

Vulnerability Assessment of Urban Floods: A Bibliometric Analysis of the Last 20 Years

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Abstract— Urban flood vulnerability is a pressing concern due to climate change and rapid urbanization. These floods stem from a mix of natural elements like heavy rain, snowmelt, and geography, along with human-made factors such as urban growth, poor drainage, and climate change. They lead to various problems, such as property damage, transportation disruption, loss of life, waterborne illnesses, and environmental harm. This study conducts a thorough bibliometric analysis of research articles on urban flood vulnerability from 2003 to 2023 using the Scopus database and VOSviewer as a key tool. It aims to reveal changing trends, major research topics, notable authors, and global collaboration networks in this field.

This study shows a significant rise in publications on this topic, highlighting its increasing significance in urban studies and disaster management. We use VOSviewer to visually represent bibliographic data, co-author relationships, and keyword associations, enhancing our grasp of the research field. Key findings reveal research clusters like "flood risk assessment," "urban planning," "climate change adaptation," and "community resilience." This underlines the interdisciplinary nature of urban flood vulnerability research, drawing from various fields, including environmental science, engineering, geography, and social sciences. This study highlights key authors and institutions in urban flood vulnerability research, explores regional differences in research output and collaboration, and provides a global view of research efforts. In conclusion, this bibliometric analysis provides a valuable overview of the research on urban flood vulnerability over the past two decades. It not only showcases the evolution of key themes and the collaborative networks within the field but also serves as a useful resource for researchers, policymakers, and practitioners working towards mitigating the impacts of urban flooding in an increasingly vulnerable world. The research can address climate change concerns, infrastructure development for improved health and social well-being.

Index Terms— Urban Flood Vulnerability, Bibliometric Analysis, Flood Risk Assessment, Vulnerability Assessment, Urban Resilience, Risk Mapping, GIS

I. INTRODUCTION

Urban flooding is an increasingly prevalent and disruptive environmental challenge, posing significant threats to public safety, infrastructure, and the overall well-being of urban populations[1]. Over the last two decades, the frequency and severity of urban floods have been on the rise due to factors such as climate change, rapid urbanization, and poor urban planning.

Global urban flood challenges demand a focus on evolving vulnerability assessment research case [2]. Urban

floods, with severe socio-economic and environmental impacts, fuel increased academic interest [3]. A holistic vulnerability assessment is crucial, given the multifaceted nature influenced by natural, social, and economic factors [4]. This urgency is underscored by rising frequency and severity, impacting urban planning, disaster management, and public health [5]. Bibliometric analysis, using tools like VOS viewer on the Scopus database, aids in identifying contributors, trends, and guiding future research [6]. This study employs bibliometric analysis to understand Urban Flood Vulnerability Assessment over the past two decades [6]. Beyond methodological aspects, it identifies contributors, nations, sources, and thematic areas, contributing to evidence-based decision-making for a more resilient urban future [7]. The entire research article is divided into five sections that address the aforementioned -

- The fundamentals of urban flood resistance and its evaluation procedure are covered in Section 1.
- The literature that already exists and the need for study are discussed in Section 2.
- The research resources and methodologies used in the work are highlighted in Section 3.
- The findings of many bibliometric analyses utilizing the VOSviewer, including trend in publications, citation and co-citation, documents by subject area, extensively cited documents word co-occurrence analysis etc. are described in Section 4.
- The summary the research's results and conclusions and suggesting further and future research areas in concluded in Section 5.

II. DATA AND METHODS

This literature review comprises two main stages- Generation of Database & Analysis using VOSviewer. Through this systematic approach, themes, authors, and countries are classified, offering valuable insights into citation patterns, publication trends, and authorship networks [6]. This information aids researchers, institutions, and policymakers in making informed decisions about resource allocation, funding priorities, and collaboration opportunities, thereby advancing scientific knowledge and innovation [8].

A. Generation of Database

The search string named "Urban Flood" OR "Floods" AND "Vulnerability Assessment" OR "Risk Assessment" AND "Urban Areas" explores the Scopus database for information on a variety of topics related to urban floods and vulnerability assessment. To comprehend the concepts and themes, the search string contains all works on urban flood vulnerability, including framework, resilience assessment, index-based approaches, tools, strategies, and methodologies. After finishing the first stage of database development, the database query provided 1098 documents in total. The second phase was including the filter for the most recent 20 years, i.e., 2003 to 2023. The literature review was done on September 22, 2023, and 984 documents were found. The articles' titles and abstracts were manually reviewed to remove duplicate and extraneous documents. Finally, another filter was applied, this time limiting the document type to Journals, and ultimately, 858 documents were kept and used for the study's further analysis.

B. Abbreviations Analysis using VOS viewer

The choice of bibliometric software was guided by three main factors: automatic data extraction, comprehensive study features, and robust visualization capabilities. VOS viewer, a free online tool, meets these criteria and is cited for its ability to perform bibliometric analysis and construct networks of essential publication data [6]. It covers details about writers, periodicals, organizations, and nations, utilizing citation, co-citation, co-occurrence, and bibliographic analysis [9]. Particularly useful for urban flood resilience evaluation, VOS viewer employs word co-occurrence analysis to uncover research topics and identify significant clusters. The software also facilitates efficient data processing by providing a unique file for cleaning up repeated terms, keywords, and authors' names. Additionally, "bibliographic coupling by country" helps identify contributions from different nations and their interrelationships [10]. The visual output of VOS viewer is based on node size and connectivity, determined by frequency output and linkage strength [6].

III. RESULT OF BIBLIOMETRIC ANALYSIS

A. VOS viewer Software application result

- *Trends in Publication*

Understanding the historical background and knowledge domain implications is aided by trends in publication. Nevertheless, the third decade saw a sharp increase in the quantity of publications. The amount of research publications produced each year has increased significantly since 2016, surpassing the average of 50 articles annually. In international, national, and local policy frameworks post-2016, there may have been a greater recognition of the need for flood resilience at the urban level, which could be the cause of this significant growth rate. The graph shows how publishing patterns have dramatically expanded during 2018 onward. According to the flooding scenario presented in numerous research studies, there has been a noticeable growth in the topic of urban flood vulnerability in the publication since 2016 as a result of no. of flooding disasters which occurred during this phase [2], [11], [12]. In year 2023, we have total 76 papers published till date and this figure will surely increase by the end of the year as this topic is the most tending in field of disaster management and mitigation as shown in Figure.1

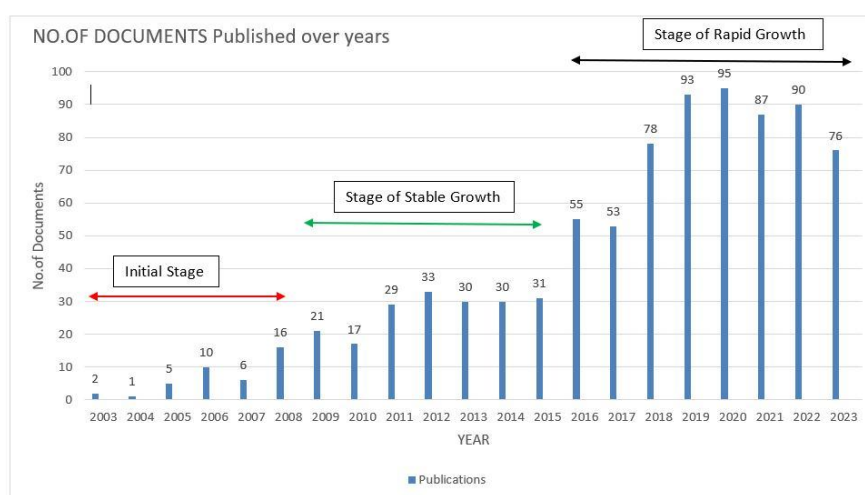


Figure 1. Number of articles published over the years

- *Co-occurrence of keywords and terms*

The major cluster and significant focus areas that regularly occur and are used to construct a thematic cluster are found using the co-occurrence approach. The software program VOS viewer was used to create the theme cluster in Figure 2. The software does not provide information on the co-occurrence of theme clusters; therefore, interpretation requires subject expertise. Without topic knowledge, it is impossible to understand theme clusters. Co-occurrence analysis has the drawback of not detailing the relationships between the terms in depth. The results of this analysis are shown in Figure 2. with the minimum number of keyword occurrences being 8. The size of the nodes in the graphic reflects how frequently the term has been used, and their closeness to one another denotes their proximity.

The network analysis reveals strong connections among floods, climate change, urban design, vulnerability, and resilience (Fig. 2). Notably, vulnerability, urban resilience, sustainability, and water management form the most robust connections with the highest occurrence value. Clusters (red, green, and blue) in Fig. 2 show significant co-occurrence, such as the red cluster focusing on urban planning and management, emphasizing vulnerability. It utilizes urban planning, urbanization, flood damage, assessment techniques, and hazard management [Fig. 2].

The green cluster prioritizes modelling and flood management, including rainfall estimation, hydrological modelling, and sustainability, with an emphasis on nature-based solutions. The blue cluster (26 words) concentrates on rivers, water pollution, and risk factors. The analysis establishes a robust link between floods, climate change, urban design, vulnerability, and resilience, underscoring the interconnected importance of water management, sustainability, and urban resilience in addressing climate change impacts.

- *Number of Documents by Subject Area*

The pie chart in Figure 3 reveals research distribution across disciplines. Environmental Science dominates with the highest number of publications [13]–[15], followed by social science and earth/planetary science. Engineering [16], Agricultural and Biological Sciences [10], [17], [18], Biochemistry, Genetics, and Molecular Biology show

moderate publication levels. Mathematics, arts and humanities, chemistry, health profession, immunology, and nursing have fewer publications in Urban Floods vulnerability assessment.

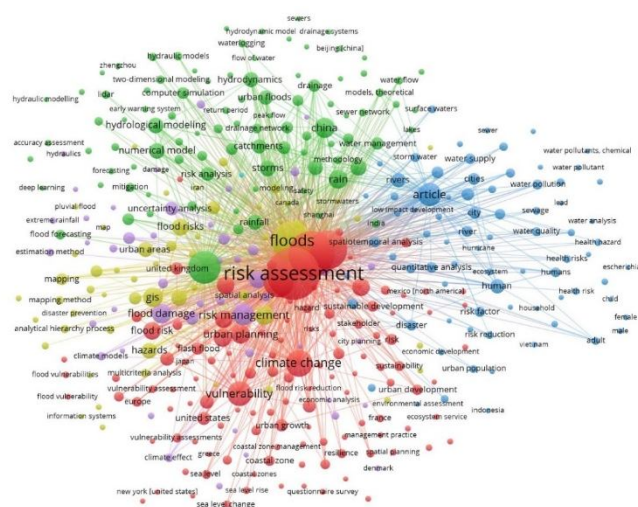


Figure 2. Results of co-occurrence analysis performed by VOSviewer show the term that appears the most often

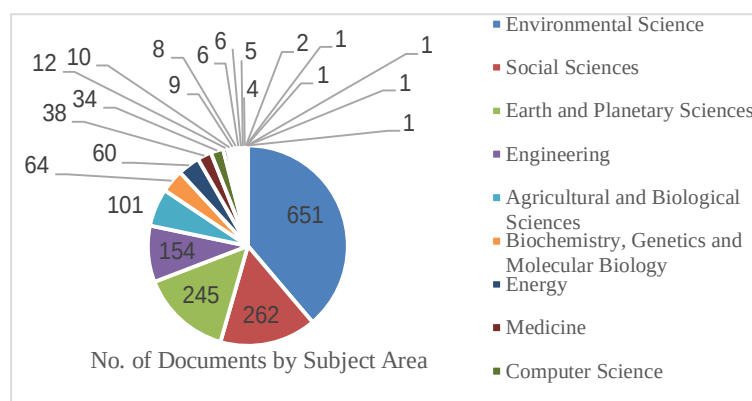


Figure 3. Number of Documents by Subject Area

- *Number of Documents per year by Journals/Source*

In 2019, Water Science and Technology led in document publications with 15, while the sprouting stage (2005-2010) saw stable growth at around 5 documents per year. Wit Transactions on Ecology and the Environment peaked in 2008 with 7 papers [19]. Major journals like Natural Hazards, Science of the Total Environment, and Journal of Hydrology [16], [20], [21] maintained balanced publication trends. From 2017 to 2020, Sustainability Switzerland and Science of the Total Environment were noteworthy. However, from 2021 to 2023, there was a slight overall decrease in publication trends, with journals like Natural Hazards and Earth System Sciences showing mixed trends [4], [13], [22], [23] which is shown in Fig 4.

- *Extensive Cited Documents*

Citation analysis reveals key publications in various areas, as depicted in the density map (Fig. 5) with a minimal citation threshold of 50. Warm colors indicate higher density and co-citation strength. Nine clusters are identified, two significant ones centered on urban hazards mitigation and vulnerability assessment. Hallegatte's work dominates the vulnerability assessment cluste [24]. Another cluster focuses on resilience index for climatic stress and vulnerability to flooding threats [3], [25], [26] Numerous smaller clusters delve into indicator selection and flood hazard index development [27]. The bottom cluster emphasizes impact, while the left one explores river and coastal flooding trends, environmental aspects, and tools for resilience assessment using green infrastructure and ecosystem services [28], [29].

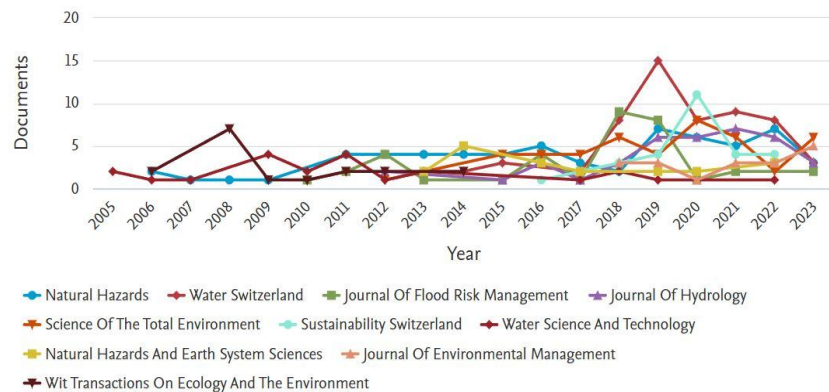


Figure 4. Number of Documents by Subject Area

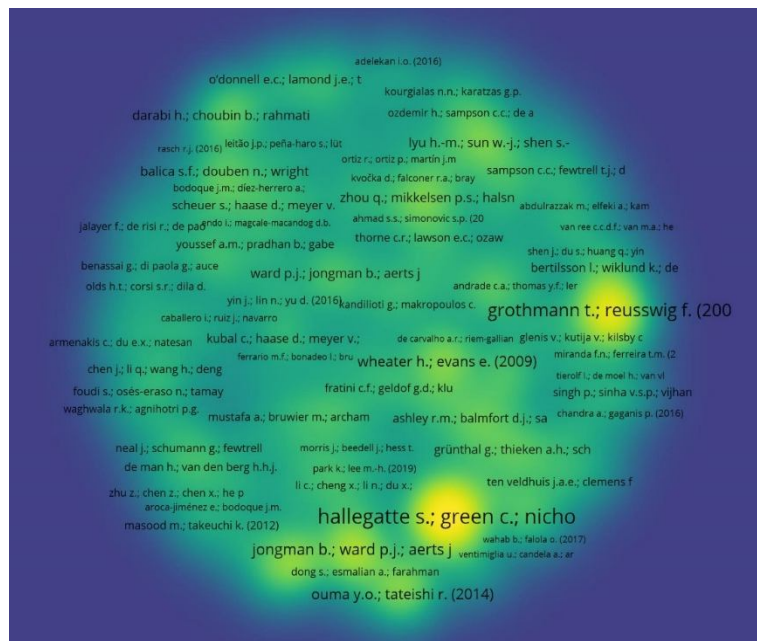


Figure 5. Density map showing influential documents in the Bibliometric Analysis

• Extensive Cited Authors in Co-citation

The results of citation analysis and co-citation analysis are covered in this section. To identify well-known authors, co-citation analysis uses the "Cited author" as a unit of analysis. The final goal of the research was to identify the prominent authors who had a substantial influence on the growth of the field. This goal can be helped by analyzing citations and co-citations. The co-citation analysis measures how often the writers are quoted together in documents. Citation analysis rates authors according to the number of citations their publications have received.

By restricting the number of citations per author (80) in Fig. 6, the density map for the study was produced. The fact that various authors are tackling the same problems is further evidenced through network visualization. The top 10 authors with the greatest number of co-citations are Bates P.D [30], Merz B, Kreibich H [31], [32], Djordjevic S, Aerts J.C.J.H [28], Thieken A.H [31]

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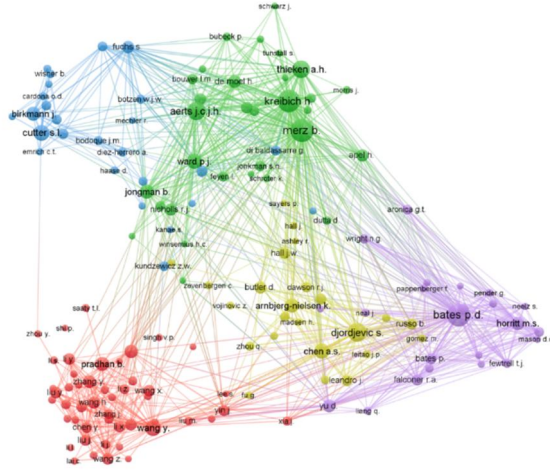


Figure 6. Result showing influential authors and clusters depicting similar work done by the authors

TABLE I. ON THE SUBJECT OF URBAN FLOODS, RESEARCHERS RECEIVED AN EXTENSIVE NUMBER OF CITATIONS (VOS VIEWER SOFTWARE RESULTS)

Author	Total Citations	Total link strength	Focus Area
Bates P.D	360	1661	Estimation of Numerical Flux in Local Inertial Models
Merz B.	353	3875	Resilience and urban risk management
Kreibich H.	342	4240	Urban flood modelling
Djordjevic S.	257	1033	Artificial intelligence in resilience
Aerts J.C.J.H.	236	3144	Global exposure to river and coastal flooding
Thieken A.H.	227	3213	Capacity building to Flood Resilience
Ward P.J.	179	2414	A global framework for future costs and benefits of river-flood
Jongman B.	157	1792	Global exposure to river and coastal flooding
De Moel H.	140	2171	Flood risk management and climate change
Fuchs S.	121	1353	Impact-Based Forecasting for Pluvial Floods

• Primary Contributing Countries

According to the Scopus database evaluation, researchers from 44 different nations contributed significantly to the 953 publications. The United States, United Kingdom, Netherlands, and China have the most contribution in terms of publications, according to the bibliographic coupling analysis performed in VOS viewer on at least four papers per country. It should be emphasized that in order to get the right results, the minimum number in this and other VOS viewer tests must be found through trial and error. More countries will come from fewer documents, which is bad for presentational reasons and leaves out crucial information on important nations.

IV. DISCUSSIONS

A. Current Research Focuses of Urban Flood Vulnerability

This study, analyzing co-occurrence networks and term clusters, reveals the evolution of urban flood vulnerability assessment research interests. The VOS viewer study identifies "Risk Assessment" as the largest cluster. Urban flood vulnerability is closely tied to flood risk management. Assessing vulnerability, including the likelihood and severity of effects, is crucial. Previous research focused on public policies, topography, and flood hydraulic characteristics. Social-demographic factors received limited attention during the initial ten-year period. The study emphasizes the importance of analysing spatial aspects in urban flood vulnerability, as evidenced by terms like "spatial pattern" and "vulnerability mapping". Pinpointing geographical variations in flood-prone areas is crucial for effective management and long-term strategies. The findings highlight correlation studies on how urbanization and climate change impact flood susceptibility, with elements categorized into urbanization and

climate change factors. The academic focus on the relationship between urban flood vulnerability, climate change, and urbanization is evident in phrase clusters like "land use change" and "climate change". Climate change significantly increases flood risks through phenomena like sea level rise and altered precipitation patterns. Coastal cities and emerging nations are highly concentrated in research topics, with increased vulnerabilities due to high populations and low-lying regions. Practical applications were initially carried out in rich countries, as shown by the cooperation network across nations.

B. Future Prospects

Urban flood vulnerability assessment holds great promise for addressing the increasing threat of flooding in cities worldwide due to climate change and rapid urbanization. The integration of technology, such as remote sensing, GIS, and artificial intelligence, enhances our ability to assess and mitigate flood vulnerability, with machine learning algorithms improving accuracy in predicting flood risks. Real-time data from weather monitoring systems and urban sensors allows for timely responses to potential flood events. Collaborative efforts between governments, researchers, and urban planners are essential for comprehensive assessments considering physical, social, and economic factors. Further research should explore the interconnected nature of flood vulnerability, risk, and resilience to develop more effective strategies for safeguarding urban areas.

V. CONCLUSION

The study conducted a bibliometric analysis of 858 articles on urban flood vulnerability from 2003 to 2023, revealing three stages of research development. Water resources, environmental science, and geoscience were primary disciplines, with the United States, China, England, and Germany leading in publications. Top-cited journals included *Natural Hazards*. Key topics shifted from physical vulnerability to multidimensional exploration, integrating social, economic, and communal aspects.

The study identifies emerging areas like urban resilience integration and climate change effects. Suggestions for future research focus on improving vulnerability assessments and analysing connections between flood vulnerability, risk, and resilience. Additionally, this paper makes some suggestions for prospective directions for future research in this area, such as improving vulnerability assessments and doing in-depth analyses of the fundamental connections between flood vulnerability, flood risk, and flood resilience.

By providing a comprehensive overview of the current state of the research and the development process on urban flood vulnerability, which was lacking in earlier studies, this paper fills the gap. It helps scholars and practitioners understand the current hot topics in this field of study and gains insight into potential directions for future study.

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