

Geospatial Technologies in Managing Urban Cascading and Compound Disasters: A Bibliometric Review

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Abstract

Urban environments face increasingly complex disaster scenarios involving cascading and compound events, yet most research focuses on isolated hazards. While geospatial technologies have advanced significantly, their integration into urban planning for multi-hazard scenarios remains poorly understood. This bibliometric study examines geospatial research on urban cascading and compound disasters from 2000 to 2025, analysing publication trends, hazard combinations, technology adoption patterns, and integration with urban planning. A systematic search identified 235 papers from Scopus and Web of Science and a bibliometric analysis was conducted using Bibliometrix and VOSviewer. Results reveal exponential growth, with 74% of publications appearing between 2020 and 2025. Research remains concentrated in Asia, Europe, and North America, with vulnerable regions like Latin America underrepresented. Hazard analysis shows a strong bias toward rapid-onset geophysical cascades (earthquake-landslide, flood-landslide, and earthquake-tsunami). In contrast, slow-onset combinations such as fire-drought and volcanic cascades remain critically understudied. Geospatial technology adoption follows a clear pattern: spatial data integration frameworks, particularly Geographic Information Systems (GIS) and remote sensing (RS), dominate the literature, followed by data acquisition and observation technologies, particularly Unmanned Aerial Vehicles (UAVs), while computational and analytical environments such as Google Earth Engine (GEE) remain emerging. Most critically, only 11% of papers integrate geospatial approaches with urban planning processes, revealing a significant research-practice disconnect. Despite advances in hazard detection and modelling, operational translation into zoning regulations, building codes, and infrastructure planning remains limited. This gap is particularly concerning in dense urban systems, where cascading disasters intensify and integrated geospatial planning frameworks are most urgently needed.

1. Introduction

Nowadays, natural disasters rarely occur in isolation. An earthquake may trigger a tsunami, and a tsunami may cause a nuclear reactor leak. One disaster often triggers another, creating a chain of compounding and cascading events that cause devastating impacts on communities and cities. These cascading disasters ultimately inflict severe economic losses, often exceeding communities' capacity to respond with conventional approaches (Moddemeyer et al., 2022). This phenomenon is occurring rapidly in urbanised areas, where the effects of climate change further intensify the expansion of natural disasters beyond single-hazard scenarios. A cascading catastrophe is a sequence of events in which one natural hazard triggers another, whereas a compound disaster involves the simultaneous occurrence of multiple hazards. Both types of events, however, can severely exacerbate the impacts on affected communities (Cutter, 2018). Often described as the domino effect, a cascading disaster is a phenomenon in which the impact of a hazard spreads across physical, environmental, social, and institutional systems, creating secondary effects that may be even more severe than the initial event (Alexander & Pescaroli, 2019).

Several catastrophic events highlight the complexity of cascading and compound disasters. The 2011 Great East Japan earthquake, with a magnitude of 9.0, triggered a massive tsunami, which subsequently caused the Fukushima Daiichi nuclear disaster (Anzai et al., 2012; Mori et al., 2012). Similarly, in January 2018, heavy rainfall triggered a series of debris flows from slopes destabilised by wildfires a month earlier, sending a

5-meter wave of mud and debris down the hillsides of Montecito, Santa Barbara, California, and killing 21 people (Vahedifard & AghaKouchak, 2018). In 2017, the United States experienced 16 separate natural disasters, including three major hurricanes (Harvey, Irma, and Maria), floods, a drought, a wildfire, a freeze, and multiple severe storms, resulting in a record \$306 billion in damages and at least 362 deaths, making it the costliest disaster year on record (National Oceanic and Atmospheric Administration, 2018). This sequence of events illustrates how multiple disasters can occur within a single year, amplifying impacts on both the economy and communities. The 2019–2020 Australian bushfires, commonly known as Black Summer, further illustrate how multiple climate-related hazards, such as drought, extreme heat, and wildfires, can occur simultaneously, leading to severe and unprecedented impacts on urban areas (Filkov et al., 2020).

Geospatial technologies, including remote sensing (RS), Geographic Information System (GIS), and Global Navigation Satellite System (GNSS/GPS), play a key role in risk and disaster management (Aggarwal et al., 2024). They offer integrated tools for data collection, spatial analysis, and visualisation, enabling authorities to predict, detect, and monitor natural disasters; conduct risk assessments; formulate response strategies; evaluate damage extent; and track recovery progress. GIS has proven particularly effective in supporting multi-hazard and multi-risk studies, including cascading events such as earthquakes triggering landslides or floods following wildfires (Kappes et al., 2012). Meanwhile, remote sensing provides high-resolution, up-to-date satellite and aerial imagery of affected areas, which helps to improve the efficiency of

emergency response operations. These technologies are central to disaster management, enabling the integration of multiple data sources to improve situational awareness, decision-making, and coordinated responses. However, further research and development are needed to integrate them with urban planning and governance frameworks and ensure their effectiveness.

A cross-country study found that even in developed countries like France, Austria, and Switzerland, hazard- and risk-informed land-use planning remains challenging, with mayors, officials, and policymakers often perceiving spatial risk information as a barrier to urban development and a challenge to their authority (Der Sarkissian et al., 2022). Besides that, the complexity of urban environments themselves, which include a mix of high-rise and complex facilities, presents new challenges for disaster preparedness and response, particularly in the context of cascading and compound disasters. The current disaster risk management has proven insufficient for integrating multi-hazard data, coordinating responses across different disaster types, and managing emergencies in complex urban settings (Hong et al., 2024). Despite the critical importance of geospatial technologies for urban disaster resilience, a systematic understanding of their evolution, application, and integration with urban planning remains limited.

This bibliometric review analyses 235 peer-reviewed publications to address the following key research questions: (1) What is the evolution of geospatial technologies in managing cascading and compound disasters? (2) How effectively are these technologies being integrated into urban planning for disaster mitigation? (3) What research gaps exist that can guide future investigations? By analysing global research trends, this study aims to inform both the technical development of geospatial approaches and their integration into policy, ultimately enhancing urban resilience to complex, cascading disaster scenarios.

2. Methodology

In this research, a systematic search was conducted across Scopus and Web of Science (WoS) databases, covering documents published from 2000 to 2025. The search query was designed to target publications addressing cascading or compound disasters in urban contexts that utilised remote sensing or geospatial methods.

The Boolean search strings applied within the titles, abstracts, and keywords fields included combinations of disaster-related terms ("cascading disaster," "compound event*," "multi-hazard*"), geospatial terms ("remote sensing," "earth observation," "GIS," "UAV," "drone," "LiDAR"), and urban terms ("urban," "city," "built environment*") for both Scopus and WoS. For clarity, the abbreviations used in the search strings are as follows: UAV (Unmanned Aerial Vehicle) and LiDAR (Light Detection and Ranging). Additionally, the query was restricted to English-language journal articles, reviews, and conference papers.

The query was applied on 30th October 2025, filtering 122 documents from Scopus and 199 documents from WoS. In RStudio, the exported data were converted to R data frames using the "convert2df" function from the Bibliometrix package. The records were then merged using the "mergeDbSources" function. During this phase, duplicates were removed. As a result, 235 English-language peer-reviewed articles, reviews, and conference papers were obtained. The dataset was analysed in R using the Bibliometrix and VOSviewer interfaces. The

analysis includes publication trends, keyword networks, thematic evolution, and hazard-technology patterns. Figure 1 illustrates the bibliometric analysis workflow used in this study.

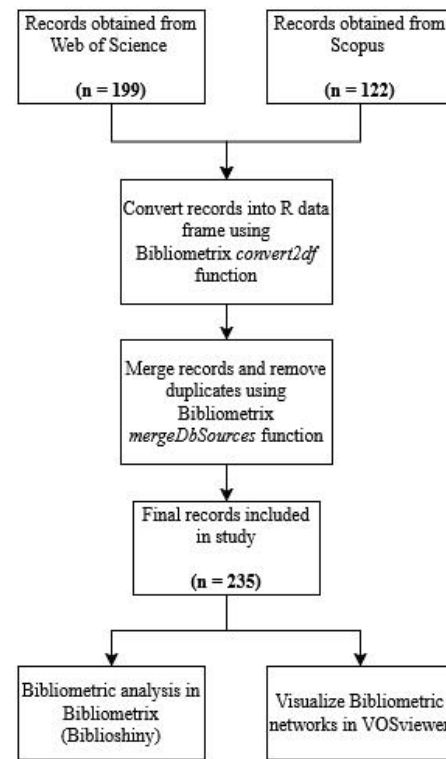


Figure 1. Overview of the systematic search, data processing, and analysis workflow for the bibliometric study.

3. Results & Discussion

3.1 Publication Trends

Figure 2 illustrates the annual scientific production in urban geospatial research on cascading and compound disasters.

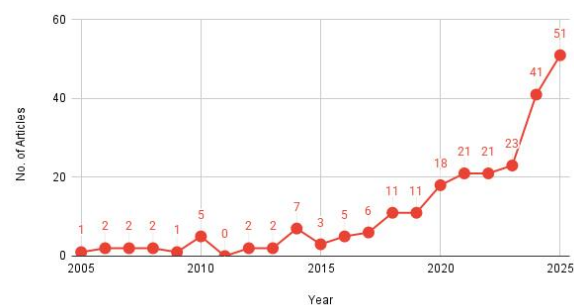


Figure 2. Annual Scientific Production.

The publication trend (Figure 2) shows that only 17 papers were published between 2005 and 2013, with none in 2011 despite the catastrophic Tohoku earthquake–tsunami–nuclear cascade. This suggests that either the frameworks had not yet emerged in geospatial disaster research, the studies did not apply geospatial techniques, or relevant studies used different terminologies, which prevented them from being captured by our search. From 2014 to 2019, a gradual growth phase was observed, with an average of 7 papers per year. This finding coincides with the

adoption of the Sendai Framework for Disaster Risk Reduction in 2015 (Pearson & Pelling, 2015), the operationalisation of Copernicus Sentinel missions in 2014 (Jutz & Milagro-Perez, 2020), and the growing recognition of climate-driven hazard interdependencies (Tilloy et al., 2019). This period likely marked the transition from single-hazard studies toward multi-hazard and compound, cascading frameworks, in both conceptual and technological aspects.

The surge from 2020 to 2025 (74% of total output) reflects the field's increasing global recognition of cascade dynamics as a distinct research domain. It also reflects the community's awareness of the need to address disasters not as a single entity, but with their connections to one another.

3.2 Geographic Distribution

Figure 3 presents a map of scientific production by country from 2000 to 2025, and Table 1 shows the top 10 countries by author affiliation contributions. In this study, it is important to distinguish between two geographies embedded in the extracted dataset: the geography of knowledge production, where authors are institutionally based and the geography of disaster study, where the studied events occurred.

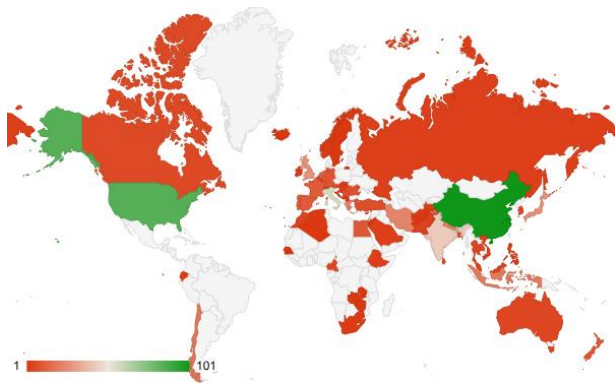


Figure 3. Countries' Scientific Production (2000 - 2025).

Country	Published Articles
China	101
Usa	85
Italy	57
India	43
Japan	27
Uk	27
Greece	23
Iran	23
Nepal	22
Indonesia	20

Table 1. Top 10 Countries by Author Affiliation Contributions (2000–2025)

The map in Figure 3 and Table 1 present the distribution of scientific production by country based on the total author affiliations rather than unique publication counts. Therefore, publications with multiple authors from different countries are counted multiple times, once for each country represented. To further examine whether research capacity aligns with the geographical distribution, a supplementary analysis was conducted by extracting the countries where the research was conducted from the titles, abstracts, and author keywords. These

locations were then compared with the countries of the authors' affiliations.

Out of the total 235 papers, only 122 papers had complete information on the author affiliation and the location of the study area. The results show that 77.9% of these papers involved domestic research, where the study of disasters is within the authors' own country. The remaining 22.1% are cross-national research, which refers to research areas that differ from the authors' country of affiliation, or involves collaboration between researchers from multiple countries examining disaster contexts beyond their own national boundaries. This suggests that most geospatial disaster research focuses on researchers' own countries rather than being strategically directed toward highly vulnerable and underrepresented regions. However, as study-area identification was based on text mining of titles, abstracts, and keywords, the method used in this study may have missed some case-study locations, particularly in studies involving multiple locations or where the study area was not explicitly stated.

The analysis on the geographical location reveals that the studies heavily focus on Asia, Europe and North America, with approximately 75% of all the publications. When the study locations were analysed separately from the authors' affiliation, India (n = 16), Italy (n = 13), and China (n = 12) still appeared as the most frequently studied countries, closely reflecting the author-country distribution (China: 14, India: 14, Italy: 14). This pattern suggests that countries with higher research output tend to focus on their own disaster contexts. In contrast, regions that are highly affected by cascading disasters remain underrepresented in both research production and study focus.

Latin America contributed only 21 authored papers, with Chile accounting for the majority with 19 publications. Chile is also the most frequently studied country in the region (n = 5). Sub-Saharan Africa, Southeast Asia (except Indonesia), and Small Island Developing States (SIDS), which are small and vulnerable island nations, are largely absent from the research, either as study areas or as contributors. This imbalance may be due to stronger research capacity and funding in developed countries, as well as language barriers and differences in terminology that may limit research visibility in these regions. Consequently, cascade-focused geospatial knowledge remains concentrated in high-capacity regions rather than in the vulnerable areas where it is most urgently needed. Future research should prioritise open-access data platforms and international collaboration to expand both knowledge production and disaster documentation in underrepresented regions.

3.3 Evolution of Geospatial Technologies

Over the years, geospatial technologies have evolved from simple mapping tools into integrated analytical systems that support spatial decision-making in urban disaster studies, making them essential for urban disaster analysis. These technologies can be grouped into three categories based on how they are applied in cascading disaster research, rather than how they are formally defined in the broader geospatial literature or technical specifications:

- **Spatial data integration frameworks:** GIS, RS, and GNSS/GPS.
- **Data acquisition and observation technologies:** LiDAR, UAVs, photogrammetry, Synthetic Aperture Radar (SAR),

and various satellite platforms.

- **Computational and analytical environments:** Digital Elevation Models (DEMs), Google Earth Engine (GEE), image processing algorithms, and environmental sensors.

The first group, Spatial Data Integration Frameworks, encompasses technologies which are primarily used in managing, integrating, and visualising spatial information. Even though fundamentally remote sensing is a data acquisition discipline, it is included in the first group because of its frequent role in providing core datasets that are directly integrated within GIS-based analytical workflows in the reviewed studies. Meanwhile, Data Acquisition and Observation Technologies (Group 2) covers the hardware and sensor systems that capture primary geospatial data. Finally, the Computational and Analytical Environments group includes computational platforms such as GEE, analytical algorithms, and commonly used derived geospatial products such as DEMs that enable modelling, processing, and cloud-based analysis. This categorisation helps to reduce the ambiguity arising from the mixed use of terms referring to disciplines, platforms, datasets, and analytical tools in the literature.

Figure 4 shows the geospatial technologies that appeared in either titles, keywords or abstracts of the extracted literature. Overall, Group 1 (64%) dominates the literature, followed by Group 2 (21.5%) and Group 3 (14.5%).

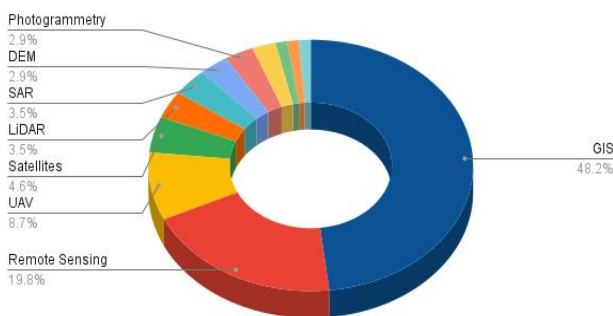


Figure 4. Geospatial Technology Frequencies.

To further examine the evolution of geospatial technologies in the context of urban cascading and compound disasters, the dataset spanning 2000–2025 was divided into three periods: 2000–2010, 2011–2018, and 2019–2025 (Figure 5).

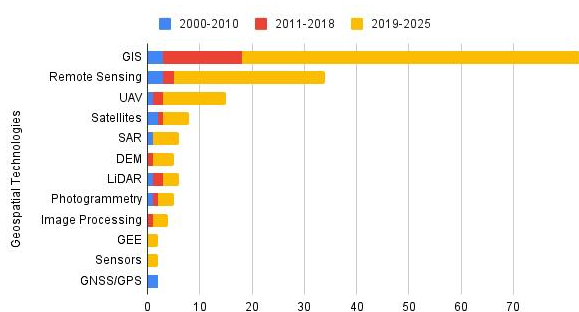


Figure 5. Geospatial Technology Evolution Across Three (3) Periods (2000-2010, 2011-2018, 2019-2025).

The dominance of spatial data integration frameworks, particularly GIS and Remote Sensing, stems from their role in providing the conceptual and operational foundation for spatial

disaster analysis. GIS's rapid growth after 2010 corresponds to the period during which it matured into a universal integration environment capable of processing data from multiple sources, such as LiDAR point clouds, UAV imagery, and DEMs. Delving deeper, while GIS and Remote Sensing experienced remarkable growth throughout the three periods, GNSS/GPS showed negative growth, eventually being completely absent in Periods 2 and 3. Rather than interpreting this as obsolescence in this field, this pattern suggests that GNSS/GPS has reached maturity and been integrated into broader systems, such as GIS and cloud-based technologies like GEE, operating as critical infrastructure for the precise perception of time and space events. Its disappearance from keyword vocabularies likely reflects its transformation into foundational infrastructure rather than a discrete analytical technology.

Meanwhile, the technologies in Group 2 function as sensory components, providing crucial support to GIS and remote sensing systems by feeding them with data. LiDAR, UAVs, and SAR systems, in particular, have revolutionised data acquisition by offering fine-scale, near-real-time observations. Most technologies in this group show a steady upward trend, especially during Period 3. Among them, UAVs stood out, with the highest growth rate between 2019 and 2025. What sets them apart from other technologies is their unique role in post-disaster assessment, where rapid and safe data collection is critical. Their portability, manoeuvrability (including the ability to navigate under tree canopies), and high-resolution imaging make them an indispensable tool for mapping surface features inaccessible to airborne or satellite imaging systems. This versatility makes UAVs a preferred tool in post-disaster research and field deployment (Ybañez et al., 2021; D'Urso et al., 2020).

Finally, Group 3 represents the computational backbone of the geospatial workflow and marks the emergence of computational transformation in recent years. The rise in popularity of GEE, image processing automation, and sensor network analytics aligns with the global shift toward cloud computing, AI-driven modelling, and integrated environmental monitoring. Their relatively low frequency reflects their novelty in this domain. Furthermore, they signify the next evolutionary stage of geospatial technologies in cascading-disaster research. Moreover, the emergence of these technologies post-2010 coincides with the era of big data and the public availability of Google Earth Engine (Gorelick et al., 2017). Overall, Group 3 reflects the emergence of new technologies, which is why the majority of the rise occurs in the third period. It is also in the third period that AI/ML started to be incorporated with other geospatial technologies for disaster analysis, reflecting the increasing use of deep learning applications across remote sensing workflows (Ma et al., 2019) and cloud-based geospatial platforms (Gorelick et al., 2017).

A general pattern emerges from these findings: geospatial technologies as a whole began with a strong foundation, expanded through multi-sensor and high-resolution data acquisition, and progressed towards automation and AI integration.

3.4 Geospatial Applications Across Disaster Types

We further explored disaster chains in the literature to investigate which disasters are commonly studied together. Papers focusing exclusively on a single hazard or without explicit geospatial components were excluded from this cascade analysis ($n = 123$), as the aim was to examine multi-hazard interactions alongside the geospatial technologies applied to them. Multi-hazard combinations were grouped into dominant cascade types such as earthquake–landslide, flood–landslide, and earthquake–tsunami. As shown in Table 2, geophysical and hydro-meteorological cascades dominate the research landscape, with earthquake–landslide ($n = 29$, 26%) and flood–landslide ($n = 22$, 20%) combinations being most prominent, followed by earthquake–tsunami sequences ($n = 19$, 17%). This distribution likely reflects both the catastrophic nature of these events and the availability of geospatial data following major disasters such as the 2011 Tohoku earthquake–tsunami (Mori et al., 2012) and the 2015 Nepal earthquake–landslide sequence (Kargel et al., 2016).

Disaster Chain	Papers (n)
Earthquake-Landslide	29
Flood-Landslide	22
Earthquake-Tsunami	19
Earthquake-related	15
Storm-Flood	11
Flood-related	10
Fire-Drought/Heat	2
Storm-related	2
Other multi-hazard	1
Volcanic-related	1

Table 2. Distribution of Disaster Cascade Types

The analysis of multi-hazard research reveals apparent gaps. Common cascades such as earthquake-landslide (29 papers), flood-landslide (22), and earthquake-tsunami (19) dominate the literature, while slower-developing or less obvious combinations are nearly absent. For instance, fire-drought/heat cascades appear in only two studies (1.8%), storm-related cascades in 2 (1.8%), and volcanic-related cascades in 1 (0.9%), despite such events often triggering complex multi-stage disasters in urban areas. This suggests that geospatial research tends to focus on rapid-onset events with clear spatial patterns, overlooking slower, less visible cascades that may pose significant long-term risk.

Figure 6 shows the heatmap distribution of geospatial techniques across cascade and compound disaster types. The colour gradient indicates the number of published papers that use each technique. The darker the shade, the more frequently the research is conducted.

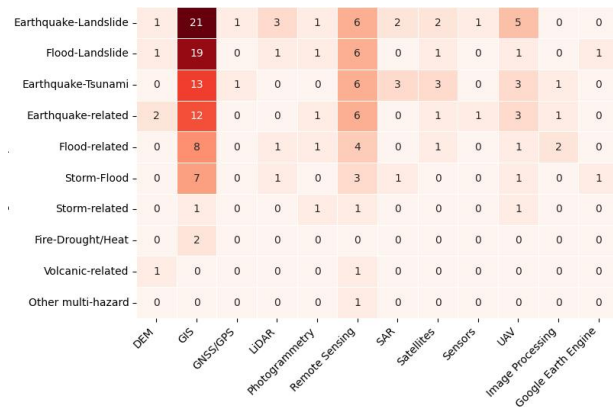


Figure 6. Distribution of Geospatial Techniques by Cascading and Compound Disaster Type.

The application of geospatial technologies varies considerably across disaster cascade types (Figure 6). GIS emerged as the most widely applied technology, appearing in 21 studies related to earthquake-landslides, 19 on flood-landslides, 13 on earthquake-tsunamis, and 12 in earthquake-related research, where it is primarily used for susceptibility mapping and spatial analysis. Meanwhile, remote sensing data appeared consistently across cascade types, especially in earthquake-landslide, flood-landslide, earthquake-tsunami, and earthquake-related studies (6 studies each), although the specific sensor platforms used varied.

However, the combination of geospatial technologies differs based on the nature of the cascade. Earthquake-landslide research demonstrates a broader methodological range than other disaster chains, employing GIS, UAVs, LiDAR, SAR, remote sensing, DEMs, and other tools for post-event terrain assessment and change detection. In contrast, while flood-landslide studies also adopt UAVs and LiDAR, the overall technology diversity remains slightly lower, reflecting that geospatial applications for cascading and compound disasters are still maturing in this research area.

The heatmap reveals that SAR applications are concentrated in earthquake-related cascades, appearing in 3 earthquake-tsunami papers and two earthquake-landslide studies. This pattern reflects radar's all-weather capability for ground deformation monitoring. UAV adoption shows cascade-specific patterns: 5 studies in earthquake-landslide research, 3 in earthquake-tsunami studies, and 3 in earthquake-related papers, but only 1 in flood-landslide research, despite UAVs' proven effectiveness for flood extent mapping and damage assessment (Karamuz et al., 2020; Munawar et al., 2021).

While computational tools such as Google Earth Engine and advanced photogrammetry have started transforming the frameworks of geospatial practices in other areas, their adoption in cascade and compound disaster research remains limited. As shown in Figure 6, GEE was reported in only two studies, and photogrammetry in five, suggesting that cloud-based and 3D reconstruction methods are still emerging in this field. This gap may partly reflect the delayed methodological translation of mainstream remote sensing advances into cascading and compound disaster research. It is also possible that some studies employ these technologies without explicitly referencing them in titles, abstracts, or keywords, which bibliometric approaches cannot fully capture. Overall, the observed geospatial adoption patterns suggest that while rapid-onset cascades are well-studied with diverse geospatial methods, slower or less visible disaster chains remain understudied.

methodology core (green cluster, Cluster 2). This indicates limited integration between planning and technical research domains despite their co-occurrence with disaster management and resilience concepts.

This pattern reveals a significant research-practice disconnect. Despite substantial growth in geospatial disaster research and advancing technical capabilities (machine learning, multi-sensor integration, high-resolution data), practical urban planning applications lag. Current studies remain essentially detached from planning practice, focusing on hazard characterisation and susceptibility mapping rather than on operational planning processes that translate risk knowledge into regulatory frameworks, land-use decisions, or infrastructure design standards. Additionally, there is a crucial need to develop suitable policies that reflect the latest research advancements to ensure that findings effectively inform governance and decision-making in urban settings.

This gap is particularly concerning, as cities with dense, interconnected systems, are where cascading disasters tend to intensify and where integrated geospatial planning approaches are most urgently needed. Interconnections among power grids, water systems, road networks, and buildings often trigger and intensify cascading and compound disasters in urban areas. Urban planning precisely controls these interconnections through zoning, building regulations, and infrastructure layouts, making planning decisions critical for reducing cascade risks. The disconnect between advances in geospatial capabilities and planning frameworks suggests a critical knowledge translation barrier: although ongoing efforts are being made to embed sophisticated tools for detecting and modelling cascading dynamics into operational planning, these initiatives may not be sufficient to shape urban development and disaster risk management effectively.

4. Conclusion

This bibliometric analysis of 235 papers on urban cascading and compound disasters (2000–2025) reveals a field experiencing fast technical advancement. Nevertheless, findings from the keyword networks reveal that geospatial methods are evolving faster than their integration into planning practice. Furthermore, the tools capable of modelling these dynamics remain significantly isolated from zoning codes, building regulations, and land-use planning, which are essential for urban planning. Without bridging this gap, these technical methodologies will remain academic exercises rather than practical decision-support tools for resilience building. Moreover, effective integration requires not only embedding geospatial tools within planning systems but also strengthening their linkage to risk assessment and management frameworks.

This study's bibliometric approach has several limitations. First, it captures only what is explicitly stated in the metadata fields (such as titles, abstracts, and keywords). In other words, technologies like Google Earth Engine may be more widely used than documented. Second, the analysis focuses on published literature and may therefore overlook government reports or operational tools used by practitioners but not formally published. Finally, the focus on English-language databases (Scopus, Web of Science) may underrepresent research from vulnerable regions published in local languages or regional journals.

Based on the findings of this research, three possible directions for future work could be proposed. First, geospatial tools should

be integrated into planning workflows to embed proactive risk reduction in urban development processes. Second, strengthening research capacity and data accessibility in underrepresented regions through open-access platforms and international collaboration is essential to expand this research area globally. Third, interdisciplinary work should move beyond conceptual theory toward practical frameworks that connect geospatial insights with planning rules and regulations.

As cities continue to expand and climate change further amplifies multi-hazard urban risks, the gap between what geospatial technologies can offer and what planning systems can act upon becomes increasingly concerning. Instead of focusing on technical sophistication, future progress should move towards institutional innovation that embeds geospatial intelligence into the regulatory and decision-making structures that shape urban form. Ultimately, the challenge is no longer proving that cascading disasters exist or that geospatial tools can track them, but rather ensuring these tools inform the everyday planning decisions that determine urban resilience.

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