing challenges of interoperability due to varying data formats and standards, and offering dynamic spatial visualisation. By harnessing the power of Web-GIS platforms, stakeholders can efficiently collect, standardise, and analyse heterogeneous datasets in real-time, facilitating rapid decision making and enhancing overall situational awareness. As the next logical step, integrating early warning systems further enhances the efficacy of real-time monitoring efforts, enabling timely alerts and proactive measures to minimise the impact of natural hazards on vulnerable populations, while addressing potential scalability issues as coverage expands to larger regions.

Initiating with the integration of Web-GIS platforms, heterogeneous datasets are efficiently collected, standardised, and utilised for flood alert determination [45,64]. Deployed during the 2015 Jammu and Kashmir floods, the event-driven system [64] demonstrated its practicality by detecting flood events promptly. This real-life application illustrates its crucial role in improving disaster response mechanisms, emphasising the importance of timely detection in mitigating the impact of natural disasters.

Subsequently, integrating wireless sensor networks with the Analytic Network Process methodology, as proposed and refined by other studies [40,87], showcases its efficacy in predicting slope disasters and debris flow; ensuring compatibility between these systems and Web-GIS platforms is crucial for seamless data flow. Moreover, the development of real-time 3D earthquake information publishing systems [76] underscores dynamic temporal visualisation for prompt hazard detection.

Wildfire management platforms like AEGIS [47] provide real-time access to critical information through remote automatic weather stations and forecast maps. GPS-based data collection strategies for locust tracking [84] emphasise efficient data synchronisation and spatial risk estimation for proactive hazard mitigation. Additionally, the integration of rule-based DSSs, real-time tide gauge measurements [53], and machine learning algorithms [42] for timely hazard detection and alert generation augments the effectiveness of early warning systems.

Furthermore, applying fuzzy time series methods for earthquake forecasting and historical seismic data analysis [96,97] enhances predictive capabilities. Incorporating space–time-variable rainfall thresholds for early warning systems [91] enhances comprehensive hazard detection mechanisms. The deployed landslide early warning system in Tuscany, Italy, leverages these thresholds for real-time monitoring. Illustrated through the December 2013 event, the system demonstrates its efficacy as alerts closely align with actual landslide occurrences, reinforcing its practical value for early warning in real-world scenarios. Efficient debris flow monitoring using wireless sensor networks [87] and integrating spatial information into warning systems [88] advance the precision and scope of early warning mechanisms.

Systems for timely landslide prediction and alert dissemination five days in advance [41] and developing Web-GIS-based DSSs for earthquake mitigation [94] exemplify further advancements in disaster management practices. Additionally, rapid data collection for disaster response [77] and for disseminating real-time hazard information [46,94] through Web-GIS platforms underscore the importance of data accessibility and dissemination in crises.

Moreover, the application for drought early warning in Nigeria [98] and the efficient forest fire monitoring via citizen-centric inputs [59] highlight the role of community engagement in enhancing early warning systems using the Android mobile app [59]. Additionally, the Web-GIS platform for the flood scenario visualisation [49] system includes a forecast sequence constructed for 48 h that helps predict the flooding extent using the total volume of rainfall and estuarine water levels. Furthermore, the platform can display the results for conditions similar to those of the forecasted scenarios, thus aiding in the timely detection of flood hazards. The rapid generation of co-seismic deformation maps using near real-time data [27] provides valuable insights into hazard visualisation and communication strategies. An operational flood forecast and alert system in Portugal [99] and using historical seismic data analysis for earthquake prediction [96] further enhance disaster preparedness and response capabilities.

Moving forward, advancements in GPUs and CPUs will boost the computational power of Real-time Monitoring and Early Warning systems. This will enhance the handling of large-scale real-time data, addressing scalability challenges for wider coverage and diverse data integration. Ensuring compatibility between Web-GIS platforms and data sources, along with overcoming interoperability issues through standardisation, will streamline these processes for more efficient and accurate disaster management. Ultimately, Real-time Monitoring and Early Warning using Web-GIS offer a transformative approach to building resilience and safeguarding communities against natural disasters.

3.3.6. Disaster Recovery and Resilience

Within the sphere of natural hazard management, Disaster Recovery and Resilience encompass methodologies and tools to mitigate damage, facilitate recovery, and fortify community capacities to withstand and rebound from catastrophic events. Unlike conventional GIS methods, Web-GIS offers a dynamic platform that integrates dynamic data, advanced analytics, and decision-support mechanisms tailored specifically for mitigating the impact of natural disasters, increasing the resilience of community.

Through the integration of sophisticated models like the Resilience Inference Measurement within the CyberGIS framework [90], Web-GIS enables stakeholders to visualise historical hazard exposures and resilience indices, facilitating precise damage assessments and guiding recovery strategies. This dynamic platform fosters stakeholder engagement, empowering decision makers to make informed choices in risk reduction strategies to bolster resilience against future hazards [93]. This perspective is extended by [63], highlighting Web-GIS's capacity to empower communities against flood risks, promoting awareness and adaptive capacity.

Adopting cutting-edge open-source geospatial technologies further enhances Web-GIS's efficacy in rapid damage estimation and hazard inventorying, essential components of informed recovery efforts and infrastructure resilience planning [43,68]. Platforms such as Da.D.O. [74] demonstrate remarkable utility in seismic risk assessment, aiding in developing vulnerability models crucial for post-disaster recovery initiatives. Moreover, enabling authorities to assess the efficacy of recovery efforts and adjust strategies accordingly facilitates the real-time monitoring of resilience metrics [31]. Additionally, deploying Web-GIS in forecasting tools supports efficient post-disaster waste management, further strengthening community resilience [97].

Pre-disaster resilience planning assumes paramount importance in mitigating the impact of natural hazards on communities. Expert-advocated urban classification systems tailored for climate adaptation indirectly inform infrastructure planning and economic assessments, reinforcing the importance of proactive measures in building societal resilience [51]. In conclusion, Web-GIS is a vital tool in natural hazard resilience and recovery efforts, offering unparalleled data integration, analysis, and decision-support capabilities in centralised way. Its role in fortifying community resilience against natural hazards is indispensable, with prospects including advancements in predictive modelling and enhanced data interoperability to further augment its efficacy in mitigating the impact of disasters on the population.

3.3.7. Citizen and Social Media Integration

Integrating citizen and social media within Web-GIS technology heralds a paradigm shift in natural hazard management. This innovative approach leverages real-time data and community engagement to transcend traditional barriers in information dissemination. It fosters collaborative decision making, enhancing risk assessment, emergency response, and community empowerment. By harnessing citizen observations and social media feeds, authorities can refine hazard mitigation strategies, bolstering resilience in natural disasters.

This transformative synergy is exemplified by incorporating social media and big data, facilitating real-time information gathering through Volunteered Geographic Information and "social sensing" [56,77]. Crowdsourcing technologies, such as those utilised for flood data collection, contribute to global flood cyber-infrastructure and stakeholder involvement [45,92]. Platforms like READY [63] underscore the engagement of communities in flood risk management, offering a Web-GIS tool tailored for citizen use. Fostering a two-way exchange of information empowers individuals to make informed decisions about their safety, enhancing social learning and preparedness.

Furthermore, anticipatory flood risk information provided by fluvial flood forecasting [99] empowers communities while emphasising the pivotal role of community acceptance in urban flood management [57]. Citizen-centric applications like eForestFire [59] and LiDAR-based real-time information systems [46] actively encourage citizen participation in hazard management. Studies also highlight community involvement in cultural heritage documentation and perception surveys, enriching citizen science endeavours [86]. ArcGIS StoryMaps serve as educational tools, enhancing flood risk awareness among individuals [78].

Moreover, community-based Web-GIS finds application in rockfall hazard management and the climate-induced disaster protection of cultural heritage, facilitated by people engagement strategies [7,67]. Integrating indigenous knowledge into landslide early warning systems exemplifies a participatory approach, catering to local stakeholders and indigenous communities [41]. In educational settings, Web-GIS technology educates students about natural disasters, fostering disaster risk awareness in children from an early age [71,89].

In the coming decade, integrating social media into Web-GIS technology will significantly increase user engagement. As more people become accustomed to using social media platforms for various purposes, including sharing information and communicating with their communities, adopting Web-GIS for natural hazard management will likely follow suit. Moreover, implementing reward systems or incentives within these platforms could further encourage user participation and data sharing, leading to a larger pool of real-time data, improving the accuracy and effectiveness of hazard assessments and emergency responses. Additionally, as more individuals contribute to these platforms, the collective knowledge and awareness of natural hazards within communities will likely increase.

3.3.8. Multi-Stakeholder Collaboration

In today's interconnected world, stakeholder collaboration in Web-GIS holds untapped potential for effective natural hazard management, especially amidst the escalating challenges of climate change. This collaboration transcends geographical boundaries, engaging stakeholders from governments, non-governmental organisations, research institutions, and local communities. By leveraging shared platforms that synthesise data and expertise, one can better address hazards with transnational impacts. This collaborative, Web-GIS driven approach embodies the global village concept, fostering international cooperation, preparedness, and comprehensive disaster mitigation policies.

While the literature recognises the promise of collaborative Web-GIS platforms, this field remains underexplored. Calls exist for enhanced communication between countries and their people, integrated hazard information, and interdisciplinary strategies [92]. To tackle climate change-induced disasters, there is a need for tailored Web-GIS tools. Proposals advocate for a standardised European approach to address these complex challenges [7]. Of course, complexities exist, such as establishing robust spatial data infrastructures and integrating advanced models for hazards like rockfalls [66].

This collaboration empowers stakeholders at all levels with tools and knowledge to build cross-border resilience. By fostering partnerships, integrating diverse perspectives, and promoting knowledge exchange, the impact and sustainability of these technological solutions are maximised. Numerous studies illustrate the power of collaborative data initiatives: government-funded LiDAR surveys in the Philippines [46], real-time contributions to OpenStreetMap [68], and research partnerships like those with the Italian Civil Protection [44]—all demonstrate a commitment to data-driven preparedness and collaboration.

Beyond data sharing, many projects advocate for the active participation of stakeholders in the Web-GIS design process. The Nepalese Landslide Information System employed surveys, interviews, and workshops to ensure the tool addressed the specific needs of governmental agencies, NGOs, and local communities [81]. Other systems place local communities at the forefront, developing Android-based applications that empower citizens to report forest fire incidents directly, optimising resource allocation for fire mitigation [59]. This participatory approach fosters ownership and wider acceptance of Web-GIS tools.

Effective communication is paramount in natural hazard management. The development of interactive fluvial flood forecast and alert systems in conjunction with civil protection authorities and citizens [99] underscores the importance of integrating end-users for better response outcomes. Tools like WildFireChat [69] facilitate communication across command centres, optimising data flow for coordinated responses. Similarly, the coastal risk observatory in Brittany, France [86], integrates diverse stakeholder inputs to inform coastal risk management. Web-GIS platforms are proving instrumental in bridging the gap between scientific expertise and the tactical requirements of those on the frontlines of disaster response.

Web-GIS plays a vital role in protecting cultural heritage from the impacts of climate change-induced disasters. Emphasising the engagement of owners and managers of cultural assets [7], tools like manuals for resilience and transnational rescue procedures promote proactive collaboration. This highlights the adaptability of Web-GIS in safeguarding cultural treasures, empowering stakeholders through knowledge sharing.

This overview demonstrates the multifaceted nature of stakeholder collaboration in the Web-GIS context for natural hazard management. From fostering cross-border partnerships [63,91,93] to empowering local communities [21,67] and heritage experts [31], Web-GIS serves as a powerful platform for aligning diverse needs and expertise. By promoting integrated frameworks, open-source solutions, and a focus on shared knowledge, stakeholder collaboration maximises the potential of Web-GIS for safeguarding communities and building resilience against the challenges of natural hazards.

4. Conclusions

This paper presents a thorough investigation into the integration of Web-GIS technologies in the management of natural hazards. The review of the selected 65 articles has highlighted the essential subtopics within the field, underscoring the comprehensive capabilities of Web-GIS. Specifically, the various facets of hazard management are explored in depth, encompassing hazard distribution, modelling, technological infrastructure, Visualisation and User Interface Design, and advancements in Decision Support Systems and spatial analysis. As frequently mentioned, it is critical to recognise confluences among these topics, reinforcing their strategic value and the system's scalability. Moreover, the insight provides a profound understanding of the diverse realms of natural hazard management, covering landslides, floods, seismic events, wildfires, coastal hazards, and heat waves.

The conclusion drawn from this systematic review is that Web-GIS is a critical asset in the ongoing effort to refine integrated and multi-hazard management. It has become increasingly apparent that Web-GIS technology not only supports real-time data analysis and decision making but also enhances the efficacy of emergency response protocols and strategic planning for resilience building. Integrating Web-GIS into the natural hazard framework has already shown promising results in seismic risk assessments, flood management, and urban disaster preparedness. This innovation trajectory is expected to evolve by including more sophisticated 3D modelling techniques among GIS and BIM environments and the convergence of Web-GIS with other cutting-edge technologies like Artificial Intelligence, Blockchain, and cloud computing within the paradigm of the Digital Twin. As these fields mature, they will offer unprecedented opportunities to enhance situational awareness, risk evaluation, and predictive capabilities, thereby prioritising effective mitigation strategies.

Findings from this analysis suggest that the future of Web-GIS is intrinsically linked to the development of more intuitive and accessible user interfaces, which would allow for more personalised and community-focused approaches to hazard management. Indeed, data visualisation techniques are critical for improving stakeholder engagement and decision making.

In addition, as climate change progresses, the necessity for dynamic and adaptable systems becomes more urgent. Web-GIS is poised to address this need by facilitating the integration of climate data into risk assessments, thus supporting more resilient infrastructure and informed land-use planning.

The escalation in the scope and utility of Web-GIS is paving the way for more comprehensive international collaborations that transcend geographical boundaries. The shared experiences and data derived from global partnerships will enhance the creation of standardised practices and protocols for disaster management across different regions.

In the end, this review has presented a detailed perspective on how Web-GIS has the potential to revolutionise the field of natural hazard management. By fostering progressive improvements and harnessing the collaborative spirit among various stakeholders, the hope is to see a world where communities are better informed, prepared, and capable of withstanding the challenges posed by natural disasters, making significant strides towards global sustainability and safety.

5. Limitation of Study

The findings from our systematic review are contingent upon the context of the 65 curated articles revolving around Web-GIS for natural hazard management. This review focuses on the literature delineated by strict inclusion criteria, including relevance, citation impact, and publication date, which may inadvertently overlook studies outside these parameters. A potential limitation stems from excluding non-peer-reviewed literature, grey literature, or seminal works published before the defined timeframe, possibly containing foundational insights or alternative perspectives. Moreover, it is possible that the potentially high-impact research published [100,101] very recently compared to the period under consideration may not have been considered, because of its still-young citation history. This study is mainly based on articles with high citation impact. Nonetheless, comprehensiveness was a priority in our review, employing a broad spectrum of search terms and databases like SCOPUS, Web of Science, and others to capture relevant data and extend reach with Google Scholar to mitigate any database indexing limitations. Although this approach streamlines the review to the most salient and current studies in the field, it may only partially represent part of the research in Web-GIS applications for hazard management. Despite these potential caveats, this systematic review synthesises critical insights into Web-GIS applications in natural hazard management, thus contributing to the strategic development of related policies and practices worldwide.

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Appendix A

Table A1. Search syntax.

Search Query (Date of Search: 6 March 2024)
(TITLE-ABS-KEY (“web GIS” OR web-gis OR webgis* OR “internet GIS” OR “WEB MAPPING” OR “WEB VISUALISATION” OR “Web Portal” OR “WEB TOOL” OR “web technology” OR “online platforms” OR “ONLINE TOOL” OR “online mapping” OR “GEOPORTAL” OR “mapping tool” OR “visualisation tool” OR “interactive mapping” OR “geospatial visualisation” OR e-learning) AND TITLE-ABS-KEY (hazard* OR disaster* OR risk* OR mitigation* OR assessment*) AND TITLE-ABS-KEY (gis* OR “geographic information science” OR “geospatial analysis” OR “spatial analysis” OR “remote sensing” OR geoinformatics OR geodatabase)) AND PUBYEAR > 2013 AND PUBYEAR < 2024 AND (LIMIT-TO (SUBJAREA, “EART”) OR LIMIT-TO (SUBJAREA, “COMP”) OR LIMIT-TO (SUBJAREA, “ENGI”) OR LIMIT-TO (SUBJAREA, “ENVI”) OR LIMIT-TO (SUBJAREA, “SOCI”) OR LIMIT-TO (SUBJAREA, “MATE”) OR LIMIT-TO (SUBJAREA, “DECI”) OR LIMIT-TO (SUBJAREA, “MULT”)) AND (LIMIT-TO (DOCTYPE, “ar”) OR LIMIT-TO (DOCTYPE, “re”)) AND (LIMIT-TO (LANGUAGE, “English”)) AND (EXCLUDE (EXACTKEYWORD, “COVID-19”) OR EXCLUDE (EXACTKEYWORD, “Geology”) OR EXCLUDE (EXACTKEYWORD, “Animals”) OR EXCLUDE (EXACTKEYWORD, “Geophysics”) OR EXCLUDE (EXACTKEYWORD, “Economics”) OR EXCLUDE (EXACTKEYWORD, “Animal”)) AND (LIMIT-TO (SRCTYPE, “j”)) AND (LIMIT-TO (PUBSTAGE, “final”))

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