Hotspots and Frontiers of Urban Floods

Subjects: Health Care Sciences & Services

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Current research shows that the number of papers published in the field of urban flooding is generally increasing year by year, and the research focus has shifted from exploring hydrological processes to adopting advanced management measures to solve urban flooding problems.

urban floods | stormwater management | Hotspots | Frontiers

1. Introduction

The occurrence of urban floods is generally related to two main phenomena: the generation of runoff during precipitation events (flash flooding) and the overflow of watercourses (fluvial or overbank flooding) [1]. As for the reasons, on one hand, climate change increases the frequency and intensity of extreme weather, with more intermittent rainstorms, more severe droughts, and higher coastal storm surges [2][3], such as the rainstorms in Europe and northern China in July 2021. On the other hand, with the development of social productivity, the progress of science and technology, and the adjustment of industrial structure in a country or region, society has gradually transformed from a traditional rural one dominated by agriculture to a modern urban one dominated by non-agriculture such as industry (secondary) and service industry (tertiary). This caused the ongoing migration of people from rural areas to cities and the continuous increase of urban areas, and the urban phenomenon in the 21st century is much more extensive [4][5][6]. For example, China's urbanization rate increased from 10.64% in 1949 to 63.89% in 2020 (see National Bureau of Statistics of China http://www.stats.gov.cn/tjsj/ndsj/#, accessed on 8 March 2021). Urbanization greatly reduces the permeable area of the urban underlying surface, causing a lot of urban rainwater to flow onto the ground or into the artificial drainage system, instead of naturally being infiltrated into the ground and absorbed by the soil [7][8]. When the rainfall exceeds the capacity of the drainage system, especially in some areas with deterioration and insufficiency of the capacity of urban drainage infrastructure and lack of excellent urban planning strategies [9][10], stormwater has no way to go, but must stay on the ground to form urban waterlogging [11][12]. In addition, rapid urban expansion exacerbates the urban heat island effect [13], leading to the formation of hot air flows over the city, which accumulate and thicken, and eventually form precipitation. This is called the urban rain island effect, which further aggravates the urban flood problem.

Many countries in the world have conducted a series of explorations on the management of urban floods and their related problems, mainly urban drainage and water pollution [14][15][16]. For instance, the United States promulgated and revised the Clean Water Act, Water Quality Act, and Federal Water Control Act, and gradually proposed the best management practices (BMPs) to handle the problems of urban water pollution in the 1940s to 1980s [17][18][19]. In the late 1970s, an integrated urban drainage system (IUDS) was started in Switzerland to develop the urban

system [20]. Low impact development (LID) was gradually implemented in the 1990s [21], aiming at achieving "natural" hydrology, namely minimizing the impact on the environment when specialists develop and design systems, by use of site layout and integrated control measures [22]. LID is commonly adopted in New Zealand and North America. Sustainable urban drainage system (SUDS), most used in the UK, originated in the 1990s [23]. In 1992, water sensitive urban design (WSUD) was first proposed by Mouritz in Australia [24], and then was presented in a report for the Western Australian government to reduce the adverse effects of urban development on the surrounding hydrological environment [25]. The United States increasingly used the concept of green infrastructure (GI), emphasizing the comprehensive application of multiple disciplines in order to achieve multiple ecosystem benefits and further explore urban stormwater management after entering the 21st century [26][27][28][29]. Sponge city was firstly proposed in the "2012 Low Carbon Urban Development and Technology Forum", held in Shenzhen, China in April 2012 [30]. This means that a city, designed to act like a sponge, has good resilience in adapting to environmental changes and dealing with natural disasters caused by rainstorms [31].

A growing number of studies on urban floods monitoring and prediction models have been carried out. As the input of real-time simulation models, monitoring data are of great importance, which not only affect the accuracy of prediction, but also are a vital reference for issuing early warnings before disasters [32]. Khalid and Alias [33] generated a 3D city by model geospatial tools and databases to monitor flood risks. Based on the visual image, Dhaya [34] and Zhao [35] used a convolutional neural network and deep neural network algorithms to monitor urban floods, respectively. Besides, the urban hydrological process simulation should be close to the actual situation as much as possible to minimize the discrepancies between simulated and observed runoff, achieving accurate prediction or other goals [36]. Examples of factors to consider include digital elevation model [37], different urban surfaces [38][39], meteorology [40], and others (e.g., hydraulic structures, soil type, precipitation) [41][42][43]. A large number of researchers focus on the prediction of urban floods, part of which aims at improving the model accuracy. The methods often used are deep learning (e.g., long short-term memory, artificial or ensemble neural networks) [44][45][46], hydrodynamic model [47], and other new proposed models [43].

2. Current Reseach

2.1. Research Hotspots Analysis

Research hotspots refer to one or more core research topics in a specific research field [48], which represent the most important theoretical knowledge and technology application of researchers. Researchers can ascertain the mainstream research direction by grasping the research hotspots in the field of urban floods.

Keywords are the theme generalization of the paper. There are some associations among the keywords given in a paper, which can be expressed by the frequency of co-occurrence. It is generally believed that the more frequently two keywords appear in the same document, the closer the relationship between the two topics is. The co-word characteristics of keywords in literature can reflect the research hotspots, and the co-occurrence frequency determines the intensity of hotspots. Co-word analysis entails obtaining statistics on the frequency of a group of words in the same groups of literature and measuring the degree of closeness by the number of co-occurrence

cases; a co-word network composed of these words can be formed by counting the frequency of subject words appearing in the same document. Researchers can analyze the topics of the research field directly through the results of the co-word analysis [49].

2.1.1. Keywords Co-Occurrence Analysis

The keyword density map and clustering map were generated by VOSviewer whose co-occurrence frequency was set more than 20 times, based on the literature from 2006 to 2020. In the keyword density map in **Figure 7**, the color blue means low density, while yellow means high density. The deeper the yellow, the higher the density; that is, the higher the co-occurrence frequency. **Table 2** shows the occurrence frequency and total link strength of the top 20 keywords. We can see that the research hotspots mainly focus on urban flood, urban stormwater, runoff, and climate change from the density map, whose co-occurrence times are 541, 469, 424, and 386, respectively, representing that the research of ontology theory and technology in urban floods is the most popular. Compared with “urban flood” and “urban stormwater”, although the frequency of other hot words, such as “climate change”, “management”, “urbanization”, and “model” is relatively high, there is still a gap compared with the former. This may be related to the research topic of this study, and “urban flood” is directly included in the retrieval formula, as well as “urban stormwater”. It is noteworthy that the keyword “management” has the highest centrality, surpassing the keyword “urban flood”, which ranks first in frequency.

In the keyword clustering map, different colors represent different clusters. The larger the nodes on the map, the more times keywords appear, indicating that their contribution to the urban floods field is greater. Closely related nodes are connected by lines, and the greater the link strength is, the stronger the internal relationship is. The node group is composed of many nodes.

As can be seen from **Figure 1**b, the clustering network is a complex co-occurrence relation, from which researchers detected seven main clusters that reflect the knowledge base for urban floods research. The red cluster, including one of the keywords as a retrieval theme, namely “urban flood”, formed the largest cluster and contained the most cited publications. In this cluster, models are used by researchers for numerical simulation on the issues of runoff. Besides, the hazards and risks of urban floods are also studied. The green cluster represented by “urban stormwater” and the purple one by “heavy metal” tend to focus on the pollution of urban stormwater. The keywords involved in these two clusters include “pollution”, “phosphorus”, “bioretention”, “pollutant removal”, “sediment”, “nitrogen removal”, and “Escherichia coli”. The yellow cluster reveals the research based on climate change and urban stormwater management in the urban floods field. On the one hand, with the change of global climate, cities’ vulnerability and resilience are studied [50][51]; on the other hand, a portion of researchers, with thoughts of the system, focus on urban stormwater management around green infrastructure and put forward policy suggestions from the perspective of the government. Climate change and urbanization are generally regarded as the two main causes of urban floods [52][53][54]. Aside from the climate change focus in the yellow cluster, other researchers emphasized urbanization and its impact, as in the dark blue cluster.

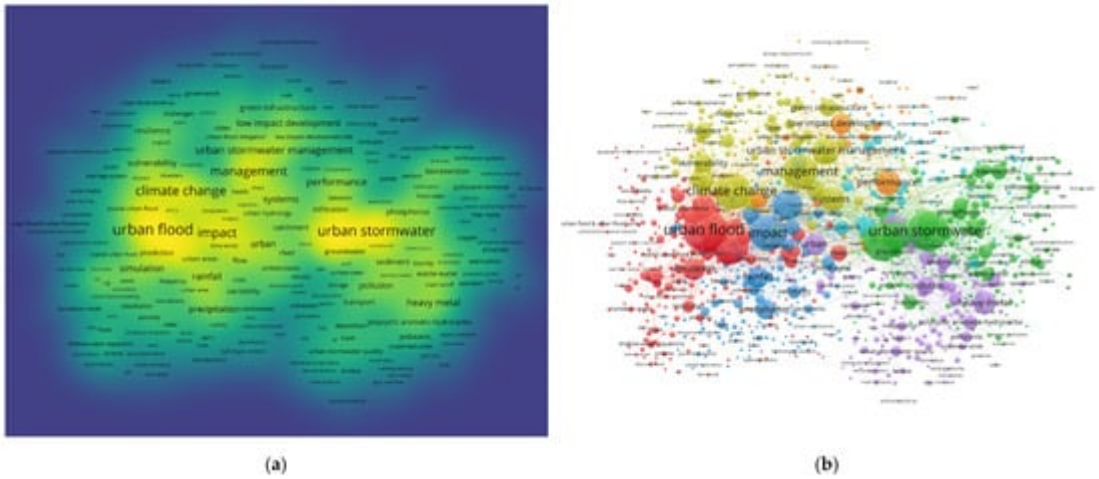


Figure 1. Density and clustering map of co-occurrence keywords in the urban floods field: (**a**) the keyword density map; (**b**) the keyword clustering map.

Table 2. The occurrence frequency and total link strength of the top 20 keywords.

Keyword	Occurrences	Total Link Strength	Keyword	Occurrences	Total Link Strength
urban flood	541	2124	performance	209	1351
urban stormwater	469	2459	quality	200	1156
runoff	424	2477	systems	192	1085
climate change	386	2059	risk	181	846
model	375	1726	heavy metal	177	966
impact	274	1983	urban	164	776
management	351	1917	simulation	164	829
urbanization	271	1573	low impact development	150	986
water	263	1361	rainfall	149	701
urban stormwater management	225	1236	precipitation	139	559

2.1.2. Co-Citation Analysis of Literature

Co-citation of references refers to the phenomenon in which two or more references are cited by the same document. The analysis of literature co-citation in CiteSpace reveals the theoretical knowledge foundation of relevant research by analyzing the high frequency of co-citation literature and the knowledge structure of a research field is revealed by analyzing the key nodes and clusters in the co-citation network [55]. The schematic of literature co-citation was obtained as shown in **Figure 2**. The nodes represent the cited literature, whose sizes

denote the citation frequency. The color of the nodes depicts the citation time corresponding with the time bar above, and the labels on the nodes are the first author and publication year of the article.



Figure 2. Co-citation network of references.

The co-citation network in the urban floods field was composed of 978 nodes and 2725 connections. Fifteen key articles with important academic influence, corresponding to the largest 15 nodes in **Figure 2**, were selected in this study. As can be seen, only one article was published earlier than 2010, and had no direct connection with the other 14 articles, while the connection between the latter was very strong. Among the 15 articles, there were 9 reviews or summaries, indicating that reviews are relatively more often cited due to their nature in all article types.

Fletcher Tim et al. published “SUDS, LID, BMPs, WSUD and more—The evolution and application of terminology surrounding urban drainage” in *Urban Water Journal* in 2015, which ranks first in citation frequency [56]. As of 8 March 2021, this article has been co-cited 88 times. In this article, the history, application, and underlying principles of terms used in urban drainage were documented, such as low impact development (LID), water sensitive urban design (WSUD), and best management practices (BMPs), making it a summary classic. What ranks second is a review, named “Urban flood impact assessment: A state-of-the-art review”, published in 2015 by Hammond MJ et

al., revealing the tangible and intangible damage of urban floods [57]. Burns Matthew et al. [58] systematically discussed the hydrologic shortcomings of conventional urban stormwater management by contrasting the hydrologic effects of two conventional approaches, namely drainage-efficiency-focused and pollutant-load-reduction-focused, and proposed a new approach, ranking third. Teng J. et al. [59] summarized the advantages and limitations of the flood inundation model. The article entitled “Performance and implementation of low impact development—A review” was published by Eckart Kyle et al. in *Science of the Total Environment* in 2017 [60]. This article provides a summary of the knowledge of low impact development (LID), as well as the current state of research. Palla Anna and Ilaria Gnecco [61] used a hydrologic model to confirm the effectiveness of LID solutions in several scenarios. Qin Huapeng et al. [62] analyzed the effects of three LID techniques, namely swales, permeable pavements, and green roofs, by simulation experiment. In 2013, the state of art regarding stormwater management was summarized by Fletcher Tim et al. [63], whose cited position ranks tenth, making it the only article that ranks not only in the top 10 of the total number of citations, but also in the top of co-cited articles. Ahiablame Laurent et al. [64] discussed and evaluated the effectiveness of low impact development practices by field and laboratory studies. In addition, Hunter et al. [65] compared the ability of six two-dimensional (2D) hydraulic models to simulate surface flows in a densely urbanized area through the simulation of a happened flood event.

2.2. Research Frontiers Analysis

The research frontier mainly discusses the emerging topics in a scientific field. It is a group of prominent concepts and potential research points. Many research frontiers may not only become research hotspots in the future under the tide of science and technology, but may also fade out of the research field after a short rise in a certain historical stage [66][67]. Therefore, timely identification of research frontiers in a specific field is bound to vigorously promote the development of this field. Research frontier, based on the latest academic work, refers to the collection of recently published and often cited literature in a scientific citation network from the perspective of scientometrics. Besides, concepts such as potential knowledge, emerging trends, and new research fields can also be classified as research frontiers.

In general, research frontiers represent the most advanced, innovative, and potentially important academic topics, which can be obtained from the highly cited collection of the latest literature in the scientific literature citation network. This study mainly analyzed the research frontier of the urban floods field according to the literature co-citation network relationship and drew the research frontier knowledge map of urban floods at the present stage through CiteSpace and VOSviewer, which can directly show the research frontier dynamics of the urban floods field evolving.

2.2.1. Overall Change Trend of Keywords

Research trend analysis is helpful to grasp the development of research and excavate the laws and driving forces behind the changes of research hotspots, providing direction for future research. The keywords are clustered and sorted according to time to obtain **Figure 3**.

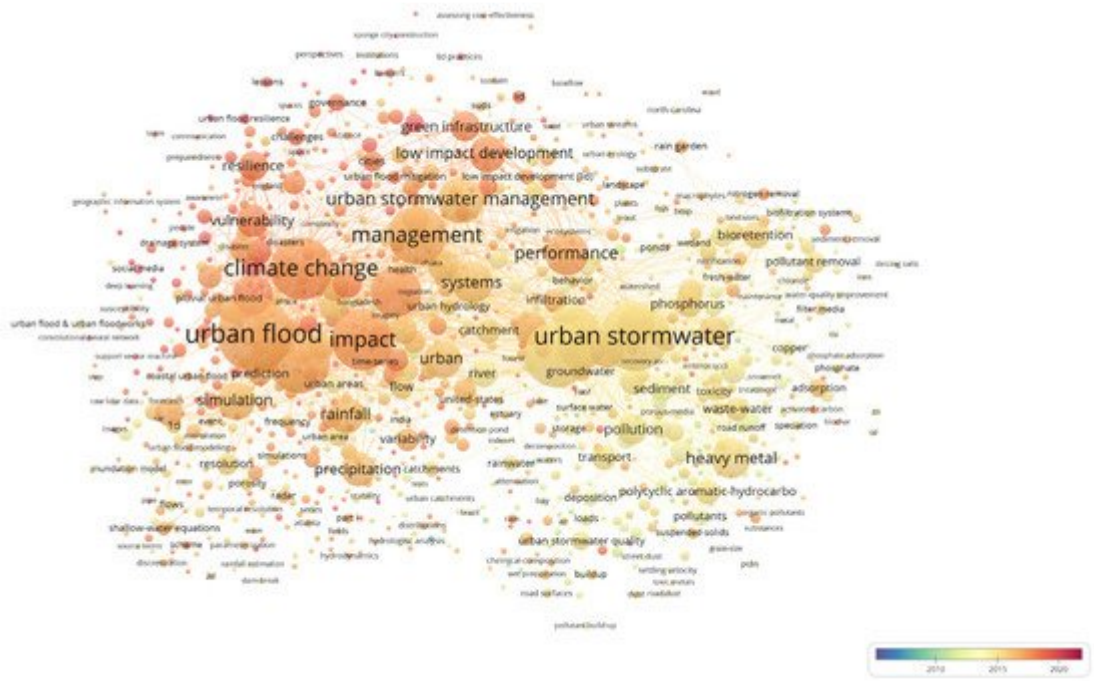


Figure 3. Overlay visualization of keywords in VOSviewer.

In this figure, it should be noted that the color of nodes is determined by the average time of each keyword year, and the bluer the node is, the earlier the research year is, while the redder the node, the more recent the research year. Researchers found that researchers paid more attention to the problem of urban floods pollution before 2015. Then, the methods of model and numerical simulation were used to research urban stormwater management, low impact development, and so on. The current studies mainly consider cities and urban vulnerability and resilience under the background of climate change and urbanization.

2.2.2. Timeline Graph Analysis

The timeline graph clearly shows the historical research results, trends, and internal relationships of each cluster unit [68][69]. The keywords timeline analysis of the documents from 2006 to 2021 on urban floods was carried out by CiteSpace, whose slicing time and clustering algorithm were set as one year and LLR, respectively; the keywords appearing more than 55 times in each period were extracted and clustered. As shown in **Figure 4**, the horizontal axis is the time span and the vertical axis is the clustering partition. The size of the arc in the graph represents the span time of the keywords, and the number of nodes represents the internal connection degree of each keyword. In CiteSpace, different settings lead to different clustering results. Under the above settings, 48 clusters are generated. This study analyzed the first 12 clusters in order to receive acquaintance with the evolution laws of the keywords on the time axis.



Figure 4. A timeline view of keywords in CiteSpace.

The clusters with the longest duration are “urban flood”, “urban stormwater”, “urban stormwater management”, “particulate matters”, and “urban hydrology”, which existed throughout the whole study period. In addition, “best management practices”, “probability distribution”, and “diffuse pollution” existed only in the early stage of the study period, while the study of “groundwater” continued until the middle of the study period. The cross and time span between the clusters of “urban flood” and “urban stormwater” are the largest, which indicates that the relationship between them is the closest because they are the names that have been chosen for the overall field of research. In the cluster of “urban flood”, there is the largest number of bursting keywords.

2.2.3. Time Zone Chart Analysis of Keywords

The time zone graph reflects the evolution of knowledge based on the transmission relationship of research hotspots expressed by two-dimensional time location and links [70][71]. **Figure 5** shows the time zone graph of keywords by frequency, from which researchers can find that most of the research topics in the field of urban floods, such as urban stormwater management, water quality, runoff, and so on, were carried out from 2006 to 2008. There was almost no major research hotspot in the field of urban floods research in the later stage. However, some new research focuses still exist from the relatively micro perspective. For example, urban floods risk was studied in 2011 and low impact development (LID) was adopted by a large number of scholars for research around 2014, while in 2018, the resilience of urban floods and cities became the research hotspot.

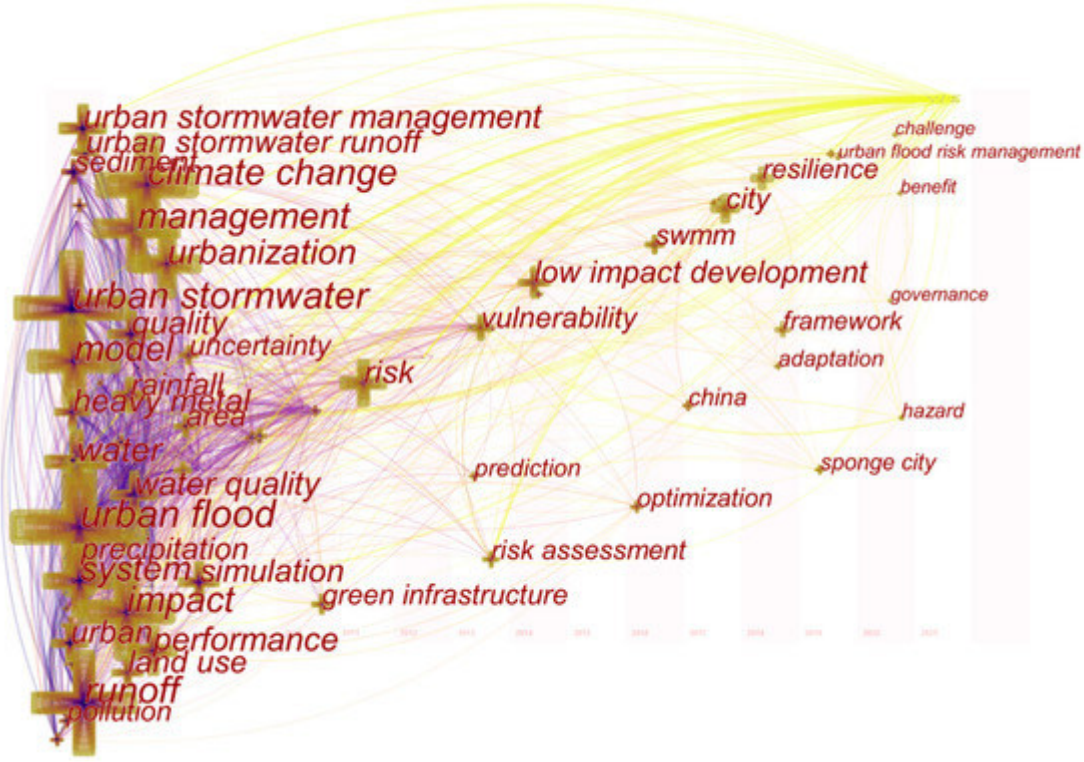


Figure 5. The evolution of subjects in the field of urban floods.

2.3. Comparative Analysis of Keywords Density Map

Researchers divided the research on the urban floods field into two stages according to the number of papers published each year. The first stage refers to the period from 2006 to 2015 and the second stage from 2016 to the present. Combined with the stage divisions, this study analyzed the changes of research hotspots in five years, that is, the first part referred to 2006–2010, the second to 2011–2015, and the third to 2016–2021. Finally, all published literature in the past three years was clustered by year, and the changes of research hotspots in each year were analyzed.

2.3.1. Comparison of Three Time Stages

The co-occurrence frequency of keywords was set to 5 times and the keywords hotspot maps of 2006–2010, 2011–2015, and 2016–2021, respectively, were obtained from VOSviewer. In **Figure 6**, the yellow areas indicate the research hotspots, and the more yellow the area is, the higher the co-occurrence frequency of keywords is.

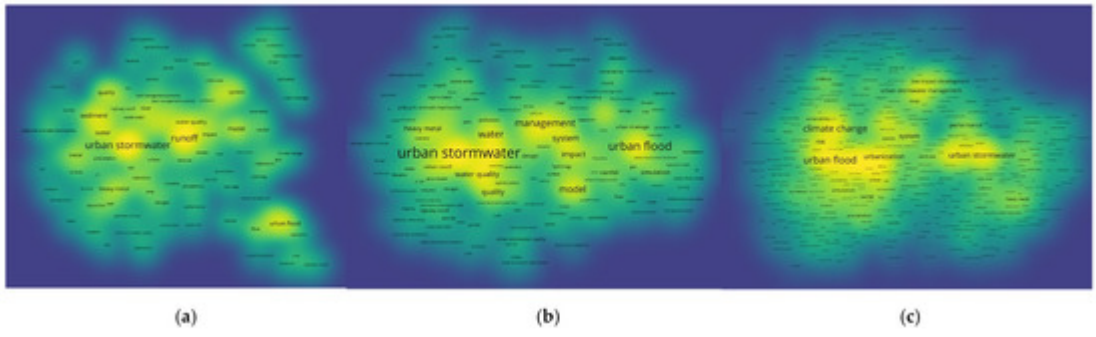


Figure 6. The density maps of the three stages' keywords: (**a**) 2006–2010; (**b**) 2011–2015; (**c**) 2016–present.

It can be seen from **Figure 6**, from the perspective of the number of keywords, the total number of articles published from 2006 to 2010 is the least; correspondingly, the number of keywords is the least, and the total frequency of 5 times or more is 109. The total number of published papers is the highest in 2016–2021, namely 723. From the perspective of research hotspots, the overall high-density areas in **Figure 6**a are relatively small, as well as scattered, indicating that the research focus in the early research stage of the urban floods field is low and the correlation between hot spots is not so strong compared to the latter. The number of research hotspots increased and the concentration became stronger in **Figure 6**b. In **Figure 6**c, the research focuses are further concentrated, which is shown in the expansion of yellow areas in the figure, and different yellow areas begin to overlap to form a new bigger yellow area. This is because more and more scholars have joined in the research of the urban floods field over time, and the number of published articles gradually increased, leading to the rise of keyword co-occurrence frequency.

From the perspective of research content, the research mainly focused on "urban stormwater" and "runoff" from 2006 to 2010, and the latter covered a wide range, including "urban runoff", "road runoff", "urban stormwater runoff", etc. At the same time, water quality attracted a lot of attention, such as the keywords "sediment", "water quality", "waste water", etc. From 2011 to 2015, in addition to the research topic "urban storm water" and "urban flood", the importance of management began to attract attention. Scholars used more models for simulation research, and the pollution of urban stormwater was still a hot topic, such as the keywords "pollution", "heavy metal", and "water quality". Between 2016 and 2021, the second stage of the research on the whole urban floods field, researchers found that the frequency of the keywords "climate change" and "urbanization" rose rapidly, becoming prevalent in this research period, representing that researchers in the field of urban floods had been paying more and more attention to global climate change and urbanization. Moreover, "urban stormwater management" and "low impact development" have become new research hotspots. In addition, the rapid development of "resilience" and "vulnerability" is also noteworthy.

2.3.2. Comparison of the Last Three Years

The top 10 keywords of co-occurrence frequency in 2019–2021 (as of 15 June 2021, the same applies to 2021 mentioned below) are similar to those in 2016–2021. **Figure 7** shows that the top four keywords in 2019, 2020, and 2021 are all "urban flood", "climate change", "model", and "impact", while "urbanization" is likely to occupy the fifth place for a long time. Although the research on runoff is not as prevalent as that in the previous 10 years, there are still a large number of scholars studying it, which was indicated by the fact that the frequency of the keyword "runoff" in the past three years was 8, 10, and 7, respectively. Significantly, "Management", which has been extensively studied from 2011 to 2015, still had a place in the recent three years, ranking 7, 6, and 12, respectively, in 2019, 2020, and 2021. It is worth noting that the published articles in 2021 show that the research popularity of "land use" and "SWMM (stormwater management model)" has increased sharply.

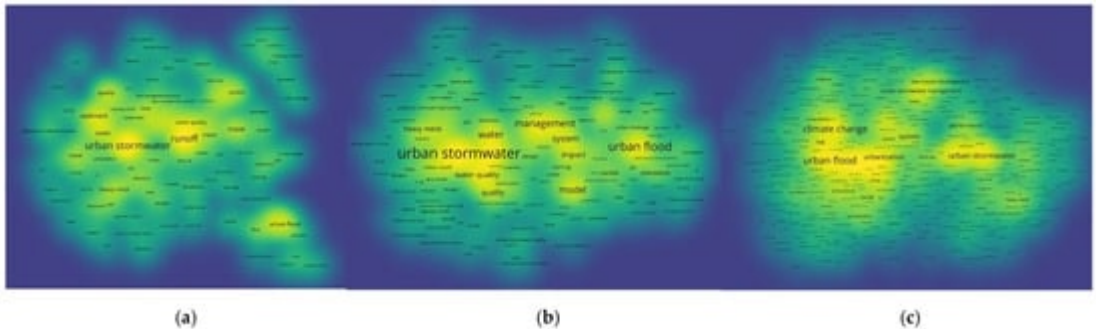


Figure 7. The density maps of the three stages' keywords: (**a**) 2006–2010; (**b**) 2011–2015; (**c**) 2016–present.

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