

Recent research approaches to urban flood vulnerability, 2006–2016

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Abstract This study examines the research trend of urban flood risk assessment and investigates what methods and approaches have been changed and how these changes have improved our understanding on multi-dimensions of urban flood vulnerability. By reviewing a total of 318 peer-reviewed journal articles during the last 10 years (2006–2016) using bibliometric and content analysis, we observed that the physical vulnerability was the most popular concerns followed by the institutional vulnerability and social vulnerability. Moreover, we found that the planning and policy approach focusing on institutional vulnerability has the potential to link physical and social dimensions of flood vulnerability, facilitating the tight collaboration between applied sciences and social sciences. This study concluded that the continuous increasing number of the comprehensive approach to urban flood risk assessment offers evidence for a new paradigm shift toward a more inclusive way to understand multi-dimensional aspects of urban flood vulnerability across disciplines and different knowledge systems.

Keywords Urban floods · Vulnerability · Comprehensive flood risk assessment · Flood governance · Holistic approach

1 Introduction

It is widely recognized that global environmental problems and climate change impacts are getting stronger worldwide. Urban areas are particularly vulnerable to extreme hydrologic events such as heavy precipitation and associated floods due to the concentration of

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population, infrastructures and human activities (Chang and Franczyk 2008). In the USA, the metropolitan area of Atlanta and the surrounding areas in northern Georgia experienced catastrophic flash floods in September 2009, and major urban floods also occurred in Boston, Chicago, Milwaukee, Nashville, Oklahoma City and Washington, DC, in 2010. According to the 5th Intergovernmental Panel on Climate change (IPCC) assessment report, the frequency and magnitude of flood hazards are projected to increase in world major urban areas where population density is high (Jiménez Cisneros et al. 2014). For more accurate and reliable flood risk assessment, researchers across different disciplines have developed various methodologies and strategies to understand who are vulnerable and where preventive intervention is required in the city. In the domain of applied science, for example, hydraulic and hydrologic analysis on physical exposure to flood risks has been widely used to understand flood dynamics and estimate future flood impacts. In the realm of social science, field surveys and interviews with city officials and local residents have been mostly used to address the uneven distribution of flood risks across the city and community.

These various research attempts to better understand flood vulnerability have largely contributed to reducing uncertainties in climate change projections and enabled the more precise assessment of urban flood risks. In particular, flood modeling and mapping research became more widespread and interdisciplinary due to the participation of hydrologists, geotechnical engineers, geographers, geologists and other various experts. These technological and engineering improvements in flood risk assessment made it possible to provide sufficient information for flood forecasting under multiple scenarios, identify risk factors and areas of high vulnerability (Cloke and Pappenberger 2009), and help planners and decision makers understand complex situations and relationships by combining spatial and temporal flood data and visualizing them in a map and related statistical form (Ouma and Tateishi 2014). Nevertheless, there still remain limitations and challenges for understanding various dimensions of flood vulnerability comprehensively because of rapidly evolving, diverse and fragmented methods of flood risk assessment.

From this point of view, using bibliometric and content analysis, this paper examines the current research trend of urban flood risk assessment and investigates what methods and approaches have been changed and how the changes have improved our understanding on multi-dimensional aspects of urban flood vulnerability. There have been some conspicuous research endeavors to investigate the changes and advances of flood risk assessment and alternatives ways of examining flood vulnerability. Through in-depth literature review, Kiparsky et al. (2012) discussed the incorporation of climate change knowledge to understand both biogeophysical changes and the vulnerability of human and natural systems. Yoon (2012) compared a deductive and inductive approach in assessing social vulnerability to natural disasters, and Fuller and Pincetl (2015) conducted a bibliometric analysis of the vulnerability studies using the Web of science journal citation reports categorization scheme. Moreover, through the content and bibliographic network analysis, Gall et al. (2015) traced the development of integrated disaster risk research between 1999 and 2013 and discussed the true integration across disciplines. However, no previous review papers have focused on urban flood vulnerability specifically. We thus seek to examine the progress of urban flood risk assessment research in addressing multi-dimensional aspects of urban flood vulnerability by reviewing research articles published during the last 10 years, from 2006 to 2016.

Academic articles reviewed in this research are inevitably selective and partial. We omitted the many details of each paper because the specific purpose of the current study is firstly to classify research articles by thematic approaches and their focus on vulnerability,

and secondly to find the meaning from the changes and advances of flood risk assessment research. This review study begins in Sect. 2 with a discussion on various concepts of flood vulnerability and different research approaches to flood risk assessment. Section 3 focuses on the data collection and analysis, which involves in selecting articles and categorizing articles in different groups based on their scope, focus and methodological approaches. Section 4 discusses some major themes of flood risk assessment research during the last 10 years and discusses the meaning of a holistic perspective and the value of comprehensive flood risk assessment.

2 Concept of vulnerability

In general, flood risk represents the probability of negative consequences due to floods and emerges from the convolution of flood hazard and flood vulnerability (Schanze et al. 2006). Along with measuring predicted flood hazard (the external risk factor), evaluating current vulnerability (the internal risk factor) has been considered as significant and urgent topics in various fields of climate change and disaster research. The concept of vulnerability in this respect provides an analytical tool for evaluating susceptibility to harm, powerlessness and marginality of both physical and social systems, and for enhancing human well-being through reduction in risk (Adger 2006). Meanwhile, it is difficult to understand the concept with a partial approach because vulnerability does not exist in isolation from the wider social, economic and political aspects of resource use and management in urban areas. In other words, vulnerability is required to be understood as a comprehensive concept that includes multilateral aspects of exposure, sensitivity and adaptive capacity (Turner et al. 2003; Polsky et al. 2007; Cutter et al. 2009) and needs to be assessed in a way to capture both direct physical impacts—exposure and susceptibility, and indirect impacts—socio-economic fragility and lack of resilience (Birkmann 2006). From this point of view, this study classified flood risk assessment articles by their particular research focus on the physical, socioeconomic and institutional dimensions of urban flood vulnerability. As the first step, we examined various definitions and frameworks of vulnerability and set up the conceptual and methodological boundaries of each dimension of flood vulnerability for effective classification.

2.1 Physical vulnerability

Climate change and disaster research based on the risk hazard (RH) framework sees vulnerability as a linear result of climate change impacts and aims at reducing the projected impacts through technological change and improvements (Fussler 2007). In this framework, particular attention is given to the physical properties of the system that could suffer damage or harm due to an external phenomenon or to the idea that disaster could occur in the system due to the technology employed (Cardona 2003). In general, various disciplines of applied science define physical vulnerability as the degree of exposure and the fragility of the exposed element to flood risks, and their so-called technological and engineering approach mainly focuses on probabilistic modeling to predict areas of hazards and estimate related physical damage of structure and infrastructure. As primary external risk factors, the approach of applied science extensively investigates natural causes of floods such as heavy rainfall (e.g., Camarasa-Belmonte and Burtrón 2015; Faccini et al. 2015), sea-level rise (e.g., Storch and Downes 2011; Jonkman et al. 2013; Lasage et al. 2014), storm surges

(e.g., Maspataud et al. 2013; Tavares et al. 2015), increasing groundwater levels (e.g., Rotzoll and Fletcher 2012) and their combinations thereof (e.g., Kulkarni et al. 2014). As a secondary cause, this approach also concerns technology- and engineering-related causes such as inefficient drainage systems (e.g., Ibarra 2012; Zhou et al. 2012), problems of evacuation routes and traffic networks (e.g., Coutinho-Rodrigues et al. 2012; Balijepalli and Oppong 2014), and the lack of proper flood defense structures (e.g., Duvat 2013).

In this study, we classified the first group as the research that concerns the physical dimension of vulnerability mainly from a technological and engineering perspective. In many cases, the environmental dimension of flood vulnerability is frequently discussed in close connection with physical vulnerability; however, since this review limits the spatial scope of topic to urban or peri-urban systems, we excluded environmental vulnerability research that merely focuses on the condition of natural environment and ecosystem.

2.2 Social vulnerability

The complexity of urban system—the variability of social relations and unique characteristics of community—makes it difficult to assess the level of exposure and sensitivity of people and places to flood risks. For this reason, the pressure and release (PAR) framework recognizes disaster as the intersection between socioeconomic pressure and physical exposure. The framework shares a viewpoint with a social constructivism which attempts to understand vulnerability as an attribute of social and ecological systems that are generated by multiple factors and processes such as political or economic marginalization that conditions the ability to respond to stress (Eriksen and Kelly 2007). In this framework, vulnerability is obtained from identifying unsafe conditions such as social fragility owing to economic weakness, marginality, and social segregation (Cardona 2003). Due to this reason, the approach of social sciences mainly focuses on people and their socioeconomic relationship to societies while emphasizing the value of equity, justice and human rights more than scientific reasoning. By placing the burden of explanation of vulnerability within the social system, disciplines of social science concentrate on the social dimension of vulnerability to explain why different communities can experience the same hazard event differently (Morrow 2008) and to suggest more effective flood mitigation strategies for socially vulnerable populations who are less likely to have access to resources during disaster events (Yoon 2012).

In this study, we classified the second group as the research that mainly focuses on the social vulnerability of urban populations through the investigation on demographic characteristics, living conditions, health status and other abilities of individuals and communities to cope with flood risks. This study uses the term social vulnerability in a broad sense as the concept that includes the economic vulnerability because both dimensions of flood vulnerability are either difficult to be distinguished from one another or often addressed at the same time in urban context.

2.3 Institutional vulnerability

According to the access model, risk is associated with the ability of people to deal with the impact of the hazards they face in terms of what level of access they have to the resources needed for their livelihoods (Wisner et al. 2004). Its argument is based on the fact that when facing an equivalent hazard, the risk could be different depending upon the capacity to absorb the impact (Cardona 2003). For this reason, as a way to evaluate the coping capacity of each city, the institutional dimension of flood vulnerability has been researched

by disciplines such as urban studies, public administration and political science. In general, institutional vulnerability is defined as the exposure and vulnerability of individuals, communities or organizations to the uncontrollable adverse consequences of another organization's critical shortcomings (Parker and Tapsell 2009). As a mirror that reflects the stability, efficiency and responsiveness of government agencies and organizations, institutional vulnerability is now widely discussed in terms of communication, cooperation and collaboration across the system boundaries.

From an institutional vulnerability perspective, this study classifies the third group of articles as the research that mainly focuses on a mismatch between understanding, knowledge, economic costs and levels of trust in flood planning and policy. Addressing structural, organizational and systematic challenges to effective urban flood governance, these research studies give considerable emphasis on the practical lessons that can be learned from an inclusive public engagement and decision-making process. Distinguishing the notion of preparation from prediction, this study uses the concept of institutional vulnerability as the coping capacity of urban systems to respond to both external flood risks and internal sociopolitical conflicts between various stakeholders at individual, group and organizational levels.

By setting up the conceptual and methodological boundaries of each dimension of flood vulnerability, this review study attempted to minimize the mistake due to subjective interpretation in analyzing and categorizing articles. However, multi-dimensional aspects of urban flood vulnerability are sometimes difficult to be clearly classified because the definition of vulnerability is still evolving with our understanding of flood risks and its impacts, and many disciplines use different kinds of criteria and methodologies to assess vulnerability in practice (Fig. 1).

3 Data analysis

We first collected peer-reviewed journal articles published from January 2006 to December 2016 via the Web of Science database service. For the last 10-year period, we initially identified 471 articles using search topics of “urban” and “flood” and “vulnerability.” We limited our analysis to the articles published in the recent 10 years because we were interested in analyzing the rapidly changing methodologies and approaches in the last decade since Adger (2006)—one of the most widely used and arguably the foremost research work on vulnerability. Although we limited the spatial scope of research to urban or peri-urban area, we considered both natural and climate change-induced flood risks and did not make an analytical distinction among different criteria of flood risk assessment—flood prevention, reduction, mitigation and resilience enhancement. In this study, we only considered the articles that are written in English and excluded other types of data such as book reviews and book chapters. This process reduced the number of articles to 345. At the second stage, we reviewed each collected article one by one and excluded some articles with no relevance to the topic. As a result, a total of 318 articles met these criteria and were included in this study. We compiled them in Microsoft Excel 2010 with the information of article titles, author names, journal names, years published, research areas and author-identified keywords. The collected data were transferred into *Sci2* and *Gephi* to perform various types of bibliometric analysis. Our approach may have limited number of articles as we primarily focused on the Web of Science indexed journals only (Table 1).

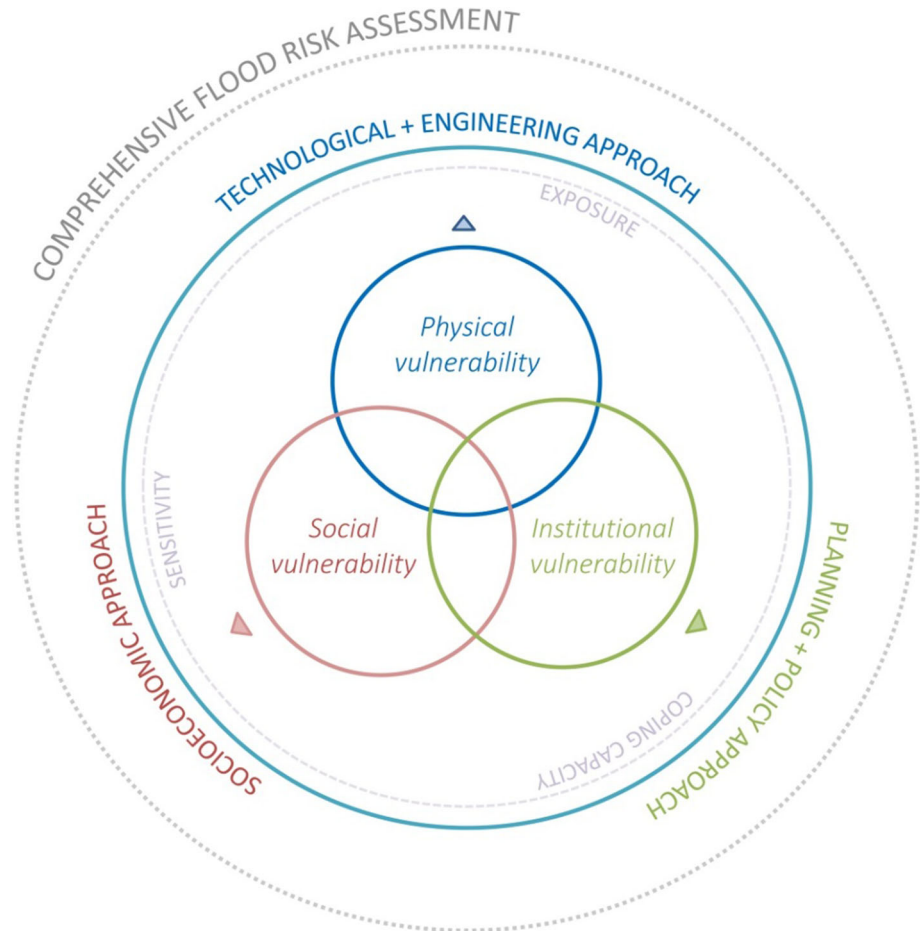


Fig. 1 The different dimensions of flood vulnerability and flood risk assessment approaches

The number of research related to urban flood vulnerability has been constantly increasing for the last decade (Fig. 2). Out of a total of 118 journals included in this dataset, three most represented journals were *Natural Hazards* (12.9%), *Natural Hazards and Earth System Sciences* (8.2%) and *Environment and Urbanization* (4.7%). It is important to note that although its selection is highly respected and thus useful for bibliometric analysis, the Web of Science does not include all journals and its coverage in certain fields is less complete than in others. After removing duplicates, a total of 839

Table 1 Descriptive statistics

Total selected articles	318
Years articles published	Jan 2006–Dec 2016
Number of journals included	118
Number of research areas	34
Number of author-identified keywords	839

keywords were identified out of the initial 1477 author-identified keywords. In this study, singular and plural forms of keywords and synonyms such as flood, floods and flooding are counted as the same keyword (Table 2).

As shown in Fig. 3, physical vulnerability was the most popular research concern (45.6%), followed by institutional vulnerability (15.1%) and social vulnerability (5.7%). Physical vulnerability was discussed most in Water Resources (22%)—an interdisciplinary discipline that encompasses from applied sciences to social sciences, while institutional vulnerability and social vulnerability were addressed most in Environmental Science and Ecology (26.5%) and Meteorology and Atmospheric Sciences (26.3%), respectively. More than one-third of total research articles discussed the multi-dimensions of flood vulnerability, and the combination of physical and social vulnerability was the first with 12.6%, and the combination of all three dimensions of vulnerability was the second with 8.8%. Based on these results, we observed that nearly half of the selected articles were focused on the physical dimension of flood vulnerability from the applied science perspective, and the research area was limited to Water Resources (18.5%), Environmental Science and Ecology (18.2%) and Geology (15.9%).

Meanwhile, we also noticed that the planning and policy approach focusing on institutional vulnerability has the potential to link physical and social dimensions of flood vulnerability leading the collaboration between disciplines of applied science and social science. Most of institutional vulnerability research reviewed in this study mainly discussed about collaborative flood governance as a way to enhance urban resilience and as an opportunity to advance interdisciplinary understanding of urban floods as not only a natural phenomenon but as a problem shaped by social conditions, policies and decision (e.g., Brown et al. 2012; Thaler 2014; Baubion 2015).

4 Major themes of flood assessment research

Before we start to review research topics and methods of selected articles, we conducted frequency analysis of author-identified keywords as an initial step to compare conceptual and terminological structure of each approach (Table 3). As expected, general keywords such as floods, vulnerability and climate change were identified as the most frequent author-identified keywords in the whole article dataset. Meanwhile, although the total number of author-identified keywords was not sufficient to reflect differentiated

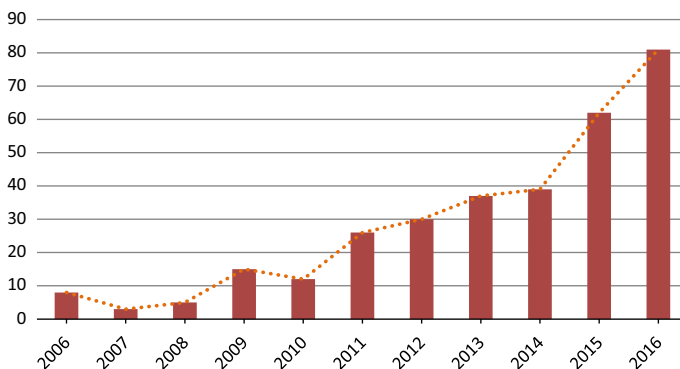


Fig. 2 The number of articles published between 2006 and 2016

Table 2 Name of journals containing the highest number of published articles in the topic of urban flood vulnerability

Journal title	No. of articles
Natural hazards	41
Natural hazards and earth system sciences	26
Environment and urbanization	15
Applied geography	11
Climatic change	9
International journal of disaster risk reduction	9

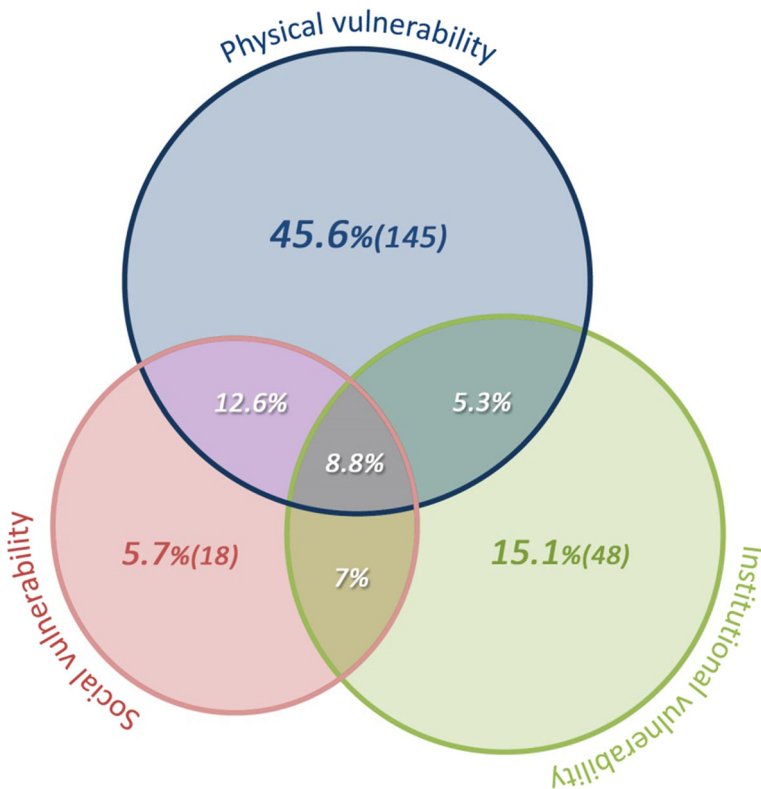


Fig. 3 The percentage of research articles on physical, social and institutional flood vulnerability

characteristics of each approach, the results showed some conspicuous distinctions among the three approaches. As shown in Fig. 4, author-identified keywords such as geographic information system (GIS), analytic hierarchy process (AHP) and sea-level rise were frequently used mainly in the technological and engineering approach, while health, evacuation and gender were newly appeared in the socioeconomic approach. In the planning and policy approach, the administrative and institutional meaning of keywords such as urban resilience, governance, spatial planning and institution was observed in the 10 most frequent author-identified keywords. Based on the results, we assume that the classification of flood risk assessment approaches used in this study is theoretically appropriate and also

Table 3 The frequency analysis results of author-identified keywords

Keywords	Count
<i>All articles</i>	
Urban floods/floods	68
Vulnerability	64
Climate change	36
Flood risk/risk	33
Adaptation	25
Natural hazards/hazard	24
Urban resilience/resilience	24
Geographic information system	23
Sea-level rise	14
Urbanization	11
<i>Physical vulnerability</i>	
Urban floods/floods	25
Vulnerability	25
Geographic information system	19
Flood risk/risk	15
Climate change	14
Natural hazards/hazard	11
Sea-level rise	7
Analytic hierarchy process	6
Risk assessment	6
Urbanization	6
<i>Social vulnerability</i>	
Urban floods/floods	5
Health*	3
Vulnerability	3
Vulnerability/hazard assessment	3
Disaster	2
Evacuation	2
Gender	2
Impact	2
Natural hazards/hazard	2
Urban resilience/resilience	2
<i>Institutional vulnerability</i>	
Urban floods/floods	12
Urban resilience/resilience	11
Adaptation	9
Climate change	8
Flood risk/risk management	6
Vulnerability	6
Governance	4
Spatial planning	4
Informal settlements	3
Institution	3

* indicates a wildcard to include associated terms in the search

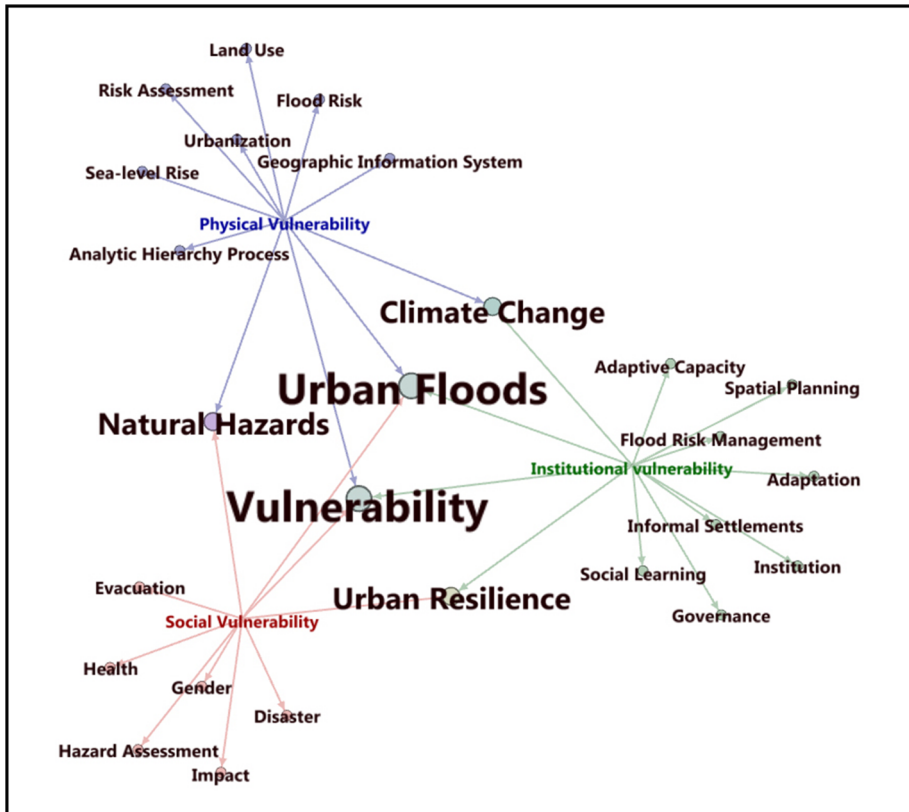


Fig. 4 The network map generated by *Sci2* and *Gephi*—the larger nodes represent higher frequency author-identified keywords

practically valid to explain various perspectives and methodologies across multiple disciplines focusing on urban flood vulnerability.

4.1 Technological and engineering approach

It is clear that the technological and engineering approach mainly uses hydraulic and hydrologic modeling—the computer simulation methods to help understand the frequency and impact of flood events (e.g., Apel et al. 2009; Huong and Pathirana 2013; Dasgupta et al. 2013; Acharya et al. 2013; Shih et al. 2014; Hlodversdottir et al. 2015; Zope et al. 2015). In this approach, various kinds of modeling are widely considered according to the type of flood causes and the climatic and geographic conditions of local environment.

One of the most visible trends of the technological and engineering approach is increasing research interests on coastal floods due to the sea-level rise (e.g., Paris-Barbosa et al. 2006; Dwarakish et al. 2009; Youssef et al. 2009; Hereher 2010; De la Torre et al. 2013; Murali and Kumar 2015; Guisado–Pintado et al. 2016). Even within the topic of coastal floods, analytical and methodological issues vary from the evaluation of coastal vulnerability to the application of effective protection measures. For example, while

Dwarakish et al. (2009) assessed physical and geologic vulnerability of the west coast of India through the indicators-based approach, Youssef et al. (2009) focused on the applicability of geomorphological hazard mapping for the Egyptian Red Sea coast using GIS, and De la Torre et al. (2013) discussed enhancing the regional knowledge on coastal floods through a monitoring network program in the Gulf of Lion, France. Another recognizable research trend is a growing attention to the estimation of potential flood damage cost and benefits of proposed flood adaptation alternatives. For example, Fedeski and Gwilliam (2009) and Neubert et al. (2016) introduced a GIS-based flood risk assessment methodology for estimating the cost of building damage in UK and Germany, respectively. Moreover, Zhou et al. (2012), Molinari et al. (2013), Lasage et al. (2014) explored the possibility of cost–benefit analysis as a tool for rational decision-making in Denmark, Italy and Ho Chi Minh City, respectively.

We identified that recent research articles consider floods as both natural and anthropogenic hazards due to urbanization and land development. In practice, the majority of research articles in the technological and engineering approach utilize GIS techniques to link hydraulic and hydrologic information to land cover and land use change (e.g., Chang et al. 2009; Luino et al. 2012; Liu et al. 2014; Tripathi et al. 2014; Murali and Kumar 2015). This shows the potential benefit of the technological and engineering approach as a rational standard of decision-making on further urban development in connection with the planning and policy approach. In terms of connecting technological and engineering knowledge to the process of decision-making, many recent articles now pay attention to the integration of models for more thorough and accurate flood risk assessment (e.g., Zope et al. 2015). Moreover, various types of decision support tools, such as multi-criteria analysis (e.g., Mukhopadhyay et al. 2016; Torresan et al. 2016), analytical hierarchy process (AHP) (e.g., Stefanidis and Stathis 2013; Ouma and Tateishi 2014) and fuzzy planning support system (e.g., Radmehr and Araghinejad 2015) have been also widely researched for flood policy and project appraisal.

4.2 Socioeconomic approach

Socially created vulnerabilities have been largely ignored in the hazards and disaster literature mainly due to the difficulty in quantifying them (Cutter 2006). Because social vulnerability can be considered as the interaction of social and place inequalities (Cutter et al. 2003), the level of social vulnerability is difficult to be assessed without deep understanding of local socio-ecological characteristics. As shown in Fig. 3, social vulnerability research has the lowest amount out of the total selected articles; however, the percentage increases from 5.7 to 21.5% when this category is combined with research on institutional vulnerability. In fact, we found that a lot of social vulnerability issues were discussed and evaluated in connection to the institutional dimension in order to find possible policy options and solutions. Meanwhile, it is noticeable that most research in the socioeconomic approach focuses on the internal social receptivity to flood risks reduction, while research in the technological and engineering approach mainly concerns the external natural factors of flood hazards and their physical impacts on urban environment.

As one of the most frequent topics, the socioeconomic approach and its combination with the planning and policy approach are concerned with economically disadvantaged and socially marginalized groups in the city. For instance, Douglas et al. (2008), Jabeen et al. (2010) and Adelekan (2010) discussed perceptions and coping strategies of the urban poor in Africa and Bangladesh, and Taş et al. (2013) and Castro et al. (2015) addressed the

spatial and temporal issues of flood vulnerability in informal settlements in Turkey and Chile, respectively. Moreover, Ajibade et al. (2013) investigated flood vulnerability among women in Lagos, Nigeria, while Oven et al. (2012) looked at the aged people in UK in terms of flood hazards and their health care. Some articles were also concerned with flood-induced health risks in the extent of relationship between urban poverty and burden of disease (e.g., Kovats and Akhtar 2008; Abbas and Routray 2014; Scovronick et al. 2015).

From the perspective of environmental justice, these articles share the view that urban population may have different capacity to prepare for, respond to and recover from flood risks and attempt to understand how various dimensions of flood vulnerability are inter-related to each other in the city. Accordingly, the socioeconomic approach is valuable to understand not only group differences but also how those groups experience and perceive flood disasters differently depending on the social infrastructure and living conditions they are confronted with. Again, this explains the tendency of the socioeconomic approach to be integrated into the planning and policy approach which mainly focuses on policy efforts and institutional mechanisms to reduce social and place inequalities in urban communities.

4.3 Planning and policy approach

Nevertheless, it is still important to understand institutional vulnerability separately from social vulnerability because once social problems are perceived and publicized, the process of envisioning and providing possible solutions is conducted in different sociopolitical domains. From this point of view, Innes and Booher (2010) emphasized that collaborative process of decision-making brings a diversity of private and public stakeholders together in a consensus-oriented forum. In the planning and policy approach, many articles recognize the practice of collaborative decision-making as the process of shared learning and cooperation and attempt to understand multiple sociopolitical interactions through the lens of governance—the institutional response to collective problems. For example, Fatti and Patel (2013) investigated residents' perceptions on local government's ability and asserted the necessity of maintaining a co-operative connection between the community and municipality in South Africa. Moreover, Head (2014) pointed out the importance of policy learning for the collaborative governance in Australia, and Drivdal (2016) emphasized community-scale adaptation and successful community leadership for external connections and internal consolidation in South Africa. Focusing on the tensions between media discourses in Mexico, Rinne and Nygren (2016) addressed the shift of urban flood governance from technological control to social resilience underlining the new emerging discursive perspective on flood resilience as a social justice and human rights issue. In a similar context, Evers et al. (2012) suggested the collaborative modeling framework for stakeholder involvement through the case studies of Germany and UK, and Musungu et al. (2016) examined the possibility of governance as the process of knowledge production through the collaboration between various actors such as researchers, residents, community leaders, NGOs and government officials in Cape Town, South Africa.

Consequently, we found that the majority of research articles focusing on institutional vulnerability emphasize public participation and cooperation in flood planning and policy in order to increase the level of preparedness and resilience of the city. Flood governance in this respect allows society to share the process of problem-solving across disciplines and different knowledge systems promoting the transformation of traditional hierarchical forms of government.

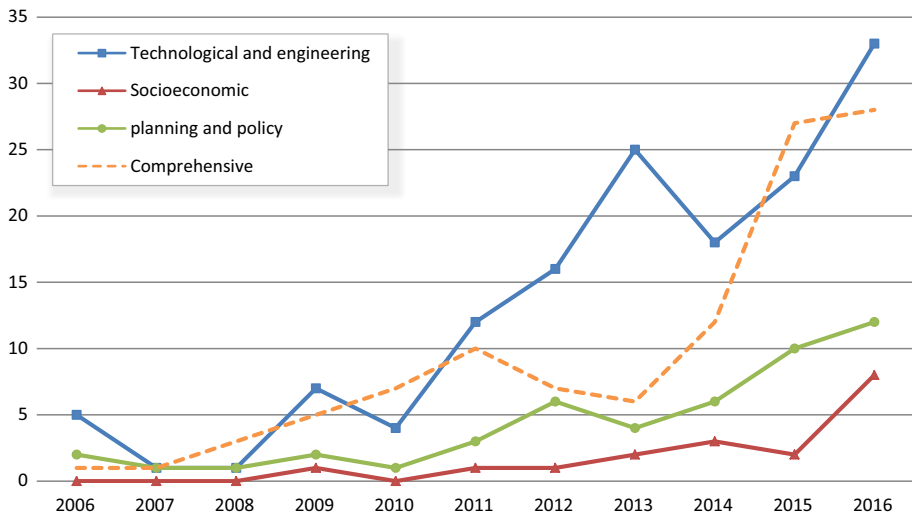


Fig. 5 The trend of research approaches to flood risk assessment

4.4 Comprehensive approach

As shown in Fig. 5, the use of the comprehensive approach to flood risk assessment has substantially increased since 2014. Recent extreme hydrologic events require the comprehensive awareness of both circular system of nature and human society. In the age of natural disaster, the comprehensive approach to flood risk assessment thus becomes important not only to develop techniques and tools for the evaluation of nature's intrinsic value, but also to forecast urban environmental changes by observing and analyzing social and institutional phenomena. From this point of view, Vojinovic et al. (2016) suggested the holistic approach based on both quantitative modeling data and qualitative data acquired through interviews and group discussions. Moreover, many other researchers explored the multi-dimensionality of flood vulnerability and examined the operational framework to comprehensively measure vulnerability and resilience through the multi-criteria indicator-based approach (e.g., Scheuer et al. 2011; Sudmeier et al. 2013; Kotzee and Reyers 2016).

5 Conclusions

In this study, we reviewed research articles on urban flood vulnerability over the last decade to examine the current research trend of urban flood risk assessment. By separating these articles into three categories based on their methodological approaches and research focus, this research attempted to explore the meaning and significance of comprehensive flood risk assessment. Increasing number of articles employ the comprehensive research approach to flood risk assessment, suggesting that there needs to be a new paradigm shift toward a more inclusive way to understand multi-dimensionality of flood vulnerability across disciplines and different knowledge systems. Within the last 10 years, this effort has expanded the scope of flood vulnerability research to the socioeconomic domain and enabled researchers to discuss various issues such as social justice, human rights and planning and policy dynamics. From a holistic perspective, urban society needs to be

understood and perceived as part of nature, and when setting an urban development plan, it is necessary to produce and share knowledge on urban environment through collaborative discussion, and comprehensively approach to the problem not only at the spatial level, but also at wider socioeconomic and institutional levels. The comprehensive flood risk assessment in this respect is expected to provide an opportunity for researchers of various disciplines, urban practitioners and decision makers to understand flood vulnerability in the diverse contexts of economic status, social characteristics and political power of people, groups and communities.

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