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Disaster Risk Assessment and Analysis of Physical Infrastructure: A Comprehensive Review of Scientific Methods and Techniques

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Abstract Physical infrastructure plays a crucial role in fostering economic development and societal well-being. However, they are susceptible to potential impacts when exposed to various hazards, which makes risk assessment and analysis essential for ensuring resilience. This paper presents a comprehensive review of the extant literature to provide an in-depth understanding of the research landscape developed to assess and analyze disaster risk to physical infrastructure. The objectives of this study are 1) to comprehend the disaster risk assessment methods and techniques from the global literature, 2) to analyze the trend and growth pattern of research on disaster risk assessment and 3) to identify the nuances in the methods for assessing disaster risk. This study employs bibliometric analysis along with a comprehensive literature review of selected papers extracted from the Scopus database.

The study realized that research focusing on disaster risk assessment is scarce in developing countries at risk, especially India, Bangladesh, China, and Pakistan. Existing studies have attempted to develop conceptual as well as theoretical frameworks for risk assessment, and also employed assessment methods such as digital twins, risk indices, risk curves, and the like. Furthermore, the study realized that a higher emphasis on assessing the risk of transportation infrastructure disregards the other major physical infrastructure.

The bibliometric analysis further indicates the need for a comprehensive and robust risk analysis tool for physical infrastructure with a standardized quantitative analysis model that can analyze the impacts of hazards. Deep learning coupled with GIS and remote sensing techniques can be considered a promising approach for risk assessment in future research.

In conclusion, this comprehensive bibliometric analysis provides a detailed overview of the research landscape of physical infrastructure risk assessment and analysis. The insights derived

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from this analysis can help to identify the research gap in the disaster risk assessment globally highlighting the potential methods and techniques for the same.

Keywords: physical infrastructure, risk assessment, model, framework, disaster, bibliometric analysis

1. INTRODUCTION

Urban regions worldwide are facing growing exposure to a wide range of risks caused by different natural hazards. Existing research has highlighted the risk of urban areas to excessive temperatures, droughts, floods, sea-level rise, and severe weather events (Bolan et al., 2024). The complex interconnections of urban systems and the dense population increase the potential repercussions of disasters, heightening the risk (Bull-Kamanga et al., 2003). Literature also have largely emphasized the substantial threat to both physical infrastructure and human populations in urban areas due to increasing disasters. Major challenges to urban resilience include disruptions to transportation networks, damage to residential and commercial structures, and risks to healthcare institutions (Shamsuddin, 2020). These interruptions might result in significant economic loss and threaten the safety and welfare of city dwellers (Casali et al., 2022).

Evaluating and measuring risk is a crucial component of disaster risk management. Studies have emphasized the significance of assessing the probability and possible outcomes of different hazards (Lallawmawma et al., 2023). Comprehending the nature, occurrence, and severity of possible risks allows stakeholders to allocate resources strategically and carry out successful interventions (Vishnu & Anurup, 2022; Sargeant et al., 2020). The report on Machine Learning-Based Surrogate Modeling for Urban Water Networks: Review and Future Research Directions by A. Garzón in 2022 highlights the need of having a thorough awareness of the various strategies and methodologies for assessing risk. Utilizing various methodologies and technological improvements is likely to improve the precision and dependability of risk assessment procedures (Garzón et al., 2022). However, it is important to thoroughly assess the strengths, weaknesses, and suitability of these methodologies in various circumstances (Einali et al., 2020).

The findings of the current study will advance the field of disaster risk management by offering insights into complete methods and procedures for measuring disaster risk in urban locations. The study aims to understand the current trend of research on the risk assessment of physical infrastructure and to identify the scope of existing methods and techniques employed in the future scenario of risk assessment. The objectives framed for this study are

1) to comprehend the disaster risk assessment methods and techniques from the global literature, 2) to analyze the trend and growth pattern in the field of research on disaster risk assessment and 3) to identify in the nuances and advances in the methods for assessing the disaster risk.

This study employs bibliometric analysis along with a comprehensive review of selected papers in this domain. The article has been structured into 6 sections. After the introduction section, the next section explains the methodology adopted for the research. Third section attempts a critical review of literature using a qualitative content analysis to reveal more structured information regarding various methods and techniques used for disaster risk assessment used in various context globally. The fourth section presents the materials and methods employed for the study The fifth section explains the data analysis and discussion of the study which includes quantitative analysis carried out using bibliometric analysis, and the last section deals with the conclusion which exhibits inferences from the research analysis.

2. METHODOLOGY

This study used bibliometric analysis to assess the literature available in the domains of disaster risk assessment and physical infrastructure (Figure 2). Bibliometric analysis provides a structured and unbiased method for assessing research output, recognizing patterns, and guiding decision-making in the area of physical infrastructure risk assessment. The benefits are backed by research showing the effectiveness of bibliometric methods in assessing scientific publications and guiding research and policy choices.

Bibliometric analysis quantitatively evaluates research output, collaboration patterns, and theme trends in a particular study field. This enables an impartial assessment of the quantity and influence of research contributions (Glänzel & Schubert, 2006).

Bibliometric analysis further allows for a thorough literature assessment by methodically discovering and analyzing pertinent publications from extensive databases. This guarantees that the study encompasses a diverse array of research outputs and prevents any bias in the selection process (Hicks et al., 2015).

As indicated by Li W, Zhao Y (W. Li & Zhao, 2015) Bibliometric analysis assists in recognizing emerging trends, influential authors, significant research topics, and developing research paradigms in a specific discipline.

The bibliometric study additionally helps to analyse the collaborative networks between authors, institutions, and countries, offering insights into knowledge sharing and multidisciplinary cooperation (Kurdistan & Karimi, n.d.).

Bibliometric analysis aids policymakers and funding organizations in allocating resources more effectively by pinpointing areas with the highest research requirements and potential influence (Ajibade et al., 2023).

Finally bibliometric analysis provides evidence-based insights that inform decision-making processes in policy, practice, and research funding (Ismail et al., n.d.).

Our goal here was to analyze current trends and pinpoint future research areas in risk assessment for physical infrastructure. This will enable us to identify the most widely accepted methods and techniques for risk assessment across the world for various types of disasters affecting physical infrastructure.

An overview of the steps carried out in this study is presented in Figure 1.

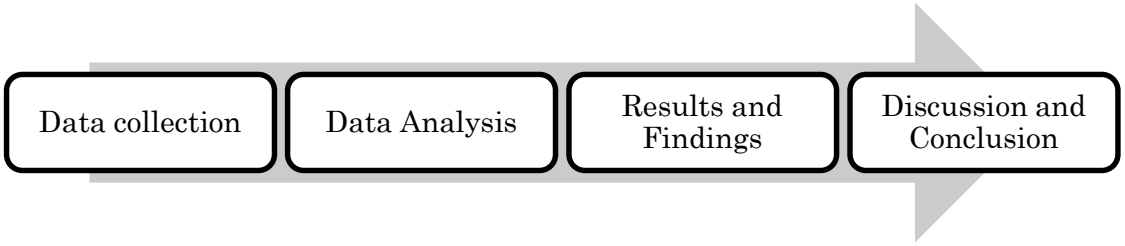

Figure 1. Workflow of the current research study
(Source: Author generated)

3. LITERATURE REVIEW

The content analysis of the publications extracted from documents chosen from a pool of 57 documents based on their high citation count (the papers with more than 30 counts of citations were selected for the content analysis) is attempted in the current section. The selection is also done based on the emphasis of disaster risk assessment methods in this research.

For example, a study carried out in 2002 introduced a simulation-based method for modeling the links between physical infrastructure systems and urban economies. It specifically focused on evaluating earthquake-related hazards to water lifeline systems in the Memphis, Tennessee, region of the United States. The methodology combines natural scientific, technical, and social science data and models to probabilistically estimate economic losses due to lifeline interruptions induced by earthquakes. The model evaluates spatial, temporal, and functional aspects of infrastructure services to compare risk management techniques, including pre-disaster mitigation and post-disaster emergency response actions.

The methodology created in the study enhances earthquake loss assessment techniques and also adds to the broader subject of modeling infrastructure-economy connections in metropolitan areas.

A study focusing on Natech Hazards (natural hazard-triggered technological disasters) in 2008 presents a methodology for the initial evaluation of Natech risk in urban areas. The article emphasizes the absence of guidance for local governments and communities in evaluating Natech risk. It suggests a technique designed for cooperation between officials and the public. This method takes into account the interactions among different urban systems, such as physical infrastructure, community demographics, natural environments, and risk management systems. The methodology provides qualitative metrics for risk assessment by assessing

aspects related to vulnerability and hazard, with the goal of efficiently managing low frequency/high consequence events.

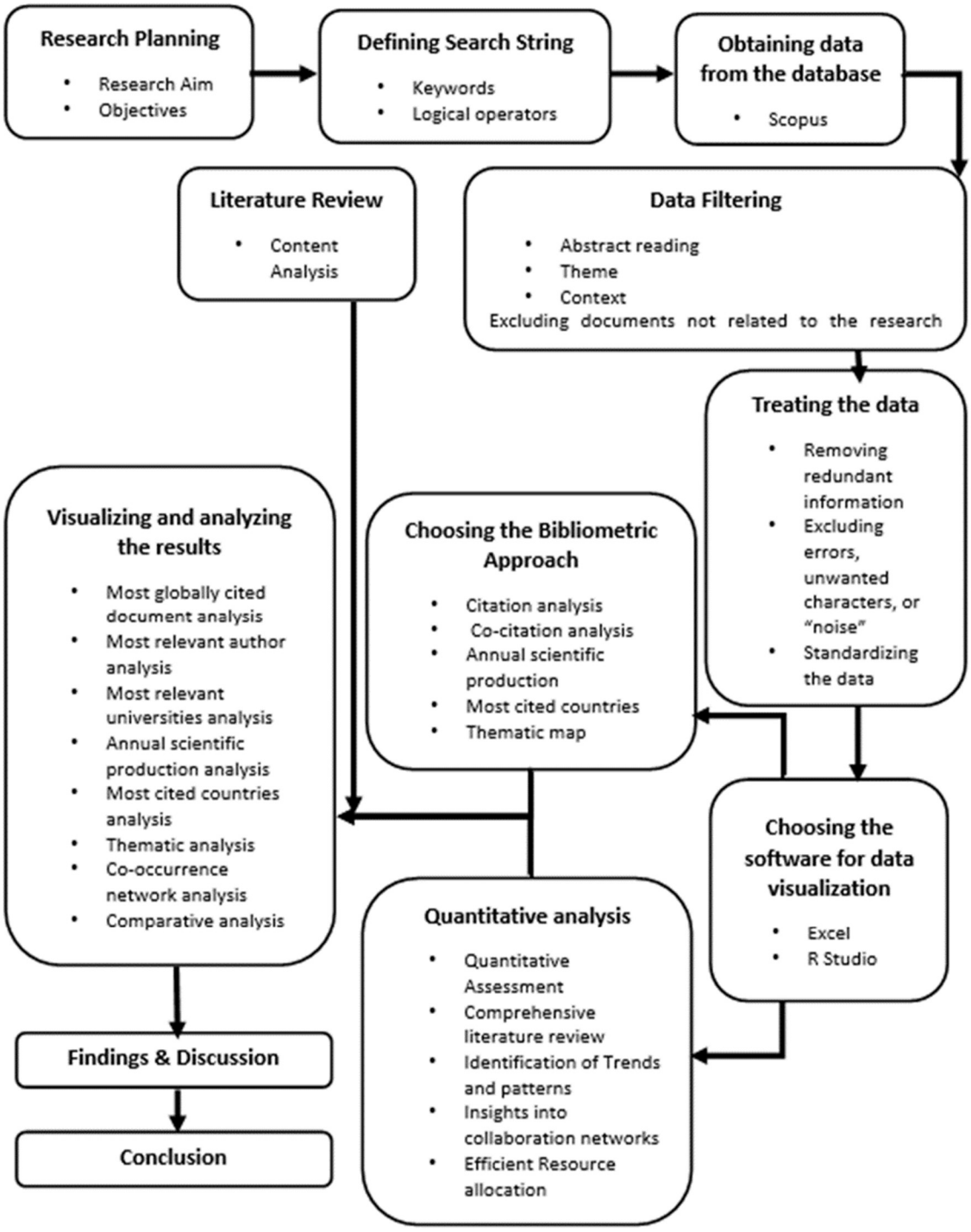

Figure 2. Methodology of the research
(Author generated)

The report showcases the effectiveness and accuracy of the suggested methodology by analyzing hazardous chemicals discharges during the Kocaeli earthquake in 1999. The comparison between estimated Natech Risk Indices (NRIs) and observed Natech risk levels

demonstrates convergent validity and highlights the methodology's usefulness in evaluating Natech risk. The study recognizes limitations, including the small sample size in the case study and the possibility of bias affecting the anticipated outcomes. The methodology offers a valuable framework for local communities to evaluate and control Natech risk in urban environments, aiding catastrophe planning and risk reduction endeavors (Cruz & Okada, 2008).

In 2012, a publication provided a thorough evaluation of 42 studies that examined the importance of local knowledge in climate adaptation in the Asia-Pacific Region. The review primarily focuses on traditional ecological and indigenous knowledge to explore how communities identify climate changes, adjust to them, and engage in learning processes. The findings indicate that the local knowledge includes a wide range of observations acquired across many time periods, from upcoming severe weather events to past climate patterns. Adaptation strategies are classified into land and water management, physical infrastructure, livelihood methods, and social institutions to address the diverse aspects of climate hazards. The study emphasizes the significance of comprehending the capabilities and constraints of local knowledge systems and stresses the necessity of integrating them meaningfully with scientific information to improve adaptation efforts efficiently.

This paper combines indigenous knowledge with scientific insights to pinpoint chances for enhancing adaption tactics. The need of valuing and validating local knowledge is highlighted, acknowledging its unique contributions to understanding climate impacts and vulnerabilities. The study supports adaptive strategies that incorporate reactions to various pressures and evolving situations, promoting resilience and empowering disadvantaged populations. It recognizes difficulties including uncertainties, power imbalances, and the necessity for thoughtful procedures to manage different knowledge systems efficiently. The report highlights the potential of local knowledge to enhance adaptation measures, offering useful insights for future research and policy development in climate resilience despite the lack of sufficient case studies and analytical frameworks (Lebel, 2013).

In 2016, a study was published introducing the Centerville Virtual Community Testbed, which focuses on developing measurement science for assessing community resilience to natural calamities. This interdisciplinary method integrates engineering, social, economic, and information disciplines to comprehend the aspects that enhance community resilience. The testbed establishes a framework for evaluating probable post-disaster consequences on Centerville's population, economy, and public services by outlining the physical infrastructure, environmental hazards, and population demographics of the area. It functions as a platform for creating and testing basic resilience assessment algorithms prior to the completion of more advanced approaches. The Centerville Testbed is a vital advancement in evaluating community resilience in the face of upcoming disasters. It allows academics to assess how risks affect communities and create decision methods based on risk, which helps optimize planning and recovery efforts considering financial limitations and community values. The testbed enables scalability in community infrastructure modeling by using specific parameters and metrics. It helps in developing advanced resilience assessment methods customized for different disaster

scenarios, improving preparedness and response capabilities at the community level (Ellingwood et al., 2016).

Another study in 2017, examines the complex connection among investments in water-related infrastructure, economic growth, and resistance to water-related hazards. The research incorporates investments that enhance water production and reduce the negative effects of floods, droughts, and waterborne diseases into a comprehensive dynamical systems model, acknowledging their importance. Findings from the model show that investing in water-related assets in the beginning enhances economic growth by strengthening resistance to water-related risks. Without investments, losses from water-related hazards can hinder growth and potentially create a poverty cycle, especially in areas with low beginning water security. The study emphasizes the importance of balanced investment methods, pointing out a relationship between investment in water security and economic growth that follows an inverted-U form. Countries with more resources and less water-related limitations can grow without obstacles from water-related issues. In contrast, nations dealing with severe hydrological circumstances need to make significant expenditures in infrastructure and institutions to support growth and handle risks efficiently. The study highlights that vulnerable countries encounter distinct problems in balancing economic growth and water-related concerns, emphasizing the context-specific nature of these processes. The findings offer useful insights for creating strong policies to support sustainable economic development and resilience in response to environmental change and water-related dangers (Dadson et al., 2017).

Later in the year 2019, a study introduces an innovative approach for simulating earthquake recurrence, with a specific emphasis on interface and intraslab seismic activity along the subduction zone in Chile. The suggested methodology intends to enhance seismic hazard analysis and risk appraisal by rectifying deficiencies in earlier models, such as the lack of earthquake declustering and inconsistent magnitude scales. Statistical study of earthquake occurrence data shows substantial discrepancies in seismic rates compared to prior models, leading to frequencies that differ significantly by several orders of magnitude. The study underscores the significance of examining temporal relationships between occurrences and stresses the necessity for strong risk assessment techniques that take into consideration these intricacies.

The study recognizes limitations in the proposed methodology, such as focusing solely on main shocks without considering foreshocks and aftershocks, the need for more research on declustering methods and zonation models, and the significance of including crustal faulting in a comprehensive seismic hazard analysis. The paper highlights the importance of further research in improving earthquake recurrence models and integrating uncertainty into reliable hazard assessments through Bayesian statistics and other quantification techniques. The work enhances risk assessment methods for earthquake-prone areas, offering valuable insights for disaster preparedness and mitigation (Poulos et al., 2019a). A consolidated findings of the literature review have been presented in Table 1.

Table 1. Consolidated findings of the literature review
(Source: Author generated)

Sl. No.	Paper Title	Overview
1	An updated recurrence model for chilean subduction seismicity and statistical validation of its poisson nature(Poulos et al., 2019a)	• Authors suggest a novel earthquake recurrence model for Chile. • Enhanced model rectifies deficiencies found in prior models. • Noticeable variations in seismic activity rates identified in contrast to prior models.
2	Methodology for Preliminary Assessment of Natech Risk in Urban Areas(Cruz & Okada, 2008)	• Presents a framework for evaluating Natech risk in urban environments. • Examines the Kocaeli earthquake case study in Turkey. • Emphasizes the necessity of efficient risk assessment techniques for heavily inhabited regions.
3	Water Security, Risk, and Economic Growth: Insights from a Dynamical Systems Model(Dadson et al., 2017)	• Analyzes the relationship among water security, risk, and economic growth. • Creates a dynamic systems model to assess how investments in water resources affect economic growth. • Emphasizes the significance of investing in water-related infrastructure for sustainable development.
4	Linking Infrastructure and Urban Economy: Simulation of Water-Disruption Impacts in Earthquakes(Chang et al., 2002)	• Proposes a simulation method for predicting the economic consequences of water interruptions caused by earthquakes. • Examines the Memphis, Tennessee, region as a case study. • Stresses the significance of incorporating natural-science, engineering, and social-science models.
5	Local Knowledge and Adaptation to Climate Change in Natural Resource-Based Societies of the Asia-Pacific(Lebel, 2013)	• Examines research on the role of indigenous knowledge in enhancing climate change adaption. • Emphasizes the importance of traditional ecological knowledge in acknowledging and adjusting to climate change. • Stresses the importance of combining scientific and local knowledge systems to enhance adaption effectiveness.
6	The Centerville Virtual Community: A Fully Integrated Decision Model of Interacting Physical and Social Infrastructure Systems(Ellingwood et al., 2016)	• Presents the Centerville Virtual Community Testbed for evaluating community resilience. • Seeks to develop a system for measuring community resilience. • Focuses on using various disciplines in resilience planning and decision-making.

4. MATERIALS AND METHODS FOR THE STUDY

A literature search using the Scopus database accessed on August 03, 2023, yielded 94 papers on disaster risk assessment methods and techniques on physical infrastructure. Later, it was refined to 57 using the filtering option. The final search criteria are listed in Table 2 below. The quantitative analysis of the database comprises of multiple essential processes, each focused on deriving relevant insights from the gathered literature.

Table 2. Criteria for the selection of publications
(Source: Author generated)

Criteria	Value
Data source	Scopus
Search terms	"*Physical infrastructure" AND hazard OR disaster AND risk AND assessment OR analysis OR method OR exposure OR quantify OR parameter OR indicator OR model OR framework.*
Publication period	2000 - 2023
Number of documents	57 / 94

4.1 Citation Analysis

Citation analysis is conducted to determine the most esteemed publications and significant authors and universities in the realm of catastrophe risk assessment and analysis of physical infrastructure. The study identifies the articles with the most citations, demonstrating their significance and relevance in the scholarly community. Authors and universities are recognized as influential depending on the number of citations their articles obtain.

4.2 Co-citation Analysis

Co-citation analysis is performed to uncover the network of writers with influential and leading publications. The study assists in identifying collaboration networks and research clusters in the subject, emphasizing important contributors and research issues.

4.3 Annual Scientific Production

Analyzing the yearly scientific production helps comprehend the research output trend over time. This sheds light on the development and expansion of catastrophe risk assessment and analysis of physical infrastructure across time.

4.4 Most Cited Countries

Studying the countries with the highest number of citations can reveal which countries have made the greatest contributions to research in the topic. This data can guide collaborative tactics and pinpoint key research areas worldwide.

4.5 Thematic Map

A thematic map is created to illustrate the present condition of the study area and its future sustainability. The map assists in pinpointing research themes, trends, and gaps to influence future research objectives and orientations.

4.6 Co-occurrence Analysis

Co-occurrence analysis is performed to pinpoint significant keywords that may be the focal point of future research on catastrophe risk assessment and analysis of physical infrastructure. This study assists in pinpointing emerging issues and areas of interest in the subject, which can then direct future research efforts.

These quantitative analysis methods provide a comprehensive understanding of the research landscape in the field of disaster risk assessment and analysis of physical infrastructure. They highlight key publications, authors, themes, and trends, guiding future research directions and informing decision-making processes.

5. DATA ANALYSIS AND DISCUSSIONS

5.1 Methodological Approaches

From the papers evaluated, various methodological approaches are employed to address research questions and are shown in Table 3.

5.2 Critical Analysis and Future Directions

The reviewed publications provide useful insights, regardless other areas require further research and critical analysis. They are shown in Table 4.

5.3 Most Globally Cited Document Analysis

Based on the bibliometric analysis conducted, the following documents in Table 5 emerge as the most globally cited in the field.

- The most globally cited document was found to be Ellingwood Br,2016, SUSTAINABLE AND RESILIENT INFRASTRUCTURE with a global citation of 127. The study aims to address the integration of sustainability and resilience in infrastructure design. They have an 8.1(2022) cite score on Scopus and a 5.9(2022) impact factor. This reflects its significant impact on the discourse surrounding infrastructure sustainability and resilience.
- Lebel L's "Mitigation Adapt Strategies" (2013) follows closely behind with 104 citations, indicating its substantial influence on discussions surrounding mitigation and adaptation strategies in various contexts. The paper aims to provide comprehensive strategies for mitigating and adapting to climate change impacts.
- Chang SE's work on "Environment Planning B: Planning Design" (2022) garnered 81 citations, highlighting its relevance in the field of environmental planning and design.

Aim of the study was to explore innovative planning and design strategies to enhance environmental sustainability.

- Dadson S's contribution to "Water Resource Research" (2017) accumulated 53 citations, showcasing its importance in advancing knowledge and understanding of water resource management. The study aimed to develop efficient water resource management strategies.
- Cruz AM's publication on "Natural Hazards" (2000) is noteworthy with 50 citations, underlining its enduring relevance in the study of natural disasters and hazard mitigation. Study focused on the effective management and mitigation of natural hazards.

These findings underscore the significance and impact of these seminal works in their respective fields, shaping research agendas, policy discussions, and practical applications globally.

Table 3. Various methodological approaches in the literature
(Source: Author generated)

Methodological Approach	Discussion
Statistical Analysis	Paper 1(Poulos et al., 2019a) applies statistical analysis to create a more advanced earthquake recurrence model, enhancing existing approaches.
Risk Assessment Methodologies	Paper 2(Cruz & Okada, 2008) proposes a strategy for the preliminary assessment of Natech risk, focusing on qualitative criteria and engaging with the community.
Systems Modeling	Papers 3 (Dadson et al., 2017) and 4(Chang et al., 2002) use systems modeling to examine the intricate relationships among water infrastructure, economic systems, and natural risks.
Literature Review	Paper 5(Lebel, 2013) performs a literature analysis to analyze the significance of local knowledge in climate change adaptation by combining findings from several case studies.
Testbed Development	Paper 6(Ellingwood et al., 2016) emphasizes on creating a virtual community test environment to support interdisciplinary research and evaluate resilience.

5.4 Most Relevant Authors Analysis

The most influential authors in this research are shown in (Table 6). The highest number of documents was published by VAN DE LUNDT JW, with a total of seven documents.

- Van De Lindt JW: With 7 documents to their name, Van De Lindt JW likely focuses on a diverse range of topics within their field of expertise, potentially spanning areas such as structural engineering, resilience, and risk assessment in infrastructure systems.
- Ellingwood BR: Ellingwood BR's 3 documents suggest a concentration on topics related to sustainable and resilient infrastructure, as evidenced by the title of their most globally cited document.

- Nofal OM: Nofal OM, with 3 documents, likely specializes in sustainable and resilient infrastructure, similar to Ellingwood BR, given the shared focus on this theme.
- CoT: While there isn't specific information about CoT's thematic focus, their 2 documents may indicate involvement in areas such as urban planning, environmental sustainability, or risk management.
- Mahmoud H: Similarly, with 2 documents, Mahmoud H may be engaged in research related to infrastructure resilience, hazard mitigation, or disaster risk reduction.
- Okaka WT: Okaka WT's 2 documents suggest a focus on topics such as water resources management, environmental engineering, or hydrology.
- Van Zandts: The 2 documents attributed to Van Zandts could indicate contributions to fields such as structural engineering, materials science, or infrastructure resilience.
- Al-Mamun S, Alam MM, and Alesheikh AA: While these authors have only one document each, their thematic focus could vary widely depending on the specific topic of their respective publications. However, their individual contributions likely reflect expertise in areas such as hazard mitigation, sustainable infrastructure, or related fields.

These insights provide a glimpse into the expertise that each author may specialize in, based on the content of their published work.

Table 4. Critical analysis and future directions in the literature
(Source: Author generated)

Methodological Approach	Discussion
Integration of Methods	Future research may consider interdisciplinary methodologies that combine statistical analysis, systems modeling, and qualitative research techniques.
Community Engagement	Increased focus on community engagement and participatory methods could improve the pertinence and efficiency of disaster resilience solutions.
Cross-Cultural Perspectives	Comparing resilience techniques in various cultural and geographic settings can help determine their universal applicability and the significance of indigenous knowledge.
Long-Term Resilience	Future research should prioritize long-term resilience planning and adaption techniques to tackle evolving concerns like climate change and urbanization.

Table 5. Most Globally Cited Documents
(Source: Author generated)

Documents	Global Citations
Ellingwood BR, 2016 Sustainable and Resilient Infrastructure	127
Lebel L, 2013, Mitigation Adapt Strategies	104
Chang SE, 2022, Environment Planning B: Planning Dessign	81
Dadson S, 2017, Water Resource Research	53
Cruz AM, 2008, Natural Hazards	50
Poulos a, 2019, Bulletin of the Seismological Society of America	36
Nofal OM, 2022, Sustainable and Resilient Infrastructure	28
Hudson S, 2012, Proceedings of the Institution of Civil Engineers: Civil Engineering	27
Ulieru M, 2007, Proceedings of the 2007 Inaugural IEEE-IES Digital EcoSystems and Technologies Conference, DEST 2007	26
Hofmann J, 2019, Geoscience	24

Table 6. Most relevant authors
(Source: Author generated)

Authors	No. of Documents
Van De Lindt JW	7
Ellingwood BR	3
Nofal OM	3
CoT	2
Mahmoud H	2
Okaka WT	2
Van Zandts	2
Al-Mamun S	1
Alam MM	1
Alesheikh AA	1

5.5 Analysis of most Relevant Universities

Based on the bibliometric analysis, several universities emerge as significant contributors to the field, with insights into the themes of research works they carry out. They are shown in Table 7.

- **Colorado State University**: With 9 documents, CSU may focus on environmental science, natural resource management, hazard mitigation, and sustainable infrastructure.
- **Texas A&M University**: With 7 documents, researches civil engineering, infrastructure resilience, disaster management, and urban planning.
- **Tohoku University**: In 7 documents, studies earthquake engineering, disaster resilience, environmental sustainability, and infrastructure development.
- **De La Salle University**: 6 publications include urban resilience, environmental management, sustainable development, and community-based disaster risk reduction.
- **Colorado State University**: has 5 documents on environmental science, natural resource management, and community resilience.
- **University of Oxford**: Four documents cover environmental policy, sustainable development, climate change adaptation, and risk governance.
- **African Centre for Technology Studies**: This center studies technology innovation, sustainable development, and policy analysis in Africa with 3 documents.
- **Banaras Hindu University (IIT-BHU)**: 3 documents focus on civil engineering, environmental engineering, and sustainable infrastructure.
- **McMaster University**: researches risk assessment, infrastructure resilience, and disaster management with 3 documents.
- **Ministry of Lands and the Environment**: This ministry studies land use planning, environmental management, and natural resource governance with 3 papers.

These insights provide an overview of the research themes and areas of expertise associated with each university or organization, based on the content of their published works.

Table 7. Most relevant universities
(Source: Author generated)

Affiliations	Articles
Colorado State University	9
Texas Aandm University	7
Tohoku University	7
De La Salle University	6
Fort Collins	5
University of Oxford	4
African Centre for Technology Studies	3
Banaras Hindu University (IIT-BHU)	3
McMaster University	3
Ministry of Lands and the Environment	3

5.6 Annual Scientific Production Analysis

From the annual scientific production of articles in this research field, the graph showing an upward trend line indicates that the research status is trending, and steady publications have been published since 2014. There is a good scope for research to be conducted in this domain for publication.

5.7 Analysis of most Cited Countries

Based on the bibliometric analysis, the following insights can be drawn regarding the most cited countries and the themes of research they focus on, as well as the types of disasters studied.

These insights provide an overview of the themes of research and types of disasters studied by the most cited countries, offering valuable insights into their respective areas of expertise and priorities in disaster research and mitigation efforts.

5.8 Thematic Map Analysis

The thematic map generated from the bibliometric analysis provides valuable insights into the key themes and clusters prevalent in the field of disaster research and risk assessment. Here are the main findings derived from the analysis.

- Risk Assessment Cluster: This cluster encompasses various aspects of risk assessment, including risk perception, vulnerability, flood risk assessments, and investments in risk management. The most frequently occurring terms within this cluster are "risk assessment," "hazards," and "risk perception," indicating a significant focus on understanding and mitigating risks associated with natural and human-made disasters. Themes within this cluster revolve around the evaluation of potential risks, decision-making processes, and strategies for enhancing resilience to disasters.

- Disasters Cluster: The disasters cluster highlights research focused on disaster management, risk mitigation, and resilience-building efforts. Terms such as "disaster management," "natural disasters," and "risk management" are prominent within this cluster, indicating a strong emphasis on preparing for and responding to various types of disasters, including floods, storms, and earthquakes. Themes within this cluster include disaster prevention, emergency services, infrastructure resilience, and community-based disaster risk reduction initiatives.
- Critical Infrastructures Cluster: This cluster centers on critical infrastructures and their vulnerabilities to disasters. Terms such as "critical infrastructures," "supply chains," and "risk analysis" are prevalent, suggesting a focus on identifying and mitigating risks to essential systems and services. Themes within this cluster include the assessment of infrastructure vulnerabilities, the development of risk-informed decision-making approaches, and strategies for enhancing the resilience of critical systems.
- Decision Making Cluster: The decision-making cluster highlights research related to risk-informed decision-making processes in disaster management. Terms such as "decision making," "uncertainty analysis," and "risk-informed decision making" dominate this cluster, indicating a focus on incorporating risk assessment findings into decision-making frameworks. Themes within this cluster include probabilistic modeling, uncertainty analysis, and strategic approaches to risk management and disaster preparedness.
- Hazard Management Cluster: This cluster focuses on hazard management strategies, including risk assessment, disaster prevention, and mitigation efforts. Terms such as "hazard management," "disaster," and "urban area" are prevalent within this cluster, suggesting a focus on identifying and addressing hazards within urban environments. Themes within this cluster include hazard identification, risk assessment methodologies, and the implementation of mitigation measures to reduce vulnerability to natural and human-made hazards.
- Risks Cluster: The risks cluster highlights research focused on understanding and mitigating various types of risks, including health risks, economic risks, and water management risks. Terms such as "risks," "economics," and "health risks" are prominent within this cluster, indicating a broad focus on assessing and managing risks across different sectors and domains. Themes within this cluster include risk analysis methodologies, economic impact assessments, and strategies for addressing emerging risks such as climate change and water scarcity.

Overall, the thematic map generated from the bibliometric analysis provides a comprehensive overview of the key themes and clusters prevalent in disaster research and risk assessment. These findings can inform future research directions, policy interventions, and practical strategies for enhancing resilience to disasters and reducing vulnerability to various

hazards. Natural hazards, flood control, and sustainable development were identified as the emerging research topics.

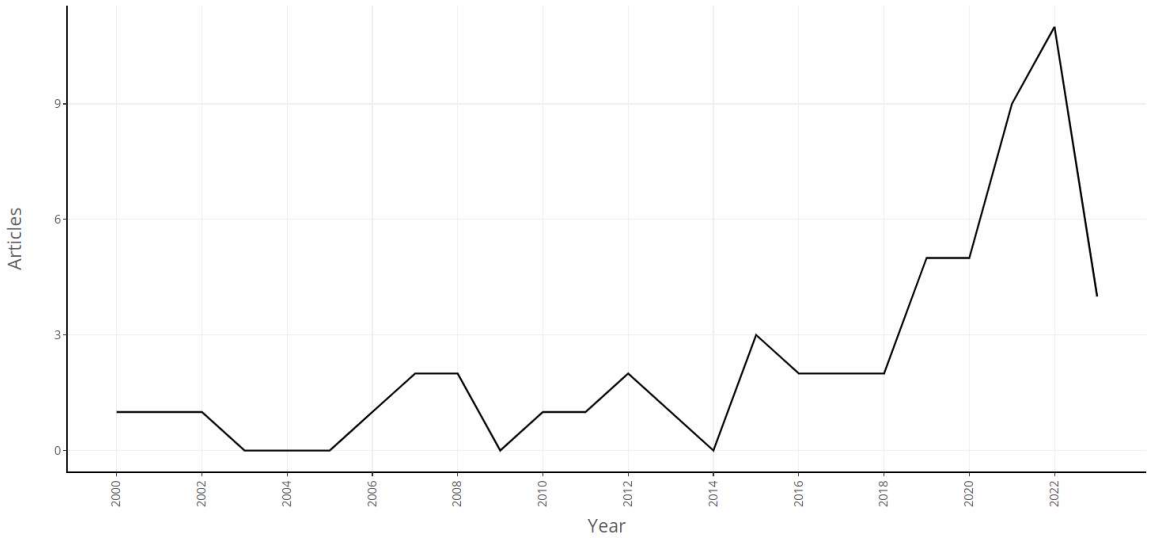

Figure 3. Annual Scientific Production
(Source: Author generated)

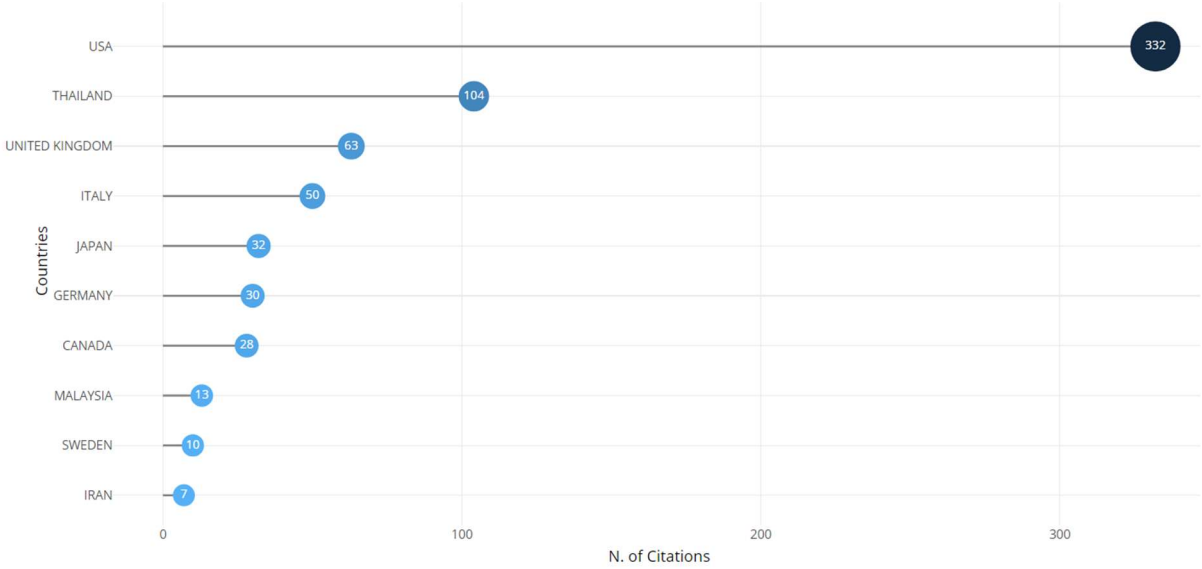

Figure 4. Most cited countries
(Source: Author Generated)

5.9 Co-occurrence Network Analysis

Using co-occurrence analysis, the most prominent topic, keywords in this research field, were revealed. The co-occurrence network presented in (Figure 6) indicates that more research has been conducted on risk assessment, disaster, and disaster management at 13%, 4%, and 4%, respectively.

Table 8. Analysis of the most cited countries (Author Generated)

Country	Citations and Theme
USA	With a significant lead of 332 citations, the USA is likely at the forefront of disaster research, covering a wide range of topics such as natural hazards, disaster management, emergency response, and resilience building. Research from the USA may encompass various disaster types, including hurricanes, tornadoes, earthquakes, floods, wildfires, and technological disasters.
Thailand	Thailand, with 104 citations, likely emphasizes research on disaster management and risk reduction strategies, particularly in the context of tropical cyclones, flooding, tsunamis, and other natural hazards prevalent in the region. Research themes may include community resilience, early warning systems, evacuation planning, and post-disaster recovery efforts.
United Kingdom	With 63 citations, the United Kingdom's research may focus on disaster risk assessment, policy development, and governance structures related to both natural and human-made disasters. Themes of research may include climate change adaptation, urban resilience, emergency preparedness, and response coordination.
Italy	Italy, with 50 citations, may concentrate on disaster research related to seismic events, given its susceptibility to earthquakes. Research themes may include seismic hazard assessment, building resilience, structural engineering, and post-earthquake recovery strategies.
Japan	With 32 citations, Japan's research likely centers on earthquake and tsunami hazards, reflecting the country's vulnerability to these events. Themes may include earthquake engineering, early warning systems, disaster preparedness drills, and community-based disaster risk reduction initiatives.
Germany	With 30 citations, Germany may focus on research related to flooding, extreme weather events, and technological hazards. Research themes may include flood risk management, climate change adaptation strategies, infrastructure resilience, and industrial disaster prevention measures.
Canada	With 28 citations, Canada's research may cover a broad spectrum of disaster topics, including natural hazards such as wildfires, floods, and winter storms, as well as technological disasters and emergency management strategies tailored to the country's diverse geographic and climatic conditions.
Malaysia	With 13 citations, Malaysia's research may emphasize disaster management in the context of tropical cyclones, floods, landslides, and urban disasters. Themes may include disaster risk reduction, community-based adaptation, early warning systems, and post-disaster recovery planning.
Sweden	With 10 citations, Sweden's research may focus on disaster risk assessment, particularly in relation to climate change impacts such as extreme weather events and sea-level rise. Themes may include sustainable urban planning, ecosystem-based adaptation, and social resilience strategies.
Iran	While no citations are attributed to Iran in this analysis, it's possible that disaster research in Iran may focus on seismic hazards, given the country's location in a seismically active region. Themes may include earthquake engineering, building codes enforcement, and disaster preparedness initiatives.

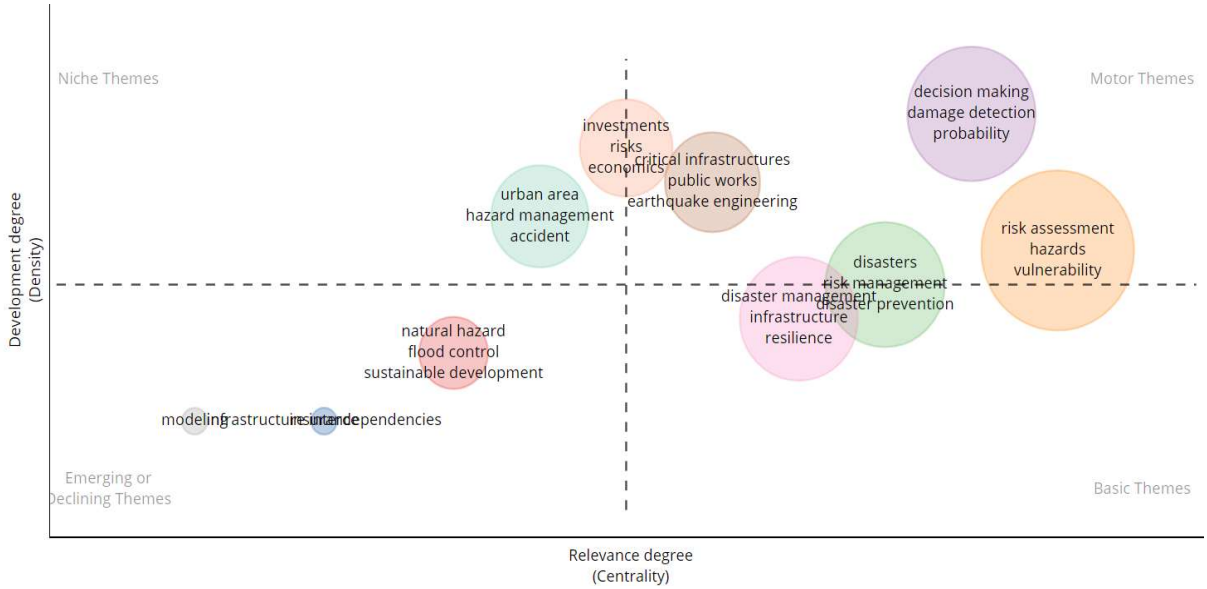

Figure 5. Thematic map
(Source: Author generated)

Figure 6. Co-occurrence network
(Author generated)

5.10 Comparative Analysis

The comparative analysis offers a complete review of 57 research articles concerning disaster risk assessment and the analysis of physical infrastructure. Each publication is classified according to five main aspects.

1. **Nature of the Disaster:** This category specifies the sort of disaster addressed in each article. Most publications primarily cover floods, with earthquakes being the next most common topic. Other subjects include winter storms, cyclones, hurricanes, landslides, typhoons, and chemical dangers.
2. **Infrastructure in Focus:** This category indicates the sort of infrastructure discussed in each article. Infrastructure types encompass transportation, social infrastructure (e.g., schools and buildings), vital infrastructure, settlements, housing, agricultural, and water-related infrastructure.
3. **Methods and Techniques:** This category details the methodology and instruments utilized in each publication for catastrophe risk assessment and analysis. Methods include statistical analysis, surveys, interviews, deep learning, convolutional neural networks (CNN), model stacking, and decision support tools like Digital Twin frameworks.
4. **Analysis/Result/Findings:** This category provides a concise overview of the primary results or conclusions of the study presented in each publication. The findings include of identifying vulnerable elements, evaluating the effects of disasters on education quality and recovery, understanding problems in risk communication, creating resilience frameworks, and assessing measures to reduce vulnerability.
5. **Country:** This category indicates the country where the study took place or the geographical area of focus for the research. Publications encompass a wide range of countries and areas such as Tanzania, Indonesia, Texas (USA), Kenya, Philippines, Canada, India, Bangladesh, Nepal, Vietnam, Turkey, and Sweden, among others.

Most of the publications focused on floods (14 publications), followed by earthquakes (6 publications), physical infrastructure (19 publications), transportation (7 publications), and social infrastructure/building (6 publications).

Transportation infrastructure has been identified as an important domain for safeguarding or improving resilience and assessing vulnerability to various hazards/disasters. The results of this comparative analysis can serve as a reference for researchers and stakeholders in disaster management and planning.

Table 9 offers a detailed summary of research endeavors in catastrophe risk assessment and analysis of physical infrastructure, showcasing the variety of methods, tactics, and geographic locations studied in the literature.

Additionally, the various paradigms and approaches being developed in the international literature for disaster risk assessment has been accomplished and is demonstrated in Table 10.

Table 10 provides a thorough summary of the various disasters and hazards analyzed in the global literature on disaster risk assessment, as well as the methodologies used to research them. The table demonstrates the interdisciplinary nature of catastrophe risk assessment research by utilizing many methodologies, from advanced technology like deep learning and convolutional neural networks to classic survey procedures. Specific techniques are used for each sort of

disaster, taking into account the distinct problems and features of each danger. Researchers employ a variety of tools, ranging from empirical methods for landslides to simulation models for hurricanes, to comprehend and reduce the hazards associated with various disasters. This compilation emphasizes the wide range of research in disaster risk assessment and emphasizes the significance of using several methodological approaches to tackle the intricate issues presented by natural and man-made disasters.

5.11 Findings of the Study

In this study, we identified the most prominent authors, publications, and institutions in the areas of research related to risk assessment and the analysis of physical infrastructure. We also identified topics or keywords that are very relevant, some of which indicate potential areas for future research. The bibliometric analysis uncovered a varied and extensive research area in disaster risk assessment and infrastructure analysis. Floods and earthquakes are significant hazards emphasizing the importance of physical infrastructure and transportation in disaster mitigation. Various strategies are used in disaster research to meet the complex difficulties of disaster management and planning, highlighting the interdisciplinary nature of the field.

Table 9. Comparative analysis of selected documents
(Source: Author generated)

Title	Disaster	Infrastructure in focus	Methods/ Techniques	Analysis/Result/ Findings	Country	Year
Predicting Dust-Storm Transport Pathways Using a Convolutional Neural Network and Geographic Context for Impact Adaptation and Mitigation in Urban Areas (Yarmohamadi et al. 2023)	Dust storms	Transportation infrastructure	Deep Learning Convolutional Neural Network (CNN)	Kappa coefficient Result: CNN model - predict the dust-transport pathway	NA	2023
Assessment of exposure, coping and adaptation strategies for elements at risk to climate change-induced flooding in urban areas. The case of Jangwani Ward in Dar es Salaam City, Tanzania(Nyashilu et al., 2023)	Urban Flooding	NA	Household interviews, Questionnaires, Focused group discussions, documentary reviews, Transect walks, surveys, observation	Statistical package - social science Result: identification of elements at risk of exposure to climate change-induced flooding: physical infrastructures, socio-economic activities, livelihoods, and eco system	Tanzania	2023
Understanding the impacts of floods on learning quality, school facilities, and educational recovery in Indonesia (Lassa et al., 2023)	Floods	Social infrastructure - School / Buildings	comprehensive school safety (CSS) framework	Result: Nuanced approach to assessing post-disaster education needs	Indonesia	2023

"I didn't know what to expect or What to do": Impacts of a severe winter storm on residents of subsidized housing in Texas(Li et al., 2023)	Winter Storm	Housing / Buildings	PMT (Protective Motivation Theory), MaxQDA	Focused group Interview Result: Insufficient risk communication, High perceived costs of preparation, Differences in physical infrastructutre conditions Social isolation	Texas, US	2023
Review of flood modelling and models in developing cities and informal settlements: A case of Nairobi city(Tom et al., 2022)	Floods	Settlements / Buildings	Model stacking and calibrations	NA	Nairobi, Kenya	2022
Pandemic response in the energy sector and impacts for infrastructure resilience management(Skarvelis-Kazakos et al., 2022)	COVID-19	Critical Infrastructure	Review	level of operational resilience required for the 21st century	NA	2022
A Risk Assessment and Reduction Approach for National Critical Infrastructure(Reinhardt et al., 2022)	NA	Critical Infrastructure	decompositions structured as directed graphs	There is no overarching analytic structure that organizes and integrates these disparate sources into a unified risk assessment Need for an integrated approach to CI risk assessment	NA	2022
Towards a Modeling Toolbox for Multi-Modal Coastal Community Supply to Support Disaster Preparedness Risk Management in Canada(Goerlandt et al., n.d.)	NA	Transportation infrastructure	Overview / toolbox	Multi-Modal Logistics network importance of interdependencies between transport networks, assets, and community needs.	NA	2022
A quantitative approach to modeling and improving community resilience to natural hazards(VAN DE LINDT et al., 2022)	NA	Physical infrastructure	Quantitative model, simulations of the damaging event Interdependent Networked Community Resilience Modeling Environment (IN-CORE)	Multidisciplinary approach, Illustrative examples	NA	2022
Digital Twin: A City-Scale Flood Imitation Framework(Ghaith et al., 2021)	Floods	Physical infrastructure	Decision support tools Digital Twin Framework to	continuous imitation of hazards affecting the city infrastructures identify vulnerable locations across the	Calgary, Canada	2022

			devise a city digital twin under flood hazards	city under hazardous events enhance the city's resilience under climate-induced hazards develop reliable preparedness plans and risk mitigation strategies under climate-related hazards		
Assessment of vulnerability reduction policies: Integration of economic and cognitive models of decision-making(Morshedi & Kashani, 2022)	Earthquake	Buildings	decision-making model agent-based model - for evaluating owners' responses	shortcomings of previous models selection of appropriate policies to enhance communities' resilience based on physical infrastructure characteristics	NA	2022
Seismic risk assessment of reinforced concrete buildings in Koyna-Warna region through EDRI method(Shendkar et al., 2021)	Earthquake	Buildings / Physical infrasructure	Survey - visual screening Risk index EDRI (Earthquake Disaster Risk Index)	Future serious risks	Maharashtra, India	2021
High-resolution flood risk approach to quantify the impact of policy change on flood losses at community-level(Nofal & van de Lindt, 2021)	Floods	Physical infrastructure	Quantitative approach Building information model modeling flood vulnerability	NA	NA	2021
Probabilistic Risk Assessment of Coupled Natural-Physical-Social Systems: Cascading Impact of Hurricane-Induced Damages to Civil Infrastructure in Galveston, Texas(Ehsan Fereshtehnejad et al., 2021)	Hurrican e	Physical infrastructure - Transportation / Buildings	Multihazard risk assessment framework	Hybrid risk metrics across built and social systems - the probability of non-connectivity to emergency services and no. of non-evacuees Hot households - buildings with non-evacuees inside	Galveston island, Texas, US	2021
Recognition of Factors that Promote Resilience to Hurricanes(Álvarez et al., 2021)	Hurricanes	Physocal infrastructure	Literature review	Factors promoting resilience: ecological, social, infrastructure and mental health	NA	2021

Social vulnerability assessment for landslide hazards in Malaysia: A systematic review study(Nor Diana et al., 2021)	Landslides	Social infrastructure	Quantitative assessment PRISMA report analysis method	Important indicators of social vulnerability	Malaysia	2021
Adaptation to climate extremes and sea level rise in coastal cities of developing countries(Le & Awal, 2021)	Sea level rise	NA	Content analysis	Physical infrastructure and ecosystem based adaptation strategies	NA	2021
Flood risk assessment and application of risk curves to enhance resilience(Zhang & Alipour, 2022)	Floods	Transportation infrastructure	Simulation - hazard, geographic features, spatial distribution of assets and traffic Simulation Risk curve	decision-makers can use this flood risk curve along with community-based prevention expectations of risk to implement proper mitigation strategies	NA	2021
Flood vulnerability and its influencing factors(Pathak et al., 2020)	Floods	Physical infrastructure	Personal interview Integrated vulnerability index	Ordinal response model	Nepal	2020
Stakeholder collaboration as a pathway to climate adaptation at coastal ports(Morris, 2020)	NA	Transportation infrastructure	Literature review	NA	US	2020
Probabilistic Flood Loss Assessment at the Community Scale: Case Study of 2016 Flooding in Lumberton, North Carolina(Nofal & van de Lindt, 2020)	Floods	NA	Empirical damage fragilities HZUS-MH - stage damage functions	mechanism to propagate uncertainty in damage and loss estimates	US	2020
Risk-based early warning system for pluvial flash floods: Approaches and foundations(Hofmann & Schüttrumpf, 2019)	Floods	NA	MPFIS - Multi functional pluvial flood information system	Georeferenced documentation of occurred events systematic risk analysis	NA	2019
An updated recurrence model for chilean subduction seismicity and statistical validation of its poisson nature(Poulos et al., 2019b)	Earthquake	Physical infrastructure	NA	NA	Chile	2019
Hindcasting Community-Level Damage to the Interdependent Buildings and Electric Power Network after the 2011 Joplin, Missouri,	Tornado	Physical infrastructure, social and economic sectors	Cellular Automata	NA	US	2019

Tornado(Attary et al., 2019)						
Identifying and analyzing interdependent critical infrastructure in postearthquake urban reconstruction(Nozhati et al., 2018)	Earthquake	Physical infrastructure	Risk based support framework - models the immpact of infrastructure dependencies on community response	Decision support algorithms to prioritize repair of damaged civil infrastructure systems	NA	2018
Local supply chains: The disaster management perspective(Pfeiffer et al., 2017)	NA	Physical infrastrctur e	Grassroots Infrastructure Dependency Model (GRID-M)	GRID-M may be used post disaster to support the identification of priority response and recovery objectives based on the disruptions of critical local supply chains	NA	2017
Framework for comprehensive assessment of a city's natural disaster risk(Brink & Davidson, 2015)	Earthquake	NA	Framework - Physical infrastructure + Social science-based index Probabilistic engineering loss estimation	NA	Indonesia	2015
Climate compatible physical infrastructure in coastal bangladesh(Saroar, 2015)	Cyclone	Physical infrastructure	Review Meta analysis DPSIR (driving forces, pressure, state, impacts, responses)	investing in climate compatible infrastructure development could minimize the exposure and sensitivity of coastal people toward the threats of climatic disasters	Bangladesh	2015
Developing a risk assessment model for typhoon-triggered debris flows(Wang & Ling, 2011)	Typhoon	Physical infrastructure	geotechnical engineering, geographical information systems disaster management	NA	Taiwan	2011
Landslide susceptibility assessment for St. Thomas, Jamaica, using geographical information system and remote sensing methods(Miller et al., 2007)	Landslides	NA	Aerial photographs geomorphological mapping Field surveys	NA	Jamaica	2007
A new tool for sustainable flood defence planning - An overview of the Eurotas research project(Samuels, 2000)	Floods	physical infrastructure	hydrological and hydrodynamic models of flood propagation with GIS and	NA	NA	2000

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			database to economic and land-use data to provide a perspective on both flood hazard and flood vulnerability. integrated Catchment Model (ICM)			

The analysis revealed several key trends in the literature.

- Floods and earthquakes are the most common disasters addressed in the literature (Figure 7). This development highlights the substantial influence of these hazards on communities and infrastructure globally.
- Emphasize Physical Infrastructure: Research articles have given significant emphasis to physical infrastructure, such as transportation networks, buildings, and vital facilities. This emphasizes the significance of comprehending and improving the resilience of infrastructure systems to endure and bounce back from calamities (Figure 8).
- The literature presented a variety of strategies used in disaster research, ranging from modern technology such as deep learning and convolutional neural networks to traditional survey methods and simulation models. This interdisciplinary methodology enables a thorough and detailed examination of disaster risk and infrastructure weaknesses (Figure 9).
- Global Perspective: Research articles from diverse countries and areas demonstrate the worldwide scope of disaster risk and the necessity for tailored solutions. The United States, Indonesia, Bangladesh, and Kenya were important study locations, reflecting a worldwide interest in disaster management across various contexts.

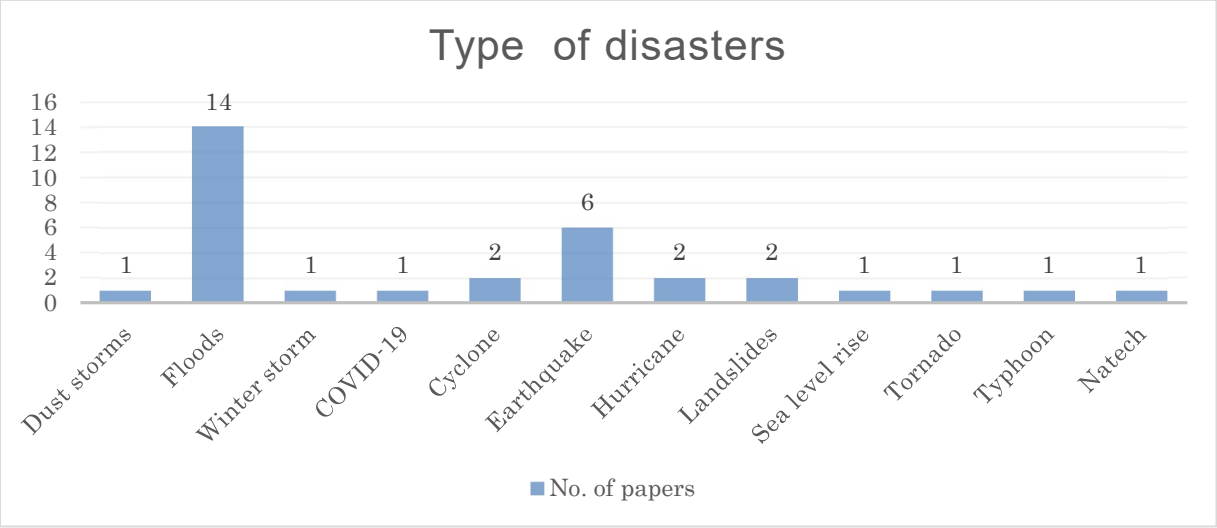

Figure 7. Bibliometric analysis reveals the frequency of papers addressing specific types of disasters
(Source: Author generated)

Table 10. Consolidated table of disaster and methods employed
(Author generated)

Disaster / Hazard	Methods employed
Dust storms	Deep Learning Convolutional Neural Network (CNN)
Floods	Household interviews/Personal interview Questionnaires Focused group discussions Reviews Transect walks Surveys, observation Model stacking and calibrations Decision support tools Digital Twin Flood modeling Quantitative approach Building information model Simulation - hazard, geographic features, spatial distribution of assets, and traffic Simulation Risk curve Integrated vulnerability index Empirical damage fragilities HZUS-MH - stage damage functions MPFIS - Multi functional pluvial flood information system Integrated Catchment Model (ICM)
Winter Storm	PMT (Protective Motivation Theory), MaxQDA
COVID-19	Input-output (I-O) model Dirichlet probability distributions for Leontief requirements matrix Review
Earthquake	Decision-making model Agent-based model - for evaluating owners' responses Survey - visual screening Risk index EDRI (Earthquake Disaster Risk Index) Risk-based support framework - models the impact of infrastructure dependencies on community response Framework - Physical infrastructure + Social science-based index Probabilistic Engineering Loss Estimation Simulation
Hurricane	Multi-hazard risk assessment framework Literature review
Landslides	Quantitative assessment PRISMA report analysis method Aerial photographs Geomorphological mapping Field surveys
Sea level rise	Content analysis
Tornado	Cellular Automata
Typhoon	Geotechnical engineering, Geographical information systems Disaster management

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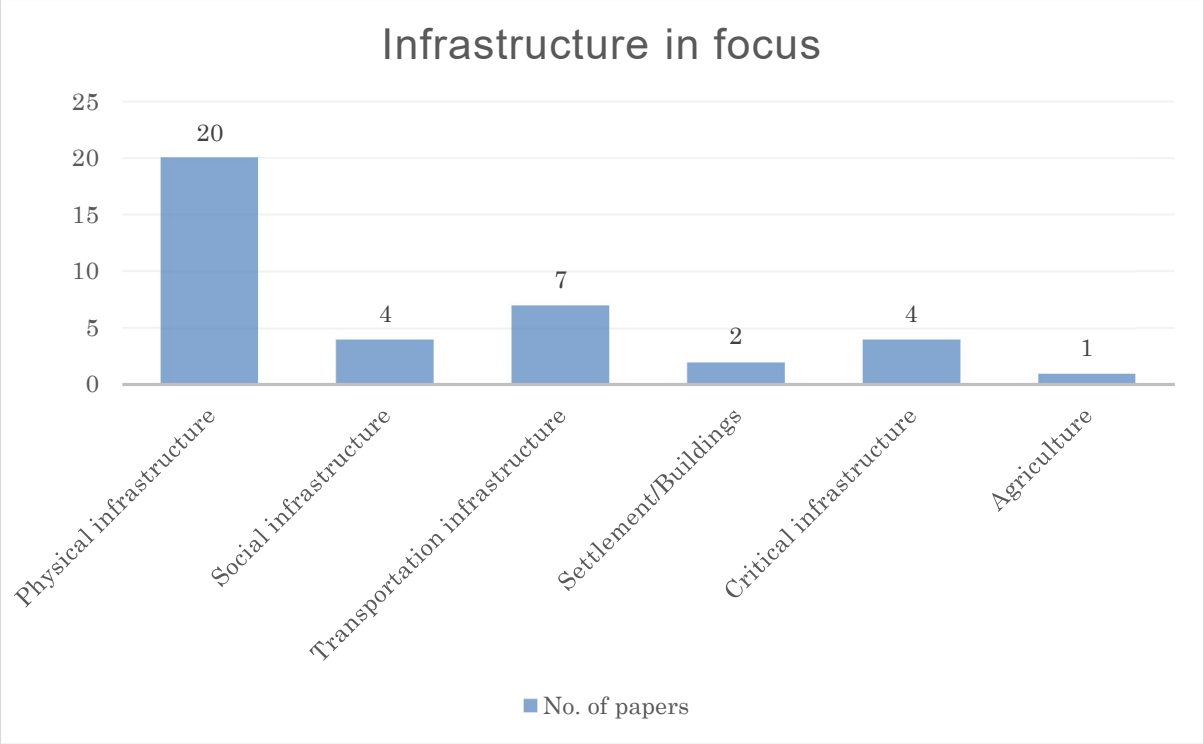

Figure 8. Bibliometric analysis reveals primary infrastructure types explored in the literature (Source: Author generated)

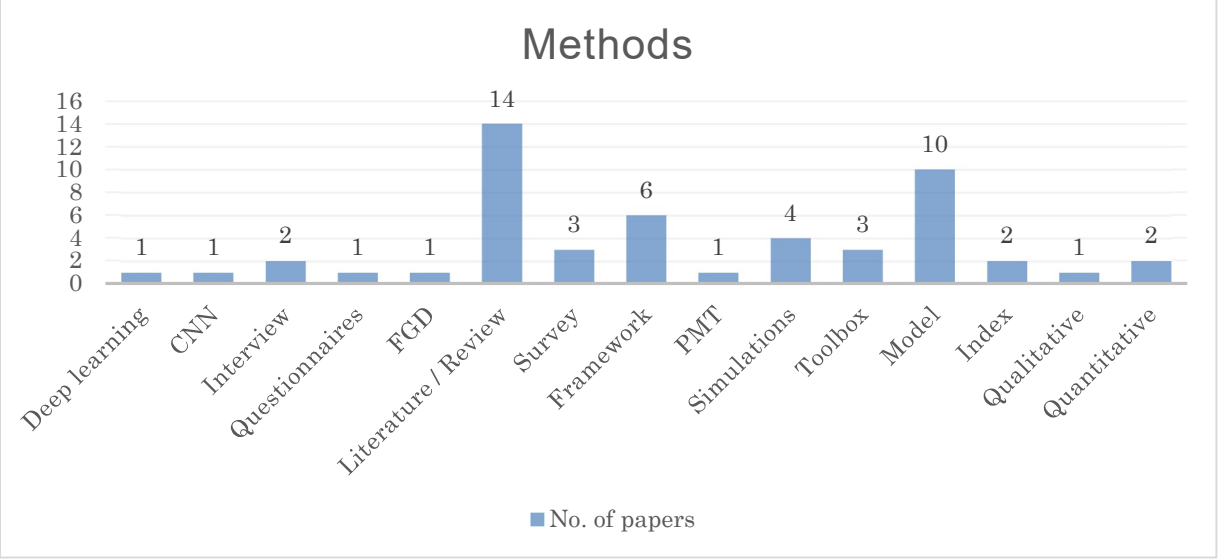

Figure 9. Bibliometric analysis reveals the frequency of papers addressing specific methods (Source: Author generated)

6. CONCLUSION

An extensive bibliometric analysis was performed to explore the complex research landscape related to risk assessment and infrastructure analysis in disaster management. Significant

insights were drawn about the most influential authors, publications, institutions, and key themes in this field in the global scenario. The trends and patterns of research were analyzed by systematically categorizing publications according to disaster nature, typology of infrastructure, and, methodology, used for the risk assessment.

The varied approaches used in disaster research demonstrate its interdisciplinary nature, emphasizing the importance of collaboration work among different fields to create comprehensive solutions. The research trend observed in the bibliometric analysis offers valuable insights and implications for the future scope of research in the study field. The emphasis on disasters such as floods and earthquakes in literature indicates the continuous necessity for solutions to develop advanced methods of risk assessment specific to these disasters. The plethora of methods used in disaster research emphasizes the significance of an interdisciplinary strategy integrating advances in engineering, social sciences, and computer science to develop comprehensive and unified solutions for risk evaluation.

In short, globally there is a greater scope for research on the risk assessment of physical infrastructure, especially transportation infrastructure. Our analysis highlighted the worldwide nature of catastrophe research, with contributions from various countries and areas. This highlights the disaster risk in the global scenario and the need for customized risk assessment methods that consider particular geographical contexts and socio-economic factors. Decision-makers and authorities can use tools like digital twins, simulations, and risk indices to develop actions that protect existing infrastructure and future projects from disasters. The results of our study will be highly beneficial for researchers, academics, policymakers, and planners, offering vital insights into the future of research in disaster risk assessments of physical infrastructure.

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