Progress in urban resilience research and hotspot analysis: a global scientometric visualization analysis using CiteSpace

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Abstract
Increasing global climate change has led to increasingly sudden, abnormal, and complex natural disasters. Global disaster governance is facing complex and severe challenges. Urban resilience research (URR) can help cities withstand disasters and quickly recover from adversities through the rational allocation of resources. Consequently, URR has attracted considerable attention from urban ecology researchers. Over the past decade, despite an increasing number of articles reported on URR, there has been no systematic theoretical framework, no comprehensive review of the research, and no clarity on how different perspectives have evolved. This research selects 1647 articles related to global urban resilience from the Web of Science Core Collection and performs a global scientometric visualization analysis using CiteSpace and ArcGIS software. In this study, we visually display the most productive institutions, authors, and sources in URR. Additionally, we explain how research topics have changed over time and analyze research frontiers. The results show that (1) URR has accelerated globally in the last decade; (2) research hotspots are mainly concentrated in environmental science and ecology, science and technology, and water resources; and (3) URR is gradually becoming a multidisciplinary research field. Our research reveals the status and future trends of URR through quantitative visualization methods, helping to address some emerging and unexpected risks and vulnerabilities.

Keywords Resilient city · Urban resilience · Disaster governance · CiteSpace · Bibliometric methods

Introduction
Global urbanization is one of the most transformative trends of society in the twenty-first century (Jouni and Juha-Pekka 2015). While urbanization and industrialization benefit humankind, they also result in various issues, such as urban overheating (He et al. 2021a; B.J. He et al. 2021b; Zhao et al. 2021a, b), water shortages (Zhao et al. 2013), urban flooding (He et al. 2019), drought and production (Zhao et al. 2022; Zhao et al. 2020), soil pollution (Li et al. 2019), and air pollution (Wei et al. 2021). These problems restrict the sustainable development of urban infrastructure, social economy, and environment (Yonglong et al. 2019; Zhao et al. 2021a, b), becoming a shared concern of all humankind.

“Resilience” first appeared in mathematics and physics to describe the stability of materials and the ability to recover from deformation under the action of external forces. It is...
a property used to describe the intrinsic, essential attributes of people or things. In terms of applicability, resilience was initially used in engineering, psychology, and disaster research. With the rise of systems thinking, resilience has gradually been introduced into ecology and social sciences (Matyas and Pelling 2015). The concept of resilience has undergone the evolution of engineering resilience, ecological resilience, and social-ecological resilience. Engineering resilience refers to the ability of the system to absorb disturbance and return to the original equilibrium state after being disturbed. That is, all external disturbances can be predicted. After the predicted disturbance, the system can rapidly recover and the equilibrium state preceding the disturbance is restored via its self-organization ability (Holling 1996). Ecologist Holling (Holling 1973) introduced resilience to the field of ecology, defining it as the amount of disturbance that a system can withstand or absorb before entering another equilibrium state. Adger (2003) believes that ecological resilience is the degree to which a system can tolerate disturbances. Disturbances can cause the system to transition between steady states, and a steady-state transition occurs if the disturbance exceeds a certain threshold. Pickett et al. (2004) proposes socio-ecological resilience based on a framework of socio-ecological systems. Socio-ecological resilience includes the ability of a system to absorb and adapt to disturbances, as well as to update and transform the system. Socio-ecological resilience emphasizes that the system must disrupt the balance, continue to change, and coexist with the changing internal and external environment to finally achieve the sustainable development of the system.

For the complex adaptive system of a city, enhancing the city’s dynamic response and adaptability to uncertainty is an effective way to promote its sustainable development. The Rockefeller Foundation proposes that urban resilience (UR) is the ability of a city to maintain normal human activities in the face of extreme disturbances. The Rockefeller Foundation launched the “Global 100 Resilient Cities” project in 2013, aiming to enhance the RC concept to meet social, economic, institutional, and other challenges of the twenty-first century (Marjolein and Bas 2017). The Third United Nations Conference on Housing and Sustainable Urban Development advocated that “city ecology and resilience” was one of the core contents of the new urban agenda, setting a new global standard for the sustainable development of resilient cities (Nan 2017). Currently, there is a tremendous worldwide emphasis on URR. For instance, cities such as Beijing and Shanghai emphasized “strengthening urban disaster response capacity and improving UR” in the recent round of urban planning (Yan and Chenzhen 2017). In recent years, administrative departments and research institutions, such as the Ministry of Emergency Management and the RC Research Center of Zhejiang University, have been set up in China. With the continuous expansion of scope and gradual improvement of theoretical methods, UR has become a new research perspective and analysis tool in the field of global environmental change and urban sustainability (He and Pingyu 2011). In particular, the outbreak of COVID-19 in 2020 has left people worldwide suffering and devastated, and cities have lost their usual pace of activity. Methods for achieving post-disaster city resilience, and gradually restoring the urban economy and development are viable directions for future research.

In this context, forming cities that can operate normally and maintain resilience in the face of increasing risks and unpredictable challenges has become an urgent topic in the urban research field. Researchers must focus on guiding URR development and devising strategies for cities to resist risks. The role of government officials is to evaluate and prioritize certain aspects of UR in policymaking. Summarizing existing research results can help us evaluate future research directions and hotspots, provide new perspectives and ideas for further policy formulation, and address emerging and unexpected risks and vulnerabilities. Researchers have summarized UR mainly from aspects of adaptive urban governance (Naomi 2016), climate change and urban resilience (Mehdi et al. 2019), sustainable management of natural resources Bertram 2011), and disaster prevention and mitigation (Daniela et al. 2018). However, these studies only analyzed UR from a social or disaster management perspective (single-dimensional evaluation) without revealing how the studies evolved or elucidating the developmental background, thereby limiting our ability to effectively integrate different disciplines with UR.

Therefore, this study aims to outline the research trend of UR from multiple perspectives. This approach is needed because previous research did not thoroughly explain the mechanism of the research trend change, nor could it accurately foretell the future research direction. Therefore, we used CiteSpace literature data visualization software to gather a large number of publications (Chen 2017). We used this method to summarize the research status, shed light on possible future development, and provide theoretical references for possible future development, and provide theoretical references for decision-makers (X. Zhang et al. 2020). The research framework is shown in Fig. 1.

### Data sources and methods

#### Database

To increase the authenticity and representativeness of data, we searched the Web of Science (WOS) Core Collection, which is one of the most comprehensive sources of literature and contains two main indexes: Science Citation Index Extended (SCIE) and Social Science Citation Index (SSCI) (Id et al. 2016). We used TS (TS: topic search) = “urban
resilience” or “resilient city.” The time period was from January 2011 to June 2021, and the article was the search type. Consequently, we obtained 4467 records. By using the refinement functions of WOS research directions and categories, we excluded publications in anesthesiology, immunology, criminology, penology, and other unrelated fields, and finally obtained 2719 records. We went through these records, and removed irrelevant publications, which made up a large percentage of the total. Finally, we obtained 1,647 publications as the basis for research (Supplementary File S1).
Methods

Knowledge graph analysis

Knowledge mapping is a multidisciplinary research method that combines applied mathematics, graphics, information visualization technology, and other disciplinary knowledge with scientometric citation analysis and co-occurrence analysis to display the developmental path, hot frontiers, and knowledge theme structure of a discipline or field. The analysis methods used in this study mainly include social network, co-citation, and co-occurrence analyses.

Social network analysis is an analytical method that takes the collection of social actors and their relationships as the object of analysis. Aspects such as overall network, individual network, centrality, preference network, and network evolution can be determined through the social network. Applying this method to the knowledge graph can objectively and scientifically reveal the relationship between various forms of knowledge, knowledge and disciplines, and various disciplines, providing strong evidence for in-depth exploration of evolutionary logic.

The principle underlying co-citation analysis is that when two or more documents are cited by other documents simultaneously, these documents are said to share a co-citation relationship. The number of citations is called the association strength or co-citation strength. The more times two papers are cited simultaneously, the stronger the connection between the two is. Literature co-citation analysis can mine the relationship between reports and identify representative literature and research directions. The greater the strength of the association between documents, the more similar the research topics, and the closer the relationship between the documents.

The principle of co-occurrence analysis is to count the number of times they appear in the same document for a set of keywords. Based on this, a co-occurrence matrix is constructed for these keywords, and cluster analysis is performed to reflect the internal relationship between these keywords. Subsequently, the structural changes, hot frontiers, and thematic structures of the subject areas represented by these keywords are analyzed.

CiteSpace software

Of the several commonly used visual analysis softwares, including HistCite, VOSviewer, RefViz, SATI, and CiteSpace, we selected CiteSpace 5.6 R3 as the main tool for a comprehensive analysis of the selected literature after comparing the characteristics of these programs. CiteSpace is a free Java application developed by the team of Professor Chen Chaomei of Dressel University (Chen 1999; Chen and Paul 2001). It is an information visualization software that can be based on multi-perspective analysis (Chen 2004). The main advantages of CiteSpace over other visualization software are as follows:

1. The original data format of databases such as WOS can be directly imported for operation and drawing without converting to matrix format.
2. The CiteSpace software is rich in functions, and multiple maps can be drawn based on the same data sample according to different needs.
3. The map is clear and easy to understand, and the results of the map analysis can be seen quickly and intuitively, which is convenient for subsequent interpretation.
4. CiteSpace has a strong theoretical background. It is a professional scientific tool that integrates visual, mathematical, and philosophical thinking (Chen et al. 2014).

Results and discussions

Basic situation analysis

Trends in the number of publications

After data screening, we obtained 1647 publications dating from 2011 to 2021. Annual publications can reflect the attention of a researcher to a particular field, and the number of publications revealed three distinct phases (Fig. 2). From 2011 to 2014, the UR theoretical research already had a foundation (Andersson 2006; Douglass 2002). During that period, the publications had shown a slow growth and accounted for 12.99% of the total. Between 2015 and 2017, publications per year exceeded 90, and the proportion of publications was almost twice that of the previous phase. Since 2018, UR research and publication has experienced exponential growth. From 2018 to 2020, more than 200 papers per year were published in each consecutive year. As of June 30, 2021, 134 papers have been published, which accounts for 61.20% of the total. Therefore, UR has become an active area of research for many scholars. Additionally, UR case studies have increased substantially (Ancuta et al. 2015; Stephen et al. 2015; Mcnally et al. 2009). Simultaneously, the principle of UR has been widely used in various aspects of urban protection and disaster management, such as urban dynamic balance (Clemente et al. 2015), urban ecology (Zhang et al. 2015), and resilient housing (Seelig 2011). Thus, URR has entered a flourishing stage of interdisciplinary development.

The United States (US), the United Kingdom (UK), and China are the leading countries in terms of publications from 2011 to 2021 (Fig. 3). The US has maintained a steady upward trend in URR and has more publications than those of the other two countries. The UK and China have similar
numbers of publications, but the changing trends are different. Consistent with Fig. 2, the number of publications in the three countries showed an upward trend before 2015. After 2015, the annual publication volume of China has increased steadily (from 2016 to 2020). Therefore, 2015 can be regarded as a new beginning for URR. As of June 2021, the number of publications in China is higher than those of the US and UK.

Cooperation network analysis

Our analysis of cooperation networks focuses on the importance and relevance of countries, institutions, and authors. It reveals the distribution of research power and cooperation intensity and the distribution among different nodes in the global network.

By analyzing the cooperation network between countries and institutions, it is possible to identify key countries and institutions that have published a large number of papers regarding URR, are influential, and are able to determine the cooperative relationship between them. We found that 359 institutions from 110 countries (regions) participated in URR (Fig. 4). Among them, three countries and five institutions have published the largest number of papers. Consistent with 3.1, the US (number of published papers \( \text{Count} = 397 \)) is in a leading position in URR, and its centrality is also the highest (Centrality \( \text{Centr} = 0.46 \)), followed by the UK (Count = 239, Centr = 0.23) and China (Count = 230, Centr = 0.13). Arizona State University, University of Exeter, Stockholm University, Chinese Academy of Sciences, and Technische Universität Delft are the top five institutions belonging to the US, Britain, Sweden, China, and the Netherlands, respectively. In addition, we used ArcGIS10.2 to map the global spatial distribution of publications (Fig. 5). It was clear that, apart from the US and UK, developed countries have the largest number of publications. Developing countries like China have experienced large-scale urbanization and land expansion, and the number of publications is also among the greatest. Other countries with relatively small territories are also included in the main force behind URR, such as Italy, Australia, the Netherlands, Germany, and Spain.
Chinese research results are concentrated in a few institutions such as the Chinese Academy of Sciences (CAS), the University of Hong Kong, Tsinghua University, Northeastern University, and Peking University. Among them, the CAS is more prominent, and its universities have 38 publications. In contrast, the US has a large number of institutions involved in URR, including Arizona State University (Count = 40), US Forest Service (Count = 17), Cary Institute of Ecosystem Studies (Count = 14), University of California Berkeley (Count = 11), Texas A&M University (Count = 10), and The New School (Count = 10). Many institutions in the UK, such as the University of Exeter (Count = 38), University of Birmingham (Count = 14), Kings College London (Count = 12), University College London (Count = 10), and the University of Leeds (Count = 10), also contribute to the URR literature. The top five institutions in terms of publication numbers also include Stockholm University in Sweden (Count = 28) and Technische Universiteit Delft in the Netherlands (Count = 23).

Centrality is paramount from the perspective of cooperative networks. It represents the strength of a node in the entire network, which is the number of connections between the node and other nodes. High centrality means that a key node strongly influences the relationship within the network (Wang et al. 2020). Spain has the highest centrality (Centr = 0.68), followed by Austria (Centr = 0.53). They also cooperate closely and have close cooperative relations with France (Centr = 0.44), China (Centr = 0.33), and the UK (Centr = 0.25).

The author cooperation network differs from the distribution of national and institutional cooperation network, which is relatively concentrated. The author cooperation network (1194 scholars) is distributed in several groups (Fig. 6). Our analysis of the number of publications by authors and the collaboration network shows that 419 authors are researching URR, and 67 have published three or more articles. David Butler, from the University of Exeter in the UK, has published the most articles (18 published papers). David Butler, Guangtao Fu (8 published papers), and Raziyeh Farmani (7 published papers) worked closely together to establish a small-scale cooperative network group. Timon McPhearson of The New School (14 published papers) ranked second. He worked closely with Niki Frantzeskaki (9 published papers) of Erasmus University and others to establish a large-scale cooperative network group. In addition, Marcelo Gomes Miguez from the Federal University of Rio de Janeiro has been committed to URR since 2019, and has published numerous papers. These may develop into more influential groups in the future.

Subject evolution analysis

The subject category network reflects the integration of disciplines in a certain field and the evolution of mainstream disciplines over time. According to CiteSpace5.6.R3, we found 26 topic categories, 13 of which have a frequency of more than 100 times (Fig. 7).

Global ecological health is gaining international attention and has promoted the maturity and innovation of ecological theories and methods (ETM). Using ETM to solve resource shortage and environmental pollution problems caused by excessive urban expansion has become a research hotspot. At present, “environmental science & ecology” and “environmental sciences” are still the main topics of URR, accounting for 15.2% and 13.3% of the papers, respectively. “Environmental science & ecology” is the largest node with 1079 counts, followed by “environmental sciences” with 940. Among the top 13 disciplines, “green & sustainable science & technology” has the highest centrality (Centr = 0.37), playing a pivotal role in the field of non-point sources (Smith et al. 2016). In second place is environmental studies (Centr = 0.31), followed by environmental sciences (Centr = 0.29), and civil engineering (Centr = 0.20).

In addition, the research results of “science and technology—other topics” (Count = 511) and “water resources” (Count = 439) have grown steadily. Through the color circle analysis, it was seen that non-point source research is multifaceted and covers a wide range of disciplines including environmental sciences & ecology, meteorology & atmospheric sciences, geosciences, geology engineering, ecology, etc. The development of various disciplines has made great
contributions to the integration of URR into multidisciplinary science.

**Knowledge base analysis**

**Co-citation clustering analysis**

The co-citation analysis revealed the research field’s knowledge base and developmental background. Document co-citation occurs when the same publication cites two documents simultaneously. This method shows the knowledge structure of academic research, predicting possible future research directions. Clustering occurs in the process of document co-citation analysis and is used for document evolution trend analysis. We found 74,622 co-cited articles among 1647 publications. For publications that have been cited more than once, see Supplementary Material 2. The common citation frequency threshold is set to 2, and the literature is clustered by keywords. We have obtained 11 clusters that reflect the knowledge base of URR (Fig. 8). The modularity $Q$ of the network is 0.8203, which indicates that the various research fields of URR can be clearly defined (Chaomei 2017). The Mean Silhouette is 0.612, which indicates that the clusters have reasonable uniformity.

Although our research spans from 2011 to 2021, there are related papers from as early as 2004. Both “gis” and “urban regeneration” are clusters that appeared in 2004. The former is closely related to land resource utilization and land cover changes. Land use and cover change are among the most important responses of global environmental changes and terrestrial ecosystems to global climate change and human activities. In this cluster, keywords mainly include spatial dynamic simulation, multi-objective land use allocation, green infrastructure, and sponge city. The latter is closely related to urban development and resources. Urban development mainly includes sustainability, urban recovery, urban renewal, and the urban system; urban resources mainly include water resources, irrigation, energy conservation, and biodiversity.

Three clusters appeared in 2005, namely, “transition” (2005–2012), “stormwater” (2005–2011), and “civic ecology” (2005–2014). Among them, the literature cited in the

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Fig. 5 Spatial distribution of global urban resilience research publications
Fig. 6 Network map of author collaborations in urban resilience research
“transition” cluster mainly focuses on the ability of cities to deal with uncertainties and emergencies, as well as the changes in resilience before and after disasters. The keywords used mainly include transformative governance, adaptive governance, energetic resilience, transformation, social vulnerability, etc. The literature cited in the “stormwater” cluster mainly focuses on the changes in all aspects of the global response to climate change. The keywords used mainly include urban water regime, path dependency, stormwater management and control, and low impact development. The “civic ecology” cluster lasted for 9 years, and is closely related to urban ecological resources and food security. Urban ecological resources mainly include social-ecological network analysis, urban political ecology, and
urban green spaces. Food security mainly includes agriculture, gardens, and quality of life.

“Planning support system” appeared in 2007 and lasted until 2015. Further, “ecosystem services” appeared in 2008 and lasted until 2019. These two clusters are related to each other and complement each other. The former is committed to building a city dynamic system that can maintain and enhance UR. Moreover, “urban ecosystem services” are inseparable from the development of cities and the health of residents. Cities must prioritize guaranteeing the elastic supply of ecosystem services to ensure livable and sustainable cities, especially considering the dynamic characteristics of urban systems that constantly respond to global environmental changes. Worldwide URR cases have confirmed that urban ecology has developed into an interdisciplinary subject integrating ecology, geography, planning, and social science. The most prominent focus of current research activities is the emerging urban sustainability paradigm, which primarily addresses urban ecosystem services and their relationship with human well-being.

“ Sustainability transitions” and “resilience” are clusters that appeared in 2010 and lasted until 2017. The former is mainly related to the research and expansion of theories, and the main keywords are environmental change, urban sustainability, sanitary city, ecology for cities, social theory, etc. The latter mainly focuses on urban practice, including the practice of theories, models, and methods. The main keywords are green infrastructure, spatial planning, planning strategies, flood hazard management, and damage model.

“Science-policy” (2011—2019) and “urban flooding” (2012—2018) are clusters that appear successively. The former keywords mainly include knowledge politics, changing social practices, redundancy, local government, and knowledge co-production. The latter mainly includes urban governance, community resilience, disaster resilience, and disaster management. In this clustering, scholars mainly used case studies to reflect the ability of a city to resist in all aspects during floods and other disasters.

**Most frequently co-cited publications**

Through co-citation analysis, we have identified 19 publications that have been cited more than 22 times (Fig. 9; Table 1). The figure shows the development of the theme so far, including the collision of views, interdisciplinary cooperation, typical case studies, modeling, and methods.

Among the most frequently cited documents, 57.9% are journal articles that provide literature reviews, opinions, or perspectives. Among them, we found a monograph (Pelling 2011) that comprehensively analyzed the climate change adaptation process of the social dimension. Based on the introduction of elasticity-related theories, the author...
discusses the elastic transition framework and analyzes an approach for cross-research on the elasticity framework and climate change. Davoudi et al. (2012) applied the elasticity view to planning, and discussing it in theory and practice. Folke (2006) systematically discussed the origin and development of resilience, using it as a method to explain the dynamics of social ecosystems. Subsequently, Folke expanded the previous research. In 2010, he published an article (Folke et al. 2010) implying that resilience thinking provided ideas for the dynamics and development of complex social ecosystems and expounded it from three aspects: flexibility, adaptability, and convertibility. Fletcher et al. (2014) recorded the history, scope, application, and basic principles of urban drainage terminology, providing recommendations for clear communication of these principles. Ahern (2013) proposed five strategies for building resilience and interdisciplinary cooperation: biodiversity, urban ecological network and connectivity, versatility, redundancy and modularity, and adaptive design. Liao et al. (2015) developed the “urban flood resilience” theory as an alternative framework for urban flood disaster management. Flood control can be replaced with flood adaptation to fully utilize the functions of natural floodplains, enhance flood resistance of the city, and reduce flood-related disasters. Colding and Barthel (2013) provided innovative insights on how the common property system can contribute to the construction of UR. They discussed the potential of urban green commons (UGCs) in managing urban culture and

Table 1 Most frequently co-cited publications (≥22 citations)

| No | Count | Centr | Author               | Title                                                                 | DOI                       |
|----|-------|-------|----------------------|----------------------------------------------------------------------|---------------------------|
| 1  | 121   | 0.06  | Meerow et al. (2016) | Defining urban resilience: a review                                  | 10.1016/j.landurbplan.2015.11.011 |
| 2  | 55    | 0.40  | Ahern (2011)         | From fail-safe to safe-to-fail: sustainability and resilience in the new urban world | 10.1016/j.landurbplan.2011.02.021 |
| 3  | 52    | 0.02  | Davoudi et al. (2012)| Resilience: a bridging concept or a dead end?                      | 10.1080/14649357.2012.677124 |
| 4  | 39    | 0.10  | Cutter et al. (2014) | The geographies of community disaster resilience                     | 10.1016/j.gloenvcha.2014.08.005 |
| 5  | 38    | 0.04  | Tyler & Moench (2012)| A framework for urban climate resilience                           | 10.1080/17565529.2012.745389 |
| 6  | 37    | 0.12  | Mugume et al. (2015) | A global analysis approach for investigating structural resilience in urban drainage systems | 10.1016/j.watres.2015.05.030 |
| 7  | 37    | 0.03  | Folke et al. (2006)  | Resilience: the emergence of a perspective for social–ecological systems analyses | 10.1016/j.gloenvcha.2006.04.002 |
| 8  | 33    | 0.21  | Fletcher et al. (2014)| SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage | 10.1080/1573062X.2014.916314 |
| 9  | 32    | 0.50  | Folke et al. (2010)  | Resilience thinking: integrating resilience, adaptability and transformability | 10.5751/es-03610–150,420 |
| 10 | 30    | 0.01  | Meerow et al. (2017) | Spatial planning for multifunctional green infrastructure: growing resilience in Detroit | 10.1016/j.landurbplan.2016.10.005 |
| 11 | 27    | 0.01  | Ahern (2013)         | urban landscape sustainability and resilience: the promise and challenges of integrating ecology with urban planning and design | 10.1007/s10980-012–9799-9 |
| 12 | 26    | 0.05  | Ernstson et al. (2010)| Resilience thinking: integrating resilience, adaptability and transformability | 10.1007/s13280-010–0081-9 |
| 13 | 25    | 0.00  | Wolch et al. (2014)  | Urban green space, public health, and environmental justice: the challenge of making cities “just green enough” | 10.1016/j.landurbplan.2014.01.017 |
| 14 | 24    | 0.06  | Pelling (2011)       | Adaptation to climate change: from resilience to transformation, Routledge, London | ISBN: 9,780,415,477,512 |
| 15 | 22    | 0.09  | Cutter (2016)        | The landscape of disaster resilience indicators in the USA           | 10.1007/s11069-015–1993-2 |
| 16 | 22    | 0.18  | Liao (2015)          | A theory on urban resilience to floods—a basis for alternative planning practices | 10.1177/0956247814550780 |
| 17 | 22    | 0.08  | Barthel et al. (2010)| Social–ecological memory in urban gardens—retaining the capacity for management of ecosystem services | 10.1016/j.gloenvcha.2010.01.001 |
| 18 | 22    | 0.01  | Revi et al. (2014)   | Urban Areas in Climate Change 2014: impacts, adaptation, and vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change | https://www.researchgate.net/publication/275035197 |
| 19 | 22    | 0.21  | Colding and Barthel (2013)| The potential of “Urban Green Commons” in the resilience building of cities | 10.1016/j.ecolecon.2012.10.016 |
biodiversity, offering key insights on how UGCs can promote UR.

The case study results accounted for 63.2% and provided a reference for the method and content of the follow-up study. Cutter et al. (2014) took the US as a research case and created an experience-based resilience measure called “Baseline Resilience Indicators for Communities (BRIC).” Midwest counties and Great Plains states have the most inherent resilience, while counties in the west, along the US-Mexico border, and the Appalachian Mountains in the east have the lowest resilience. Therefore, BRIC can guide policymakers to invest in intervention strategies based on the analytical results of UR improvement. Tyler & Moe (2012) published a review based on case studies, which analyzed the development of the general concept of urban climate resilience into an operational framework for planners. The framework combines theoretical and empirical knowledge of factors contributing to resilience with the process of translating these concepts into practice. The feasibility of the proposed framework has been proved by the exemplary disaster resilience planning activities carried out in ten Asian cities (funded by the Rockefeller Foundation). Ernstson et al. (2010) expanded the discussion on UR and proposed that urban governance transformation enables cities to manage changes, withstand shocks, and use experimentation and innovation during uncertainty. In addition, an empirical analysis was carried out with New Orleans, Cape Town, and Phoenix as examples. Wolch et al. (2014) reviewed the Chinese and American literature on urban green space, compared the efforts of the US and China in green cities, and analyzed the application of urban green space strategies in each country. Barthel et al. (2010) analyzed the social-ecological memory of allotment gardens in Stockholm, Sweden. They discovered the role of urban gardens in generating ecosystem services during periods of crisis and change, which indicated that managers of urban green spaces and the social memories they carry might help offset a further decline in key ecosystem services.

Cited documents focusing on models and methods accounted for 42.1% of the citation frequency, indicating that scholars are gradually realizing the importance of exploring innovative modeling in UR. The article by Ahern (2011) has the highest centrality among the most frequently cited articles (98 citations, DC = 0.33). It discusses the applicability of disaster resilience theory to cities and provides a series of strategies to enhance the UR, including multifunction, redundancy and modularity, diversity, and adaptive planning. Mugume et al. (2015) studied and applied a new analytical method based on global resilience analysis to systematically evaluate the performance of urban drainage systems in various structural failure scenarios caused by random cumulative connection failures. They used this novel method to test and characterize the existing urban drainage system in Kampala, Uganda. The effectiveness of the potential adaptation strategy in enhancing its resilience to cumulative link failures was also tested. The most frequently cited publication is by Meerow et al. (2016) on how to define UR (243 citations, Centrality = 0.18). This article proposes six concepts that are critical to UR: (1) definition of “city,” (2) understanding system balance, (3) the flexible concept of positive and neutral (or negative), (4) the mechanism of system reform, (5) adaptability and general adaptability, and (6) action schedule. This article has been widely cited because it is comprehensive, broadens the research scope of UR, and lays a suitable theoretical foundation for follow-up research. Cutter (2016) examined 27 resilience assessment tools, indicators, and scorecards, investigating 14 cases to propose a set of core attributes/assets, capabilities, and methods to measure the resilience of a community. The IPCC Fifth Assessment Report Working Group II report (Revi et al. 2014), “Urban Areas in Climate Change 2014: Impacts, Adaptation, and Vulnerability,” assessed the impact of climate change on different fields (regions) and confirmed that climate change is the main cause of adverse effects and key risks in natural and human social systems. This report contains four main parts: (1) policy formulation and concept analysis, (2) overview of climate change risk assessment and management technologies, (3) overview of the relationships and risks among factors (ecosystems, population, and freshwater) at different scales and regions, and (4) the impact, adaptation, and vulnerability of multi-disciplinary fields to climate change.

Research frontier analysis

Term co-occurrence analysis

The term co-occurrence analysis provides basic information on core content and helps scholars track the development of research topics in different stages of URR. We set the time interval to 2011–2021, the threshold to top 40 per slice, and the thresholds of C, CC, and CCV to 2, 2, and 20, respectively. Using PNS to simplify the network, we got 358 nodes and 760 connection lines with a density of 0.0119. According to the statistics and analysis of terms by CiteSpace, a total of 125 research topics (Supplementary Material S3) appeared more than five times. We sorted them into five categories: subject, content, methods, factors, and purpose (Fig. 10; Table 2).

From 2011 to 2014, URR had a particular theoretical basis, and the number of publications increased slowly. Many new terms were defined at this stage, and the number of new terms reached 54.4% of the total. From 2015 to 2017, the number of publications increased exponentially, and the number of new terms decreased compared to that of the previous phase, accounting for 29.6% of the total. Since
2018, although the number of papers has grown steadily, the number of new terms has decreased because most of the relevant terms have been defined in the previous literature.

From 2011 to 2014, most of the emerging UR terms were related to factors (27.9%), subject (22.1%), and purpose (20.6%). Content (17.6%) and methods (11.8%) received relatively low attention. Under the term “factors,” climate change (Rogers and John 2000) frequently appeared, approximately 342 times, during the entire period. It is the most important node in the term co-occurrence network, and is a continuous term in the three research stages. This is because the term “resilience” was first applied to system ecology to define the characteristics of the stable state of the ecosystem, and then it gradually extended from natural to human ecology. The URR was initiated to facilitate the adaptation of cities to global climate change. At this stage, adaptive capacity (Pelling 2002) and natural disasters are two important factors. UR is the main research subject, while urban area (Durant et al. 1994) is the research scope covered by most publications (202 times during the entire period).

From 2015 to 2017, the number of publications increased dramatically, and the topics explored continued to grow. Based on previous theoretical research, the growth rate of new terms has decreased compared with that of the previous stage, with 29.6% of new terms appearing in this stage. The terms under the categories of factor (29.7%) and subject (24.3%) still occupy the mainstream position. “Rapid urbanization” (Lei Ding Kun-lun Chen et al. 2015) is critical factor (24 citations, Centr = 0.03), and “developing countries” is the main research subject (31 citations, Centr = 0.04). The mainstream research methods are nature-based solution (Raymond et al. 2017), geographic information system (Li et al. 2017), adaptation measure, integrated approach, semi-structured interviews (Camps-Calvet et al. 2016), and other...

Fig. 10 Numbers and proportions of new terms during the three stages of the evolution of urban resilience research

| Stage I: 2011—2014 | No | Count | Centr | Year | Term | Category |
|-------------------|----|-------|-------|------|------|----------|
| 1                 | 342| 0.04  | 2011  | Climate change | Factors |
| 2                 | 202| 0.03  | 2011  | Urban area    | Subject |
| 3                 | 150| 0.01  | 2012  | Urban resilience | Content |
| 4                 | 90 | 0.11  | 2012  | Ecosystem service | Subject |
| 5                 | 78 | 0.06  | 2011  | Urban planning | Purpose |
| 6                 | 69 | 0.12  | 2011  | Case study    | Content |
| 7                 | 64 | 0.22  | 2011  | Adaptive capacity | Factors |
| 8                 | 62 | 0.02  | 2011  | Sustainable development | Purpose |
| 9                 | 61 | 0.09  | 2012  | Natural disasters | Factors |
| 10                | 58 | 0.01  | 2011  | Urban development | Purpose |
| 11                | 57 | 0.06  | 2014  | Green infrastructure | Content |
| 12                | 54 | 0.04  | 2012  | Natural hazards | Factors |
| 13                | 53 | 0.06  | 2012  | Urban system   | Subject |
| 14                | 45 | 0.10  | 2012  | Urban environment | Factors |
| Stage II: 2015—2017 | 17 | 38    | 0.01  | 2016 | Nature-based solution | Methods |
| 18                | 38 | 0.06  | 2016  | Urban flooding | Content |
| 19                | 31 | 0.04  | 2015  | Developing countries | Subject |
| 20                | 28 | 0.00  | 2017  | Geographic information system | Content |
| 21                | 25 | 0.05  | 2015  | Climate resilience | Purpose |
| 22                | 24 | 0.01  | 2016  | Green space | Content |
| 23                | 24 | 0.03  | 2015  | Rapid urbanization | Factors |
| 24                | 22 | 0.02  | 2015  | Extreme weather event | Factors |
| Stage III: since 2018 | 31 | 14    | 0.00  | 2020 | Urban floods | Content |
| 32                | 12 | 0.00  | 2020  | Urban flood resilience | Content |
| 33                | 11 | 0.06  | 2018  | Local authorities | Subject |
| 34                | 10 | 0.00  | 2020  | Sustainable management | Methods |

Table 2 Major terms used in urban resilience research (the top 20% of terms for each stage)
high-frequency standardized methods. The terms under the categories of content and purpose have been reduced. At this stage, urban flooding (38 citations, Centr = 0.06), green space (24 citations, Centr = 0.01), and urban green infrastructure (10 citations, Centr = 0.04) are the research areas covered by most publications. Climate resilience (25 citations, Centr = 0.05), negative impacts (Georgeson et al. 2016), and disaster risk reduction (Salgado-Gálvez et al. 2016) are the main research purposes.

Since 2018, articles on UR have been increasing. However, there are fewer new terms than those of the previous two stages, and they account for only 16.0% of the total, mainly because many terms have been defined before. The most frequently used terms are still urban floods (12 citations) and urban flood resilience (14 citations; Lb et al. 2019), and others belong to the content category, which is the extension and development of UR in the field of water resources. In contrast to the previous stages, content terms account for a large proportion (35%) of new terms. “Policy makers” and “sustainable urban development” are the only two terms under the purpose category. With the development of UR, more practical projects have emerged, and there is a greater need for the implementation and operation of projects based on national policies since this is of great significance to the realization of sustainable urban development. “Local authorities” is a term used frequently and centrally under the subject category. Since 2018, the Covid-19 pandemic (24 citations) (Xu et al. 2020) has become a key term under the factor category, reflecting the fact that people pay attention to the ability of cities to resist natural disasters but pay more attention to their endurance and resilience in the face of major health and safety accidents. The world has faced major challenges, especially since the 2019 outbreak of Covid-19. Once the epidemic was under control, methods to quickly resume economic operations and development in cities became a research hotspot for scholars. Hence, sustainable management, water management, and cascading effects have become important topics under the methods category in URR. This shows that with the acceleration of urbanization, people focus on economic and sustainable development within the urban system, as well as on management measures to improve the resilience of the system. In the past decade, URR has become more mature and comprehensive in its research hotspots and contents, practical methods, and measures, laying a solid foundation for the formation of a systematic theoretical framework.

Evolution of the term clusters

By clustering the terms, we identified nine main clusters (Fig. 11). These clusters cover four aspects: research topic, research content, research method, and research purpose. The longest duration is urban floods and pandemic (2011–2021), and these two clusters run through the entire period. The early terms of these clusters are relatively general, mostly including urban planning, urban green space, resilience thinking, urban communities, urban morphology, and other broader terms. In the mid-term, specific issues such as urban population, geographic information system, urban infrastructure, ecological resilience, urban ecosystem, and urban flood resilience have gradually received attention.

![Fig. 11 Clusters of urban resilience research based on the terms](image-url)
According to the research subject, we chose “urban water” (2011–2015) to describe the largest cluster. This cluster focuses on the flow and transformation of water, energy, materials, and waste driven by human activities. This shows that our focus is not only on the state of cities facing natural disasters but, more importantly, on the future ability of cities to resist hazards in various fields. The term “urban settlements” also belongs to the research subject (2012–2020). The terms of this cluster are mainly related to the resistance of cities and communities in the face of uncertain factors, including climate change adaptation, environmental resilience, adaptive governance, disaster risk management, and global change.

The research contents of the seismic risk (2012–2021) and heavy rainfall (2011–2020) clusters are related to external adversities, including natural disasters and injuries caused by human activities. The terms mainly include physical damage, flash floods, communication technology, multilayered safety, risk assessment, and citizen participation. UR refers to the ability of cities to withstand disasters with their own capabilities, reduce disaster losses, and rationally allocate resources to quickly recover from disasters. The purpose is to enable cities to learn from past disasters and improve their ability to adapt to future disasters.

Around 2012, urban sustainability (2011–2020) and UR (2012–2021) appeared successively. These two clusters are used for research purposes and cover the entire period. The main terms include the scenario planning process, future generations, drainage system, limited resources, developed framework, cascading effects, mathematical model, and watershed scale. The former illustrates that the ultimate purpose of URR is to achieve sustainable urban development and improve the internal stability of the urban system. The latter aims to realize the normal operation of urban public safety, social order, and economic development through reasonable preparation, buffering, and response to unpredictable disturbances.

The last cluster of innovation (2012–2017) is the research method. To promote urban renewal and achieve sustainable urban development, it is necessary to transform urban development and construction methods, promote urban structural optimization, and improve urban system functions. This involves adhering to the simultaneous development of “retention, reform, and demolition,” focusing on regeneration and improvement, and conducting surveys and evaluations of existing buildings, while establishing a coordinated mechanism to stock resources.

Conclusions

It has been nearly 3 years since the outbreak of the COVID-19. The rapid evolution of the virus challenges our ability to guard against it, and the world is suffering from negative shocks and pressures. Therefore, an increasing number of scholars are paying more attention to how cities can restore system resilience from external disturbances and how urban system resources can be allocated to face and adapt to sudden events or disasters as well as resist and resolve external disturbances after experiencing major public health emergencies.

In this study, we analyzed a large number of publications in the field of URR over the past decade and used CiteSpace and ArcGIS software to conduct a quantitative and visual review of academic achievements in this field. This study interprets URR from multiple perspectives and analyzes how the field changes as society develops and provides support for the effective and accurate prediction of changes in UR, thereby providing guidance for government and disaster management officials as well as references for the future development of the field.

The field of URR has evolved from a theoretical framework to being practically applicable in the present day, from single disciplinary research in fields such as engineering, disaster science, and ecology to multidisciplinary research. The development of URR has yielded many results in terms of theoretical frameworks, methodological models, and case applications. According to our analysis, the field of URR will maintain a diversified development trend in the future. We propose the following directions for future research, to provide new insights for scholars and new ideas for decision-makers.

(1) Theoretical framework. The emergence of urban flooding clusters in knowledge base analysis and the appearance of terms such as stormwater, transition, and sustainability transitions shows that, in the context of global climate change, carbon emissions, and carbon neutrality, more scholars are searching for ways to solve the problem of urban water use from the perspective of UR, as well as ways to conserve and protect water resources worldwide. Water is a major agent of extreme weather events and the impacts of climate change. Adapting to the impacts of climate change on water resources through rational and efficient use of water resources will help reduce floods, droughts, water scarcity, and pollution. Simultaneously, realizing the efficient and intelligent utilization and protection of water resources is a common key foundation for promoting energy structure adjustment, low-carbon technology development, and environmental protection in addition to coping with global climate change and achieving the goal of “carbon peaking and carbon neutrality.” Therefore, energy, carbon emissions, water conservation, and climate resilience are important topics for future research, and are factors that need to be considered in policy formulation.
(2) Methods and models. The terms related to research methods, which appeared between 2011 and 2014, were primarily theory-based guidance methods. Most of the urban risk identification and resilience assessment methods that emerged since 2015 are relatively mature. There are different identification methods and evaluation criteria according to the type of space, including built-up areas in large cities as well as small and medium-sized cities, rural settlements, and coastal areas. Therefore, in the context of global intelligence, with the introduction of big data and artificial intelligence, the scope of URR will be expanded, and technology will enable research on resilient cities. The focus of URR will gradually shift from hardware construction to the application of comprehensive scientific and technological means in actual disaster prevention scenarios. From emergency response in disasters to real-time multidirectional monitoring and scientific quantitative assessment, data-driven and decision-making models are used to guide the construction of resilient cities, making urban disaster prevention management brighter and response decisions more scientific.

(3) Case application. According to our analysis, the practical application of RC is largely observed in cities in developed countries, with relatively few case studies in developing countries. Moreover, research in developing countries is generally aimed at first-tier cities (Shenzhen, Beijing, Shanghai) with high comprehensive economic strength. Therefore, future case studies should broaden the types of cities, select non-first-tier cities, and explore the problems and loopholes in UR construction of such cities, as well as the differences between different city types. By applying the concept of RC in specific cases, the feasibility and universality of the method model can be verified, and the theoretical framework of this field can also be enriched and expanded.

However, this study also has certain limitations:

(1) Although we have established a relatively comprehensive literature database, the criteria for our selection of publications may not allow the collection of all the articles on UR because URR covers a wide range of fields. Future bibliometric analysis can consider adding more databases (non-English publications) to provide a more comprehensive development strategy for URR.

(2) In the process of using CiteSpace, some unavoidable formatting problems and technical issues might have arisen, resulting in some documents or information not being recognized. Although such problems cannot be momentarily solved, we have avoided the interference caused by human factors to the greatest extent, and all publications were browsed and screened to ensure the reliability of the data. Nonetheless, we will extend the direction of this research in the future and carry out more in-depth content interpretation and policy analysis based on engineering projects.

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Data availability All data generated or analyzed during this study are included in the manuscript and supplementary material.

Declarations

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