International Journal of Disaster Risk Science (2024) 15:45–57
https://doi.org/10.1007/s13753-024-00544-y

www.ijdrs.com
www.springer.com/13753

ARTICLE

A Systematic Analysis of Systems Approach and Flood Risk Management Research: Trends, Gaps, and Opportunities

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Accepted: 7 February 2024 / Published online: 16 February 2024

Abstract
Flooding is a global threat, necessitating a comprehensive management approach. Due to the complexity of managing flood hazards and risks, researchers have advocated for holistic, comprehensive, and integrated approaches. This study, employing a systems thinking perspective, assessed global flood risk management research trends, gaps, and opportunities using 132 published documents in BibTeX format. A systematic review of downloaded documents from the Scopus and Web of Science databases revealed slow progress of approximately 11.61% annual growth in applying systems thinking and its concomitant approaches to understanding global flood risk management over the past two decades compared to other fields like water resource management and business management systems. A significant gap exists in the application of systems thinking methodologies to flood risk management research between developed and developing countries, particularly in Africa, highlighting the urgency of reoriented research and policy efforts. The application gaps of the study methodology are linked to challenges outlined in existing literature, such as issues related to technical expertise and resource constraints. This study advocates a shift from linear to holistic approaches in flood risk management, aligned with the Sendai Framework for Disaster Risk Reduction 2015–2023 and the Sustainable Development Goals. Collaboration among researchers, institutions, and countries is essential to address this global challenge effectively.

Keywords Flood risk management research · Gaps and opportunities · Global trends in flood research · Systematic review · Systems thinking

1 Introduction

Humanity and the environment are facing grave threats to their long-term sustainability posed by climate change and rapid population growth, which has increased global disasters, with hydrometeorological disasters among the worst (Mavrouli et al. 2022). In the last decades, there has been a tremendous increase in the number of extreme hydrological events, which has led to severe damages (Cloke et al. 2017). In 2013, hydrological disasters accounted for 159 (48.2%) of all major disasters globally in comparison to meteorological disasters (storms) at 32.1%; climatological disasters (extreme temperatures, droughts, and wildfires) at 10%; and geophysical disasters (earthquakes, volcanic eruptions, and dry mass movements) at 9.7% (Guha-Sapir et al. 2014).

According to the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report of 2022, a temperature increase of 1.5 °C is projected to affect approximately 24% of the global population through flood hazards and an increase of approximately 30% with an additional temperature increase of 0.5 °C, with particular emphasis in coastal cities due to anticipated increases in sea level rise, storm surges, and coastal flooding. In the United States, the risk of flooding is predicted to increase by more than 25% within the next 30 years due to climate change (Sadiq et al. 2019). This elevated risk not only poses a threat to human lives and infrastructure but also leads to substantial economic losses, as climate-induced flooding has already caused severe economic damage worth more than an estimated USD 147 billion between 1980 and 2019 (Newman and Noy 2023) and USD 30 billion in 2020, exacerbating the economic strain in areas already affected by floods (Fields 2022).

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The Organization for Economic Cooperation and Development (OECD) report highlights that economic losses associated with flood events have been consistently increasing since 1970, partially attributed to shifts in weather patterns (OECD 2021). This heightened risk has significant implications for the global population and economies, increasing vulnerability in flood-prone regions, especially in developing countries.

According to Polka (2018), flood risks are a near-universal threat. While developed countries suffer significant damage from floods, their lower vulnerability is attributed to better prevention and risk management strategies. The Netherlands, a developed country with high flood risk, with over half of its population at risk of flooding, exemplifies this paradox (Klijn et al. 2012; Jongman et al. 2014). Despite the available resources, developed countries face substantial economic and social losses, necessitating continued investment in flood prevention (McDermott 2022). Developing countries are more vulnerable due to rapid urbanization, poor land use, and population growth and are more prone to flooding, resulting in increased damage and disruptions (Kovacs et al. 2017). Poverty exacerbates flood exposure, with 89% of the world's flood-exposed population in low and middle-income countries (Rentschler et al. 2022). According to Yuen and Kumssa (2010), Africa is one of the world's fastest-growing continents, including large urban and coastal cities. Given that population growth and urbanization have led to unrestricted land use and encroachment on previously uninhabited swampy zones, Africa is particularly vulnerable to floods, which have caused significant losses (CRED 2015; WMO 2022). According to the United Nations (2022), Africa has an annual population growth rate of 2.5%. Between 1970 and 2019, extreme weather, climate, and hydrological events were responsible for half of all disasters, 45% of recorded deaths, and 74% of documented economic losses (WMO 2022). Flood risks are increasingly becoming complex, and addressing complex challenges requires a holistic and participatory approach encompassing adaptation, mitigation, and consideration of socioeconomic and environmental aspects of flood risk management (Madu 2017; Nur and Shrestha 2017; Rehman et al. 2019; Salazar-Briones et al. 2020; Costa 2021; Hagedoorn et al. 2021; Islam et al. 2022).

Flood risks are complex, induced through the interactions of multiple components and their underlying drivers that can sometimes lead to short- and long-term synergies and trade-off outcomes (Ceres et al. 2022). Consequently, to address complex interconnections and identify practical solutions to flood challenges, the systems thinking approach is widely appreciated for its holistic and practical viewpoint than other analytical approaches, given that it considers connectedness, relationships, and context (Nyam et al. 2020; Perrone et al. 2020). This methodology facilitates an accurate comprehension of the system implications of complex human–environment sustainability. Without this, there is a risk that policies and technological breakthroughs would have unanticipated implications (Saviano et al. 2019; Mehryar and Surminski 2022). The increase in flood frequency and intensity coupled with population growth has led to the emergence of concepts like "living with floods" (Hellman 2015; Chetry 2022) and "building back better" (Cheek and Chmutina 2022; Mendis et al. 2022). However, achieving successful outcomes requires scientific knowledge and evidence-based techniques to understand gaps and potential interventions in the face of increased population growth and urbanization. Despite the growing application of systems theory and its associated tools in business, water management, and economics, its application to disaster risk management has not been thoroughly evaluated empirically. Limited knowledge exists regarding the application of systems thinking to understand flood risk management, particularly in the context of developing countries, hence necessitating this study. This research evaluated published articles on systems thinking and flood risk management to identify global trends, gaps, and opportunities. It aimed to enhance an understanding of the application of system thinking approaches to flood risk management research.

Systems thinking (ST) is widely recognized as a method to address complex problems in various domains and has been extensively documented. The system dynamic (SD) methodology based on the principle of systems thinking has proven to be an innovative method for comprehending the structure and behavior of complex systems within the context of systems thinking over time (Azar 2012; Sterman et al. 2015; Saunders and Truong 2019; Nyam et al. 2020; Laurien et al. 2022). Using system dynamics, encompassing qualitative and quantitative models enables the perspicacity of relevant feedback and causal connections that govern the behavior and structure of intricate systems (Awah et al. 2024). The study of systems thinking often involves the examination of fundamental and widely used concepts such as feedback, variables, and time delays frequently explored within system dynamics, specifically through causal loop diagrams (CLD) (Wolstenholme and Coyle 1983; Schaffernicht 2010; Barbrook-Johnson and Penn 2022). Loop diagrams depict variables that exhibit patterns depending on particular feedback and circular causality. These concepts are used to explain the reciprocal relationships between variables, where arrows indicate the mutual influence that can be negative (balancing feedback loop) or positive (reinforcing feedback loop) as explained by Watson and Watson (2013). To thoroughly understand systems, practitioners use systems thinking as a suitable approach to describe and analyze the interactions and influences among varied factors and components (Betley et al. 2021; Schoenenberger et al. 2021).

2 Data and Methods

In this study, descriptive and network analysis techniques were employed to provide an overview of the evolution of systems thinking methodology and its application in flood risk management research. This study considered search words to retrieve scientific documents relating to system theory and flood research globally as shown in Table 1. The bibliometric method is a good innovation for literature reviews as it tries to retrieve relevant documents needed for research through databases such as Web of Science (WoS), PubMed, Scopus, and others. The scientometric analysis provides a rigorous process allowing the analysis of various aspects of published academic materials (articles, books, and so on) to show the past and current structure of the concerned field through citation, co-authorship, bibliographic coupling, keyword occurrences, and cluster analysis. The analysis was conducted using Biblioshiny (Ogundeji and Okolie 2022; Salleh 2022) in the R-Studio environment, Vosviewer (free online analysis tool), and Scopus and WoS databases, to understand the multidimensional structure and identify the trends, gaps, and opportunities for future flood risk management research. The analysis involved projecting key aspects such as themes, authors, countries, institutions, and keywords, among others, from 2002 to 2022.

2.1 Sourcing Relevant Information on the Published Materials

The Scopus and WoS databases were employed to procure scientific publications because they are widely recognized as a comprehensive and interdisciplinary repository of peer-reviewed literature within social sciences. Compared to alternative databases such as Dimension, they exhibit a greater prevalence of keyword-based article searches that is particularly relevant for this review. Several eligibility and exclusion criteria were considered during the article search process. Locating and accessing relevant information was based on a targeted search focused on keywords, titles, and abstracts given its efficacy as previously acknowledged by Atanassova et al. (2019) and corroborated by Mejia et al. 2021). The analysis incorporated all published peer-reviewed documents especially articles from academic journals focused solely on environmental science and social science-related fields. The review only considered articles in English given that English is a widely known language worldwide. A span period of 21 years was considered to encompass the majority of literature on system dynamics and flood risk management. Table 1 presents comprehensive information regarding the criteria, eligibility, and exclusionary measures employed to identify pertinent articles for in-depth analysis. Document search employed keywords such as “systems thinking” AND “flood risk.” Table 1 presents the comprehensive search string.

2.2 The Review Process

The review process followed the guidelines proposed by Tranfield et al. (2003) and applied the four-phase systematic review methodology suggested by Ogundeji and Okolie (2022). The keywords on systems thinking and flood risk management were based on the research objective (Table 1). The search yielded a total of 234 published materials

Table 1 Search focus, criteria, eligibility, and elimination strategies in the flood risk management research study

Search focus (string)		
Search focus 1	Search focus 2	Search focus 3
“System theory*”	(AND) “flood management*”	(AND) “disaster management*”
“Systems approach*”	(AND) “flood risk management*”	(AND) “disaster management*”
“Systems thinking*”	(AND) “flood management*”	(AND) “disaster management*”
“System dynamics*”	(AND) “flooding*” (AND) “flood*”	(AND) “disaster management*”
Criterion	Eligibility	Elimination
Scopus and WoS databases		
Document type	Only published articles, books, reviews, and so on	Notes, editorial reviews, short surveys, errata, and so on
Source forms	Journals, books, and so on	Conference proceedings, undefined sources, and so on
Publication point	Final	Article in press
Subject field	Environment and social sciences	Business management and accounting, pharmacology, toxicology, pharmaceutics, material science, chemistry, multidisciplinary, and so on
Language	English language only	Non-English language
Span	Between 2002 and 2022	< 2002 and > June 2022

(articles, books, and so on). A screening process was conducted leading to the elimination of 102 articles from the original sample of 234 articles. The elimination of articles was done taking into consideration certain factors such as the lack of primary focus on system dynamics and flood risk management, the publication stage, and/or language.

2.3 Data Processing and Analysis

This scientometric analysis was conducted using R-Studio V.3.4.1 software in conjunction with the bibliometrix R-package. Upon conducting a comprehensive review of pertinent literature for this study, the collected data were imported into R-Studio and converted into a bibliographic format, ensuring uniformity in identifying and removing potential duplicates. The author names, keywords (DE), and keywords-plus (ID) were extracted to enhance visualization. The extraction procedure entailed meticulously examining the abstracts and comprehensively analyzing the complete articles to ascertain relevant themes and sub-themes. The study employed a qualitative content analysis technique to identify the themes and subjects related to systems thinking and flood risk management. After the selection process, the selected documents underwent descriptive and bibliometric analysis using Biblioshiny, as presented in the result section.

3 Results

Studies published on system dynamics, systems thinking, and flood risk management from 2002 to 2022 were evaluated in this study as this period coincides with the increased prominence and adoption of systems thinking principles in the field of disaster management. Analyzing certain parameters/matrices helps us identify gaps or limitations regarding research outputs in a specific sector. These matrices include the (1) most cited countries, (2) highly cited articles, (3) most referred articles, (4) number of articles with a high impact factor, (5) country's most relevant affiliations, (6) most productive authors, (7) corresponding authors and the number of articles produced from a country, and (8) number of citations per country. This article, however, focuses on identifying the publication trends, the most productive countries, collaboration networks between authors and institutions, and keyword and thematic evolution of research based on keyword search that will allow the researchers to identify gaps and opportunities for further research.

3.1 Analyzing Data Output and Thematic Evolution

The study analyzed 234 published articles on systems thinking, system dynamics, and flood risk management from 2002 to 2022. The research showed an annual growth rate of 11.61% in the number of publications, with a peak in 2021 and 2022, consistent with the findings of Yang et al. (2021) who highlighted an increase in flood-related studies globally. The average annual total citations per article fluctuated, with 2018 having the highest average. The past decade has seen a rapid upswing in using systems thinking tools, particularly in sustainability studies and natural sciences. As elucidated by Hossain et al. (2020), this upturn can be attributed to practitioners, academia, and industry recognizing the imperative need to embrace systems thinking as a novel cognitive approach for addressing contemporary intricate challenges. The number of publications in this field has gradually grown from 2 in 2002 to 11 in 2015 and 18 in 2022 (Fig. 1), suggesting the gradual integration of systems thinking tools in flood research worldwide.

The study used a Sankey diagram to visualize the evolution of study themes, structures, and contexts over three distinct periods: 2002–2006, 2007–2015, and 2016–2022 (Fig. 2). A Sankey diagram is often used to understand and visualize the thematic evolution of keywords over time (Cobo et al. 2011; Okolie et al. 2022). The themes identified during 2002–2006 were disaster management, climate change, system dynamics, and hydrology. From 2007 to 2015, themes like system dynamics and climate change persisted, while additional themes emerged, including floodplain, ecosystem, systems theory, sustainable development, floods, and flooding. The last segment (2016–2022) added hydrological modeling and simulation. It should be noted that systems theory and related themes, such as systems thinking and system dynamics, have been used in the literature but have shown limited application in flood risk management research. This highlights the application gaps in systems thinking methodologies and flood risk management research. Previous studies have demonstrated the usefulness of systems thinking in understanding complex systems, such as economic systems, agriculture, and natural resource management (Bosch et al. 2007; Laspidou et al. 2020). However, given the inherent complexities of flood systems, a holistic methodology is necessary to gain a profound and precise understanding of underlying dynamics and the systems approach is the most effective and optimal methodology (Nyam et al. 2020).

3.2 Country Research Output

According to Wang et al. (2018), a country's influence in a research field is often determined by parameters such as publication output, H-index, citation count, and collaboration network. For the top 15 most productive countries, the United States ranked first in terms of published documents and total citations, followed by China, Canada, the United Kingdom, South Korea, Australia, Germany, the Netherlands, Austria, India, Spain, Belgium, Denmark, South

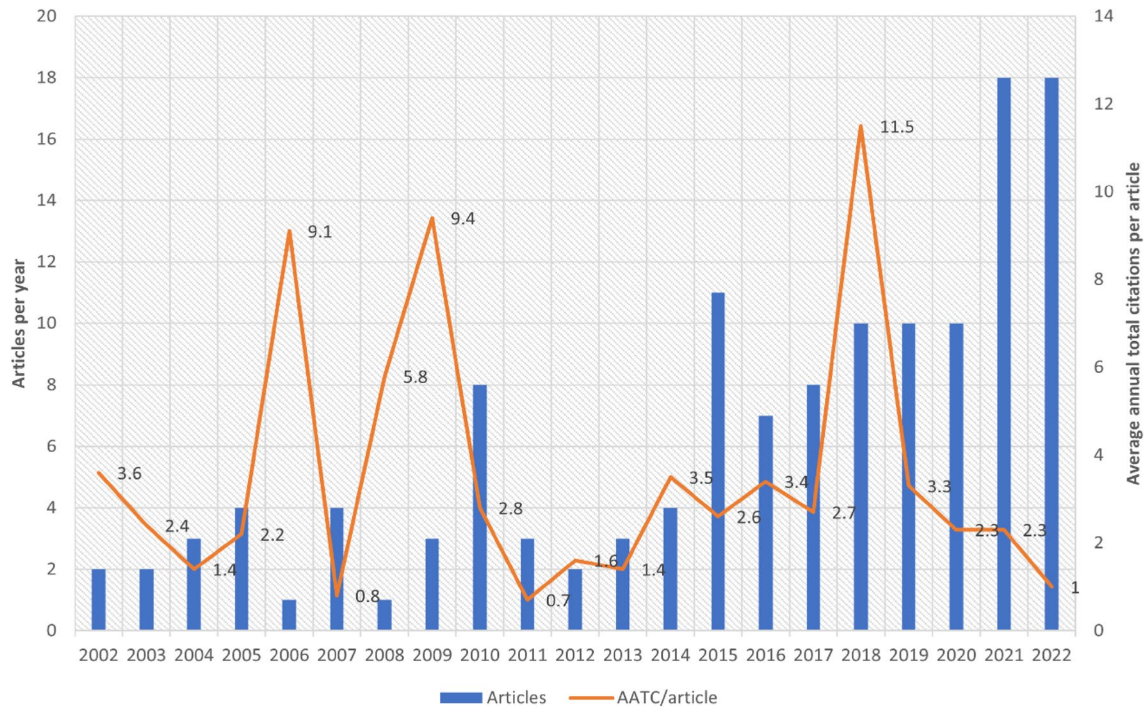

Fig. 1 Annual scientific production applying system dynamics and systems thinking in flood research from 2002 to 2022. *AATC* average annual total citations

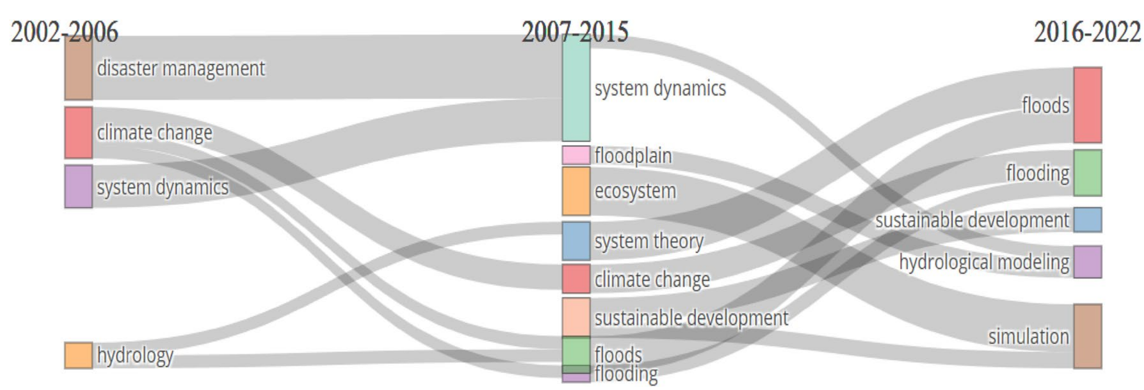

Fig. 2 Thematic evolution in research on system dynamics, systems thinking, and flood risk management based on keyword occurrences from 2002 to 2022

Africa, and Sweden (Fig. 3). The publishing frequency of the top countries varied from 0.8 to 19.8%, highlighting substantial variations in country productivity and total citations. The study found that a country's ability to produce a considerable number of publications does not necessarily guarantee high citation rates. For example, Australia ranked sixth in total publications (n = 13, 5.5%) but was not among the top 15 in total citations. This finding aligns with the findings of Di Bitetti and Ferreras (2017) that factors like language, discipline, and accessibility (open access or not) significantly influence the total citation count of a publication.

Country-wise author collaboration was analyzed to gain collaboration insight. Figure 3 indicates that single-country production accounted for approximately 73.5% compared to multiple-country production, which accounted for 26.5% of research related to system dynamics, systems thinking, and flood risk management. This finding highlights the need for more collaboration among authors, countries, institutions, and continents. Collaboration within sectors, as emphasized by Peffer and Renken (2016), will enhance knowledge and productivity, thereby reducing knowledge gaps, whether in specific methodologies or broader skill sets.

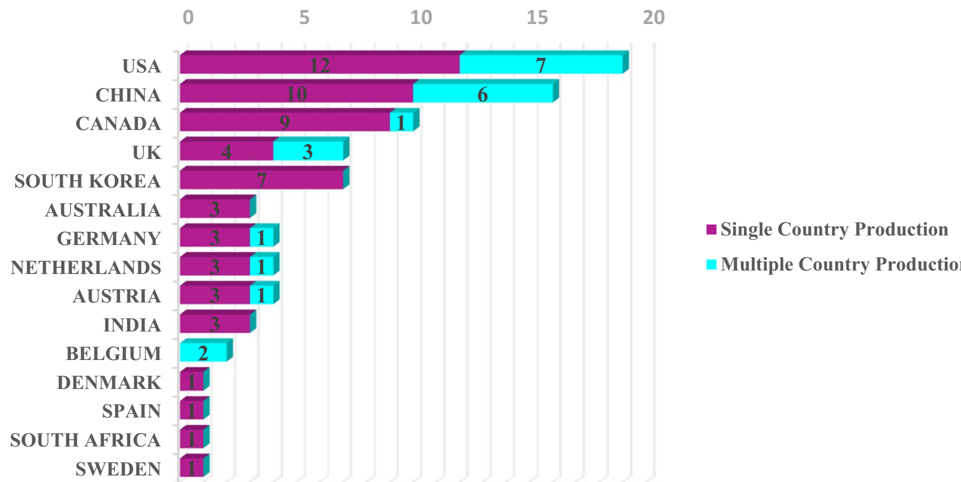

Fig. 3 Top 15 most productive countries in the research on system dynamics, systems thinking, and flood risk management from 2002 to 2022

The calculations based on the top 15 most productive countries in system dynamics, systems thinking, and flood risk management research publications from 2002 to 2022 indicate that the continent of America represented by the United States and Canada emerged as the leading continent with a combined total publication count of 34.9%. Asia, encompassing China, South Korea, and India, recorded total publication counts of 31.3%, standing as the second most productive continent. Europe, represented by the Netherlands, United Kingdom, Germany, Austria, Spain, Belgium, Denmark, and Sweden, ranked third, accounting for 28.9% of the total publication count. The Australian and African continents ranked fourth and fifth with a total publication count of 3.6% and 1.2%, respectively.

3.3 Most Productive Journals

Journal publications are crucial for disseminating information about a specific topic or sector of interest (El-Omar 2014). An analysis of journals allowed us to understand the state of flood risk management research, identify trends, and identify gaps for effective flood risk management strategies. Through journal publications, researchers become aware of the scientific outputs of scholars in their sector of interest. It was, therefore, vital to identify journals that have contributed to understanding systems thinking, system dynamics, and flood risk research through conceptual frameworks, risk analysis methodologies, or providing practical solutions for effective flood risk management. This is important as it can assist researchers in quickly identifying journals that are suitable for the publication of their research on system dynamics and flood risk management. An analysis of journals publishing research related to systems thinking and flood risk management from 2002 to 2022—based on publication frequency and total publications—revealed that the journal *Science of the Total Environment* ranked first (10.56%), followed by *Water Resources Management* and *Water Resources Research* (9.24%), while *Water* ranked third (7.92%), *Earth and Environmental Science* ranked fourth (6.6%), and the *Journal of Cleaner Productio*n ranked fifth (5.28%). The journals *Advances in Global Change Research*, *Ecology and Society*, *Hydrology and Earth System Sciences*, and *Disaster Prevention and Management* ranked sixth (3.96%).

3.4 Network Visualization Analysis

A network visualization map was used to explore the co-occurrence of author keywords (Fig. 4). The density network unravelled the intricate nature of the research landscape. The size of each circle in the intellectual network corresponds to the frequency of use of a specific keyword in the analyzed documents. Based on the author's keyword search, system dynamics, floods, and flood control are the prominent keywords within this research domain. The interconnectedness and linkages observed in the network visualization indicate the complex relationships among these keywords, underscoring the shared interests of authors in advancing flood-related research with a focus on systems thinking. The size of each keyword in the density and network visualization reflects its significance and frequency of appearance in the literature on system dynamics and flood risk management. The proximity of keywords to one another suggests the likelihood of their interaction throughout the study period. The results of the literature research exhibit notable variations in the density and network visualization of co-occurring author keywords across individual articles, emphasizing the multidimensional and multifaceted nature of this scientific field. These findings align with previous studies conducted by Okolie et al. (2022) and (Orimoloye et al. (2021).

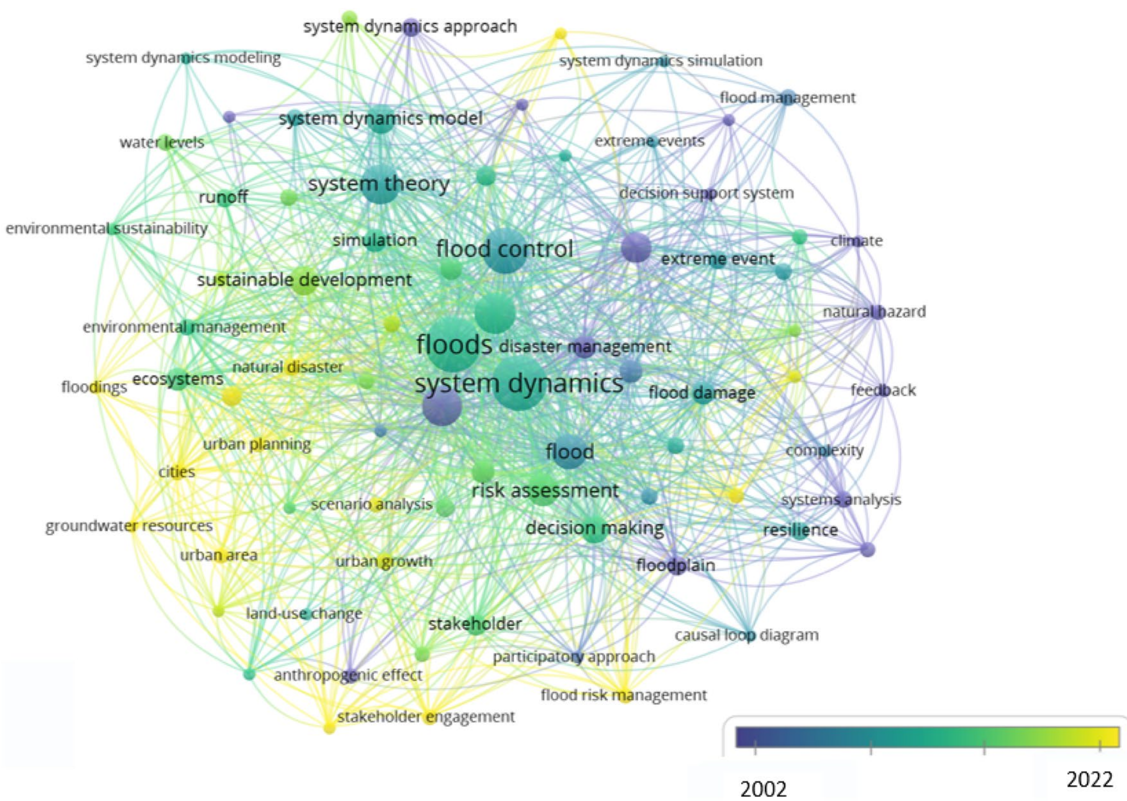

Fig. 4 Network analysis for co-occurrence of keywords in system dynamics and flood risk management research from 2002 to 2022

4 Discussion

In the face of increasing challenges posed by climate change, urbanization, and population growth, flood risk management has emerged as a critical global concern. The following discussion delves into the current state of flood risk management research, highlighting emerging trends, identifying critical research gaps, and exploring opportunities for future studies. The evolving landscape of flood risk management demands a closer examination of the adoption of holistic approaches, particularly the shift towards systems thinking methodologies.

4.1 Trends, Gaps, and Opportunities in Flood Risk Management Research

Understanding trends, gaps, and opportunities in flood risk management studies is important as it helps identify areas where research is lacking and which areas of research require more efforts. This is important as it can help improve flood risk management strategies and policies, leading to better outcomes for communities and individuals affected by flooding.

First, three significant trends were identified by this research: (1) flood is a global phenomenon affecting both developed and developing countries (McDermott 2022); (2) floods have become very complex, especially with increased climate change, population growth, and urbanization (Salmon et al. 2012; Cavallo and Ireland 2014; De Ruiter et al. 2020); and (3) there has been a shift towards community engagement in flood risk research (Perrone et al. 2020; Atanga 2020). All of these have necessitated a shift towards a more holistic approach. This study highlights a shift from linear to nonlinear methodologies such as systems thinking approaches to enhance our understanding of complex flood systems. However, the growing adoption of systems thinking approaches in flood risk management research is visible in most developed countries as opposed to less developed countries.

The low adoption of this holistic approach in less developed countries in flood risk management research could explain the implementation of reactive rather than proactive flood risk management measures as opposed to most developed countries. Through an in-depth examination of the literature, several challenges were identified as limiting factors to adopting the systems approach in flood risk management research, as summarized in Table 2.

Despite the gaps and challenges, adopting a systems thinking approach presents several opportunities that could inherently improve our understanding of flood risk

Table 2 Challenges in systems thinking application in flood risk management research

Systems thinking application challenges	Literature
Comprehensiveness and simplification	Tavasszy and de Jong (2014)
Model validation	Maskrey et al. (2022)
Complexity and data requirements	Vojinović et al. (2014), Bernhofen et al. (2022)
Interdisciplinary collaboration	Perrone et al. (2020), Caretta et al. (2021)
Resource constraints	Tariq et al. (2020), De Bruijn et al. (2022)
Model complexity	Apel et al. (2006), Zischg (2018)
Communication challenges	Maskrey et al. (2022), Duncan (2023)
Political and stakeholder dynamics	Ziga-Abortta et al. (2021)
Technical expertise	Rehman et al. (2019)

management research. Applying systems thinking in flood risk management research offers a holistic understanding of complex interdependencies within flood systems, utilizing methodologies such as causal loop diagrams to identify feedback mechanisms and dynamic behaviors (Anisah et al. 2022; Awah et al. 2024). This approach considers physical, social, economic, and environmental factors, allowing stakeholders to pinpoint flood risk catalysts, trade-offs, and synergies, ultimately informing the development of more efficient and resilient flood risk management strategies (Rehman et al. 2019; Mai et al. 2020). Moreover, systems thinking fosters stakeholder collaboration, encourages interdisciplinary cooperation, and enhances inclusive decision making, making it a comprehensive and effective approach to addressing flood-related challenges (Perrone et al. 2020; Zevenbergen et al. 2020; Chang et al. 2021; Shmueli et al. 2021; Tate et al. 2021; Maskrey et al. 2022; Mehryar and Surminski 2022).

Table 3 presents some studies on systems thinking, its related methodologies, and its application in flood risk management research. It also identifies gaps and opportunities for applying systems thinking in flood risk management research. The findings and conclusions of these studies have prompted the further exploration of this methodology in Cameroon, a developing country in West Africa that faces recurrent floods annually. The study employed the systems thinking approach to collaboratively engage stakeholders to develop an integrated flood risk management framework to build resilience in flood-prone communities (Awah et al. 2024).

4.2 Application of Systems Thinking to Flood Risk Management Policy Discourse

The systems thinking approach is increasingly recognized as important in understanding and managing flood risks. This approach provides comprehensive methods to assess flood risks, identify interactions, and quantify feedbacks within systems (De Bruijn 2005; Schröter et al. 2021). Integrating the systems approach into flood risk management can lead to more cost-effective and resilient strategies (Mai et al. 2020). The transition from risk-based to resilience-based flood management is highlighted by the Sendai Framework for Disaster Risk Reduction 2015–2030, emphasizing the need for more resilient and sustainable approaches to cope with flood disasters (Wang et al. 2022; Vitale 2023). The policy discourse on systems approach and flood risk management research should focus on integrating resilience into flood risk governance and policy, addressing institutional stability, participatory practices, and sustainable flood risk management (Moon et al. 2017; Graveline and Germain 2022). Additionally, there is a need to move the discourse toward a resilience-focused approach, taking into account perspectives from engineering, ecology, and social sciences. Adopting a systems approach in flood risk management enhances resilience and sustainability. The discourse on holistic approaches to disaster resilience is closely tied to systems thinking approaches. The policy discourse should be targeted at policymakers and stakeholders at national and international levels (Kaufmann and Wiering 2022) to promote the integration of the systems approaches to flood risk management policies and strategies, as attaining resilience requires a coordinated effort at the national and international levels to ensure effective implementation and to address the drivers of policy change.

5 Conclusion

The concept of systems thinking has been widely explored across various domains, significantly enhancing the comprehension of systems thinking methodologies. However, its application in comprehending flood risks has been notably limited. This study revealed an upward trend in the adoption of systems thinking methodologies in flood risk management. However, developing countries still lag when it comes to its methodological application hence more research is required to understand why this disparity persists particularly in developing countries. The study systematically reviewed published research indexed in Scopus and WoS

Table 3 Systems thinking application in flood risk management research

Author	Article title	Summary	Identified from study	
			Gaps	Opportunities
Kreibich and Sairam (2022)	Dynamic flood risk modelling in human-flood systems	Discusses the benefits, challenges, and limitations of this approach, and highlights the importance of considering dynamics to improve the understanding and manage flood risks	Incorporating human behavior in system dynamics models as human behaviors can be difficult to predict and model accurately	The use of dynamic flood risk modeling to identify effective strategies for managing flood risks that consider the complex interactions and feedbacks in human-flood systems
Mai et al. (2020)	Defining flood risk management strategies: A systems approach	Examines the use of the systems approach in identifying potential drivers and triggers of flooding, identifying trade-offs and synergies, anticipating and managing unintended consequences, promoting stakeholder engagement and collaboration, encouraging long-term planning and resilience, and integrating multiple disciplines in flood risk management	Some challenges involved complexity in system dynamics research as well as data availability and quality	The systems approach emphasizing stakeholder engagement and collaboration offering a proactive approach to flood risk management
Rehman et al. (2019)	Applying systems thinking to flood disaster management for sustainable development	Focuses on applying systems thinking to flood disaster management for sustainable development and discusses the challenges and opportunities in implementing this approach, aiming to build resilience and effectively manage flood disasters	Data and technical expertise being limited to support systems thinking-based approaches	The opportunity to develop more cost-effective and proactive flood risk management strategies

and a bibliographic analysis using R-Studio for the selected 132 published materials between 2002 and 2022. The United States, China, and Canada were the leading countries in scientific production within the study period. The journal *Science of the Total Environment* had the highest source impact of publications on systems thinking and flood risk management. Considering that many developing countries, particularly in Africa, continue to suffer significant losses due to the increasing frequency and intensity of floods resulting from climate change, this study advocates for a reorientation of research and policy efforts. The focus should be on research that enables a holistic approach to flood risk management. With the growing emphasis on advancing the Sendai Framework and the Sustainable Development Goals, there is a burgeoning interest in transitioning from linear to non-linear approaches for sustainable mitigation of flood risk hazards. It is anticipated that scientific production using this methodology will likely increase over time, especially given the heightened interest of prominent research organizations such as the World Bank.

The study is limited by the fact that it solely relied on publications indexed in the Scopus and WoS databases, thereby limiting its scope. Other comprehensive bibliographic databases, such as PubMed, Dimension, and Lens.org were not included. Also, including other languages such as French and Chinese, among others presents an opportunity for further exploration of this research area. It is recommended that in-depth research be conducted to examine the application of the systems thinking approach in disaster management generally, not just in flood research. This study underscores the value of applying a systems thinking approach to enhance the understanding of flood risk. A promising avenue for advancement involves active engagement with governmental and funding entities, urging them to allocate resources for this research. The potential outcomes of this approach surpass conventional statistical methodologies, offering more practical insights. While this methodology has proven innovative and successful in certain applications, its universal implementation may pose challenges under various circumstances.

Acknowledgements The authors would like to acknowledge and appreciate the European Union-sponsored project Fostering Research & Intra-African Mobility & Education (FRAME) (Reference Number FRAM2000567), for the financial support in executing this research.

References

Anisah, A., B.H. Santosa, and D.B. Sencaki. 2022. Conceptual framework of systems thinking based flood risk management: A preliminary study. In *Proceedings of 2022 IEEE Asia-Pacific Conference on Geoscience, Electronics and Remote Sensing Technology (AGERS)*, 21–22 December 2022, Surabaya, Indonesia, 1–5.

Apel, H., A.H. Thieken, B. Merz, and G. Blöschl. 2006. A probabilistic modelling system for assessing flood risks. *Natural Hazards* 38(1–2): 79–100.

Atanassova, I., M. Bertin, and P. Mayr. 2019. Editorial: Mining scientific papers: NLP-enhanced Bibliometrics. *Frontiers in Research Metrics and Analytics*. https://doi.org/10.3389/frma.2019.00002.

Atanga, R.A. 2020. The role of local community leaders in flood disaster risk management strategy making in Accra. *International Journal of Disaster Risk Reduction* 43: Article 101358.

Awah, L.S., J.A. Belle, Y.S. Nyam, and I.R. Orimoloye. 2024. A participatory systems dynamic modelling approach to understanding flood systems in a coastal community in Cameroon. *International Journal of Disaster Risk Reduction* 101: Article 104236.

Azar, A.T. 2012. System dynamics as a useful technique for complex systems. *International Journal of Industrial and Systems Engineering* 10(4): 377–410.

Barbrook-Johnson, P., and A.S. Penn. 2022. Causal loop diagrams. In *Systems mapping: How to build and use causal models of systems*, ed. P. Barbrook-Johnson, and A.S. Penn, 47–59. Cham: Springer.

Bernhofen, M.V., S. Cooper, M. Trigg, A. Mdee, A. Carr, A. Bhave, Y.T. Solano-Correa, and E.L. Pencue-Fierro et al. 2022. The role of global data sets for riverine flood risk management at national scales. *Water Resources Research* 58(4): Article e2021WR031555.

Betley, E., E.J. Sterling, S. Akabas, A. Paxton, and L. Frost. 2021. Introduction to systems and systems thinking. *Lessons in Conservation* 11: 9–25.

Bosch, O.J.H., C.A. King, J.L. Herbohn, I.W. Russell, and C.S. Smith. 2007. Getting the big picture in natural resource management—Systems thinking as "method" for scientists, policy makers and other stakeholders. *Systems Research and Behavioral Science: The Official Journal of the International Federation for Systems Research* 24(2): 217–232.

Caretta, M.A., R. Fernandez, N. Zegre, and J. Shinn. 2021. Flooding hazard and vulnerability. An interdisciplinary experimental approach for the study of the 2016 west Virginia floods. *Frontiers in Water*. https://doi.org/10.3389/frwa.2021.656417.

Cavallo, A., and V. Ireland. 2014. Preparing for complex interdependent risks: A system of systems approach to building disaster resilience. *International Journal of Disaster Risk Reduction* 9: 181–193.

Ceres, R.L., C.E. Forest, and K. Keller. 2022. Trade-offs and synergies in managing coastal flood risk: A case study for New York City. *Journal of Flood Risk Management* 15(1): Article e12771.

Chang, H., A. Pallathadka, J. Sauer, N.B. Grimm, R. Zimmerman, C. Cheng, D.M. Iwaniec, and Y. Kim et al. 2021. Assessment of urban flood vulnerability using the social–ecological–technological systems framework in six US cities. *Sustainable Cities and Society* 68: Article 102786.

Cheek, W., and K. Chmutina. 2022. "Building back better" is neoliberal post-disaster reconstruction. *Disasters* 46(3): 589–609.

Chetry, B. 2022. Living with floods: Community-based coping and resilience mechanism of mising from floods; A study of Majuli District of Assam. In *Challenges of disasters in Asia:*

Vulnerability, adaptation and resilience, ed. H. Sajjad, L. Siddiqui, A. Rahman, M. Tahir, and M.A. Siddiqui, 371–411. Singapore: Springer.

Cloke, H., G. Di Baldassarre, O. Landeg, F. Pappenberger, and M.H. Ramos. 2017. Hydrological risk: Floods. https://drmkc.jrc.ec.europa.eu/portals/0/Knowledge/ScienceforDRM/ch03_s02/ch03_s02_subch0304.pdf. Accessed 8 Feb 2024.

Cobo, M.J., A.G. López-Herrera, E. Herrera-Viedma, and F. Herrera. 2011. An approach for detecting, quantifying, and visualizing the evolution of a research field: A practical application to the Fuzzy Sets Theory field. *Journal of Informetrics* 5(1): 146–166.

Costa, C.G.F. 2021. Disaster management and climate adaptation roadmap for coastal cities based on the ten essentials of UNDRR. *Journal of Integrated Coastal Zone Management* 21(1): 33–53.

CRED (Centre for Research on the Epidemiology of Disasters). 2015. EM-DAT | The international disasters database. https://www.emdat.be/. Accessed 8 Feb 2024.

De Bruijn, K.M. 2005. *Resilience and flood risk management: A systems approach applied to lowland rivers*. Delft: Delft University Press.

De Bruijn, K.M., B.A. Jafino, B. Merz, N. Doorn, S.J. Priest, R.J. Dahm, C. Zevenbergen, J.C. Aerts, and T. Comes. 2022. Flood risk management through a resilience lens. *Communications Earth & Environment* 3(1): Article 285.

De Ruiter, M.C., A. Couasnon, M.J. van den Homberg, J.E. Daniell, J.C. Gill, and P.J. Ward. 2020. Why we can no longer ignore consecutive disasters. *Earth's Future* 8(3): Article e2019EF001425.

Di Bitetti, M.S., and J.A. Ferreras. 2017. Publish (in English) or perish: The effect on citation rate of using languages other than English in scientific publications. *AMBIO* 46: 121–127.

Duncan, J. 2023. Unlocking the power of context: The crucial factor in communicating flood risk data. https://aecom.com/without-limits/article/unlocking-the-power-of-context-the-crucial-factor-in-communicating-flood-risk-data/. Accessed 8 Feb 2024.

El-Omar, E.M. 2014. How to publish a scientific manuscript in a high-impact journal. *Advances in Digestive Medicine* 1(4): 105–109.

Fields, S. 2022. Flood risk to rise more than 25% in the next few decades because of climate change. *Marketplace*, 2 February 2022. https://www.marketplace.org/2022/02/02/flood-risk-to-rise-more-than-25-in-the-next-few-decades-because-of-climate-change/. Accessed 8 Feb 2024.

Graveline, M.H., and D. Germain. 2022. Disaster risk resilience: Conceptual evolution, key issues, and opportunities. *International Journal of Disaster Risk Science* 13(3): 330–341.

Guha-Sapir, D., P. Hoyois, and R. Below. 2014. *Annual disaster statistical review 2013: The numbers and trends*. Brussels: CRED.

Hagedoorn, L.C., P. Bubeck, P. Hudson, L.M. Brander, M. Pham, and R. Lasage. 2021. Preferences of vulnerable social groups for ecosystem-based adaptation to flood risk in central Vietnam. *World Development* 148: Article 105650.

Hellman, J. 2015. Living with floods and coping with vulnerability. *Disaster Prevention and Management* 24(4): 468–483.

Hossain, N.U.I., V.L. Dayarathna, M. Nagahi, and R. Jaradat. 2020. Systems thinking: A review and bibliometric analysis. *Systems* 8(3): Article 23.

Islam, M.A., A.L. Griffin, D.J. Paull, and S. Murshed. 2022. Assessing critical infrastructure resilience in terms of its service-providing capacity in coastal Bangladesh: A synthesis of geospatial techniques and social responses. *International Journal of Disaster Risk Reduction* 67: Article 102633.

Jongman, B., E.E. Koks, T.G. Husby, and P.J. Ward. 2014. Increasing flood exposure in the Netherlands: Implications for risk financing. *Natural Hazards and Earth System Sciences* 14(5): 1245–1255.

Kaufmann, M., and M. Wiering. 2022. The role of discourses in understanding institutional stability and change—An analysis of Dutch flood risk governance. *Journal of Environmental Policy & Planning* 24(1): 1–20.

Klijn, F., K.M. de Bruijn, J. Knoop, and J. Kwadijk. 2012. Assessment of the Netherlands' flood risk management policy under global change. *AMBIO* 41: 180–192.

Kovacs, Y., N. Doussin, M. Gaussens, C.L. Pacoud, and O.G. Afd. 2017. *Flood risk and cities in developing countries*. Paris: French Development Agency.

Kreibich, H., and N. Sairam. 2022. Dynamic flood risk modelling in human-flood systems. In *Climate adaptation modelling*, eds. C. Kondrup, P. Mercogliano, F. Bosello, J. Mysiak, E. Scoccimarro, A. Rizzo, R. Ebrey, and M. de Ruiter et al., 95–103. Cham: Springer.

Laspidou, C.S., N.K. Mellios, A.E. Spyropoulou, D.T. Kofinas, and M.P. Papadopoulou. 2020. Systems thinking on the resource nexus: Modeling and visualisation tools to identify critical interlinkages for resilient and sustainable societies and institutions. *Science of the Total Environment* 717: Article 137264.

Laurien, F., J.G. Martin, and S. Mehryar. 2022. Climate and disaster resilience measurement: Persistent gaps in multiple hazards, methods, and practicability. *Climate Risk Management* 37: Article 100443.

Madu, C.N. 2017. *Handbook of disaster risk reduction & management: Climate change and natural disasters*. Hackensack: World Scientific Publishing Company.

Mai, T., S. Mushtaq, K. Reardon-Smith, P. Webb, R. Stone, J. Kath, and D.A. An-Vo. 2020. Defining flood risk management strategies: A systems approach. *International Journal of Disaster Risk Reduction* 47: Article 101550.

Maskrey, S.A., N.J. Mount, and C.R. Thorne. 2022. Doing flood risk modelling differently: Evaluating the potential for participatory techniques to broaden flood risk management decision-making. *Journal of Flood Risk Management* 15(1): Article e12757.

Mavrouli, M., S. Mavroulis, E. Lekkas, and A. Tsakris. 2022. Infectious diseases associated with hydro-meteorological hazards in Europe: Disaster risk reduction in the context of the climate crisis and the ongoing COVID-19 Pandemic. *International Journal of Environmental Research and Public Health* 19(16): Article 10206.

McDermott, T.K. 2022. Global exposure to flood risk and poverty. *Nature Communications* 13(1): Article 3529.

Mehryar, S., and S. Surminski. 2022. Investigating flood resilience perceptions and supporting collective decision-making through fuzzy cognitive mapping. *Science of the Total Environment* 837: Article 155854.

Mejia, C., M. Wu, Y. Zhang, and Y. Kajikawa. 2021. Exploring topics in bibliometric research through citation networks and semantic analysis. *Frontiers in Research Metrics and Analytics* 6: Article 742311.

Mendis, N., S. Siriwardhana, and U. Kulatunga. 2022. Implementation of build back better concept for post-disaster reconstruction in Sri Lanka. In *A system engineering approach to disaster resilience: Select proceedings of VCDRR 2021*, ed. C. Ghosh, and S. Kolathayar, 33–48. Singapore: Springer.

Moon, J., W. Flannery, and A. Revez. 2017. Discourse and practice of participatory flood risk management in Belfast, UK. *Land Use Policy* 63: 408–417.

Newman, R., and I. Noy. 2023. The global costs of extreme weather that are attributable to climate change. *Nature Communications* 14(1): Article 6103.

Nur, I., and K.K. Shrestha. 2017. An integrative perspective on community vulnerability to flooding in cities of developing countries. *Procedia Engineering* 198: 958–967.

Nyam, Y.S., J.H. Kotir, A.J. Jordaan, A.A. Ogundeji, A.A. Adetoro, and I.R. Orimoloye. 2020. Towards understanding and sustaining natural resource systems through the systems perspective: A systematic evaluation. *Sustainability* 12(23): Article 9871.

OECD (Organisation for Economic Co-operation and Development). 2021. *Managing climate risks, facing up to losses and damages*. Paris: OECD Publishing. https://doi.org/10.1787/55ea1cc9-en.
Ogundeji, A.A., and C.C. Okolie. 2022. Perception and adaptation strategies of smallholder farmers to drought risk: A scientometric analysis. *Agriculture* 12(8): Article 1129.
Okolie, C.C., G. Danso-Abbeam, O. Groupson-Paul, and A.A. Ogundeji. 2022. Climate-smart agriculture amidst climate change to enhance agricultural production: A bibliometric analysis. *Land* 12(1): Article 50.
Orimoloye, I.R., J.A. Belle, and O.O. Ololade. 2021. Exploring the emerging evolution trends of disaster risk reduction research: A global scenario. *International Journal of Environmental Science and Technology* 18: 673–690.
Peffer, M., and M. Renken. 2016. Practical strategies for collaboration across discipline-based education research and the learning sciences. *CBE Life Sciences Education* 15(4): Article es11.
Perrone, A., A. Inam, R. Albano, J. Adamowski, and A. Sole. 2020. A participatory system dynamics modeling approach to facilitate collaborative flood risk management: A case study in the Bradano River (Italy). *Journal of Hydrology* 580: Article 124354.
Polka, B.E. 2018. Global flood risk under climate change. *Public Health Post*, 17 April 2018. https://www.publichealthpost.org/databyte/global-flood-risk-under-climate-change/. Accessed 8 Feb 2024.
Rehman, J., O. Sohaib, M. Asif, and B. Pradhan. 2019. Applying systems thinking to flood disaster management for sustainable development. *International Journal of Disaster Risk Reduction* 36: Article 101101.
Rentschler, J., M. Salhab, and B.A. Jafino. 2022. Flood exposure and poverty in 188 countries. *Nature Communications* 13(1): Article 3527.
Sadiq, A.A., J. Tyler, and D.S. Noonan. 2019. A review of community flood risk management studies in the United States. *International Journal of Disaster Risk Reduction* 41: Article 101327.
Salazar-Briones, C., J.M. Ruiz-Gibert, M.A. Lomelí-Banda, and A. Mungaray-Moctezuma. 2020. An integrated urban flood vulnerability index for sustainable planning in arid zones of developing countries. *Water* 12(2): Article 608.
Salleh, S.Z. 2022. Bibliometric and content analysis on publications in digitization technology implementation in cultural heritage for recent five years (2016–2021). *Digital Applications in Archaeology and Cultural Heritage* 25: Article e00225.
Salmon, P.M., N. Goode, F. Archer, C. Spencer, D. McArdle, R. McClure, and M.D.R. Initiative. 2012. New perspectives on disaster response: The role of systems theory and methods. In *Proceedings of the 2012 Australian and New Zealand Disaster and Emergency Management Conference*, 16–18 April 2012, Queensland, Australia, 353–367.
Saunders, S.G., and V.D. Truong. 2019. Social marketing interventions: Insights from a system dynamics simulation model. *Journal of Social Marketing* 9(3): 329–342.
Saviano, M., S. Barile, F. Farioli, and F. Orecchini. 2019. Strengthening the science-policy-industry interface for progressing toward sustainability: A systems thinking view. *Sustainability Science* 14: 1549–1564.
Schaffernicht, M. 2010. Causal loop diagrams between structure and behaviour: A critical analysis of the relationship between polarity, behaviour and events. *Systems Research and Behavioral Science* 27(6): 653–666.
Schoenenberger, L., A. Schmid, R. Tanase, M. Beck, and M. Schwaninger. 2021. Structural analysis of system dynamics models. *Simulation Modelling Practice and Theory* 110: Article 102333.
Schröter, K., M. Barendrecht, M. Bertola, A. Ciullo, R.T. da Costa, L. Cumiskey, A. Curran, and D. Diederen et al. 2021. Large-scale flood risk assessment and management: Prospects of a systems approach. *Water Security* 14: Article 100109.
Shmueli, D.F., C.P. Ozawa, and S. Kaufman. 2021. Collaborative planning principles for disaster preparedness. *International Journal of Disaster Risk Reduction* 52: Article 101981.
Sterman, J., R. Oliva, K.W. Linderman, and E. Bendoly. 2015. System dynamics perspectives and modeling opportunities for research in operations management. *Journal of Operations Management* 39: Article 40.
Tariq, M.A.U.R., R. Farooq, and N. Van de Giesen. 2020. A critical review of flood risk management and the selection of suitable measures. *Applied Sciences* 10(23): Article 8752.
Tate, E., V. Decker, and C. Just. 2021. Evaluating collaborative readiness for interdisciplinary flood research. *Risk Analysis* 41(7): 1187–1194.
Tavasszy, L., and G. de Jong. 2014. Comprehensive versus simplified models. In *Modelling freight transport*, ed. L. Tavasszy, and G. de Jong, 245–256. Amsterdam: Elsevier.
Tranfield, D., D. Denyer, and P. Smart. 2003. Towards a methodology for developing evidence-informed management knowledge by means of systematic review. *British Journal of Management* 14(3): 207–222.
United Nations. 2022. Fueled by rapid growth in Africa, global population hits 8 billion. *The Christian Science Monitor*, 15 November 2022. https://www.csmonitor.com/World/2022/1115/Fueled-by-rapid-growth-in-Africa-global-population-hits-8-billion. Accessed 4 Sept 2023.
Vitale, C. 2023. Understanding the shift toward a risk-based approach in flood risk management, a comparative case study of three Italian rivers. *Environmental Science & Policy* 146: 13–23.
Vojinović, Z., Y. Abebe, A. Sanchez-Torres, N. Medina, I. Nikolic, N. Manojlovic, C. Makropoulos, and M. Pelling. 2014. Holistic flood risk assessment in coastal areas: The PEARL approach. In *Proceedings of the 11th International Conference on Hydroinformatics*, 17–21 August 2014, New York City, USA.
Wang, L., S. Cui, Y. Li, H. Huang, B. Manandhar, V. Nitivattananon, X. Fang, and W. Huang. 2022. A review of the flood management: From flood control to flood resilience. *Heliyon* 8(11): Article e11763.
Wang, Z., Y. Zhao, and B. Wang. 2018. A bibliometric analysis of climate change adaptation based on massive research literature data. *Journal of Cleaner Production* 199: 1072–1082.
Watson, S.L., and W.R. Watson. 2013. Chapter Six: Critical systems theory for qualitative research methodology. *Counterpoints* 354: 111–127.
WMO (World Meteorological Organization). 2022. State of climate in Africa highlights water stress and hazards. https://wmo.int/news/media-centre/state-of-climate-africa-highlights-water-stress-and-hazards. Accessed 8 Feb 2024.
Wolstenholme, E.F., and R.G. Coyle. 1983. The development of system dynamics as a methodology for system description and qualitative analysis. *Journal of the Operational Research Society* 34(7): 569–581.
Yang, Q., X. Zheng, L. Jin, X. Lei, B. Shao, and Y. Chen. 2021. Research progress of urban floods under climate change and urbanization: A scientometric analysis. *Buildings* 11(12): Article 628.
Yuen, B., and A. Kumssa. 2010. Africa and Asia: Two of the world's fastest-growing regions. In *Climate change and sustainable urban development in Africa and Asia*, ed. B. Yuen, and A. Kumssa, 3–18. Dordrecht: Springer.

Zevenbergen, C., B. Gersonius, and M. Radhakrishan. 2020. Flood resilience. *Philosophical Transactions of the Royal Society A* 378(2168): Article 20190212.

Ziga-Abortta, F.R., S. Kruse, B. Höllermann, and J. Ntajal. 2021. Stakeholder participation in flood-related disaster risk management in Ghana. In *Proceedings of the 23rd EGU General Assembly*, held online 19–30 April 2021.

Zischg, A.P. 2018. Floodplains and complex adaptive systems—Perspectives on connecting the dots in flood risk assessment with coupled component models. *Systems* 6(2): Article 9.