

Bibliometric Mapping of Flood Barrier Research Trends and Collaborative Networks from Physical Infrastructure to Social Resilience 2008 to 2026

Mohamad Hasan As'adi

mohamadhasanasadi59@gmail.com

Yayasan Wahid Hasyim Yogyakarta

Justin Arafa Picasso

Yayasan Wahid Hasyim Yogyakarta

Raihan In'ami Su'ida

Yayasan Wahid Hasyim Yogyakarta

Systematic Review

Keywords: Flood barriers, bibliometric analysis, resilience, fragmentation, boundary object, climate change adaptation, integrated flood risk management

Posted Date: September 30th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10968024/v1>

License:  This work is licensed under a Creative Commons Attribution 4.0 International License.
[Read Full License](#)

Additional Declarations: No competing interests reported.

Bibliometric Mapping of Flood Barrier Research Trends and Collaborative Networks from Physical Infrastructure to Social Resilience 2008 to 2026

Mohamad Hasan As'adi¹, Justin Arafa Picasso¹, Raihan In'ami Su'ida¹

¹SMA Sains Al-Qur'an, Yayasan Wahid Hasyim Yogyakarta, Indonesia

mohamadhasanasadi59@gmail.com, justinrafa9678@gmail.com,

raihan.inami.suida@gmail.com

Data availability

Not applicable

Acknowledgements

The authors thank the editorial team of *Discover Geoscience* for the quality check and constructive feedback on the initial submission.

Funding

The authors received no funding for this research.

Author information

SMA Sains Al-Quran, Yayasan Wahid Hasyim Yogyakarta

Mohamad Hasan As'adi, Justin Arafa Picasso, Raihan In'ami Su'ida

Contributions

Author contributions: MHA designed the review, performed the literature search and data curation, conducted the bibliometric analysis, and wrote the main text, tables, and figures; JAP contributed to conceptual planning, wrote the introduction, performed author collaboration cluster and thematic cluster analyses, and reviewed the manuscript; RIA contributed to conceptual planning and cluster analysis. All authors read and approved the final manuscript.

Corresponding author

Correspondence to Mohamad Hasan As'adi

Ethics declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Dual Publication

The results, data, and figures presented in this manuscript have not been published elsewhere and are not under consideration by any other publisher.

Authorship

I have read the Nature Portfolio journal policies on author responsibilities and submit this manuscript in accordance with those policies.

Third Party Material

All of the material is owned by the authors and/or no permissions are required.

Abstract

This study maps the intellectual structure of flood barrier research using bibliometric analysis. Despite rapid development in flood risk management encompassing structural, policy, economic, and modelling dimensions, whether flood barrier research forms an integrated program or fragmented streams has not been systematically evaluated. A bibliometric analysis of 210 Scopus-indexed documents (2008–2026) was conducted using the Bibliometrix R package (Biblioshiny) and VOSviewer, integrating co-authorship, keyword co-occurrence, co-citation, and thematic evolution analyses. Seven thematic and 14 collaborative clusters emerged, each developing distinct aspects of flood barrier research. Three novel insights emerged: (1) flood barrier research is structurally fragmented, with minimal cross-citation between technical and socio-political clusters; (2) flood barriers function as a boundary object interpreted differently by engineers, planners, policymakers, and ecologists; and (3) a temporal shift from structural-technical approaches (2008–2017) to resilience and ecosystem-based approaches (2022–2026) confirms an ongoing paradigm shift while deepening the fragmentation between parallel conceptual streams. Geographically, research is concentrated in five developed countries (China, Netherlands, UK, US, and Germany), accounting for 45.23% of publications, with limited representation from developing countries facing high flood vulnerability. This study relied on a single database (Scopus), excluded non-English publications, and covered the period from 2008 to the present day. Future research should expand the data sources and conduct qualitative cluster analyses to examine the integration mechanisms across fragmented research communities. This first bibliometric mapping of flood barrier research offers a data-driven corrective to narrative accounts that present integrated flood risk management as operationally coherent. Revealing structural fragmentation, boundary object dynamics, and the persistence of technical approaches amid socio-ecological transitions opens new agendas for managing fragmentation to enrich the field's diversity while fostering genuine cross-disciplinary integration toward resilient, sustainable, and equitable flood management.

Keywords: Flood barriers, bibliometric analysis, resilience, fragmentation, boundary object, climate change adaptation, integrated flood risk management

Introduction

Global warming increases sea levels due to ice melting and the effect of gravity on regional tides (Creach, 2021; Dawson et al., 2011). In the eastern Last Ice Area, climate change triggers sea-level rise, affecting the salinity and biogeochemistry of the North Atlantic (Wang et al., 2026). Tropical cyclone activity and rainfall runoff indicate increased tidal events for the 5–100 year return period (Anyifang Zhang, 2026). Climate change also alters the hydrological system through changes in land cover and human intervention, thereby creating complex and interconnected flood threat systems (Scussolini et al., 2024). This complexity demands integrated and adaptive mitigation strategies to address the issue.

In response, flood mitigation has evolved from structural to integrated approaches. Integrated Flood Risk Management (IFRM) incorporates climate change and socioeconomic conditions (van Herk et al., 2013), giving rise to water-sensitive urban design (WSUD) as an adaptive strategy (Tasnia & Growe, 2025). The Netherlands expanded the 4R model to 6R by adding risk avoidance and recovery (Zevenbergen et al., 2020), encompassing levee strengthening (Jonkman et al., 2018), asset management optimisation (Gersonius et al., 2020), as well as

sustainable urban design that combines probability reduction and consequence reduction (Hooimeijer et al., 2022). These efforts are crucial given the tidal changes resulting from sea-level rise, land subsidence, and spring tides that amplify flood impacts (Triet et al., 2017). However, these technical advancements face implementation barriers because their effectiveness is highly determined by socioeconomic and policy dimensions.

The European commitment to flood risk management is reflected in policy support for operational solutions, with the 6R model forming an integral part of the national strategy (Zevenbergen et al., 2020). European spatial planning policy is designed with a focus on process legitimacy (Krieger, 2013). Outside Europe, nature-based approaches have been applied in Japan and China through river irrigation development (Luo et al., 2015). Low-impact development (LID) techniques integrate BRC, PP, and RB, which have been proven to reduce runoff volume, peak runoff, flood volume, and overall flood risk, restoring hydrological conditions close to those before development (Ahmad et al., 2025). From European policy to Asian nature-based approaches and technologies, such as LID (Ahmad et al., 2025) and HEC-HMS (Juma et al., 2022; Tu et al., 2020), a diverse array of schools of thought is evolving in parallel; whether this reflects integration or fragmentation remains uncharted.

The economic dimension is also important because SMEs are more vulnerable to flood losses than households (Hudson et al., 2021). Net present value (NPV) and real options (RIO) analyses demonstrate that RIO is superior in responding to uncertainty (Berry, 2012). The Spuikom model (retaining and diverting overflow water) delivers broader social value and better economic efficiency compared to the Vlissings Model as conventional gray infrastructure (Hooimeijer et al., 2024). At the operational level, HEC-HMS is effective for flash flood management through early warning indicators (Tu et al., 2020) and estimation of peak discharge and direct runoff volume (Juma et al., 2022). Thus, the economic, policy, and technological dimensions are interconnected, shaping a complex knowledge landscape of flood risk management.

Although research on flood barriers has developed rapidly, encompassing structural aspects (Hooimeijer et al., 2022; Jonkman et al., 2018), policy and governance (Krieger, 2013; van Herk et al., 2013), economics (Berry, 2012; Hudson et al., 2021), and even modelling (Juma et al., 2022; Tu et al., 2020), no yet been a study has systematically mapped the intellectual structure of this field using bibliometric methods. Consequently, important questions remain unanswered: How is flood barrier research adopted and cited across disciplines? Does it form an integrated or a fragmented program? To what extent has it shifted from technical to policy implementation? These gaps motivate this study, as without an understanding of the knowledge landscape, efforts to build transformative resilience in the built environment will be hampered by fragmentation and a lack of cross-disciplinary integration.

Bibliometric analysis enables the exploration of intellectual structure and fragmentation through citation patterns, co-occurrence, and collaboration that are overlooked in conventional narrative reviews (As'adi, 2026b). This study covers publications from 2008 to 2026, a period of significant development in flood barriers in line with global awareness of climate change risks and major floods driving infrastructure investment. Based on this gap, this study proposes five research questions: RQ1–RQ3 map the publication landscape. (1) What are the trends in annual publications, leading journals, most productive authors, and dominant affiliations in the flood barrier literature? (2) What thematic clusters emerge from keyword co-occurrence

analysis, and how do they develop? (3) What are the patterns of international and inter-institutional collaboration in this field? RQ4–RQ5 are conceptual: (4) Does the flood barrier literature constitute an integrated research program, or has it fragmented into separate intellectual streams? (5) What new conceptual understandings of flood barriers emerge from bibliometric mapping, understandings that cannot be obtained through narrative reviews alone?

This study offers three main insights. Methodological: demonstrating how bibliometrics reveal hidden fragmentation that hampers holistic approaches. Theoretical: reframing the flood barrier as a boundary object interpreted differently by diverse communities of engineers, planners, climate scientists, policymakers, and affected communities. Practical: providing a strategic map for researchers, practitioners, and policymakers regarding key actors, influential journals, collaboration hubs, and underexplored themes (justice, community participation, nature-based approaches), as well as future research directions for flood barriers that are resilient, sustainable, and equitable amid the challenges of global climate change.

Methodology

To capture the multidisciplinary breadth of flood barrier research, this study employs a bibliometric method using the Scopus database as its primary data source. Scopus was selected due to its broad coverage of social sciences, urban planning, and environmental policy journals, which are central to this research (As’adi, 2026b; Hossain et al., 2026). Its data export features are compatible with Biblioshiny and VOSviewer, ensuring reproducibility and superior deduplication mechanisms. Data identified through keyword searches were exported in CSV format for further processing. The initial data cleaning phase involved identifying and removing duplicate data to ensure dataset integrity before analysis. The search strategy followed a multi-level process (Table 1) guided by the PRISMA protocol.

Table 1 Data selection steps

Stairs	Questions on Scopus	Description	Question	Question number	Calculating
1	Title/Abstract/Key words	Contains one of the flood barriers	#1 OR #2 OR #3	#1	73.360
2	Title/Abstract/Key words	Contains one of the constructions	#1 OR #2 OR #3	#2	20.471
3	Title/Abstract/Key words	Contains one of the climate change	#1 OR #2 OR #3	#3	3.906
4	Title/Abstract/Key words	Contains one of the flood risk management	#1 OR #2 OR #3	#4	280
5	Pubyear	Before 18 August 2026	AND PUBYEAR > 2005 AND PUBYEAR < Before 18 August 2026	#5	278
6	doctype	Citation-based	AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "ch") OR LIMIT-TO (DOCTYPE, "bk"))	#6	210

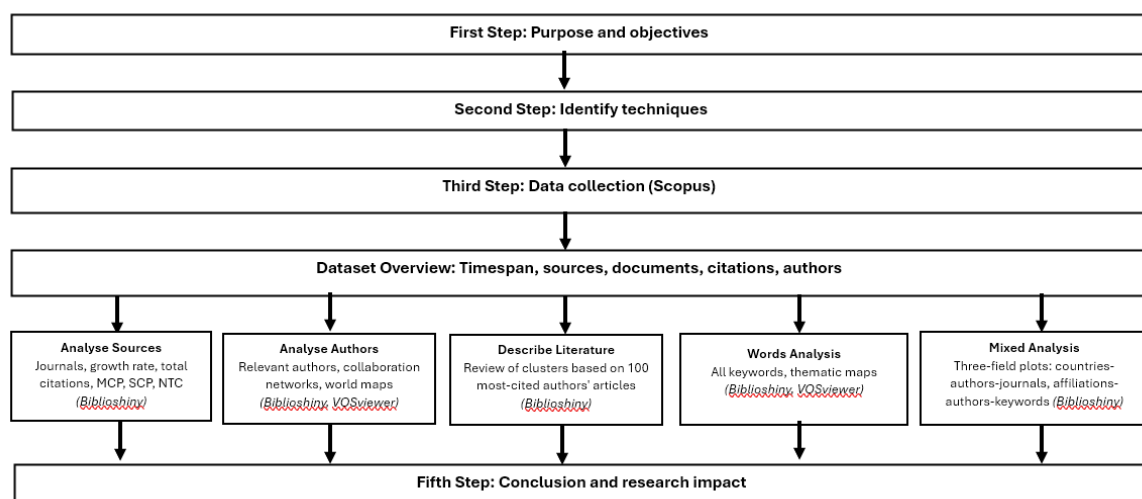
Source: author's work

All analyses were conducted in August 2026 using Biblioshiny (the Bibliometrix R package version 4.3.3, RStudio environment) for comprehensive and longitudinal trend analysis (Aria & Cuccurullo, 2026; As’adi, 2026b). Biblioshiny offers a robust graphical interface for various types of bibliometric analyses, including descriptive statistics, network visualisation, and thematic mapping.

Biblioshiny is also used to generate collaboration maps, three-field plots, and co-author networks, enabling the effective identification and presentation of the most relevant data. The visualisation of collaboration networks and conceptual mapping was carried out using VOSviewer version 1.6.20 (As'adi, 2026b, 2026a). VOSviewer was chosen for its ability to visualise large networks using layout algorithms optimised for readability.

Following data collection from Scopus, the dataset was subjected to a comprehensive analysis in accordance with the protocol illustrated in Figure 1, using the R-based Bibliometrix package (Biblioshiny interface). First, a source analysis was performed to identify the most productive and influential sources, including an evaluation of publication growth and total citations (TC). Second, the analysis involved mapping the most relevant authors, examining the top authors' work over time, and identifying the most relevant affiliations. Collaborative networks between institutions and authors were visualised using VOSviewer. Furthermore, the geographical distribution of authors was examined using an RStudio world map.

Figure 1



Methodological approach to bibliometric analysis Source(s): Author's work

Third, keyword analysis was deepened through the creation of keyword co-occurrence networks using VOSviewer and thematic mapping using Biblioshiny to identify the intellectual structure and thematic evolution within the field of second-order cybernetics. At this stage, the analysis was refined to examine clustering among the top 100 most-cited authors. Fourth, a mixed analysis was conducted using a three-field plot to connect elements such as countries, affiliations, authors, keywords, and journals, thereby exploring multidimensional relationships within the literature. Finally, drawing on the results of these analyses, this study synthesises the main findings and articulates the significant contributions of second-order cybernetics scholarship to the advancement of scientific knowledge.

Result

RQ1: The annual publication trends, leading journals, most productive authors, and dominant affiliations in Flood Barrier literature

Table 2 summarises the dataset characteristics, including sources, authors, and temporal scope. The dataset encompasses 116 unique sources and a corpus of 210 documents from 2008 to the

end of 18 August 2026. The mean number of years since publication across these documents was 5.96 years, with an average of 35.68 citations per document and a total of 11728 references. This distribution reveals a disparity in the number of articles addressing specific subfields within second-order cybernetics, indicating a tendency for researchers to concentrate their efforts on certain thematic areas.

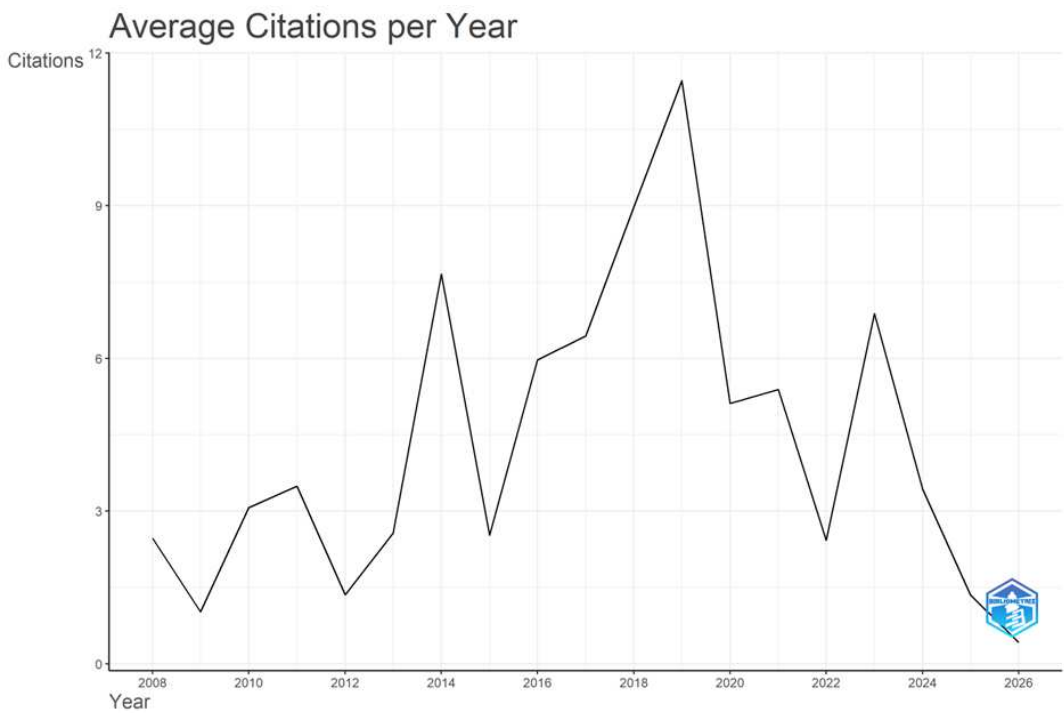
Table 2 Principal information about the data

Indicator	Value
Timespan	2008:2026
Sources	115
Documents	210
Document Average Age	5.96
Average citations per document	35.68
References	11728
Annual Growth Rate of the Corpus	19.31%

Source(s): Author's work

Publication activity began in 2008 with a single paper, followed by a fluctuating trajectory marked by peaks in 2011, 2013, 2017, 2019, and 2025. The highest number of publications was recorded in 2025, with a total of 26 papers (Figure 2). The compound annual growth rate during this period was approximately 19.31%.

Figure 2



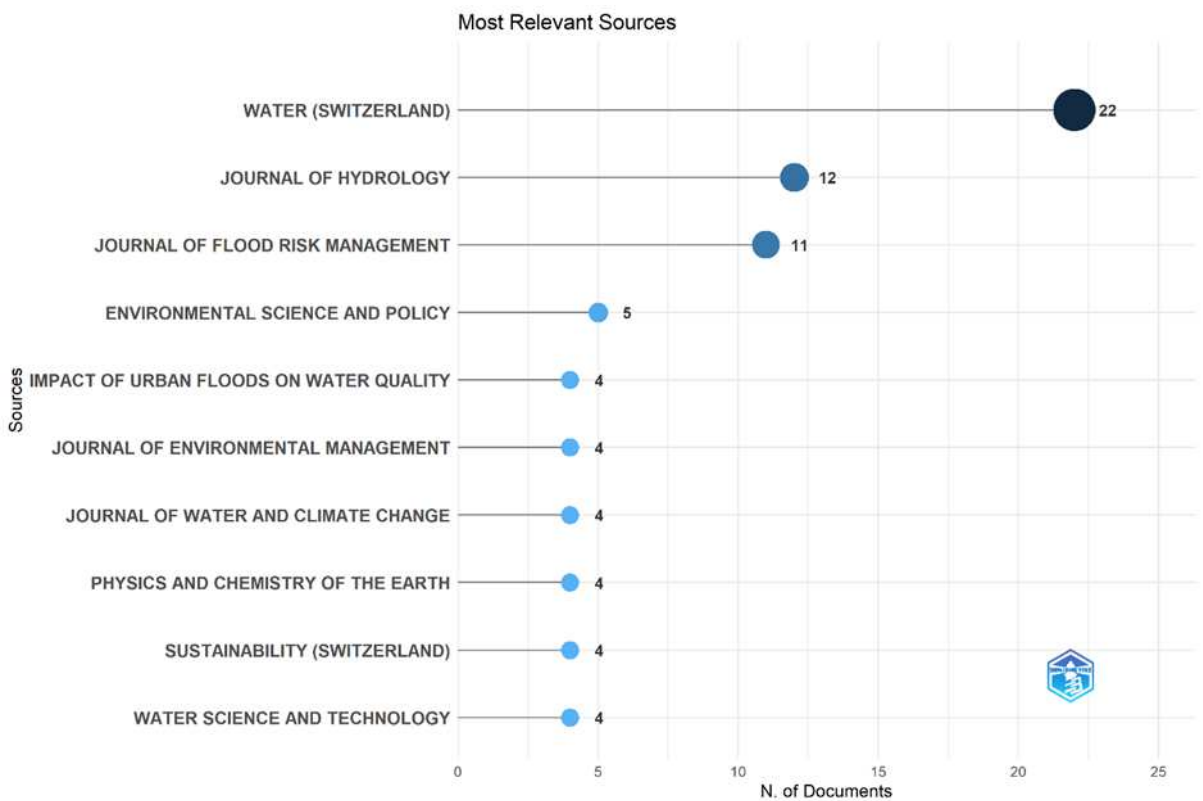
Evolution of annual scholarly output Source(s): Author's work

Figure 2 shows the average citations per paper per year, starting from the initial years of publication in 2008, which recorded an initial average of 2.5 citations per year. Subsequently, a significant increase was observed in 2014, with a peak average of 7.7 citations per year, and

in 2019 with a peak average of 11.5 citations per year, which was the highest value achieved during the review period.

Water (Switzerland) is the most prominent source, with 22 articles, followed by the Journal of Hydrology (12 articles) and the Journal of Flood Risk Management (11 articles). Environmental Science and Policy ranked fourth, with 5 articles. The other sources in the top ten show a much lower number of papers, as illustrated in Figure 3.

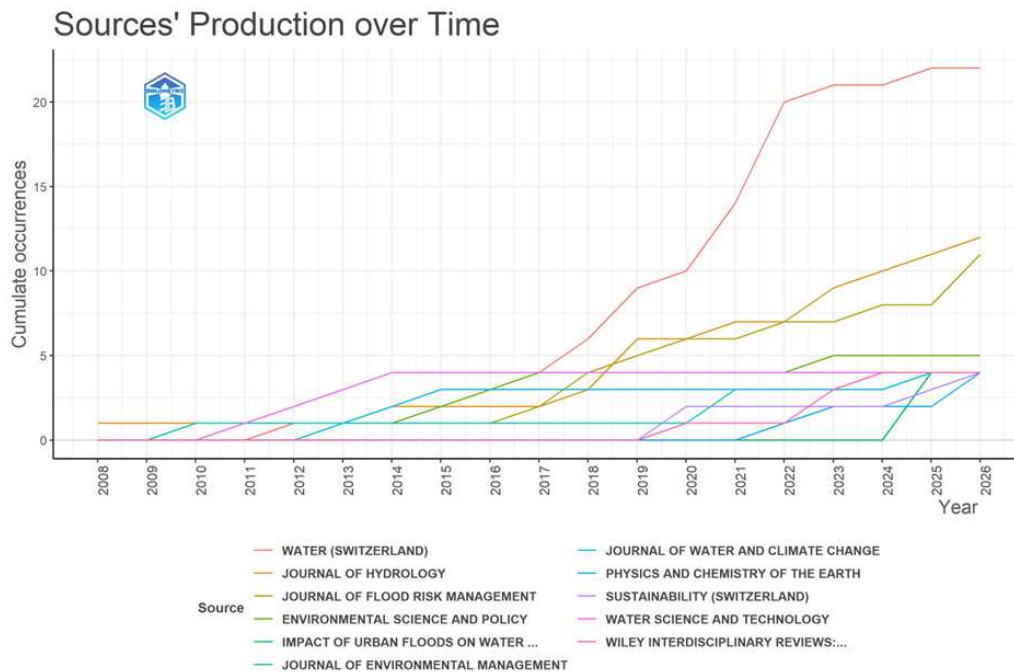
Figure 3



The ten most relevant journals. Source(s): Author's work

Analysis of publication trends among the most prominent sources in second-order cybernetics studies from 2008 to 2026, as shown in Figure 4, highlights that Water (Switzerland) is a pioneering journal. Water (Switzerland) published its first article in this field in 2012 and has since maintained consistent leadership and influence, accumulating 22 papers by the end of 2026.

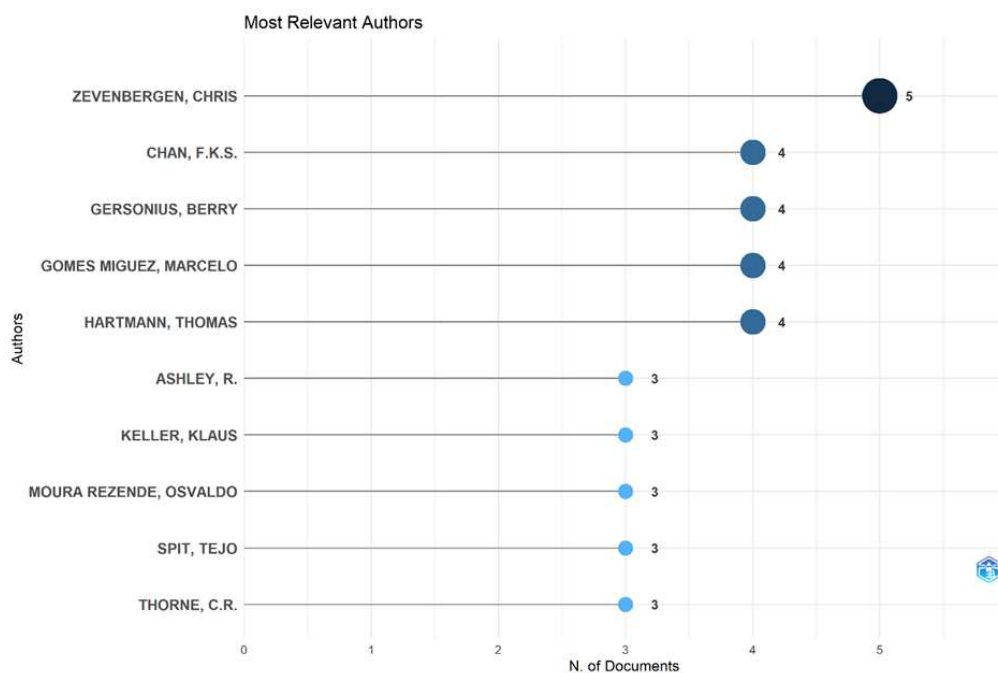
Figure 4



Cumulative growth of journals by number of papers. Source: Author's work.

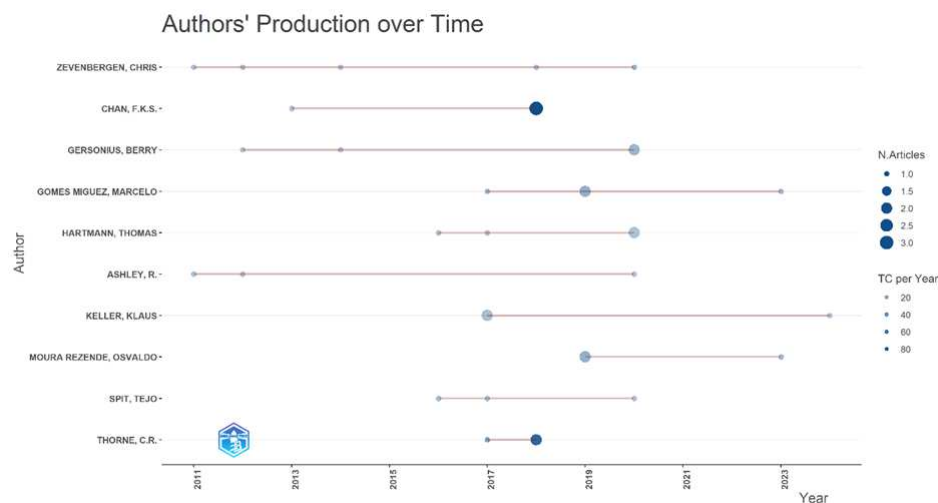
The authors play a crucial role in the analysis, so their contributions need to be investigated further. As illustrated in Figure 5, the ten most influential authors in this field are highlighted. (ZEVENBERGEN, CHRIS) is the most productive author, with five papers, followed by (CHAN, F.K.S.), (GERSONIUS, BERRY), (GOMES MIGUEZ, MARCELO), and (HARTMANN, THOMAS), each of whom wrote four papers. The other authors in the top ten produced three papers; however, their contributions are relatively less substantial compared to the top five authors.

Figure 5



The ten most productive authors were based on the number of publications. Source: Author works

The publication history of authors in the field of flood barrier provides convincing evidence of the ongoing relevance of this field and the need for continual scientific development. This field gained wide recognition in 2011 with the publication of the first article by (ZEVENBERGEN, CHRIS), making him the most influential author. The contribution of (ZEVENBERGEN, CHRIS) includes four papers published from 2011 to 2020. Another major contributor, (CHAN, F.K.S.), debuted in 2013 and has published one to two papers at intervals of one to three years, averaging 2.0 citations per year. Figure 6 presents a complete list of the top 10 authors.



RQ2: Thematic clusters, evolution, and temporal distribution

Figure 7

Overlay visualisation of the keyword co-occurrence analysis. Source: Image by the author

Table 3 Cluster Co-occurrence themes

Cluster	Color	Items	Core themes	Key Keywords
1	Red	44	Climate Change Adaptation, Flood Risk Management, and Decision Support Systems	adaptation, adaptive management, climate change adaptation, climate effect, coastal zone, computer simulation, cost-benefit analysis, decision making, decision support system, decision support system, design, economic analysis, economics, England, environmental policy, Europe, flood control, flood protection, flood risk, flood risk management, floodplain, hazard management, hydraulic structures, hydrodynamics, integrated approach, land use planning, levees, mitigation, netherlands, numerical model, risk analysis, risk assessment, sea level change, sea level rise, socio-economic change, spatial planning, stakeholder, storm surge, uncertainty, uncertainty analysis, united kingdom, united states, Vietnam, water supply
2	Green	31	Hydrological Modeling, Flood Frequency Analysis, and the Impact of Global Climate Change	china, climate models, design flood, extreme event, flood, flood forecasting, flood frequency, flood frequency analysis, flood risks, frequency analysis, future prospect, geographic information, gis, global warming, hydrological modeling, japan, nonstationary, planning, precipitation intensity, probability, rain, rainfall, reservoirs (water), return period, return periods, risk perception, river basins, river management, rivers, watershed, watersheds
3	Blue	28	Urban Flood Resilience, Nature-Based Solutions, and Sustainable Infrastructure	Australia, biodiversity, climate change, drainage, ecosystems, flood management, flood mitigation, flood resilience, governance approach, infrastructure, nature-based solutions, quantitative analysis, storm sewers, stormwater, sustainability, sustainable development, urban area, urban design, urban development, urban drainage, urban flooding, urban floods, urban planning, urban water management, urbanization, vulnerability, water management, water quality
4	Yellow	16	Disaster Prevention, Hazard Assessment, and Machine Learning-Based Mapping	disaster prevention, disasters, flood hazards, floods, hazard assessment, hazards, hydraulic models, learning systems, losses, machine learning, mapping, population statistics, resilience, risk management, sea level, urban growth
5	Purple	12	Rainfall-Runoff Modeling and Spatio-Temporal Analysis in the Watershed	catchment, catchments, Germany, peak flow, precipitation (climatology), precipitation (meteorology, rainfall-runoff modeling, runoff, spatial distribution, spatiotemporal analysis, storms, water levels
6	Cyan	12	Environmental Planning, Land Protection, and Watershed Management	article, environmental manager, environmental planning, environmental protection, flood defence, flooding, floodings, human, land use, priority journal, river, river basin
7	Orange	9	Flash Flood Disaster Management, Policy Formulation, and Strategic Simulation	disaster management, flash flood, flood damage, policy making, simulation, strategic approach, surveys, water planning, water resource

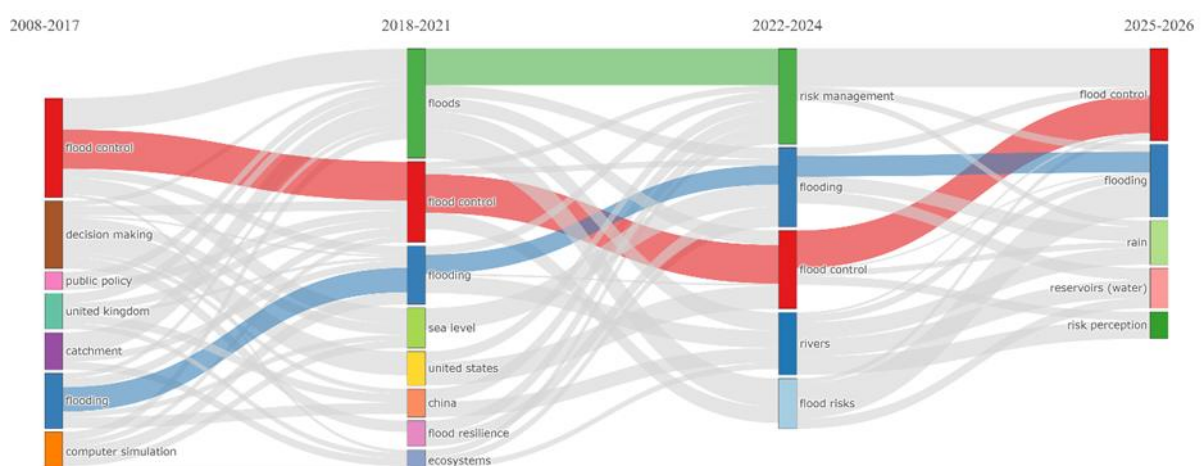
Source(s): Author's work

Based on the keyword co-occurrence analysis conducted in this study, seven thematic clusters were identified that reflect the intellectual structure of flood barrier research from 2008 to 2026. Cluster 1 (Red), with 44 items, focuses on climate change adaptation, flood risk management, and decision support systems, which includes keywords such as adaptation, climate change adaptation, flood risk management, decision support system, cost-benefit analysis, land use planning, sea level rise, spatial planning, stakeholder, uncertainty, and case studies in the Netherlands, United Kingdom, United States, and Vietnam. Cluster 2 (Green), with 31 items, carries the theme of hydrological modelling, flood frequency analysis, and the impacts of global climate change, represented by the keywords hydrological modelling, flood frequency analysis, return period, rainfall, climate models, GIS, global warming, and case studies in China

and Japan. Cluster 3 (Blue), with 28 items, highlights urban flood resilience, nature-based solutions, and sustainable infrastructure, with keywords urban flooding, nature-based solutions, sustainable development, urban drainage, water quality, ecosystems, and vulnerability. Cluster 4 (Yellow), with 16 items, emphasises disaster prevention, hazard assessment, and machine learning-based mapping, which includes hazard assessment, machine learning, mapping, resilience, and risk management. Cluster 5 (Purple), with 12 items, discusses rainfall-runoff modelling and spatiotemporal analysis in catchment areas, with keywords catchment, rainfall-runoff modelling, spatial distribution, spatiotemporal analysis, and water levels. Cluster 6 (Light Blue), with 12 items, is oriented toward environmental planning, land protection, and river basin management, which includes environmental planning, land use, river basin, and flood defense. Cluster 7 (Orange), with 9 items, raises the themes of flash flood disaster management, policy formulation, and strategic simulation, with keywords flash flood, disaster management, policy making, simulation, and water planning.

This thematic diversity indicates that flood barrier research does not develop as a unified, integrated stream, but rather is fragmented into seven distinct conceptual orientations, ranging from technical-hydrological aspects (Clusters 2 and 5), policy planning (Clusters 1, 6, and 7), to socio-ecological and advanced technology (Clusters 3 and 4). This fragmentation shows that the flood barrier concept functions as a boundary object interpreted differently by various scientific communities; engineers and hydrological modellers emphasise technical and simulation aspects, urban planners and policymakers focus on urban resilience and governance, while environmental scientists and ecologists highlight nature-based solutions and sustainability. This understanding is important because it reveals that although the flood barrier literature has developed rapidly, with an annual growth rate of 19.31%, efforts to build truly integrated approaches in flood risk management still face challenges of fragmentation and lack of cross-disciplinarity, which need to be addressed through more targeted collaborative efforts in the future.

Figure 8



Thematic Evolution (2008–2026). Source: Author's work

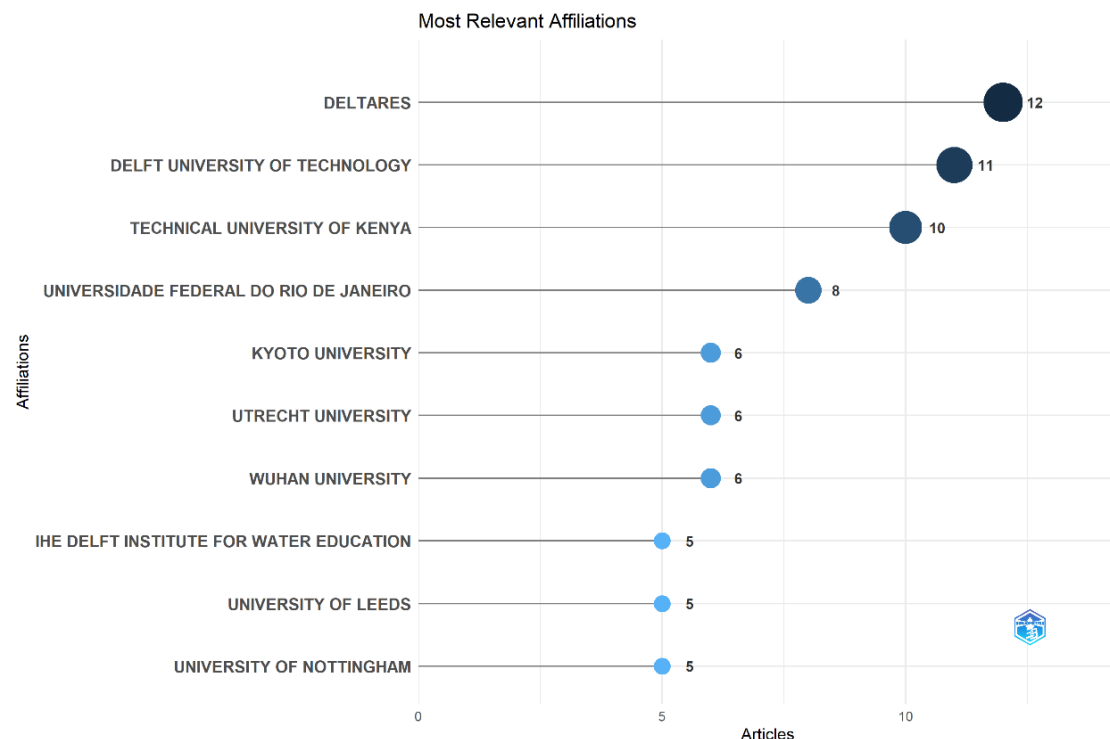
As illustrated in Figure 8, overall, this thematic evolution analysis reveals three phases of flood barrier research development: First, the Technical Phase (2008–2017), dominated by structural

flood control approaches and hydrological engineering. Second, the Transitional Phase (2018–2021) began to show increasing attention to flood impacts, risk perception, and triggering factors. Third, the Integrative Phase (2022–2026): Marked by a shift towards resilience, ecosystem-based approaches, and a more holistic understanding of risk. Nevertheless, it is important to note that despite the evolution toward a more integrative approach, thematic fragmentation still persists. Technical themes of flood control remain present in all periods, indicating that structural approaches have not been fully replaced. This confirms the findings from the keyword co-occurrence analysis, which identified seven distinct thematic clusters. In other words, although a paradigm shift from technical to socio-ecological approaches is underway, flood barrier research has yet to achieve full integration and continues to operate across various parallel conceptual streams. These findings imply that efforts to develop a truly integrated flood risk management approach, which combines technical excellence, ecological sustainability, and social justice, still require more intensive cross-disciplinary collaboration in the future.

RQ3: international and inter-institutional collaboration in this field

The affiliations associated with the most significant contributions to flood barriers are worthy of further attention. Deltares was at the forefront with 12 papers, followed by Delft University of Technology with 11 papers. The remaining top ten affiliations: a complete list is provided in Figure 9.

Figure 9

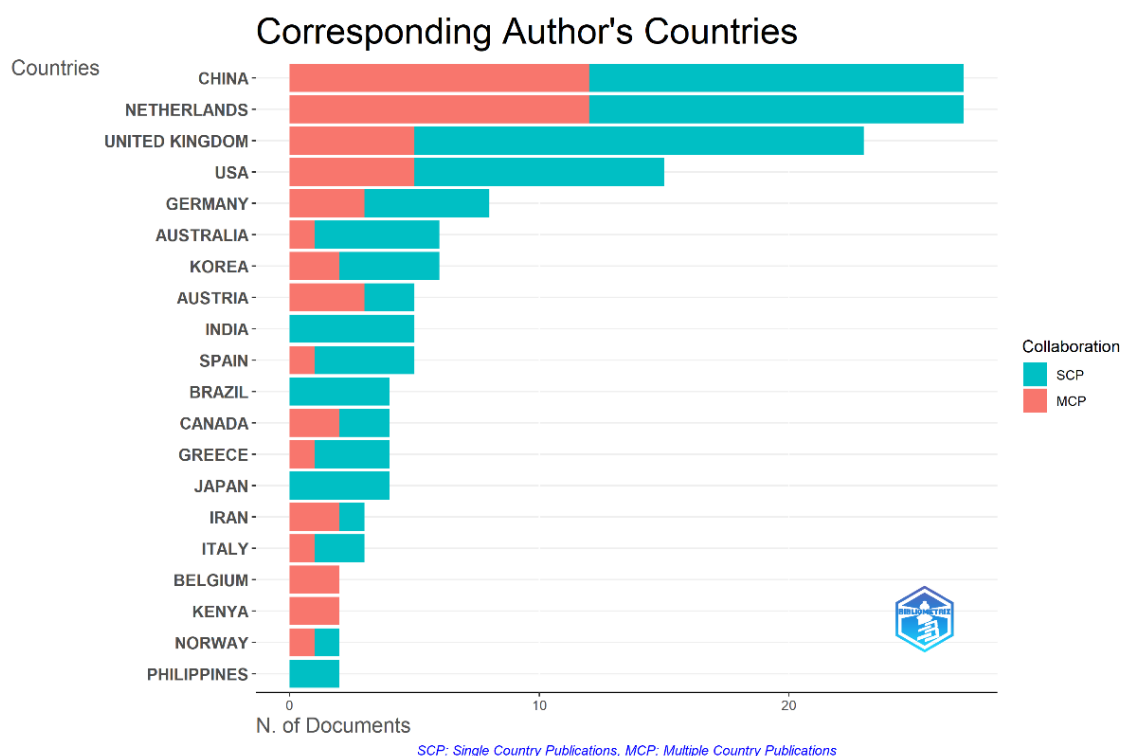


Ten most relevant affiliations. Source(s): Author's work

Based on the distribution data of countries by corresponding author, it was identified that China and the Netherlands are the countries with the highest contribution, each producing 27 articles or 12.86% of the total publications, with an identical pattern of international collaboration,

namely 15 single-country publications (SCP) and 12 multi-country publications (MCP), resulting in an MCP percentage of 44.44%, indicating a balance between domestic research and strong international collaboration. The United Kingdom ranks third with 23 articles (10.95%), consisting of 18 SCP and 5 MCP with an MCP percentage of 21.74%, indicating that research in the United Kingdom is more domestically oriented compared to China and the Netherlands. The United States is in fourth place with 15 articles (7.14%), consisting of 10 SCP and 5 MCP with an MCP percentage of 33.33%, while Germany has 8 articles (3.81%) with an MCP percentage of 37.5%, Australia and South Korea each have 6 articles (2.86%), Austria, India, and Spain each have 5 articles (2.38%) with Austria showing the highest MCP percentage of 60%, and countries such as Brazil, Canada, Japan, and Greece each have 4 articles (1.90%). Complete information regarding all countries along with details of articles, percentages, SCP, MCP, and MCP% can be seen in Figure 10. Overall, this distribution reveals that flood barrier research is dominated by five developed countries (China, the Netherlands, the United Kingdom, the United States, and Germany) which together contribute 95 articles or 45.23% of the total 210 publications, while developing countries such as India, Brazil, and South Africa have very limited contributions, indicating a significant geographical concentration where developed countries dominate knowledge production, while developing countries—which actually have high flood vulnerability—are still underrepresented.

Figure 10

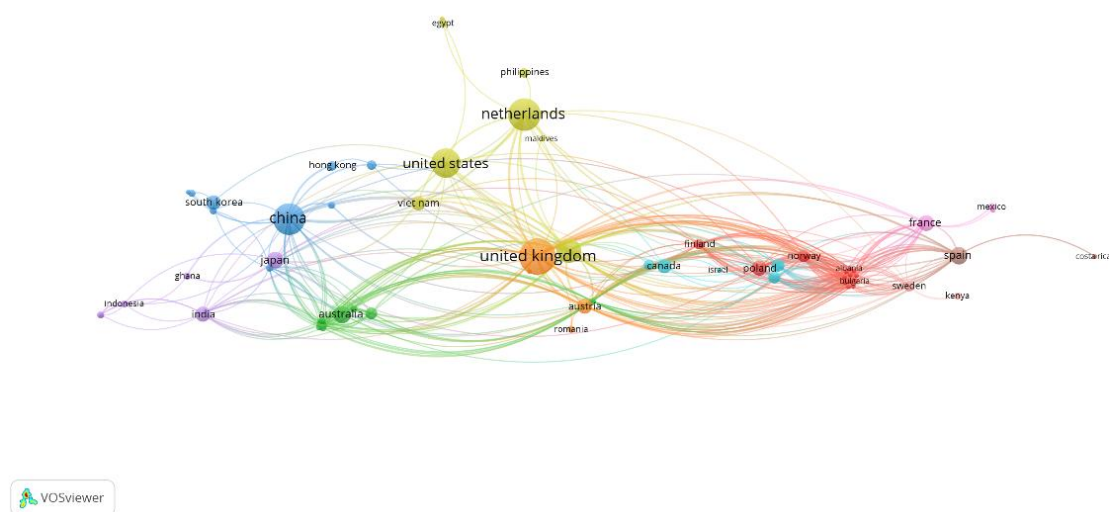


Countries of the 20 most relevant corresponding authors Source(s): Author's Work

Figure 11 shows the visualisation of the international collaboration network generated by VOSviewer, and it was identified that developed countries such as the United States, United Kingdom, Netherlands, Germany, and Australia serve as centres of international collaboration in flood barrier research. China emerges as one of the countries with high connectivity, indicating its active role in the global collaboration network, while other Asian countries such

as South Korea, Japan, Hong Kong, and the Philippines are also involved in this network despite having lower connectivity levels. In the European region, in addition to the Netherlands and the United Kingdom, countries such as France, Germany, Austria, and Sweden demonstrate participation in cross-country collaboration, while in the Americas, the United States and Canada are the main collaborative partners, with Mexico and Costa Rica as countries with more limited involvement. Interestingly, African countries such as Kenya and Ghana also appear in this collaboration network, indicating research collaboration efforts with developed countries, although the relatively small node size shows a still limited contribution. Overall, this visualisation reveals that international collaboration in flood barrier research remains dominated by developed countries in Europe, North America, and East Asia, with limited involvement from developing countries in Africa, South Asia, and Latin America, indicating a global collaboration gap that needs to be addressed to ensure that flood management knowledge and solutions can be accessed and applied more equitably around the world.

Figure 11



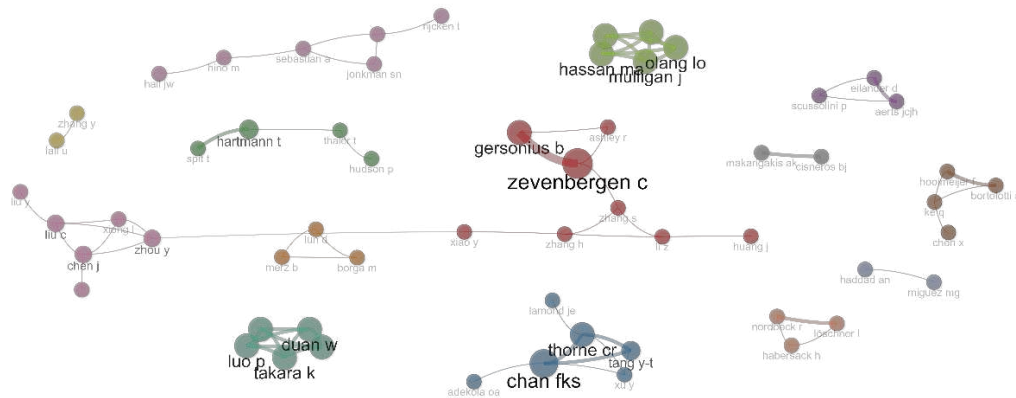
Seventy-one most relevant country networks were identified. Source(s): Figure by author

Discussion

RQ4: Structural fragmentation of researcher collaboration

To map the intellectual collaboration structure of second-order cybernetics, the R package Bibliometrix and its web interface, Biblioshiny, were used to construct a co-authorship network among authors, which identified collaborative clusters using the Louvain algorithm (Figure 12). The resulting network consisted of 14 distinct clusters. Each cluster represents a group of researchers connected through collaborative ties, where the node size reflects author productivity or centrality, edges indicate collaborative relationships, and colours distinguish cluster affiliation. To interpret the substance of each cluster, abstracts from representative articles in each group were qualitatively examined and labelled based on their dominant thematic orientation. The following section presents a brief description of each cluster, highlighting central figures, main contributions, and specific appropriations of the Flood Barrier conceptual legacy, which form the empirical foundation for the subsequent thematic synthesis across the field.

Figure 12



Collaboration author network Source(s): Author's work

The intellectual architecture of contemporary flood risk management finds its genesis in the ecological and socio-ecological resilience concepts elaborated within Cluster 1, which collectively furnish the theoretical scaffolding for constructing more robust systems through an integrated triad of protection, prevention, and preparedness (Zevenbergen et al., 2020). Operationalizing this resilience framework, the Dutch Delta Program exemplifies how national-scale climate adaptation can be systematically actualized through the multi-layer-safety (MLS) approach, subsequently refined into an integrated flood risk management (IFRM) program whose effectiveness has been empirically validated (Hooimeijer et al., 2022; Rijcken et al., 2012; van Herk et al., 2014). In a parallel development, China's sponge city initiative represents an adaptive water management paradigm designed to concurrently attenuate urban flood risk and elevate urban environmental quality (Zhang et al., 2018). Complementing these physical interventions, the real in options (RIO) approach to flood risk analysis demonstrates economic advantages through its inherent flexibility in accommodating uncertainties pervading long-term economic projections (Berry, 2012). The FAIR (Flood Asset Infrastructure Renovation) Project further strengthens this portfolio by furnishing a comprehensive framework that ensures asset management processes remain adaptive, holistic, and capable of effectively integrating strategic, tactical, and operational considerations (Gersonius et al., 2020).

Non-structural flood management interventions, encompassing spatial land use planning, insurance mechanisms, and flood-resistant construction that explicitly internalizes socio-economic parameters, have been implemented in the Thames Estuary, yielding valuable case study insights (Dawson et al., 2011). Nevertheless, a persistent tension exists wherein development policies frequently contravene flood risk reduction imperatives, thereby shaping land use dynamics in floodplain environments (Hino et al., 2024). To systematically evaluate the efficacy of these diverse approaches, four cardinal performance indicators have been operationalized: effectiveness, robustness, reliability, and cost, which collectively equip end-users with analytical tools for appraising, selecting, and implementing flood adaptation innovations (Lendering et al., 2019). Moreover, structural condition monitoring within river system management provides essential diagnostics for assessing the necessity of upgrading and reinforcing hydraulic infrastructure to sustain adequate protection levels (Jonkman et al.,

2018). Advancing the predictive frontier, recent scholarship has modelled flood hazard trajectories from 1970 through 2150 under scenarios without dike protection, employing both low (RCP2.6) and high (RCP8.5) emission pathways to deconstruct the compounded impacts of sea level rise and urban development on the Maeslant Barrier (Oerlemans et al., 2025). Collectively, these investigations substantiate Cluster 1's preoccupation with developing and applying ecological and socio-ecological resilience constructs, exemplified by IFRM, RIO, FAIR, and the Thames Estuary case, toward the overarching objective of strengthening flood management in an era of accelerating sea level rise and intensifying urban development.

Whereas Cluster 1 establishes the theoretical underpinnings of resilience thinking, Cluster 2 pivots to examine the policy transformations unfolding within European flood management regimes. Traditional flood protection methods, predicated on preventing water ingress into terrestrial areas, have historically operated through a systematic differentiation between internal risks and external hazards to guide governmental decision-making (Roos et al., 2017). However, the European policy landscape has undergone a fundamental paradigmatic reorientation through the Flood Directive (FD), which reconceptualizes the enterprise from flood protection toward integrated flood risk management that explicitly incorporates management considerations, nature conservation, land use, spatial planning, navigation, and port infrastructure. Quantitative methodologies have been developed to enhance interactive governance structures engaging governmental actors (Nouzari et al., 2020).

Spatial planning for flood prevention across Europe necessitates careful deliberation over compensation schemes whose distributive and procedural dimensions carry significant implications for social justice (Thaler et al., 2020). Furthermore, European spatial planning for flood risk demands meaningful stakeholder and citizen participation, with due consideration for the legitimacy of processes, inputs, and outcomes (Hartmann & Spit, 2016). The successful implementation of Natural Flood Management (NFM) is contingent upon social interactions, institutional arrangements, and the enabling role of government (Hudson et al., 2021). Critically, Cluster 2 encapsulates the transformation of European flood management from defensive approaches toward integrative risk governance, wherein successful policy implementation, spanning FD, spatial planning, and NFM, remains highly dependent upon social interaction, procedural-distributive justice, and the active engagement of government and stakeholders.

Shifting geographical focus from the European context, Cluster 3 directs analytical attention toward coastal metropolitan areas confronting flood hazards intensified by climate risks. Climate-induced flooding has afflicted coastal metropolitan regions including Hong Kong, Singapore, Ningbo, and the United Kingdom, prompting scholarly efforts to develop community socio-economic-based infrastructure concepts (Chan et al., 2018), sustainable flood risk assessment frameworks incorporating public participation (Chan et al., 2013), and the Blue Green City concept alongside political campaigns for sponge city initiatives (O'Donnell et al., 2017; Tang et al., 2018). The central insight emerging from Cluster 3 scholarship is the recognition that flood infrastructure in coastal cities will achieve sustainability only when supported by robust public participation and appropriately contextualized socio-economic frameworks. Cluster 3 thus concludes that flood infrastructure in coastal metropolitan areas remains contingent upon public participation and relevant socio-economic frameworks for its long-term viability.

Deepening the urban dimension introduced in Cluster 3, Cluster 4 examines the escalating flood risk confronting urban areas and open spaces, generating not merely social and economic repercussions but also significant deleterious effects on water quality (Cisneros & Makarigakis, 2025). In response to this multidimensional challenge, researchers have advanced sustainable urban design through sustainable urban drainage systems (SUDS) that integrate water quality considerations into flood risk management, while simultaneously introducing online-based urban flood forecasting models that underscore the critical importance of early warning systems (Jiménez Cisneros & Makarigakis, 2025). These developments indicate that urban flood management can no longer be decoupled from water quality concerns and rapid response capacities, rendering integrated approaches combining green infrastructure, predictive modeling, and early warning systems an operational imperative.

Cluster 5 centers on evaluating method applications in the Rabba river reach, encompassing flood protection project planning, infrastructure development, and future settlement planning with findings collectively demonstrating flood risk reduction. Interdisciplinary integration between RegioFEM in river development planning and river development and risk management concepts (GERM) has been deployed to support these planning efforts (Wesemann et al., 2020). Concurrently, hydropower impacts, flood control measures, and engineering works along the Danube River have been assessed through a holistic catchment scale approach, notwithstanding that existing river management remains inadequately integrated (Habersack et al., 2016). Future flood risk prevention has been operationalized through effective risk reduction measures, including land provision for runoff and flood retention (Nordbeck et al., 2019). These findings indicate that integrated method applications such as RegioFEM, GERM, and holistic catchment-scale approaches constitute critical enablers of effective flood risk prevention in river reaches.

Subsequently, Cluster 6 redirects analytical attention from spatial and infrastructural dimensions toward hydrological systems and modeling. This cluster examines hydrological systems, irrigation, and dam construction through explicit incorporation of data and hydrological hydrodynamic models capable of comprehensively representing hydrological processes (Scussolini et al., 2024). Anticipation of unprecedented storm surge events is accomplished through consideration of the full spectrum of climate variability, utilizing 525 year seasonal reforecast archives (Benito et al., 2025). Researchers have estimated two risk indicators: asset damage and potential loss of life, while simulating current and future flood risk (2050–2100) using IPCC scenarios addressing sea level rise and socio-economic change (Chi & City, 2017). Findings from this cluster reinforce the argument that hydrological systems, irrigation, and dam infrastructure supported by hydrodynamic models and IPCC scenarios are essential for anticipating storm surges and projecting future flood risk.

Distinct from preceding clusters oriented toward riverine and hydrological systems, Cluster 7 directs attention toward coastal urban areas confronting extreme sea level rise causing damage along the northern coastline. Adaptation strategies encompass the Vlissingen model infrastructure-based and the Spuikom model (diverting runoff) (Hooimeijer et al., 2024). Risk probability is defined through the risk equation ($\text{risk} = \text{probability} \times \text{consequence}$), revealing that the Dutch approach emphasizes probability reduction through dike construction, whereas the United States prioritizes consequence reduction through evacuation and recovery (Hooimeijer et al., 2022). The Hydrologic Modelling System from the Hydrologic Engineering Center (HEC-HMS) has been employed to simulate flash flood processes (Tu et al., 2020).

Cluster 7 underscores that adaptation strategies for extreme sea level rise can be operationalized through infrastructure approaches (Vlissingen model) or runoff diversion (Spuikom model), each reflecting distinct risk reduction philosophies between the Netherlands and the United States.

Cluster 8 elevates the discussion to a more strategic level, emphasizing planning and decision-making dimensions. This cluster addresses flood risk management incorporating cost-benefit analysis and residual risk calculation while accounting for uncertainties including climate change and uncontrolled urban growth (Moura Rezende et al., 2019). An index-based approach has been developed to qualitatively assess flood-prone areas through the Physical Susceptibility to Floods Index (PhySFI) (Miranda et al., 2023). Planning for Urban Flood Resilience Index (UFRI) and Future Scenarios Criteria (FSC) implementation incorporates two flood control design alternatives: centralized and decentralized measures (Miguez, 2019). It can be concluded that effective flood risk management must incorporate climate change uncertainties and urban growth, with index-based approaches such as PhySFI, UFRI, and FSC serving as decision-support tools in flood control planning.

Remaining within the modeling domain, Cluster 9 specifically addresses the technical aspects of hydrodynamic simulation. This cluster examines coupled one-dimensional and two-dimensional hydrodynamic models modified from the Hydrological Engineering Centre's River Analysis System (HEC-RAS), with model parameters applied for simulation under various hydrological regimes (Juma et al., 2023). Additionally, the Hydrologic Engineering Centre's Hydrologic Modelling System (HEC-HMS) has been employed for rainfall-runoff simulation in the upper Ngong River Basin, Kenya (Juma et al., 2022). These discussions reveal that HEC-RAS and HEC-HMS hydrodynamic models function as reliable rainfall-runoff simulation tools across diverse hydrological regimes, thereby supporting basin-scale flood management.

Cluster 10 expands analytical scope through historical comparisons and cross-national approaches. This cluster examines runoff under 2006 land use conditions generating higher discharge compared to 1976 conditions, while identifying rainfall patterns producing the most hazardous hydrological responses from urban planning and flood risk management perspectives (Luo et al., 2018). China and Japan are recognized for effective flood management, with China emphasizing cultural connections and historical experience, whereas Japan prioritizes civil engineering technology development (Luo et al., 2015). These findings indicate that land use change significantly influences flood discharge, while flood management approaches in China and Japan reveal fundamental differences between culture- and experience-based approaches versus civil engineering technology development.

Moving beyond technical and physical dimensions, Cluster 11 addresses the often neglected social dimension of flood management. This cluster examines citizen involvement in spatial planning through co-creation processes, reflecting on social benefits and constraints encountered in implementing Nature-Based Solutions (NBS) from a sustainability perspective specifically, the extent to which NBS integrates economic, ecological, and social considerations (Paauw & Crabbé, 2025). These discussions lead to the understanding that NBS success depends critically upon citizen engagement through co-creation processes and the capacity of NBS to sustainably integrate economic, ecological, and social benefits.

As an extension of environmentally sensitive approaches, Cluster 12 examines low-impact development (LID) models designed to control urban runoff while comparing flood risk management across selected countries (Jia et al., 2025). LID models contribute to pre-development hydrological recovery and emphasise the importance of integrated LID approaches for sustainable city design and flood risk management in rapidly urbanising environments (Ahmad et al., 2025). Integrated LID approaches play a critical role in controlling urban runoff, restoring pre-development hydrology, and mitigating flood risks in rapidly urbanising areas.

Continuing within the domain of nature-based and green infrastructure solutions, Cluster 13 addresses Sustainable Drainage Systems (SuDS), encompassing flood resilience, benefits, sustainable drainage approaches, evidence of SuDS effectiveness, maintenance requirements, and integration into Water-Sensitive Urban Design (WSUD) at the city scale (Charlesworth et al., 2025). Natural Flood Risk Management (NFRM) is implemented through natural processes including afforestation, drainage system modification, and wetland and floodplain modification to reduce current and future flood risk (Lavers & Charlesworth, 2016). Combinations of multiple linear regression (MLR), multiple nonlinear regression (MNLr), and multiple binary logistic regression (MBLR) have been employed in catchment studies, demonstrating accurate prediction of intensive storm-induced flooding triggered by climate change (Daniel et al., 2018). Integrated flood resilience systems through SuDS, WSUD, and NFRM offer sustainable approaches combining green infrastructure solutions, natural processes, and statistical modeling to effectively reduce flood risk.

As the concluding cluster, Cluster 14 addresses long-term challenges in flood management, particularly concerning warning systems and preventive measure effectiveness. This cluster examines the development of warning systems characterized by high uncertainty, identifying current developments, knowledge gaps, and proposed research directions to enhance warning capabilities for extreme hydrogeomorphological processes (Borga et al., 2014). Increased autumn and winter precipitation has elevated flood frequency in Northwestern Europe (Blöschl et al., 2019). Household-level flood prevention measure effectiveness tends to decline rapidly, generating higher and earlier costs compared to proactive measures (Carr et al., 2025). VMD simulations indicate peak flood increases of 9–13 cm; however, substantial tidal dynamics ranging from 19–32 cm confirm that high dike construction paradoxically increases downstream flood risk (Triet et al., 2017). These findings underscore that extreme precipitation increases due to climate change exacerbate flood risk, while household-level preventive measure effectiveness tends to diminish over time, necessitating more reliable early warning systems and comprehensive adaptive policies.

Based on the analysis of 14 author collaboration clusters, these clusters can be grouped into five broad categories: Theoretical Foundations of Socio-Ecological Resilience (Cluster 1); Policy and Governance Transformation (Clusters 2, 8, 10); Urban Infrastructure and Public Participation (Clusters 3, 4, 11); Hydrological Modeling and Technical Simulation (Clusters 5, 6, 7, 9); and Green Solutions and Early Warning Systems (Clusters 12, 13, 14). Although all reference the concepts of resilience and flood risk management, cross-group communication remains minimal, as reflected in the low rate of cross-citation. Thematic isolation is most evident in Cluster 9 (Hydrodynamic Simulation) and Cluster 13 (Sustainable Drainage Systems), indicating that flood barrier research has expanded into highly specialised areas.

illustrates the collaborative network structure described above

RQ5 Three conceptual understandings of flood barriers

Based on an analysis of 14 author collaboration clusters, these clusters can be grouped into five broad categories: Theoretical Foundations of Socio-Ecological Resilience (Cluster 1); Policy Transformation and Governance (Clusters 2, 8, 10); Urban Infrastructure and Public Participation (Clusters 3, 4, 11); hydrological modelling and technical simulation (Clusters 5, 6, 7, 9); and Green Solutions and Early Warning Systems (Clusters 12, 13, 14). Although they

Based on an analysis of 14 author collaboration clusters, the

share references to the concepts of resilience and flood risk management, cross-group communication remains minimal, as reflected in the low level of cross-citations. Thematic isolation is most evident in Cluster 9 (Hydrodynamic Simulation) and Cluster 13 (Sustainable Drainage Systems), indicating that flood barrier research has expanded into highly specialised areas.

However, this collaborative fragmentation does not imply an absence of a shared intellectual foundation. A co-citation analysis of references that received at least two citations revealed three clusters of references. Cluster 1 comprised the founding figures of flood barrier research, including Zevenbergen, Chan, Gersonius, Gomes Miguez, Hartmann, Ashley, Keller, Moura Rezende, Spit, and Thorne, who collectively represented the epistemological core of the field. Cluster 2 connects flood management to policy, governance, and stakeholder participation through the works of (Dawson et al., 2011; Hartmann & Spit, 2016; Hudson et al., 2021; Nouzari et al., 2020; Thaler et al., 2020; van Herk et al., 2013). Cluster 3 extends the research into hydrological modelling, hydrodynamic simulation, and early warning systems through the works of (Benito et al., 2025; Juma et al., 2022, 2023; Scussolini et al., 2024; Triet et al., 2017; Tu et al., 2020). Thus, despite significant thematic fragmentation, there is a shared intellectual foundation linking the three main domains of theory of resilience, policy and governance, and technical modelling, which collectively constitute the knowledge structure of contemporary flood barrier research.

Conclusion

This study systematically mapped the intellectual structure of flood barrier research from 2008 to 2026 through a bibliometric approach to 210 documents from 115 sources. The main findings reveal that although the field has grown rapidly, with an annual growth rate of 19.31%, flood barrier research has not formed an integrated research program but is instead fragmented into seven thematic clusters and 14 distinct author collaboration clusters. This fragmentation is reflected in the low level of cross-cluster citation as well as limited cross-group communication, especially between technical clusters (hydrological modelling and hydrodynamic simulation) and socio-political clusters (public participation, governance, and social justice). This indicates that integrated approaches, such as integrated flood risk management, IFRM remain aspirational rather than operational in actual research practice.

Geographically, flood barrier research is dominated by five developed countries China, the Netherlands, the United Kingdom, the United States, and Germany which together account for 45.23% of total publications, while developing countries with high flood vulnerability have a very limited contribution. Institutional concentration is also evident, with Deltares and Delft University of Technology as the most productive institutions, and Water (Switzerland), Journal of Hydrology, and Journal of Flood Risk Management as the main publication channels. The most productive author is Zevenbergen, with five articles, followed by Chan, Gersonius, Gomes Miguez, and Hartmann, with four articles each, who collectively form the epistemological core of this field through their work on socio-ecological resilience.

Thematic evolution from 2008 to 2026 shows a paradigm shift from structural technical approaches (2008–2017) toward a focus on flood impacts and risk perception (2018–2021), and finally shifting to resilience, ecosystem-based approaches, and a more holistic understanding of risk (2022–2026). However, technical themes, such as flood control, remain present in all periods, indicating that structural approaches have not been entirely replaced, and

thematic fragmentation persists. Thus, efforts to develop a truly integrated flood risk management approach that combines technical excellence, ecological sustainability, and social justice still require more intensive cross-disciplinary collaboration, expanded geographic and institutional representation, and more balanced integration of technical, policy, economic, and social dimensions in future flood barrier research.

Reference

- Ahmad, S., Jia, H., Ashraf, A., Yin, D., Chen, Z., Ahmed, R., & Israr, M. (2025). Quantifying LID impact: A modified metric for enhanced flood mitigation and urban resilience. *Resources, Conservation and Recycling*, 215, 108089. <https://doi.org/https://doi.org/10.1016/j.resconrec.2024.108089>
- Anyifang Zhang, K. S. X. Y. (2026). A Physics-Based Approach to Project the Impact of Climate Change on Occurrence of Compound Floods in a Large River Delta. *Water Resources Research*, 1–15. <https://doi.org/10.1029/2025WR043041>
- Aria, M., & Cuccurullo, C. (2026). *Science Mapping Analysis - A Primer with Biblioshiny*.
- As'adi, M. H. (2026a). Ideological plurality and misinformation dynamics in Indonesia's digital islamic sphere. *Contemporary Islam*. <https://doi.org/10.1007/s11562-026-00620-8>
- As'adi, M. H. (2026b). The fragmented legacy of Heinz von Foerster: bibliometric mapping of second-order cybernetics, 1981–2025. *Kybernetes*, 1–24. <https://doi.org/10.1108/K-03-2026-0588>
- Benito, I., Ward, P. J., Aerts, J. C. J. H., Eilander, D., & Muis, S. (2025). *Uncovering unprecedented storm surges in European and Mediterranean coastlines OPEN ACCESS Uncovering unprecedented storm surges in European and Mediterranean coastlines*.
- Berry, G. (2012). How the Failure to Account for Flexibility in the Economic Analysis of Flood Risk and Coastal Management Strategies Can Result in Maladaptive Decisions. *Journal of Waterway, Port, Coastal, and Ocean Engineering*, 138(5), 386–393. [https://doi.org/10.1061/\(ASCE\)WW.1943-5460.0000142](https://doi.org/10.1061/(ASCE)WW.1943-5460.0000142)
- Blöschl, G., Hall, J., Viglione, A., Perdigão, R. A. P., Parajka, J., Merz, B., Lun, D., Arheimer, B., Aronica, G. T., Bilibashi, A., Boháč, M., Bonacci, O., Borga, M., Čanjevac, I., Castellarin, A., Chirico, G. B., Claps, P., Frolova, N., Ganora, D., ... Živković, N. (2019). Changing climate both increases and decreases European river floods. *Nature*, 573(7772), 108–111. <https://doi.org/10.1038/s41586-019-1495-6>
- Borga, M., Stoffel, M., Marchi, L., Marra, F., & Jakob, M. (2014). Hydrogeomorphic response to extreme rainfall in headwater systems: Flash floods and debris flows. *Journal of Hydrology*, 518, 194–205. <https://doi.org/https://doi.org/10.1016/j.jhydrol.2014.05.022>
- Carr, G., Seebauer, S., & Lun, D. (2025). Interactions Between Public and Private Flood Adaptation: Insights From a Socio-Hydrological Model. *Water Resources Research*, 61(11), e2025WR040502. <https://doi.org/https://doi.org/10.1029/2025WR040502>
- Chan, F. K. S., Adekola, O. A., Mitchell, G., & McDonald, A. T. (2013). Appraising sustainable flood risk management in the Pearl River Delta's coastal megacities: a case study of Hong Kong, China. *Journal of Water and Climate Change*, 4(4), 390–409. <https://doi.org/10.2166/wcc.2013.018>

- Chan, F. K. S., Chuah, C. J., Ziegler, A. D., Dąbrowski, M., & Varis, O. (2018). Towards resilient flood risk management for Asian coastal cities: Lessons learned from Hong Kong and Singapore. *Journal of Cleaner Production*, 187(November 2011), 576–589. <https://doi.org/10.1016/j.jclepro.2018.03.217>
- Charlesworth, S., Castro-Fresno, D., & Rodriguez-Hernandez, J. (2025). *Integrating Water Quality in Urban Flood Risk Management: Structural Approaches* (pp. 26–43). <https://doi.org/10.1017/9781316340332.004>
- Chi, H., & City, M. (2017). *Water Resources Research*. 841–857. <https://doi.org/10.1002/2017WR021344>
- Cisneros, B. J., & Makarigakis, A. K. (2025). Introduction. In B. Jiménez Cisneros & A. K. Makarigakis (Eds.), *Impact of Urban Floods on Water Quality* (pp. 1–3). Cambridge University Press. <https://doi.org/DOI: 10.1017/9781316340332.001>
- Creach, A. (2021). Coastlines with increased vulnerability to sea-level rise. In *Spatial Impacts of Climate Change* (pp. 71–92). <https://doi.org/10.1002/9781119817925.ch4>
- Daniel, J.-E., Nora, S., Ignacio, A.-D., & Jorge, R.-H. (2018). Flood Risk Assessment in Urban Catchments Using Multiple Regression Analysis. *Journal of Water Resources Planning and Management*, 144(2), 4017085. [https://doi.org/10.1061/\(ASCE\)WR.1943-5452.0000874](https://doi.org/10.1061/(ASCE)WR.1943-5452.0000874)
- Dawson, R. J., Ball, T., Werritty, J., Werritty, A., Hall, J. W., & Roche, N. (2011). Assessing the effectiveness of non-structural flood management measures in the Thames Estuary under conditions of socio-economic and environmental change. *Global Environmental Change*, 21(2), 628–646. <https://doi.org/https://doi.org/10.1016/j.gloenvcha.2011.01.013>
- Gersonius, B., Vonk, B., Ashley, R. M., Den Heijer, F., Jan Klerk, W., Manojlovic, N., Rijke, J., Sayers, P., & Pathirana, A. (2020). Maturity improvements in flood protection asset management across the north sea region. *Infrastructures*, 5(12), 1–13. <https://doi.org/10.3390/infrastructures5120112>
- Habersack, H., Hein, T., Stanica, A., Liska, I., Mair, R., Jäger, E., Hauer, C., & Bradley, C. (2016). Challenges of river basin management: Current status of, and prospects for, the River Danube from a river engineering perspective. *Science of The Total Environment*, 543, 828–845. <https://doi.org/https://doi.org/10.1016/j.scitotenv.2015.10.123>
- Hartmann, T., & Spit, T. (2016). Legitimizing differentiated flood protection levels – Consequences of the European flood risk management plan. *Environmental Science & Policy*, 55, 361–367. <https://doi.org/https://doi.org/10.1016/j.envsci.2015.08.013>
- Hino, M., BenDor, T. K., Branham, J., Kaza, N., Sebastian, A., & Sweeney, S. (2024). Growing Safely or Building Risk?: Floodplain Management in North Carolina. *Journal of the American Planning Association*, 90(1), 50–62. <https://doi.org/10.1080/01944363.2022.2141821>
- Hooimeijer, F., Diaz, A., Bortolotti, A., Ke, Q., van der Heuvel, J., & Bricker, J. (2024). Design & assessing the flood risk management paradigm shift: an interdisciplinary study of Vlissingen, the Netherlands. *Journal of Urbanism: International Research on Placemaking and Urban Sustainability*, 17(4), 555–576. <https://doi.org/10.1080/17549175.2022.2093258>
- Hooimeijer, F., Yoshida, Y., Bortolotti, A., & Iuorio, L. (2022). *Chapter 18 - Integrated*

- urban flood design in the United States and the Netherlands* (S. Brody, Y. Lee, & B. B. B. T.-C. F. R. R. Kothuis (Eds.); pp. 241–254). Elsevier.
<https://doi.org/https://doi.org/10.1016/B978-0-323-85251-7.00018-4>
- Hossain, I., Haque, A. K. M. M., Masud, A. Al, Zahangir, M., & Uddin, S. (2026). *A bibliometric analysis of governance pathways in environment , urbanization and climate change*.
- Hudson, P., Bubeck, P., & Thieken, A. H. (2021). A comparison of flood-protective decision-making between German households and businesses. *Mitigation and Adaptation Strategies for Global Change*, 27(1), 5. <https://doi.org/10.1007/s11027-021-09982-1>
- Jia, M., Xu, C., & Jia, H. (2025). General Approaches on Urban Water Challenges. In B. Jiménez Cisneros & A. K. Makarigakis (Eds.), *Impact of Urban Floods on Water Quality* (pp. 14–25). Cambridge University Press. <https://doi.org/DOI:10.1017/9781316340332.003>
- Jiménez Cisneros, B., & Makarigakis, A. K. (Eds.). (2025). Impact of Urban Floods on Water Quality. In *Impact of Urban Floods on Water Quality* (pp. iii–iii). Cambridge University Press. <https://www.cambridge.org/product/50B127AF8287A3FA4B41A7DD5B8672CF>
- Jonkman, S. N., Voortman, H. G., Klerk, W. J., & van Vuren, S. (2018). Developments in the management of flood defences and hydraulic infrastructure in the Netherlands. *Structure and Infrastructure Engineering*, 14(7), 895–910.
<https://doi.org/10.1080/15732479.2018.1441317>
- Juma, B., Olang, L. O., Hassan, M. A., Chasia, S., Mulligan, J., & Shiundu, P. M. (2023). Flooding in the urban fringes: Analysis of flood inundation and hazard levels within the informal settlement of Kibera in Nairobi, Kenya. *Physics and Chemistry of the Earth, Parts A/B/C*. <https://api.semanticscholar.org/CorpusID:264413088>
- Juma, B., Olang, L. O., Hassan, M. A., Mulligan, J., & Shiundu, P. M. (2022). Simulation of flood peak discharges and volumes for flood risk management in the ungauged urban informal settlement of Kibera, Kenya. *Physics and Chemistry of the Earth, Parts A/B/C*, 128, 103236. <https://doi.org/https://doi.org/10.1016/j.pce.2022.103236>
- Krieger, K. (2013). The limits and variety of risk-based governance: The case of flood management in Germany and England. *Regulation & Governance*, 7(2), 236–257.
<https://doi.org/https://doi.org/10.1111/reg.12009>
- Lavers, T., & Charlesworth, S. M. (2016). Natural Flood Risk Management and its Role in Working with Natural Processes. In *Sustainable Surface Water Management* (pp. 157–176). <https://doi.org/https://doi.org/10.1002/9781118897690.ch12>
- Lendering, K. T., Sebastian, A., Jonkman, S. N., & Kok, M. (2019). Framework for assessing the performance of flood adaptation innovations using a risk-based approach. *Journal of Flood Risk Management*, 12(S2), e12485.
<https://doi.org/https://doi.org/10.1111/jfr3.12485>
- Luo, P., Apip, He, B., Duan, W., Takara, K., & Nover, D. (2018). Impact assessment of rainfall scenarios and land-use change on hydrologic response using synthetic Area IDF curves. *Journal of Flood Risk Management*, 11(S1), S84–S97.
<https://doi.org/https://doi.org/10.1111/jfr3.12164>
- Luo, P., He, B., Takara, K., Xiong, Y. E., Nover, D., Duan, W., & Fukushi, K. (2015).

- Historical assessment of Chinese and Japanese flood management policies and implications for managing future floods. *Environmental Science & Policy*, 48, 265–277. <https://doi.org/https://doi.org/10.1016/j.envsci.2014.12.015>
- Miguez, M. G. (2019). *A Framework to Evaluate Urban Flood Resilience of Design Alternatives for Flood Defence Considering Future Adverse Scenarios*.
- Miranda, F., Franco, A. B., Rezende, O., Costa, B. B. F., Najjar, M., Haddad, A. N., & Miguez, M. (2023). *A GIS-Based Index of Physical Susceptibility to Flooding as a Tool for Flood Risk Management*. 1–22.
- Moura Rezende, O., Ribeiro da Cruz de Franco, A. B., Beleño de Oliveira, A. K., Pitzer Jacob, A. C., & Gomes Miguez, M. (2019). A framework to introduce urban flood resilience into the design of flood control alternatives. *Journal of Hydrology*, 576, 478–493. <https://doi.org/10.1016/j.jhydrol.2019.06.063>
- Nordbeck, R., Steurer, R., & Löschner, L. (2019). The future orientation of Austria's flood policies: from flood control to anticipatory flood risk management. *Journal of Environmental Planning and Management*, 62(11), 1864–1885. <https://doi.org/10.1080/09640568.2018.1515731>
- Nouzari, E., Hartmann, T., & Spit, T. (2020). Interactive governance for satisfaction measurements: Stakeholder involvement in design processes for flood risk management. *Journal of Flood Risk Management*, 13(4), 1–15. <https://doi.org/10.1111/jfr3.12650>
- O'Donnell, E. C., Lamond, J. E., & Thorne, C. R. (2017). Recognising barriers to implementation of Blue-Green Infrastructure: a Newcastle case study. *Urban Water Journal*, 14(9), 964–971. <https://doi.org/10.1080/1573062X.2017.1279190>
- Oerlemans, C., van den Boomen, M., Rijcken, T., & Kok, M. (2025). Flood exposure in Rotterdam's unembanked areas from 1970 to 2150: sensitivities to urban development, sea level rise, and adaptation. *Natural Hazards and Earth System Sciences*, 25(10), 3921–3937. <https://doi.org/10.5194/nhess-25-3921-2025>
- Paauw, M., & Crabbé, A. (2025). *The Social Dimension of Nature-Based Solutions: The Potential of Co-Creation Processes for NBS to Reduce Social Vulnerability to Floods BT - Handbook of Nature-Based Solutions to Mitigation and Adaptation to Climate Change* (G. J. Nagy & D. Y. Ayal (Eds.); pp. 2011–2031). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-34967-6_19
- Rijcken, T., Stijnen, J., & Slootjes, N. (2012). “Simdelta”-Inquiry into an internet-based interactive model for water infrastructure development in the Netherlands. *Water (Switzerland)*, 4(2), 295–320. <https://doi.org/10.3390/w4020295>
- Roos, M. M. D., Hartmann, T. T., Spit, T. T. J. M., & Johann, G. G. (2017). Constructing risks – Internalisation of flood risks in the flood risk management plan. *Environmental Science & Policy*, 74, 23–29. <https://doi.org/https://doi.org/10.1016/j.envsci.2017.04.007>
- Scussolini, P., Luu, L. N., Philip, S., Berghuijs, W. R., Eilander, D., Aerts, J. C. J. H., Kew, S. F., van Oldenborgh, G. J., Toonen, W. H. J., Volkholz, J., & Coumou, D. (2024). Challenges in the attribution of river flood events. *Wiley Interdisciplinary Reviews: Climate Change*, 15(3), 1–17. <https://doi.org/10.1002/wcc.874>
- Tang, Y. T., Chan, F. K. S., O'Donnell, E. C., Griffiths, J., Lau, L., Higgitt, D. L., & Thorne, C. R. (2018). Aligning ancient and modern approaches to sustainable urban water

- management in China: Ningbo as a “Blue-Green City” in the “Sponge City” campaign. *Journal of Flood Risk Management*, 11(4), 1–14. <https://doi.org/10.1111/jfr3.12451>
- Tasnia, T., & Growe, A. (2025). A Systematic Literature Review of Water-Sensitive Urban Design and Flood Risk Management in Contexts of Strategic Urban Sustainability Planning. *Land*, 14(2), 1–24. <https://doi.org/10.3390/land14020224>
- Thaler, T., Doorn, N., & Hartmann, T. (2020). Justice of compensation for spatial flood risk management – comparing the flexible Austrian and the structured Dutch approach. *Erde*, 151(2–3), 104–115. <https://doi.org/10.12854/erde-2020-467>
- Triet, N. V. K., Dung, N. V., Fujii, H., Kummu, M., Merz, B., & Apel, H. (2017). Has dyke development in the Vietnamese Mekong Delta shifted flood hazard downstream? *Hydrology and Earth System Sciences*, 21(8), 3991–4010. <https://doi.org/10.5194/hess-21-3991-2017>
- Tu, H., Wang, X., Zhang, W., Peng, H., & Ke, Q. (2020). *Flash Flood Early Warning Coupled with Hydrological Simulation and the Rising Rate of the Flood Stage in a Mountainous Small Watershed in*. <https://doi.org/10.3390/w12010255>
- van Herk, S., Zevenbergen, C., Gersonius, B., Waals, H., & Kelder, E. (2013). Process design and management for integrated flood risk management: exploring the multi-layer safety approach for Dordrecht, The Netherlands. *Journal of Water and Climate Change*, 5(1), 100–115. <https://doi.org/10.2166/wcc.2013.171>
- van Herk, S., Zevenbergen, C., Gersonius, B., Waals, H., & Kelder, E. (2014). Process design and management for integrated flood risk management: Exploring the multi-layer safety approach for Dordrecht, The Netherlands. *Journal of Water and Climate Change*, 5(1), 100–115. <https://doi.org/10.2166/wcc.2013.171>
- Wang, Q., Shu, Q., Chen, J., Jung, T., Liu, C., Wang, S., & Danilov, S. (2026). *Sea level rise and fall north of Greenland reorganize Arctic freshwater export to North Atlantic*. 1–13.
- Wesemann, J., Eder, M., Habersack, H., Hogn, K., Löschner, L., & Nordbeck, R. (2020). *Regionale Entwicklung des Hochwasserrisikos unter Berücksichtigung zukünftiger Entwicklungen*. 110–126. <https://doi.org/10.5675/HyWa>
- Zevenbergen, C., Gersonius, B., & Radhakrishnan, M. (2020). Flood resilience. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 378(2168), 20190212. <https://doi.org/10.1098/rsta.2019.0212>
- Zhang, S., Zevenbergen, C., Rabé, P., & Jiang, Y. (2018). The influences of sponge city on property values in Wuhan, China. *Water (Switzerland)*, 10(6), 1–20. <https://doi.org/10.3390/w10060766>