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A Bibliometric and Visual Analysis of Global Urban Resilience Research in 2011–2020: Development and Hotspots

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Abstract: Urban resilience (UR), which promotes the implementation of resilient cities, has received widespread attention. The purpose of this study is to visualize the knowledge background, research status, and knowledge structure of relevant literatures by using a Citespace based scientometrics survey. The results show that UR is an increasingly popular topic, with 2629 articles published during the study period. (1) The most prolific publications and journals involved in the flourishment of UR research were identified by co-citation. The United States was the most productive contributor, with numerous publications and active institutions. *Journal of Cleaner Production*, *Sustainability*, *International Journal of Disaster Risk Reduction* were the three most cited journals. (2) Co-occurrence analysis was employed to determine the highly productive keywords, and subject categories in the UR domain, including "environmental science & ecology", "environmental sciences, "science & technology", "environmental studies", "green & sustainable science & technology", and "water resources". (3) The diversity of highly cited authors in different countries and regions confirmed the evolution of UR studies. (4) Furthermore, the classification of UR knowledge was performed in the form of clusters and knowledge structure to achieve ten distinct sub-domains (e.g., Urban floods and stormwater management, Urban ecosystem services, Urban landscapes, and Trauma). This study provides an overview of UR research and research topics so that future researchers can identify their research topics and partners.

Keywords: urban resilience; bibliometric analysis; knowledge map; research trend

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Citation: Guo, P.; Li, Q.; Guo, H.; Li, H.; Yang, L. A Bibliometric and Visual Analysis of Global Urban Resilience Research in 2011–2020: Development and Hotspots. *Sustainability* **2022**, *14*, 229. https://doi.org/10.3390/su14010229

Academic Editors: Yuantian Sun, Kui Wu, Bo Hu and Baojie He

Received: 28 October 2021
Accepted: 21 December 2021
Published: 27 December 2021

1. Introduction

Cities, serving as the centers of social and economic life, play an important role throughout the world. Frequent natural and man-made disasters seriously threaten the stability of urban systems. These shocks are highly uncertain, but they are the embodiment of the objective laws of social and natural development and cannot be completely avoided [1]. Due to the increasingly dense urban space and population distribution, coupled with the lack of political efforts in infrastructure and services, the positive process of urbanization is difficult to be continuously guided [2]. Therefore, the uncertainties and unknown risks faced by contemporary urban development are unprecedentedly complex, and their potential impacts and catastrophic consequences have become more significant. In the face of these shocks and disturbances, different urban systems have responded differently. Improving the ability of urban adaptation, disaster resistance, and recovery has become an important topic in the field of urban development. Resilience, as a new research paradigm of urban safety, has been widely studied by scholars.

Urban resilience (UR) is a relatively new but popular multidisciplinary concept in the field of urban research. In the late 1990s, scholars first applied resilience to complex urban ecosystems, primarily to address urban issues, e.g., climate change [3] and urban disasters [4], with an emphasis on prevention and mitigation actions. At present, the general definition of UR in academic circles refers to the ability of urban systems and regions to realise the normal operation of public security, social order, and economic construction through reasonable preparation, buffer, and response to uncertain disturbance [5]. Godschalk and David (2003) believe that resilient cities should be a combination of sustainable physical systems and human communities, and the planning of physical systems should function through the construction of human communities [6]. In contrast, Cimellaro (2016) focuses on the power of human communities. He assessed the city performance of New Orleans in the United States after Hurricane Katrina and argued that UR essentially depended on a more resilient and resourceful citizen [7]. Jha et al. (2013) further discussed four main components of UR: infrastructural resilience, institutional resilience, economic resilience, and social resilience [8]. Meerow reviews the scholarly literature on UR and identifies six conceptual tensions fundamental to UR: definition of 'urban'; understanding of system equilibrium; positive vs. neutral (or negative) conceptualizations of resilience; mechanisms for system change; adaptation versus general adaptability; and timescale of action [9]. Gomes reviewed the scientific and technical literature about UR highlighting its definitions, dimensions, application areas, characteristics and challenges and opportunities to create a systematic approach and a clear view about UR for building and strengthening cities against new disturbances [10]. Elmqvist proposes a new conceptual framework that addresses the vague or narrow definitions of the concepts of UR in global and local policy processes, with a view to actively responding to the global sustainability of the urban century [11].

With the rapid rise of UR, there is also uncertainty about how to establish resilience and how to combine different practices and methods to implement resilience [12,13]. In fact, exploring definitions and meaning of UR has been one of the major discussions on urban resilience in the past decade. Which included the tension within the same UR definitions between robustness vs. transformational aspects [14]. Another major discussion point of UR is demolishing the assumption that resilience is a positive attribute of a system. Resilience being hyper explored by engineers and ecologists, and receiving skeptical feedback from planners (as the Social Ecological System thinkers—i.e., Folke [15], Elmqvist [16], Mc phearson [17], etc., from Resilience Alliance—introduced within their papers on ecosystems) because when applied to cities, resilience to something could imply negative consequences on others or other aspects of resilience (or resilience trade-offs), thus opening the floor to new research topics as climate justice, green gentrifications.

Although research on UR has made important progress in recent years, little attention has been paid to the knowledge mapping and evolution trend of UR research. Traditional literature research is limited by time and has certain limitations. It is difficult to comprehensively and accurately grasp the overall characteristics, frontier dynamics, and inherent evolutionary laws of scientific knowledge from massive data. For this shortcoming, scientometrics can provide important guidance.

Scientometrics are statistical and mathematical methods that can map the links between topics, publications, authors, and research institutions that may be overlooked in the existing literature. In the field of urban development research, bibliometrics has mapped emerging topics such as urban carrying capacity [18], urban sustainable development [19,20], smart cities [21,22], urban disaster risk [23] and urban environmental governance [24,25]. In this sense, scientometric research can provide useful information for UR research, and highlight possible interdisciplinary solutions.

In this study, with the assistance of CiteSpace, technologies such as co-citation, co-words, collaborative networks, and cluster analysis were used to conduct bibliometrics and visualisation analysis. Through the collected scientific atlas of 2629 document records, a complete picture of the structure and evolution of UR research from 2011 to 2020 was formed. This article aims to analyze influential journals, keywords, scholars and articles in UR field, and the results help researchers worldwide to better understand the knowledge map of the field and identify the frontiers of UR research. Based on this, the remainder of this paper is organised as follows. Section 2 introduces bibliometrics and describes the sources of the data. Section 3 presents the results of the bibliometrics. The core topics and important knowledge systems in the field are presented in Section 4. Section 5 summarises the study.

2. Methods and Data

2.1. Methods

Scientometric analysis is a technique that demonstrates the development process and structural relationships of disciplines based on the field of knowledge. It uses mathematical and statistical methods to quantitatively analyse specific fields. This study was completed using CiteSpace [26,27], an econometric analysis tool developed by Chaomei Chen, written in Java script, which is useful and well-adopted for visualisation of patterns and trends in scientific literature. It is mainly based on co-citation analysis and a path finder algorithm to measure literature in specific fields to determine the critical path and knowledge inflection point of discipline evolution [28]. By drawing a series of visual atlases, we can analyse the potential dynamic mechanism of discipline evolution and map the development frontier of the discipline.

2.2. Data Sources

The data sources used were taken from the Web of Science core database (WoS) [29,30]. The WoS database is a globally influential journal citation database, which has been widely used in bibliometric analysis. Compared with other databases, WoS search records are more consistent and standardised. This database includes all bibliographic information about their authors, citations, journals, and more information that can be used for analysis.

To accurately reflect the academic field of UR, a rigorous search process was formulated, as shown in Table 1. The search term was "Urban resilience" under the basic search category. The search field was limited to "Topic", and the document type was limited to article and review, thus, excluding proceedings paper, editorial material, and book review. The time span was set from 2011 to 2020, and the search was conducted on 20 November 2020. Excluding irrelevant items, a total of 2629 documents were retrieved as the original data for bibliometric analysis.

Table 1. Data retrieval program.

Retrieval Mode	Publication Type	Year	Retrieval Results	Retrieval Time
TS = ("urban resilience")	Article; review	2011–2020	2629	20 November 2020

Ultimately, 2629 source documents and 37,345 citations were collected. Among the 2629 source documents, journal articles accounted for 92.28% (2426), and review papers accounted for 7.72% (203). Figure 1 shows the total publications (TP), total citations (TC), and annual average citations (AAC) of 2629 source literature during the study period, which are correlated with the publication frequency shown in the bibliometric study conducted by Zhang et al. (2018) and Li et al. (2020) [31,32] . The proper use and full significance of the UR concept did not emerge in the field of urban development planning until 2015, thus, only a small part of UR literature was published between 2011 and 2014. Since then, UR has received significant attention from the academic community, with the number of published papers continuously increasing between 2015 and 2020. Especially in the years after 2018, there has been exponential growth. This is probably due to the increasing emphasis on UR in international and local policies issued since 2015, such as the New Urban Agenda [33], Paris Agreement [34], the United Nations Sustainable Development Goals [35], and the Disaster Risk Reduction Framework [36]. According to the fitting curve, the variation trend formula of the number of published UR research papers can be obtained, as shown in Formula (1).

$$y = 3.3211x^2 + 23.633x + 1 \quad (1)$$

$$R^2 = 0.9724$$

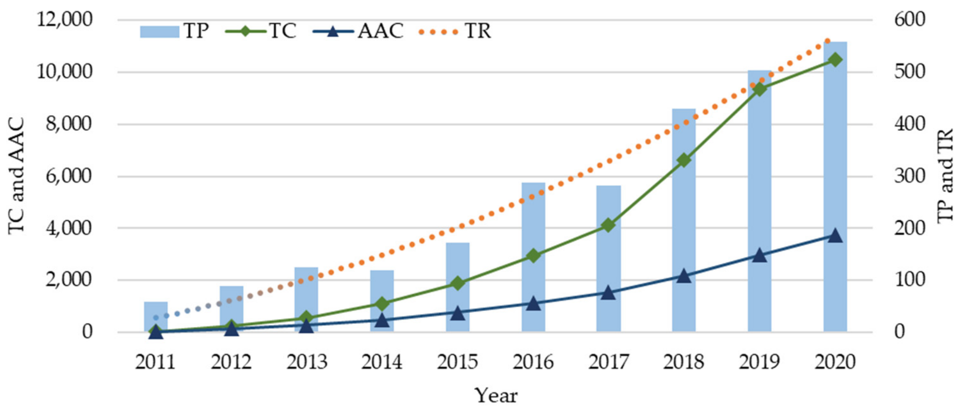

Figure 1. Statistics of publications and citations.

3. Results of Scientometric

This paper aims to explore and capture critical points and development paths during 2011–2020 through visual analysis. The first section below summarises the co-citation analysis based on WoS; the second section conducts co-word analysis to determine important subtopics based on UR research; the third section analyses the cooperative relationship between scholars and institutions engaged in research in this field; and the fourth section further explores research clusters and future research trends through cluster analysis.

3.1. Co-Citation Analysis

In the co-citation network, each node represents a research article, which is usually cited by a large number of researchers. When two references appear in one paper at the same time, there is a co-citation relationship. Co-citation frequency defines the similarities in cognitive proximity and content between the two papers. By analysing the indexed bibliographic records in the WoS database, the journal co-citation network and document co-citation network were generated.

3.1.1. Co-Citation Journals

This section introduces the distribution of publications in different journals. Table 2 shows the top 25 source journals for UR studies and their influencing factors. Meanwhile, eight of the top 25 source journals were from The Netherlands, and five each from the United States and the United Kingdom.

Analysing each citation in the index research database, a network of co-cited journals with 135 nodes and 868 links was generated to determine the most important cited journals, as shown in Figure 2. The node size represents the co-citation frequency of each journal in the dataset. Therefore, the most frequently cited journals are *Global Environmental Change Human and Policy Dimensions* (frequency = 897), *Landscape and Urban Planning* (845), *Science* (744), *Ecology and Society* (697), and *Proceeding of the National Academy of Science of the United States of America* (664). These journals have made significant contributions to UR research, so they are more cited by researchers in this field, which is consistent with their extensive influence in the field of UR research.

Citation bursts in cited journals indicate that articles in these journals obtained a large number of citations within a short time-period. The burst strength is reflected by the red depth of the inner circle of nodes in the co-citation network [27,37,38]. According to the calculation information in Figure 2, a citation burst appeared in 41 journals, of which 21 had a burst strength of more than 20. Represented by *Conservation Biology* (burst = 41.39), *Biological Conservation* (31.79), *Disasters* (31), *Bioscience* (29.2), *Environmental Management* (28.2), and *Frontiers in Ecology and Environment* (28.13), they are recommended for researchers to study along with the top 25 source journals.

In the network, some nodes obtained a high intermediate centrality score marked by a purple band, such as *PLOS ONE* (centrality = 0.34), *Environment and Behaviour* (0.31), *Global Environmental Change Human and Policy Dimensions* (0.3), *Health & Place* (0.29), *Social Science & Medicine* (0.26), and *American Journal of Public Health* (0.21). These journals serve as a link between different journals and as important knowledge centres for scholars and practitioners.

Table 2. Top 25 most productive journals in the database.

Journal	Count	Percentage (%)	IF	Publisher	Host Country
Sustainability	287	10.9	2.576	MDPI	Switzerland
International Journal of Disaster Risk Reduction	94	3.57	2.896	Elsevier Ltd.	The Netherlands
Landscape and Urban Planning	61	2.317	5.441	Elsevier Science BV	The Netherlands
Sustainable Cities and Society	61	2.317	5.268	Elsevier	The Netherlands
Science of the Total Environment	60	2.279	6.551	Elsevier Science BV	The Netherlands
Natural Hazards	58	2.203	2.427	Springer Nature	USA
Water	58	2.203	2.544	MDPI	Switzerland
Ecology and Society	49	1.861	3.890	The Resilience Alliance	Canada
Journal of Cleaner Production	46	1.747	7.246	Elsevier Ltd.	USA
Environmental Science & Policy	45	1.709	4.767	Elsevier Science BV	USA
International Journal of Environmental Research and Public Health	40	1.519	2.849	MDPI	Switzerland
Urban Forestry & Urban Greening	40	1.519	4.021	Elsevier GMBH	Germany
PLOS ONE	34	1.291	2.74	Public Library of Science	USA
Journal of Environmental Management	27	1.025	5.647	Academic Press Inc	UK
Urban Ecosystems	25	0.949	2.547	Kluwer Academic Publishers	USA
Current Opinion in Environmental Sustainability	24	0.912	5.658	Elsevier	UK
Natural Hazards and Earth System Sciences	24	0.912	3.102	European Geosciences Union	Germany
Ecological Indicators	23	0.874	4.229	Elsevier	The Netherlands
Climatic Change	22	0.836	4.134	Springer Netherlands	The Netherlands
Global Environmental Change Human and Policy Dimensions	22	0.836	10.466	Elsevier Ltd.	UK
Journal of Flood Risk Management	21	0.798	3.066	Blackwell Publishing	UK
Building Research and Information	20	0.76	3.887	Taylor and Francis Ltd.	UK
Ecosystem Services	19	0.722	6.33	Elsevier BV	The Netherlands
Water Resources Management	19	0.722	2.924	Springer Netherlands	The Netherlands
Regional Environmental Change	17	0.646	3.481	Springer Verlag	Germany

Note: IF = Impact Factor in 2019.

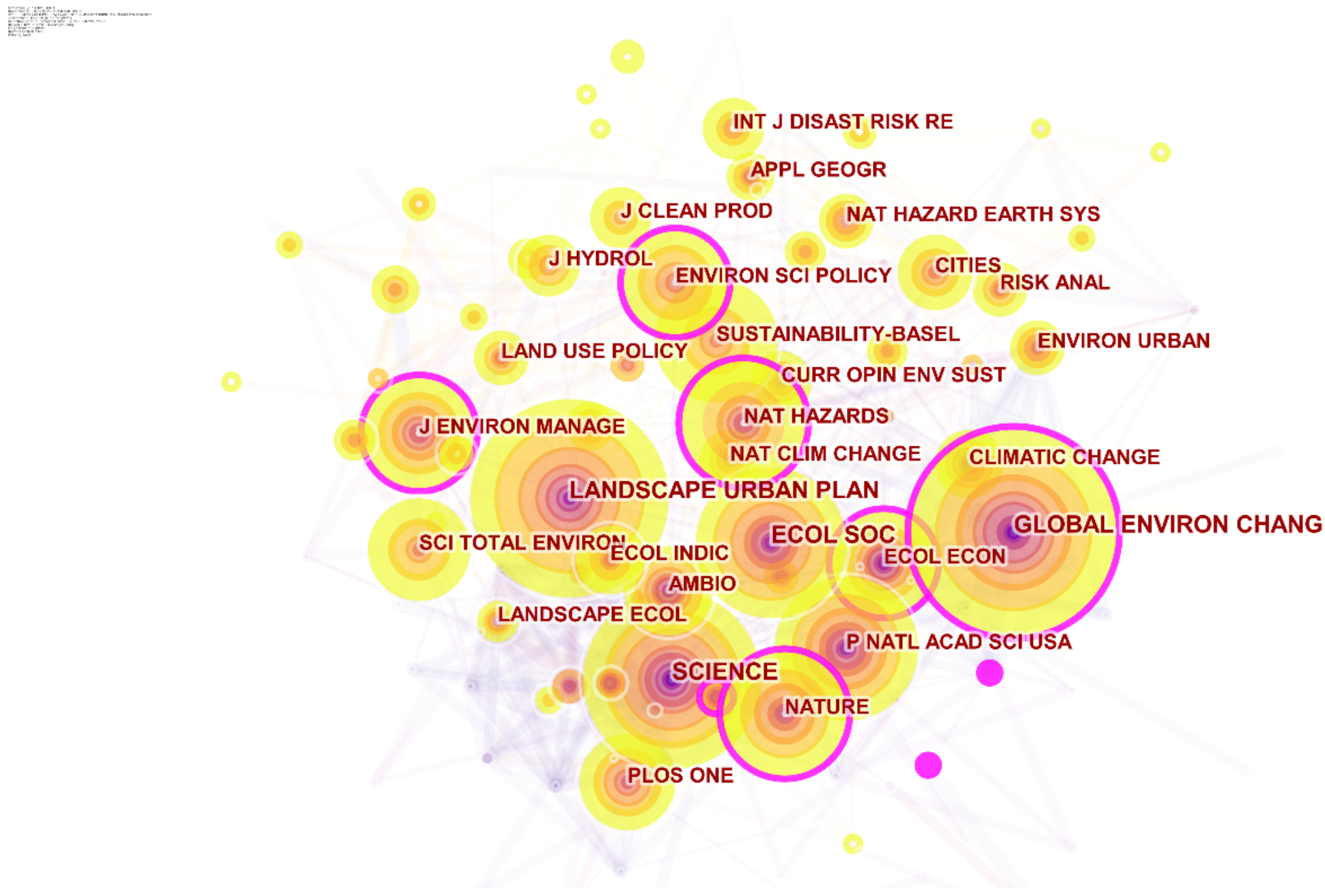

Figure 2. Co-citation journal network.

3.1.2. Co-Citation Document

References in 2629 bibliographic records were co-cited and analysed to understand the knowledge structure in the research field of UR. According to the WoS retrieval records, Table 3 lists the top 30 cited references. Gomez-Baggethun and Barton (2013) classified and evaluated ecosystem services for urban planning. They described valuation languages (economic costs, socio-cultural values, and resilience) that capture distinct value dimensions of urban ecosystem services. They discussed various ways through which urban ecosystem services can enhance resilience and quality of life in cities and identified a range of economic costs and socio-cultural impacts that derive from their loss [39]. Broto and Bulkeley (2013), from the perspective of diversity in response to climate change, uncovered the heterogeneous mix of actors, settings, governance arrangements, and technologies involved in the governance of climate change in cities in different parts of the world [40]. Ahern (2014) proposed a framework for "safe to fail" adaptive urban design to integrate science, professional practice, and stakeholder participation. Similar studies all reflect the early focus of UR and form a foundation for the research [41].

Table 3. Top 30 most cited articles based on WoS citation metric.

S/N	Article	Total Citations	S/N	Article	Total Citations	S/N	Article	Total Citations
1	Barthelemy 2011 [42]	1099	11	Andersson, Barthel et al., 2014 [43]	211	21	Barthel and Isendahl 2013 [44]	162
2	Gomez-Baggethun and Barton 2013 [39]	566	12	Ahern 2013 [45]	210	22	Hammond, Chen et al., 2015 [46]	157
3	Meerow, Newell et al., 2016 [9]	430	13	Cao, Fang et al., 2020 [47]	209	23	McPhearson, Pickett et al., 2016 [48]	155
4	Broto and Bulkeley 2013 [40]	391	14	House-Peters and Chang 2011 [49]	185	24	Ahern, Cilliers et al., 2014 [41]	150
5	Ahern 2011 [50]	336	15	Kabisch, Frantzeskaki et al., 2016 [51]	179	25	Gunawardena, Wells et al., 2017 [52]	145
6	Sandifer, Sutton-Grier et al., 2015 [53]	320	16	Schoennagel, Balch et al., 2017 [54]	176	26	Wilby and Keenan 2012 [55]	143
7	Hunt and Watkiss 2011 [56]	316	17	Meerow and Newell 2017 [57]	175	27	Evans, Fletcher et al., 2013 [58]	139
8	Ouyang, Duenas-Osorio et al., 2012 [59]	279	18	Pelling and Manuel-Navarrete 2011 [14]	174	28	Bendt, Barthel et al., 2013 [60]	136
9	Leichenko 2011 [61]	236	19	Ernstson 2013 [62]	171	29	Lin, Philpott et al., 2015 [63]	134
10	Lovell and Taylor 2013 [64]	228	20	Colding and Barthel 2013 [65]	162	30	Liao 2012 [66]	133

In co-citation analysis, the literature corresponding to each node is represented by the first author and the year of publication [27] (Figure 3). These link lines reflect the co-citation relationship between the two. The node size indicates the frequency of co-citation. As shown in Figure 3, a co-citation hybrid network with 710 nodes and 3270 links in the UR study was constructed (density = 0.013). The top nine co-cited documents with more than 30 co-citation counts are Meerow, Newell et al., 2016 [9] (frequency = 148), Meerow and Newell 2017 [57] (frequency = 39); Colding and Barthel 2013 [67] (frequency = 38); Mugume, Gomez et al., 2015 [39] (frequency = 36); Hosseini, Barker et al., 2016 [68] (frequency = 36); Fletcher, Shuster et al., 2015 [69] (frequency = 33); McPhearson, Andersson et al., 2015 [70] (frequency = 32); Wolch, Byrne et al., 2014 [71] (frequency = 31); Edenhofer 2014 [72](frequency = 30).

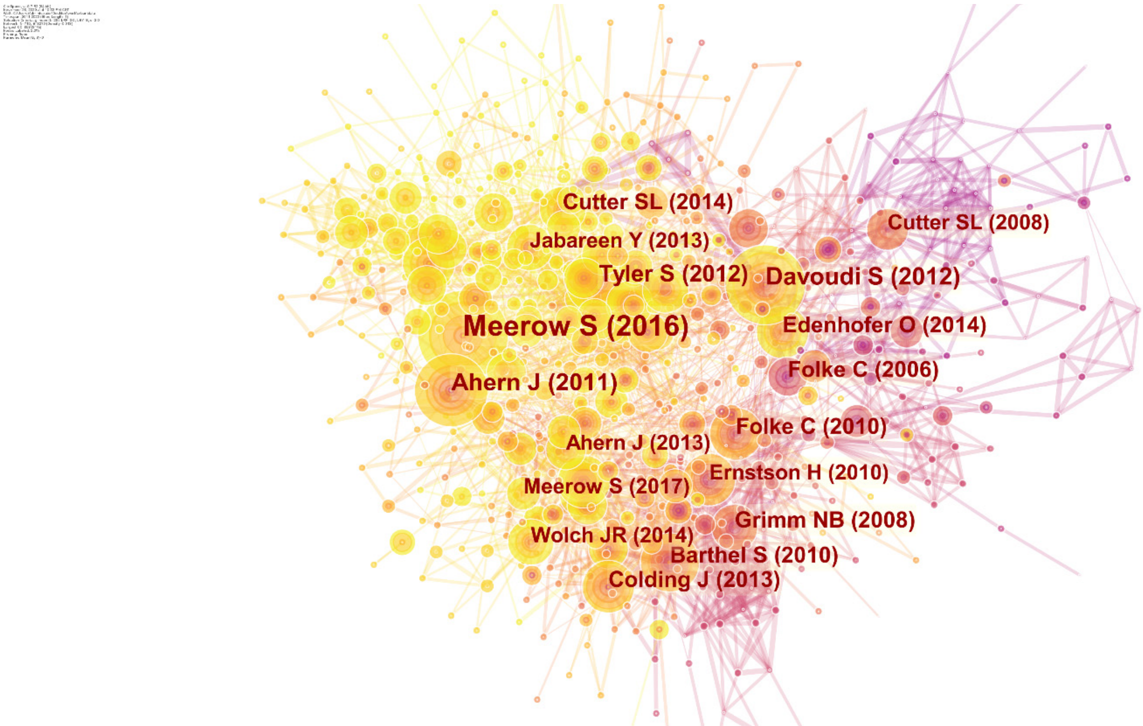

Figure 3. Document co-citation network.

A total of 95 documents experienced citation burst, among which the top 10 documents for burst intensity include Meerow and Newell 2017 [57] (burst = 11.37); Fletcher, Shuster et al., 2015 [69] (burst = 9.6); Colding and Barthel 2013 [65] (burst = 9.44), Ahern 2011 [50] (burst = 9.44), Barthel, Folke et al., 2010 [73] (burst = 9.15); Davoudi, Shaw et al., 2012 [74] (burst = 8.16); Gomez-Baggethun and Barton 2013 [39](burst = 8.11); Edenhofer 2014 [72] (burst = 7.91); Chelleri, Waters et al., 2015 [75] (burst = 7.83); Mugume, Gomez et al., 2015 [76] (burst = 7.69). For instance, Meerow and Newell introduced the Green Infrastructure Spatial Planning (GISP) model, a GIS-based multi-criteria approach that integrates six factors: (1) stormwater management; (2) social vulnerability; (3) green space; (4) air quality; (5) urban heat island amelioration; and (6) landscape connectivity. As the GISP model reveals, it provides an inclusive, replicable approach for planning future green infrastructure to maximise social and ecological resilience. Fletcher, Shuster et al. documented the history, scope, application, and underlying principles of terms used in urban drainage and provided recommendations for clear communication of these principles. Terminology evolves locally and thus plays an important role in establishing awareness and credibility of new approaches. Colding and Barthel discussed the role that cultural diversity plays in the resilience building of urban systems and provided innovative insights on how common property systems could contribute to UR building. These articles have been widely cited because of the foundational and universal nature of their concerns.

3.2. Co-Word Analysis

The integration and development of several research topics and subject categories of UR research represent the frontiers and future trends of this research field. Data from WoS bibliographic records were used to evaluate and identify common keywords and subject categories in the UR research field.

3.2.1. Co-Occurring Keywords

Keywords are the vital contents of articles that play a critical role in revealing the development of research topics. Through Cite Space analysis, the frequency of co-occurrence words in the UR research field was established. In this way, quantitative analysis is conducted on the creative activities of scientists to study the development trend and research hotspots in a field.

In the keyword clustering co-occurrence map (Figure 4) the node is a cross. The larger the node, the larger the keyword font, indicating that the overall frequency of the keyword is higher. The thickness of the cross is proportional to the frequency of the keywords in the year. The line between the keywords indicates that two keywords often appear in the same literature. The thicker the line, the higher the co-occurrence frequency. As shown in Figure 4, a co-occurrence keyword network with 556 nodes and 4677 links was established. Co-occurring keywords network shows that there are 21 high-frequency keywords in the dataset that exceeds 100. For example, "resilience" (frequency = 1105); "climate change" (492); "city" (363); "vulnerability" (357); "management" (355); "impact" (289); "sustainability" (271); "framework" (257) and "adaptation" (251).

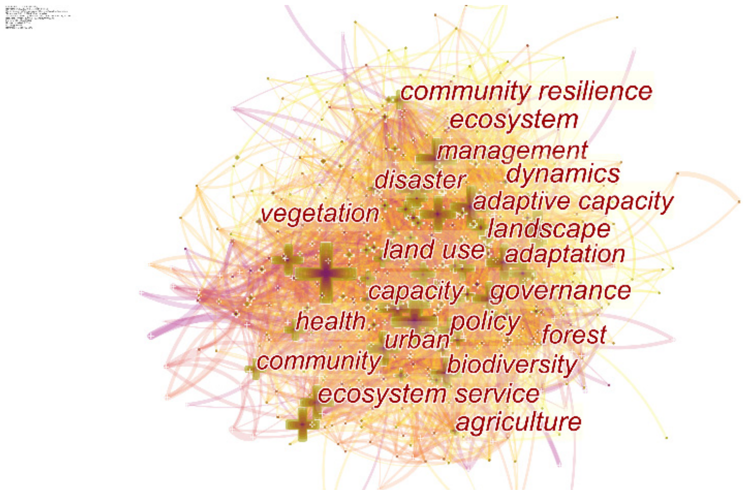

Figure 4. Network of co-occurring keywords.

From the co-occurring keyword network map, 50 keywords with the strongest citation burst were identified. Table 4 shows the top 20 keywords according to burst intensity. Among them, "diversity", "Social-ecological system", "sustainable development", "capacity", and "environment" are also frequently cited words, which highlights the attention they have been given in UR research.

Table 4. Keywords with the strongest citation bursts.

S/N	Keywords	Burst Strength	Span	S/N	Keywords	Burst Strength	Span
1	Social-ecological system	13.62	2011–2016	11	Resource	4.21	2012–2013
2	Diversity	11.56	2012–2016	12	Stress	4.09	2013–2014
3	Capacity	8.73	2012–2017	13	PTSD	3.80	2011–2012
4	Growth	8.25	2012–2015	14	Stream	3.80	2011–2012
5	Ecosystem	7.76	2012–2015	15	Depression	3.65	2011–2014
6	Built environment	6.28	2011–2016	16	Community garden	3.50	2013–2014
7	Knowledge	5.58	2011–2016	17	Poverty	3.27	2012–2014
8	Forest	4.85	2012–2015	18	Pattern	3.27	2013–2014
9	Transition	4.65	2011–2013	19	Future	3.01	2012–2013
10	Biodiversity conservation	4.21	2012–2013	20	Urban heat island	2.97	2012–2013

Words with a high score for betweenness centrality included "urban" (centrality = 0.13); "climate change" (0.12); "management" (0.12); "health" (0.11), "resilience" (0.1), "risk" (0.09); "urbanization" (0.09); "disaster" (0.09); "vulnerability" (0.07) and "sustainability" (0.07). These keywords and themes have greatly influenced the development of the UR research field, and it helps to link and merge multiple themes.

3.2.2. Co-Occurring Subject Categories

The bibliographic records in the WoS core database are divided into different subject categories according to the scope of the corresponding journal. An article may be divided into one or more subject categories. Co-occurrence analysis of subject categories helps to discover the subjects involved in the development of a certain field. Figure 5 shows the co-occurring network and the most frequently occurring subject categories from 2011 to 2020.

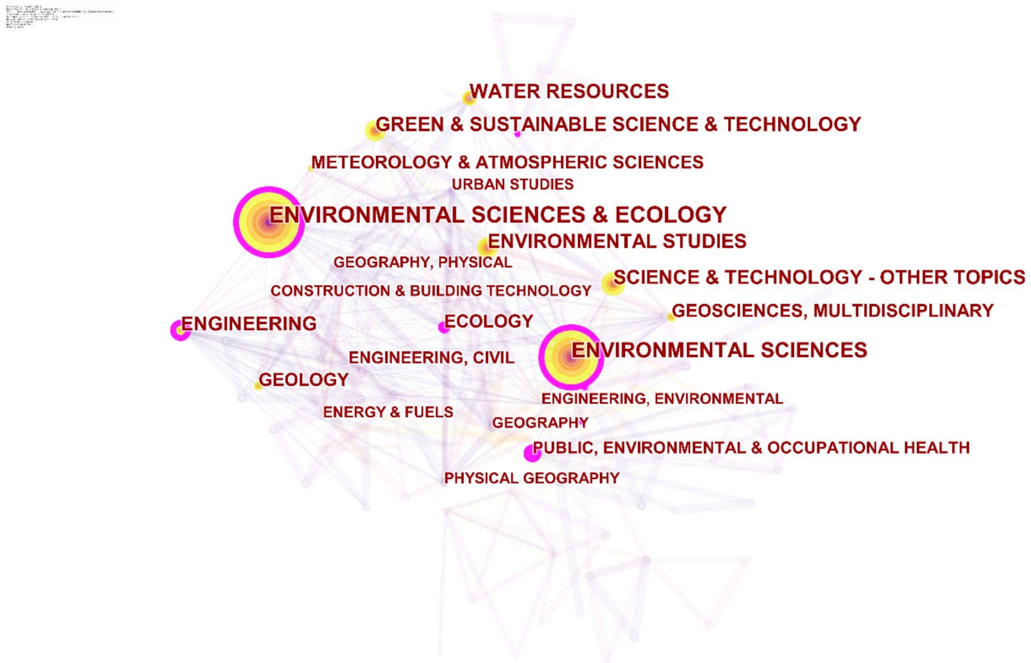

Figure 5. Network of co-occurring subject categories.

As shown in Figure 5, a network of co-occurring subject categories was developed, with a modularity of Q = 0.4934, and mean Sihouette = 0.6325. The node size for each subject category represents the number of articles under each category in the dataset. Six subject categories with 100 articles or more were identified: Environmental science & ecology (1312 articles); environmental sciences (1043); science & technology, other topics (589); environmental studies (566); green & sustainable science and technology (492); and water resources (488). Some significant UR-related studies have been published under these subject categories. The colours of the generated networks and links reveals an increasing number of publications in the fields of engineering, geosciences, geology, meteorology and atmospheric sciences, and ecology.

The top-ranked item by bursts is ECOLOGY (2011–2013) with bursts of 10.60, followed by GEOGRAPHY (burst strength = 6.58, 2013–2014), PHYSICAL GEOGRAPHY (5.42, 2013–2014); PSYCHOLOGY (4.97, 2013–2016); AGRICULTURE (4.39, 2014–2015); PSYCHIATRY (4.07, 2011–2016). Such subject categories represent the most active areas in UR. In recent years, the literature related to UR research in these subject disciplines has been widely cited, which is similar to of the reports of Masnavi, Gharai et al. [77].

In Figure 5, the width of the purple circle represents the centrality of the subject area. Subject areas with high node centrality scores include public (centrality = 0.49), engineering (0.34), environmental sciences & ecology (0.32), ecology (0.26), and environmental sciences (0.23).

3.3. Cooperation Analysis

According to the definition of scientometricians Katz and Martin, scientific collaboration is when research scholars work together for the common purpose of producing new scientific knowledge. In practice, scientific cooperation has many forms and manifestations [78–80]. In this study, the presence of different authors, institutions, and countries in a paper is considered a collaborative relationship. Relevant author details used to establish which authors, institutions, and countries have been collaborating. These data can be used to map micro-collaborator networks, mesoscale institutional cooperation networks, and macro-national cooperation networks.

3.3.1. Co-Authorship Network

Based on WoS statistical data, information, and analysis of the most prolific authors were generated, as shown in Table 5. David Butler (University of Exeter), Timon McPhearson (New School, Urban Ecology Lab), and Niki Frantzeskaki (Erasmus University) are the top three researchers with the most published papers in this field.

Table 5. Top 16 most productive authors.

Authors	Institution	Country	Counts	h-Index
David Butler	University of Exeter	UK	23	39
Timon McPhearson	New School, Urban Ecol Lab	USA	21	18
Niki Frantzeskaki	Erasmus University	The Netherlands	18	30
Sara Borgstrom	Stockholm University	Sweden	15	14
Thomas Elmqvist	Stockholm University	Sweden	15	48
Yan Wang	Virginia Polytechnic Institute & State University	USA	14	5
Chris Zevenbergen	Delft University of Technology	The Netherlands	14	17
Erik Andersson	Stockholm University	Sweden	13	23
Raziyeh Farmani	University of Exeter	UK	11	23
Guangtao Fu	University of Exeter	UK	11	28
Yangfan Li	Xiamen University	China	11	14
Berry Gersonius	IHE Delft Institute for Water Education	The Netherlands	10	11
Marcelo Gomes Miguez	Universidade Federal do Rio de Janeiro	Brazil	10	3
Steward Pickett	Cary Institute of Ecosystem Studies	USA	10	47
Christopher DF Rogers	Birmingham Ctr Resilience Research & Education	UK	10	22
Damien Serre	Avignon Université	France	10	9

Note: h-index of a researcher is defined as a maximum of h papers cited at least h times each.

Figure 6 shows the scientific collaborative co-authorship network, with the node size corresponding to the number of published articles per author, and link thickness indicating the strength of the collaborative relationship between authors. Timon McPhearson, David Butler, and Niki Frantzeskaki are the three largest nodes in the co-authorship network. Timon McPhearson is director of the Urban Systems Lab and Associate Professor of Urban Ecology at the New School in New York City. He is the lead author or co-author of approximately 115 ISI papers with a total of 4849 citations. He studies the ecology of cities to advance UR, sustainability, and justice [11,17,48,70]. David Butler is a professor of water engineering at the University of Exeter, UK, where he is Head of Engineering. He has co-authored a total of 226 journal articles with a total of 5357 citations. He has devoted himself to urban water management research, developed a strategic plan for resilience and sustainability in the integrated management of urban wastewater systems [81,82], and proposed Safe & Sure—A new paradigm for urban water management [76,83,84]. Niki Frantzeskaki is a Professor of Urban Sustainability Transitions at the Swinburne University of Technology in Melbourne. She researches contemporary sustainability transitions in cities and their governance across Europe, the USA, Brazil, and in developing countries like Vanuatu and Ghana [85,86]. Niki coordinated research on environmental governance and urban sustainability transitions through her leadership and involvement in a portfolio of research projects.

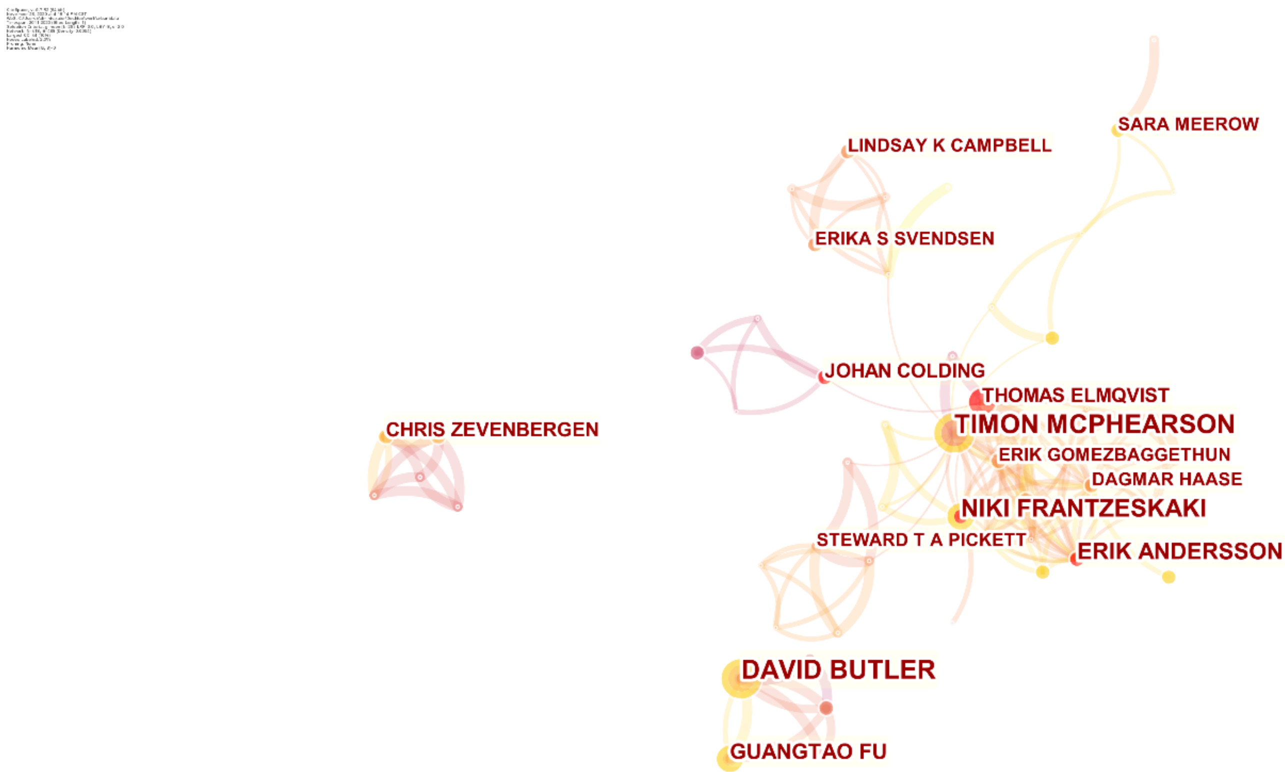

Figure 6. Co-authorship network.

The two scholars with the most prominent outbreak intensity are Guangtao Fu and David Butler. Guangtao Fu is a Professor of Water Intelligence at the Centre for Water Systems, University of Exeter. Fu focuses on developing and applying new computer models, data analytics, and artificial intelligence tools to tackle urban water challenges in water supply resilience, network leakage, flood risk, urban stormwater, and wastewater management. To tackle uncertainty, Fu worked on developing a new theoretical uncertainty analysis framework of imprecise probabilities, which enables an accurate representation of uncertainty of various types and thus the quantification of their impacts on water systems. The new framework has been applied to climate modelling, flood analysis, and water system design.

According to the parameters in the upper left corner of the spectrum, the network density is 0.0054. In general, nodes are relatively scattered, with fewer connections between nodes. This shows that although UR researchers have formed certain connections, they are scattered. There are many isolated authors and only a few closely related research teams. Among them, the cooperative group with Timon McPhearson, Niki Frantzeskaki, and David Butler as the core is the largest and most closely connected cooperative group.

3.3.2. Network of Institutions and Countries

This section discusses the contributions of various institutions and countries/regions to the knowledge system in this field. At the research institution level, there are 151 institutions engaged in UR research, which are located in 112 countries/regions. Table 6 presents the 10 most productive institutions. These institutions are based in countries with a high level of urbanisation or in the process of urbanisation, such as the United States, the United Kingdom, Sweden, China, and the Netherlands. The United States ranks first with 330 articles, the United Kingdom ranks second with 109 articles, and Sweden ranks third with 52 articles.

Table 6. Top 10 Institutions by Total Volume of Publications.

Rank	Institution	Country	TP	Percent (%)
1	Arizona State University	USA	121	4.442
2	University of California System	USA	78	2.863
3	University of London	UK	62	2.276
4	Stockholm University	Sweden	52	1.909
5	State University System of Florida	USA	51	1.872
6	University of Exeter	UK	47	1.725
7	United States Department of Agriculture	USA	41	1.505
8	United States Forest Service	USA	39	1.432
9	Chinese Academy of Sciences	China	38	1.395
10	Wageningen University & Research	The Netherlands	36	1.322

Similarly, we have established a network diagram of institutional cooperation, as shown in Figure 7. The network generated 374 nodes and 885 links with a density of 0.0127. At the institutional level, several universities have achieved remarkable results in UR research and are critical institutional nodes in the network. These include Arizona State University (frequency = 56), Stockholm University (48), University of Exeter (46), University Melbourne (30), and University of British Columbia (25). In general, the top 21 institutions have relatively close partnerships (co-cited frequency $\geq$ 20). In particular, Arizona State University and Stockholm University play a central role in the collaborative network, building close cooperative relations with multiple institutions.

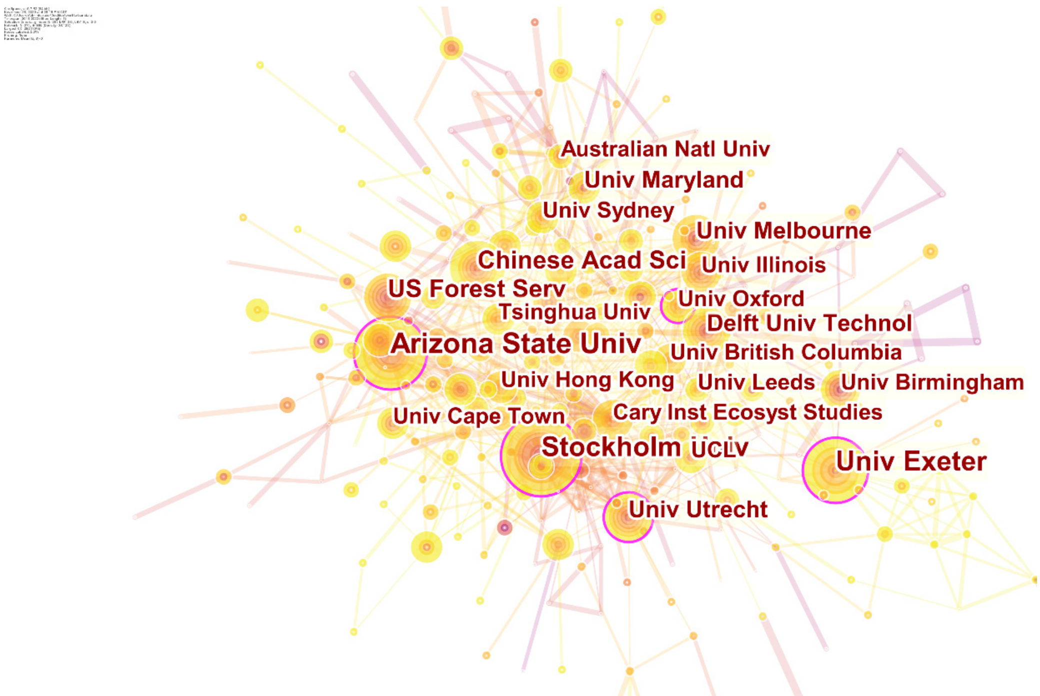

Figure 7. Network of institutions.

3.4. Clusters Analysis

Cluster analysis is an exploratory data mining technique used to identify and analyse prominent terms, backgrounds, trends, and their correlations in a field of research [87]. Through various algorithms, the cluster label can be identified from the title, keywords, and noun phrases in the abstract of the publication by the cluster members. The logarithmic likelihood ratio (LLR) algorithm, which aims to compare the goodness of fit between two models, is used to select labels for clustering [26]. This is because it guarantees the uniqueness and homogeneity of the labels within the cluster and is widely used in similar research [88,89].

3.4.1. Keywords Clusters

To clarify the research hotspots of UR in different periods, the temporal pattern of how the keyword clusters evolve over time was further examined. Information about term and cluster frequency was transformed into a timeline view, as shown in Figure 8. In timeline view, the literature of the same cluster is placed on the same horizontal line, and the label for each cluster is displayed at the end of the cluster timeline. The legend at the top of the display area is marked every 3 years, and only the top three keywords are displayed for each timeline each year. The colour of the connection between the keywords represents the time when the first co-occurrence relationship occurred.

Figure 8 shows seven of the most frequent keywords in the UR research field. Each cluster has a clear meaning, among which #0 "Sustainability" and #1 "Ecosystem Services" are the largest clusters. Cluster results show that the evolution path of UR research can be divided into two stages.

The first stage (2011–2014) is the basic stage of UR research. The focus of research during this period was scattered, with researchers focusing on the following keywords: climate change, ecosystem service, land use, green infrastructure, biodiversity, and urban heat island. The second stage (2015–2020) is the development stage of UR research. The research content became more detailed and in-depth during this period. Risk management, stormwater management, green space, and nature-based solutions gained attention, and research ideas also concerned reliability, uncertainty, security, and politics.

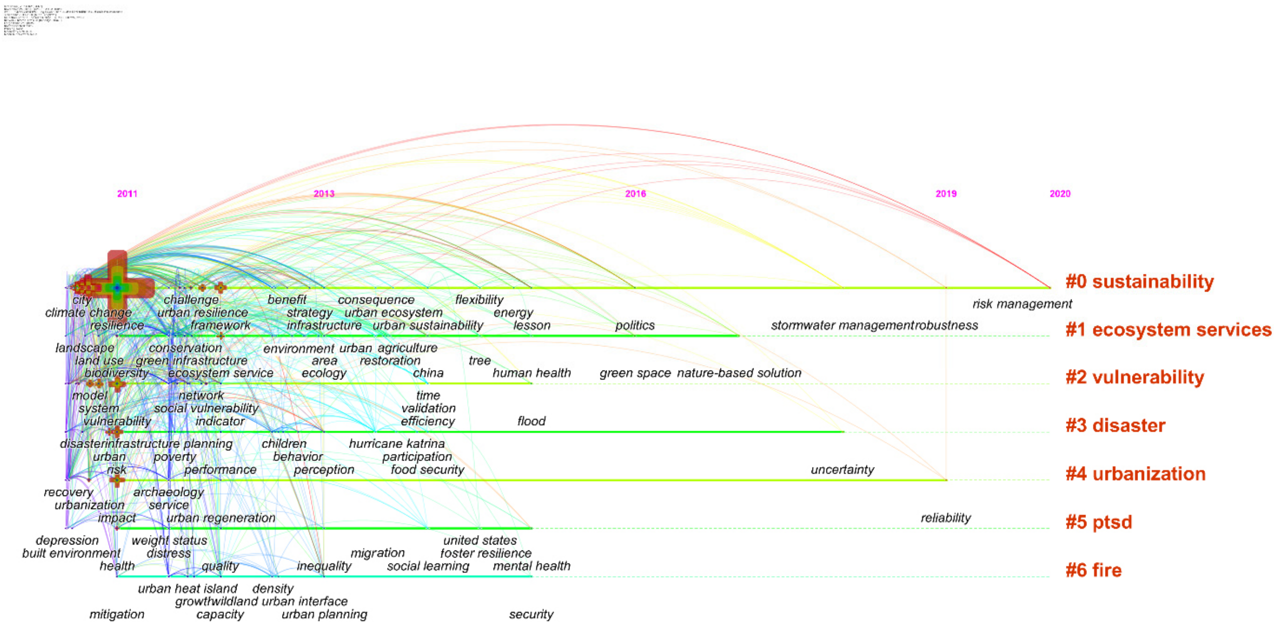

Figure 8. Timeline view of keyword clustering.

3.4.2. Documents Co-Citation Clusters

The LLR algorithm used in the study generated 10 significant co-citation clusters, as shown in Figure 9. The 10 significant clusters are sorted by scale, as shown in Table 7. Cluster #0 "urban floods" with 108 members is the largest cluster, and cluster #8 "Urban regeneration", with 39 members being the smallest cluster. Most relationships between groups were formed between 2011 and 2014, depicted by the coloured lines in the figure. This period formed the foundation period for UR research.

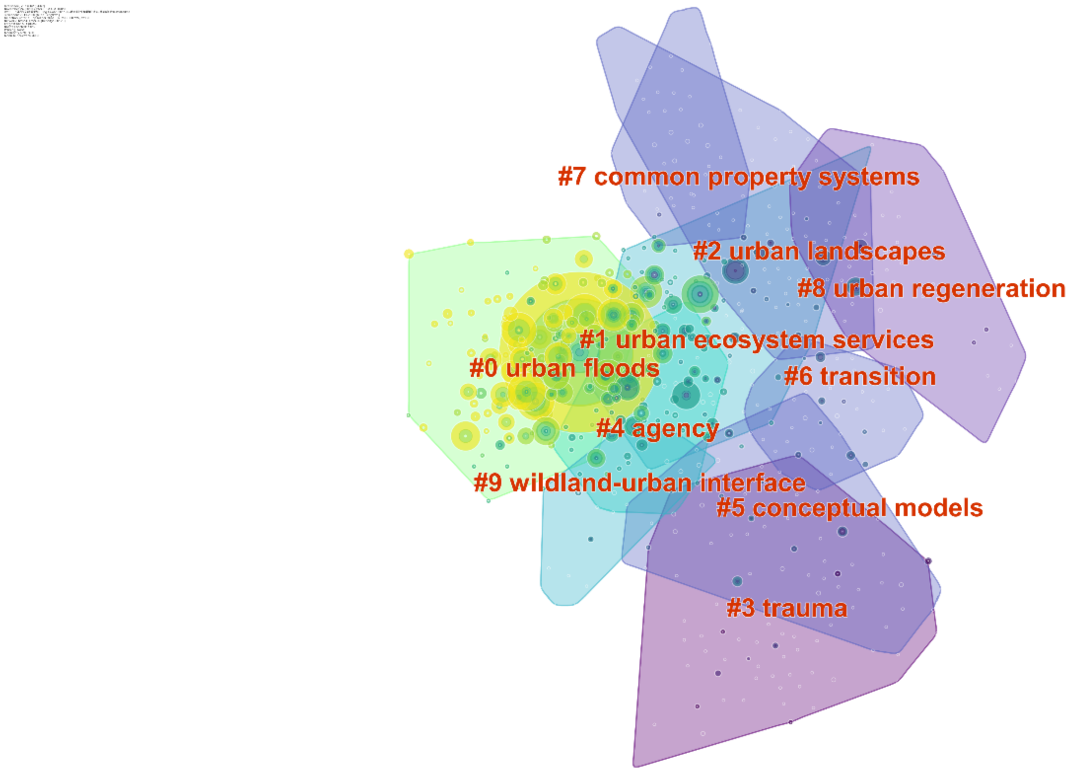

Figure 9. Document co-citation clusters.

Table 7. Documents co-citation clusters.

Cluster ID	Size	Silhouette	Cluster Label (LLR)	Alternative Label	Mean Year	Representative Documents
#0	108	0.806	Urban floods	Urban floods; stormwater management	2015	[66]
#1	76	0.746	Urban ecosystem services	Urban ecosystem services; ecosystem services	2012	[70]
#2	56	0.747	Urban landscapes	Urban landscapes; urban ecosystems	2010	[45]
#3	56	0.929	Trauma	Trauma; regime shifts	2007	[90]
#4	42	0.832	Agency	Agency; ecosystem services	2012	[91]
#5	48	0.775	Conceptual models	Conceptual models; public health administration	2009	[10]
#6	41	0.903	Transition	Transition; urban water	2010	[92]
#7	41	0.950	Common property systems	Common property systems; Patagonia	2009	[67]
#8	39	0.916	Urban regeneration	Urban regeneration; water supply	2009	[93]
#9	144	0.958	Wildland-urban interface	Wildland-urban interface; wildfire	2012	[94]

The silhouettes of the 10 significant clusters are all between 0.758 and 1.000, indicating consistency among cluster members (Figure 9). Meanwhile, based on the average year of the cluster, most clusters were formed by the earlier literature, and is consistent with the research basis of UR in the 2011–2014 period. In addition, each cluster has representative documents, that is, the most frequently cited documents in each cluster. Representative literature affects the label of each cluster, is widely cited in UR research, and is the essential reading of the field.

4. Discussions

4.1. Research Topics

The academic structure of UR research is described based on the analysis of the main research topics of each cluster. The significant clusters of UR research are ranked #0 to #9, as shown in Table 7. Considering the length of this study, cluster #0 to cluster #3 were analysed, each of which has more than 50 members.

4.1.1. Urban Floods and Stormwater Management

Cluster #0 "Urban Floods" has 108 members, and the Silhouette value is 0.806. By referring to the related cited and co-cited literature, the cluster label was combined into a "resilient basis analysis". This cluster focuses on the basic theories and methods of resilience and is widely used in urban disaster management and land planning, including complex systems, hybrid multiple-attribute group decision-making, regulatory measures, green governance, interventions, and resilience enhancement. The representative document in Cluster 0# is Liao [66]. He defined urban flood resilience as a city's capacity to tolerate flooding and to reorganise if physical damage and socioeconomic disruption occur, to prevent deaths and injuries, and maintain socioeconomic identity. By applying the theory of resilience to solve the continuous changes of the system, the theory of "UR to floods" is defined as the framework of urban disaster management, and an alternative measure to assess the resilience of cities, namely "the percent of floodable area" was developed. A number of studies on UR concept and basic theory aim to characterize and assess the

UR concept by identifying the types and characteristics of resources that resilient urban systems must possess. It can be concluded that UR has been applied in various different scientific areas that are related to the study and functioning of the different urban systems (e.g., disaster science [95], ecology [96], public health [97]), demonstrating the application scope of this concept.

4.1.2. Urban Ecosystem Services

Cluster #1 "Urban ecosystem services" has 76 members. This cluster involves multidisciplinary research including landscape design, green infrastructure construction, resilience planning, ecosystem service value, and public health management. The representative document is McPhearson et al. [70]. Research suggests that urban ecosystem services provide key links for bridging planning, management, and governance practices seeking transitions to more sustainable cities, and serve an important role in building resilience in urban systems. Emerging city goals for resilience should explicitly incorporate the value of urban ecosystem services in city planning and governance. In 2013, Gomez-Baggethun and Barton classified and evaluated ecosystem services for urban planning [39]. This study highlighted various ways through which urban ecosystem services can enhance resilience and quality of life in cities and identified a range of economic costs and socio-cultural impacts that derive from their loss. These studies have focused more on the constructed environment and infrastructure of urban ecosystems, but the ones on environmental governance and policy are limited. Not surprisingly, the environment and infrastructure provide the necessary infrastructure for public survival after a disaster and have thereby been the focus of many scholars. But the role that environmental governance and policy play in cities' response to risk should not be overlooked, which is a promising area for improvement in the literature.

4.1.3. Urban Landscapes

Cluster #2 "Urban landscapes" represents the interdisciplinary integration of sustainable development and resilience research. Landscape ecologists are prominent among these disciplines because of the inherent interdisciplinarity in their field and have also contributed to a greater understanding of the concept of resilience and its implications for urban sustainability. The representative document of Cluster #3 [45] points out five strategies to improve UR based on the concept of landscape ecology: biodiversity, multifunctionality, multiscale networks, modularity, and adaptive design. Individually and collectively, these strategies suggest a transdisciplinary working method in which scientists and professional experts collaborate with stakeholders and decision-makers continuously throughout ongoing, iterative, and adaptive planning, design, and management processes [98]. Research that combines sustainability and UR is also a valuable direction in future development. The close relationship between the two concepts has been recognized. Cities' sound development can only be achieved if resilience and sustainability are guaranteed. The two factors are essential capabilities that urban systems should have, especially in the field of safety management. With evolving research, interdisciplinary studies remain a worthwhile endeavor.

4.1.4. Trauma

Cluster #3 "Trauma" refers to urban disaster resilience and UR practices, where researchers focus on the theory of adaptive cycles. The representative document [90] argues that concepts of vulnerability and resilience are useful for separating extra-local patterns and regularities from the context-laden urban environment, and help to reveal the reciprocal feedback effect of human action and urban ecosystem transformation. In their research, they provided a conceptual framework to assess the impact of government policies, programmes, and other forms of activity on the transformation of organisational couplings in a dynamic urban ecosystem. Meanwhile, Marcus and Colding (2014) showed that the urban form can be contextualised by the adaptive renewal cycle, which is a dynamic framework model for resilience science. The dynamics of complex adaptive systems are discussed in relation to urban form and other social variables, with special attention paid to the "back loop phase" of the adaptive renewal cycle. They conclude by postulating ways in which resilience thinking could contribute to the development of a new research frontier for designing resilient urban social-ecological systems, and end by proposing the strategic areas of research in such a field [99]. In recent years, numerous disasters have occurred around the world, causing significant negative impacts on urban development and people's lives. Research on urban disasters provides useful references for enhancing resilience, including disaster response, disaster risk management, and post-disaster recovery strategies, among others. Due to the uncertainty and complexity of disasters, research in this field still has much room to evolve, and UR in specific disaster contexts can be explored in depth in future studies.

4.2. Research Limitations

This study provides timely and valuable insights into the UR knowledge system, enables scholars to better understand current research progress, and highlights potential opportunities for future research and collaboration. Admittedly, there are some limitations in this paper. From a methodological perspective, several limitations need to be considered carefully.

First, scientific research results that cannot be included in bibliometrics research are not easily explored by this research. For example, in practice, the most important factors driving UR are capital, financial mechanisms, and resilient urban economies. It is difficult to do any research with the public in this study, because all the data has signed a confidentiality agreement or cannot be published due to other reasons.

Secondly, the multi-disciplinary nature of UR leads to the fact that quantitative analysis cannot fully show the research topic. A few years ago, in 2015, prof. Ayyoob Sharifi (one of the most well-known scholars on UR which has written extensively on UR Frameworks and Assessments) organized a global workshop with top experts and scholars in UR research, to debate the evolution of our discipline, and a year later MC Therrien did a follow-up workshop in Canada, and after 3 years of experts' brainstorming a paper was published, putting light on the XXI Century research challenges in urban resilience [8]. This paper, for example, among others, represents a lot, in terms of influencing research cluster of research and work in UR, beyond its bibliometric scoring. UR is a huge issue, but scholars have given more attention to urban issues which are less bibliometric.

Finally, the setting of search terms will affect the analysis of the results of bibliometrics. There are documents that cannot be included in this study because of no "resilience" in the title. For example, the most intensive research on UR conducted on cities is hidden, or called climate adaptation (e.g., indices, indicators, or energy conversion [100]) and they are not called "resilience" in their titles, so again invisible here. In summary, there is enough space for us to carry out more comprehensive and systematic work in the future.

5. Conclusions

This study provides a comprehensive scientometric review of UR research over the past decade (2011 to 2020), establishing the latest research topics and knowledge systems. The results show that the steady growth of the literature in this field indicates that increasing efforts and resources are being devoted to the research and development of UR. (1) Through co-citation analysis, it was established that studies were mainly from the United States, the United Kingdom, and the Netherlands. Meanwhile, the Journal of Cleaner Production, Sustainability, International Journal of Disaster Risk Reduction, Landscape and Urban Planning, Sustainable Cities and Society, Science of the Total Environment have published important UR studies. (2) Through co-word analysis, words such as "Social-ecological system", "Diversity", "Capacity", "Growth", "Ecosystem", "Built environment", "Knowledge", "Forest", "Transition" "Biodiversity conservation" have been used many times in recent years and represent topics crucial to the research and development of UR. Scientific categories such as "Environmental science & ecology"; "environmental sciences; "science &

technology"; "environmental studies"; "green & sustainable science & technology"; "water resources" have exerted considerable influence on the research structure and development of UR and contributed to the connection and integration of different conceptual approaches in the research field. (3) In terms of author productivity and contribution, David Butler, Timon McPhearson, and Niki Frantzeskaki are the leading authors in this field. Meanwhile, Arizona State University, University of California System, University of London, Stockholm University, and State University System of Florida are the most effective institutions in the field of UR research. The diversity of highly cited authors in different countries and regions proves the widespread evolution of research on UR development. Active, interconnected, and interactive communication platforms have also been established between countries and institutions. (4) Based on cluster analysis, seven keyword clusters and 10 document co-citation clusters were identified, and the research hotspots and notable terms of UR were analysed. These hotspots are urban floods and stormwater management, urban ecosystem services, urban landscapes, and trauma. Several promising areas of UR research that deserve public concern have also been analyzed (e.g., application of UR in different urban systems; UR related environmental governance and policy system research; interdisciplinary integrative research; UR research under specific disasters). The limitations of the research were summarized to highlight potential opportunities for future research and collaboration.

Author Contributions: P.G.: Conceptualisation; Methodology; Investigation; Writing—Original Draft; Writing—Review and Editing. Q.L.: Project administration; Resources; Funding acquisition. H.G. and H.L.: Project administration; Resources. L.Y.: Supervision; Validation. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by 2019 annual project of the 13th Five-Year Plan for Education and Science of Beijing (CDDB19167); China Construction Education Association Project (2019061); and Special fund support for basic scientific research business expenses of municipal Universities of Beijing University of Civil Engineering and Architecture(x20055).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

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