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Review

Twenty Years of Resilient City Research: Reviews and Perspectives

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Abstract: The resilient city plays an increasingly important role in coping with the challenges raised by economic, social, and environmental risks. In this review, we examine approximately 27,094 papers published in the Web of Science Core Collection (WOSCC) and perform extensive bibliometric and scientometric analyses to identify the research themes, evolutionary history, and potential research trends in the state of the art in resilient city studies. Seven main resilient city research themes are identified, with significant differences persisting across regions. Specifically, the research on resilient cities in Europe, Asia, Africa, and North America reveals clear regional characteristics in macro development planning and strategies, technological methods, urban economic growth, urban water resource protection, and so on. The analysis also reveals the collaborative networks among different countries and regions in the study of resilient cities. The evolutionary history of resilient city research shows that it has gradually evolved from a single research field into a multidisciplinary field and further formed a unique discipline. Moreover, the urban ecological environment, urban economic development, urban sprawl, and urban mobility have become key research hot spots and trends in resilient city research. This study provides a systematic and data-driven analytical demonstration of resilient city research, which provides empirical support for policy formulation and practice.

Keywords: urban study; resilient city; urban risk; climate risk; urban resource

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1. Introduction

Due to the impact of extreme weather and disaster events caused by global climate change and economic recession, the risks and hazards faced by cities are increasing. In 2022, the volcano in Tonga erupted and had a catastrophic impact on the capital Nuku'alofa. The same year, Sudan experienced a severe flood, and the Nile and North Kordofan were critically affected. In 2021, Europe and North America suffered from extreme heat waves, which caused significant harm to many urban areas, such as Berlin, Paris, and London. On World Meteorological Day on 23 March 2023, the UN Secretary-General Guterres stated that climate change is triggering more extreme weather events and exacerbating heat waves, droughts, floods, wildfires, and famine while threatening to inundate low-lying countries and cities. With the frequent occurrence of hazards and extreme weather events, urban risk increases each year.

How cities cope with the impacts of various uncertain disasters and risks has become a key topic of global concern. In 2010, the United Nations Office for Disaster Risk Reduction (UNDRR) launched the "Making Cities Resilient" campaign [1]. In 2013, the Rockefeller Foundation launched the "Global 100 Resilient City" project [2]. Furthermore, in 2016, the United Nations Conference on Housing and Sustainable Urban Development made the ecology and resilience of cities among the core elements of the New Urban Agenda [3]. On World Cities Day 2018, the United Nations proposed that most of the world's cities are highly vulnerable to disasters; thus, building cities that are sustainable and resilient to disaster risk is critically important for the future [4]. The resilient city reflects the ability of cities to take measures to cope with climate change dynamically and effectively.

Along with international agencies' advocacy and promotion of resilience, research on resilient cities has flourished. Resilient city research has gradually covered urban infrastructure, the urban economy, urban society, and urban ecological resilience. In the field of urban infrastructure, studies have focused on infrastructure integration [5], external threats to urban infrastructure [6], and the rationalization of urban sanitation [7], as well as the study of urban culture and urban traffic congestion [8]. With respect to urban economic resilience, researchers have focused on urban fiscal crises [9] and the role of urban industrial manufacturing in high-value cities [10]. In the area of urban social resilience, research is relatively extensive, including studies on urban public health crises caused by urban structural inequality, urban density, etc. [11,12]; studies on the risk and vulnerability of shortage of urban resources, such as energy, food, and water, caused by the excessive rate of urbanization [13,14]; rational planning and layout of urban water resources in urban planning [15]; and how to improve a city's self-organizing capacity to cope with urban disasters [16,17]. In the sector of urban ecological resilience, numerous studies have concentrated on urban climate resilience transitions [18]; the role of local governments and local communities in urban climate resilience [19]; and even the health of residents due to climate change risk adaptation [20,21]. Emerging democratic countries lack awareness of establishing lasting diplomatic relations in terms of urban cooperation and collaboration.

However, although urban resilience has been studied extensively, there is obviously a large gap in the current research, which is mainly reflected in the unclear research themes, uncertain global distributions, and unknown evolutionary development trends. Therefore, in this paper, we address the following questions:

1. What are the main themes of resilient city research to date? What are the main hot spots of research on each topic, and what is the evolutionary development of each subject?
2. What is the distribution of regional research on resilient cities globally, and are the research focuses consistent or unique in each region? What are the reasons for these differences?
3. What are the main hot spots and trends in current research on resilient cities? What insights does the study of resilient cities provide for solving the urgent problems faced by global cities today?

The research objective of this article is to clarify the definition, core characteristics, and theoretical framework of resilient city research in order to provide clear guidance for research and practice; identify the main challenges cities have faced in the past 20 years in the face of natural disasters, climate change, socioeconomic inequality, etc.; promote the integration of multiple disciplines, such as urban planning, environmental science, sociology, and economics; provide evidence-based recommendations for policy makers; support the development and implementation of policies and measures that enhance urban resilience; promote international cooperation and knowledge sharing; help cities learn from global experiences; improve overall resilience; identify current research shortcomings and future research needs; and provide clear research directions for academics and practitioners. This study aims to enhance cities' ability to respond to various challenges and promote sustainable and inclusive urban development.

We gradually identify the main theme, characteristics, and evolutionary history and highlight research frontiers and potential development trends through the clearest, most intuitive, and most up-to-date methods.

2. Resilient City Overview and Literature Trends

Resilience is defined as the ability of a system to absorb disturbances and reorganize when changes occur to maintain essentially the same function, structure, properties, and feedback [22]. Originally, this term was used by physical scientists to denote the properties of a spring, describing its stability and its resistance to external shocks [23].

Given the broad framework of resilient cities, the research covers a wide range of areas. Xia Y et al. stressed the importance of integrating biophilic design concepts into

urban planning regulations, fostering interdisciplinary research, and raising public awareness [24]. de Andrade et al. concluded that urban resilience policies should not only focus on disaster risk prevention by developing brown infrastructure plans but also address social and environmental–natural aspects as fundamental to building a resilient city [25]. Zhao R et al. developed a quantification method to evaluate the resilient performance of sustainability [26]. Li L et al. analyzed the reactions of citizens during emergency rescues as social media users [27].

In urban studies, a resilient city is a city that can deal with various crises, such as earthquakes, floods, sociopolitical crises, and mass migration [28–32]. The key concept of the resilient city varies in different fields, as is shown in Table 1, and there is no unified authoritative definition of a resilient city. In this work, we adopted the view that resilient cities are urban areas with socioecological systems and technological network systems that can be restored to their original levels in time and space when facing disruptions [33].

Table 1. Definition of different domains of a resilient city.

Field	Definition	Source	Focus
City Infrastructure	A resilient city is a city with sustainable networks of physical systems and human communities. Physical systems are the constructed and natural environmental components of cities, including roads, buildings, infrastructure, and communication and energy facilities, as well as waterways, soils, topography, geology, and other natural systems [34].	Godschalk, D. R., 2003 [34]	Urban physical systems
Urban Governance	A resilient city is a city with the ability to maintain some dynamic mechanism and for which urban governance can build change in response to uncertainty and change [35].	Ernstson et al., 2010 [35]	Urban governance
Urban Ecology	A resilient city is a city that responds dynamically and effectively in the face of climate change, including the ability to resist or withstand shocks, recover, and reorganize while building the necessary physical response to prevent catastrophic events, minimize damage, and return all city functions to normal operations [36].	Brown, A., Dayal, A., Rumbaitis Del Rio, C., 2012 [36]	Climate change
Urban Social Ecology Network	A resilient city has socioecological and sociotechnical network systems to maintain and recover to desired levels of functionality in time and space when subjected to disruptions or disturbances; this includes the ability of cities to adapt to change and rapidly transform to limit current or future adaptive systems [33].	Meerow et al., 2016 [33]	Urban social ecology network

We analyzed the temporal distribution trend of resilient city research. As shown in Figure 1, it is worth noting that the average yearly growth rate of resilient city research is 16%. Also, it cannot be denied that part of the increase in research output is due to the expansion of the WOSCC database itself [37,38], but it is substantially higher than the average scientific growth rate of approximately 8–9% [39]. The research showed an overall growth trend from 2000 to 2022, and the number of papers exhibited a slow annual growth in the first five years from 2000 to 2015; however, after 2015, the number of papers increased explosively from 1245 to 4147 per year, reaching 4147 in 2021. This growth trend is likely related to the "Global 100 Resilient Cities" project launched by the Global Project

Rockefeller Foundation in 2013. The international agenda of the resilient city is important in leading research forward.

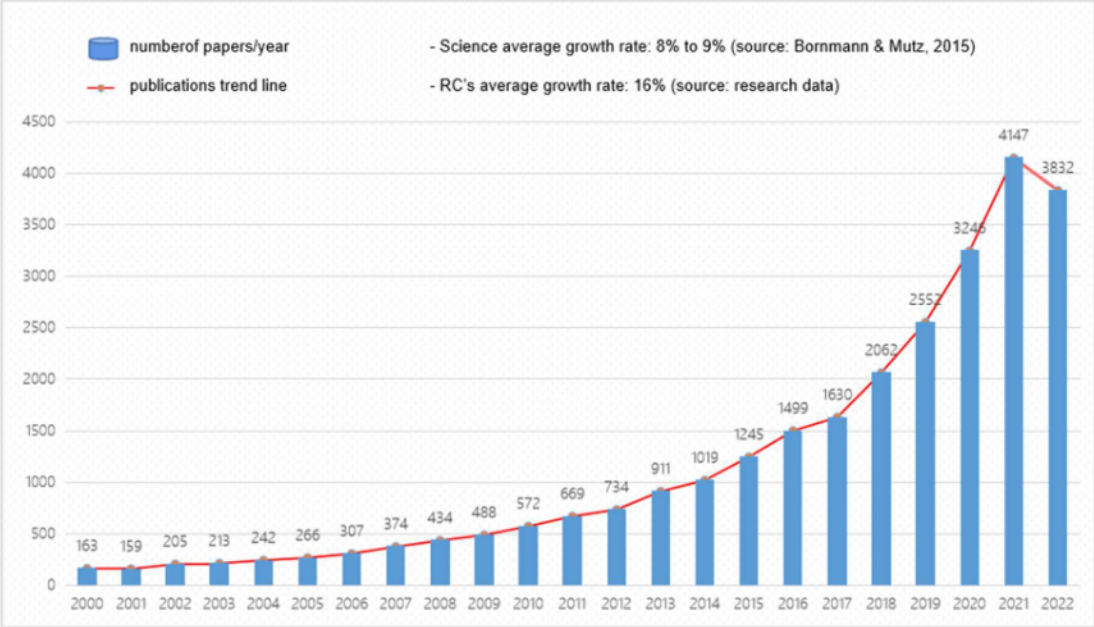

Figure 1. Number of papers per year about resilient city research [39]. Source: prepared by the author.

3. Materials and Methods

In this study, we carry out a scientometric and bibliometric review to identify the main characteristics of the resilient city and its evolution and to highlight the potential trends for prospective studies.

Scientometrics technology is a method that involves visualizing or mapping knowledge domains, and it is also a bibliometric method that applies to the published literature [40,41]. Through network modeling and visualization, it draws the structure and evolution of numerous disciplines on the basis of large-scale academic datasets. Scientometrics research aims to analyze the relationship between knowledge in a research field and collaboration among researchers, as well as the methods and research objectives they develop to achieve this goal [42–48].

Bibliometric analysis is a systematic research method that includes goals and clearly expressed data and methods through precise and reproducible methods [49]. Bibliometric analysis helps to measure and understand a given research topic in a research field; it provides a clear view of the historical evolution of a research field and simultaneously highlights research topics and technical analysis; and it also provides evidence and a basis for future research trends in a particular field.

The general research idea of this study is shown as follows. First, we divided the analysis's scope and data preparation and selected the WOSCC database. Second, we analyzed the number and trends of published papers. We then explored the classification and themes of resilient city research, including the disciplinary category, keyword timeline clustering, and the country cooperation network. Then, we analyzed the knowledge flow and citation trajectory of resilient city research through keyword time-line clustering and dual-map overlay to understand the historical evolution of resilient city research. Finally, we conducted disciplinary burst detection and keyword burst detection analysis to understand the research hot spots and frontier trends. The research framework is shown in Figure 2.

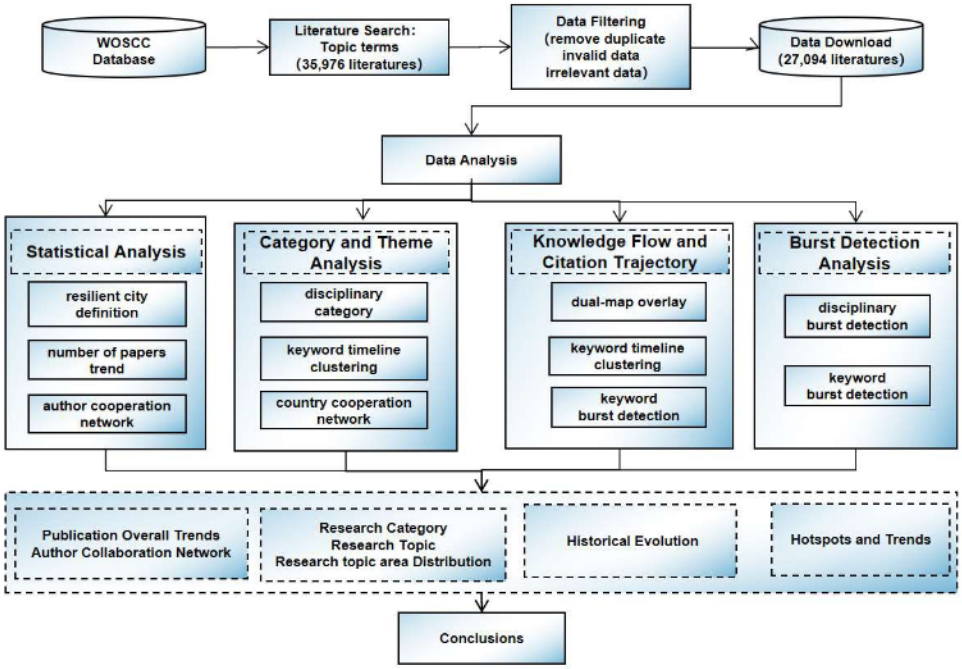

Figure 2. Research framework. Source: prepared by the author.

3.1. Data

The articles were searched on the Tomson Reuters WOSCC (Web of Science Core Collection) from 2000 to 2022; at the same time, we chose the Web of Science Core Collection of the database. According to the definition of a resilient city, the papers were selected using the following terms in the title, abstract, or keyword fields using the Boolean operator "OR.": city resilience, resilient city, city resident, city robust, city robustness, city recovery, city recoverability, urban resilience, resilient urban, urban resident, urban robust, urban robustness, urban recovery, and urban recoverability, as is shown in Appendix A. Finally, the search resulted in 35,976 results. Then, after deduplication, removal of invalid data, and the deletion of irrelevant data, 27,094 papers were entered into the research database.

3.2. Research Methods

We implemented a combined approach of scientometrics and bibliometrics analytic methods to investigate the study of the resilient city in various ranges using the visual software CiteSpace 6.3.3. Numerous statistical techniques were used, including timeline clustering, cooperative networks, burst detection, and dual-map overlay. The details of these methods are presented below.

3.2.1. Scientometrics and Bibliometrics

Scientometrics is a method for visualizing information in the field of scientific knowledge and a quantitative bibliometric technical approach to published papers [49]. The networks and knowledge maps can be depicted differently by choosing different information as the network actor, e.g., the author, institute, or country keyword, to reflect knowledge structures at the micro, meso, and macrolevels, respectively. Ravikumar, S et al. revealed the trends and patterns of scientometrics in the journal *Scientometrics* by measuring the association strength of selected keywords that represent the produced concept and idea in the field of scientometrics. Bibliometrics is a systematic approach to research on the basis of objectives [49]. It is primarily used to analyze a given topic, provide a clear view of the historical evolution of a field, present thematic and technical analyses, and provide evidence and a foundation for future research. Nobre, GC and Tavares, E analyzed the application of big data and the Internet of Things in the circular economy using bibliometric methods.

3.2.2. Keyword Clustering

To summarize the main theme of the resilient city, we chose keyword clustering to label the clusters in the timeline view, which is a method for depicting clusters of research topics along horizontal timelines in which each cluster is displayed from left to right [50]. The legend of the publication time is shown at the top. The clusters are arranged vertically in descending order of size. The largest cluster is shown at the top. The colored curves represent co-citation links added in the year of the corresponding color. Large nodes or nodes with red tree squares are of particular interest because they are either highly cited, they have citation bursts, or both.

3.2.3. Cooperation Network

To examine how the authors and countries collaborate, we implemented a network approach to study authors' publications and co-countries. Then, to quantify the impact on researchers, we counted the number of publications of each author and analyzed the result through Price's Elitism Law. According to Price's Elitism law, the number of productive authors who write half of all papers is equal to the square root of all scientific authors [51]. The formula can be expressed as:

$$\sum_{m+1}^{i} n(x) = \sqrt{N}$$

where $n(x)$ represents the number of authors who wrote x papers; $i = n(\max)$ represents the number of papers by the most prolific authors in the field; and N represents the total number of all authors.

Furthermore, to analyze the regional distribution characteristics of resilient city research, we built country cooperation networks in which each node represents a country and each link represents the cooperative relationship between different countries. The betweenness centrality indicator measures the extent to which the node is a part of a path that connects an arbitrary pair of nodes in the network [52–54]. Additionally, it refers to the number of times a node serves as the shortest path bridge between the other two nodes. From the perspective of information transmission, the higher the betweenness centrality, the greater the importance of nodes. Nevertheless, its calculation formula is as follows:

$$BC_i = \sum_{s \neq i \neq t} \frac{n_{st}^i}{g_{st}}$$

where g_{st} is the number of the shortest paths from node s to node t. The n_{st}^i is the number of shortest paths passing through node i among the shortest paths from node s to node t.

3.2.4. Burst Detection

The burst detection algorithm is designed to identify research front concepts [53,55]. The burst detection algorithm can be adapted for detecting sharp increases in interest in a specialty. The algorithm is generic enough to be applied to a time series of multiword terms or citations of articles. We mainly conducted disciplinary burst detection and keyword burst detection to analyze the hot spots and development trends of resilient city research. The calculation formula is as follows:

$$burst[t_1, t_2] = \sum_{t=1}^{t_n} (\sigma(0, r_t, d_t) - \sigma(1, r_t, d_t))$$

$$\sigma(i, r_t, d_t) = -ln\left[\left(\frac{d_t}{r_t}\right) p_i^{r_t} (1 - p_i)^{d_t - r_t}\right]$$

There are n batches of documents; the t-th batch contains r_t relevant documents out of a total of d_t; $r = (r_1, r_2, \ldots\ldots, r_n)$; $d = (d_1, d_2, \ldots\ldots, d_n)$. $R = \sum_{t=1}^{n} r_t$, $D = \sum_{t=1}^{n} d_t$.

3.2.5. Dual-Map Overlay

We imported a journal dual-map overlay interactive map, which is mainly used to analyze and display the distribution, citation trajectory, center of gravity drift, and other information regarding research in various disciplines and to explore the relationships between disciplines [56,57]. Each node represents a journal, and the connection between nodes indicates the number of citations between the published papers in the two journals. Curves of different colors are used to represent the evolution of journals in different fields. To compare and analyze the results more clearly, we use the z score option to convert the original score to a standardized score [55]. The z score indicator calculation formula is as follows:

$$z = \frac{\chi - \mu}{\sigma}$$

where x represents the original data of the links between the two nodes; μ represents the mean value of all of the data; and σ represents the standard deviation.

4. Author Cooperation Network

There was significant heterogeneity according to the number of each author's published papers. According to the WOSCC results, 27,094 papers were written by 95,818 authors, with a square root of all authors of approximately 310. The 310 elites should have published approximately 13,547 (half of 27,094) papers according to Price's Elitism Law [51]. However, the top-ranked 310 authors published 2690 studies in the research database. The value was lower than that estimated using Price's Elitism Law, indicating that it is not a fully constructed science.

Author collaboration is attractive, as shown in Figure 3; it is mainly dominated by nodes, such as green and red nodes, that represent research in the recent year, and fewer collaborative nodes, such as gray, that represent research in earlier periods. This indicates that the study of the resilient city is an important research field. The frequency rankings and degree centralities of the authors' publications are shown in Table 2. The five authors with the most papers were Sharifi, Ayyoob (30), Mcphearson, Timon (29), Frantzeskaki, Niki (27), Prezant, David J (26), and Li, Xin (26). We found that Sharifi, Ayyoob and Mcphearson, Timon focused more on urban climate change, urban ecology, and urban sustainability development [58–61], which are popular research topics. Similarly, Mcphearson, Timon was an important researcher in the field of urban sustainability who also played a key bridging role between collaborative groups (as shown in Figure 3).

Figure 3. Author cooperative network. Source: prepared by the author.

Table 2. Authors' cooperative network analysis.

Author	Rank	Frequency	Degree	Year	Institution
Sharifi, Ayyoob	1	30	1	2019	Hiroshima University
Mcphearson, Timon	2	29	29	2013	The New School
Frantzeskaki, Niki	3	27	19	2013	Erasmus University Rotterdam
Prezant, David J	4	26	37	2006	New York University School of Medicine
Li, Xin	5	26	10	2014	Shanghai Jiao Tong University
Butler, David	6	24	41	2010	University of Exeter
Manaia, Celia M	7	23	22	2010	Universidade Católica Portuguesa
Wang, Wei	8	23	14	2010	Cranfield University
Yang, Yang	9	23	11	2011	State University of New York College
Zeig-owens, Rachel	10	22	26	2010	New York City Fire Department, Bureau of Health Services

Unlike social networks and general citation networks, which show overall compatibility between highly nested nodes [62,63], the author collaboration networks in resilient city research do not present a core or degree-assortative structure [64]. Instead, it shows a star-shaped network structure, with highly decorative degree–degree correlations, implying that in resilient city research, there are great diversity and distributed research hubs in the community.

According to the dissimilarity network structure, as shown in Figure 2, the authors' collaborative network structure included three subtypes: the first mainly focused on self-independent research work; the second appeared as an individual network structure and independent team research; and the third appeared as a betweenness centrality structure, which was also a multiple collaborative network structure. The research core played an important role as a bridge between different research groups.

5. Disciplinary Categories

We analyzed the disciplinary categories according to the WOSCC classification to understand the research hot spots and key areas in resilient city research. The top 20 disciplines are shown in Figure 4. The main mostly focused on "environmental science", "green & sustainable", "urban studies", "engineering", "geosciences", "geography", "economics", "energy & fuels", "infection disease", and "ecology", followed by "transportation science" and "construction & building".

Among the disciplines studied, the two disciplines "environment science" and "environment studies" accounted for 19% and 10%, respectively, and they represented the main research area. The remaining disciplines were distributed with a proportion of more than 5% and less than 10%, which were concentrated in "green & sustainable science", "ecology environment", and "urban studies". Research in the fields of the ecological environment and urban areas has received a great deal of attention, accounting for more than 50% of the top 20 disciplines. Additionally, according to the analysis, studies in the fields of "engineering", "geosciences", "geography", "economics", "energy & fuels", "infectious disease", "transportation science", and "construction & building" were also popular and promising research fields.

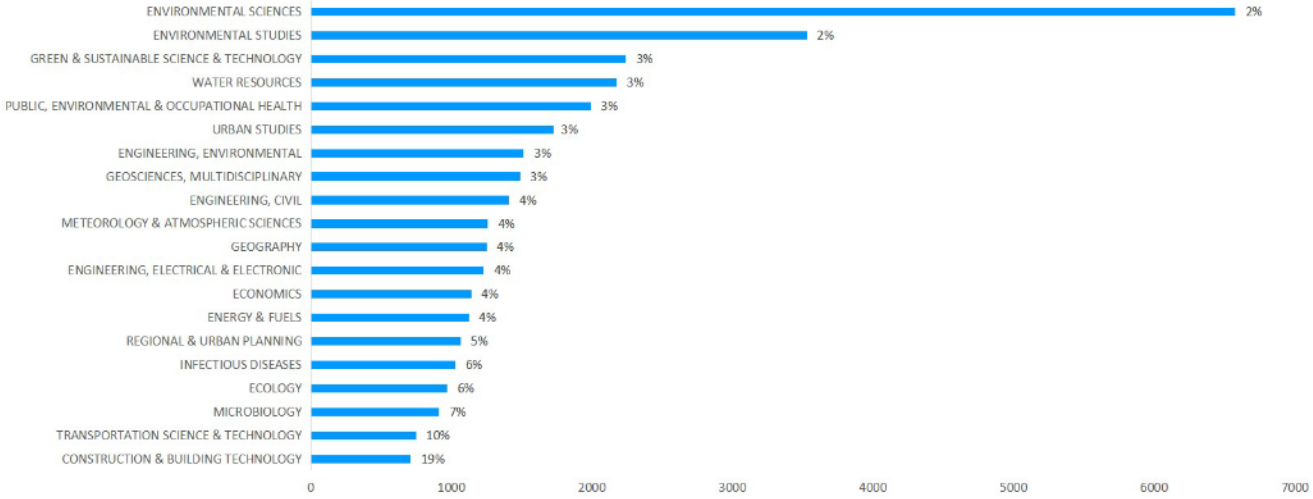

Figure 4. Disciplinary categories of the research. Source: prepared by the author.

6. Keyword Clustering Timeline

The keyword clustering timeline was mainly used to clarify the research themes and the historical evolutionary development of resilient city studies in this paper. The main themes of resilient city research, the research hot spots of each theme, and the development and changes in research hot spots over time are shown. The top seven major themes are shown in Figure 5.

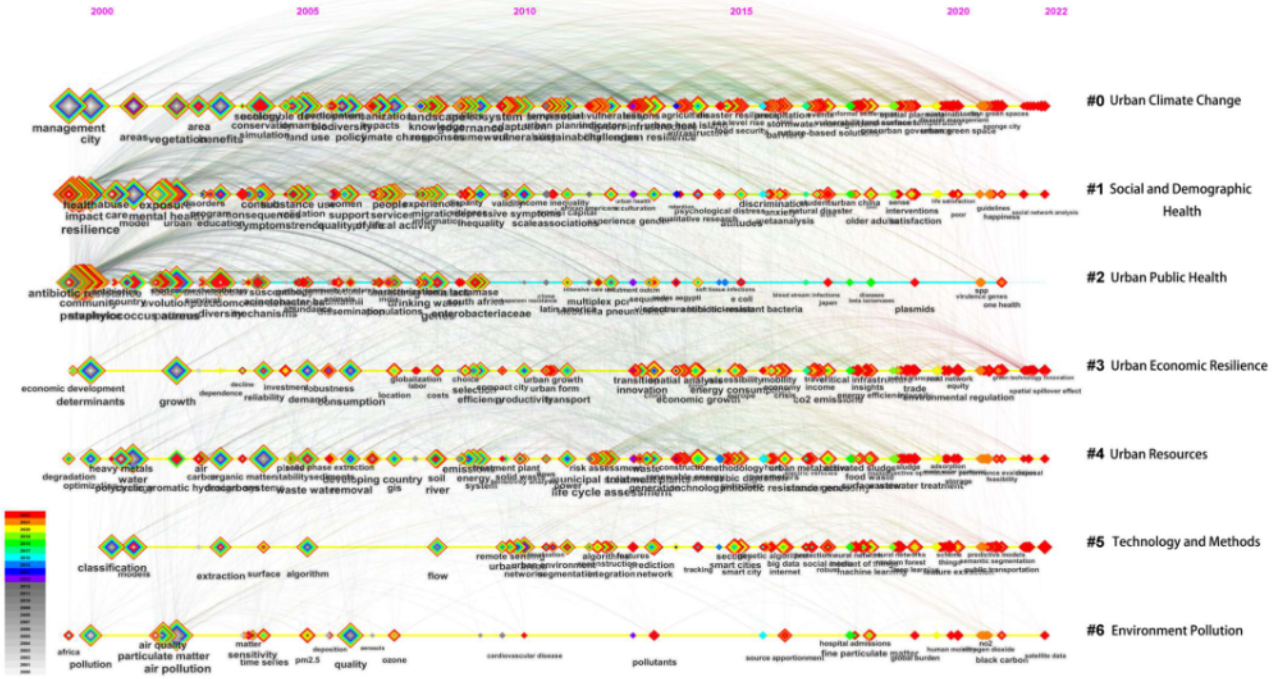

Figure 5. Keyword clustering timeline of resilient city research. Source: prepared by the author.

Figure 5 shows that from 2000 to 2022, the top seven major themes of the keyword clusters were as follows.

The largest cluster, "#0 urban climate resilience", focuses on urban climate change, the urban ecosystem, and urban management. It has recently become the most popular research theme, with a large number and variety of keywords representing many more red circles of recent research keywords, such as "climate change", "ecosystem services", "community resilience", and "urban planning". Apparently, urban climate resilience shows

an explosive growth trend after 2015, as the red squares have become crowded together since then. This may be related to several important agendas in the development of the resilient city since 2015. For instance, New York released its urban development blueprint "One New York: A Prosperous and Equitable Urban Development Plan" in 2015; Berlin announced the "Berlin Adaptation to Climate Change Impact Plan" in 2016; Paris launched the Paris Resilience Strategy "Paris Climate Action Plan" in 2018; and London announced the "London Urban Resilience Strategy 2020" in 2020.

The second major cluster, "#1 social and demographic health", focuses on human mental health following disasters and event-based trauma, with the main keywords being "mental health", "children", "stress", "depression", "inequality", and so on. There were various types of keywords and a high frequency of research categories before 2010, which may be impacted by terrorist events that had a significant impact on human mental health. These include the 9/11 terrorist attacks in 2001; the London Underground bombing in 2005; and a series of terrorist attacks in Mumbai, India in 2008.

The third major cluster, "#2 urban public health", focused on the fields of urban public health, environmental water pollution, and epidemiology. The main keywords were "prevalence", "antibiotic resistance", "escherichia coli", "mortality", and "trans- mission". With the widespread use of antibiotics in human society, antibiotic resistance has become a severe ecological and environmental problem that threatens ecological security and human health [65]. *Escherichia coli*, as a common bacterium in nature, is abundant, and the problem of antibiotic resistance in pathogenic *Escherichia coli* is becoming increasingly serious [66]. The hot keywords appear to have concentrated before 2008, which may be explained by several social reasons, such as the prevalence of *Escherichia coli*, which may be related to regional economic conditions and social health conditions [67], which have improved over time.

The fourth major cluster, "#3 urban economic resilience", focused on urban and regional studies and the world economy.

The main keywords were "consumption", "innovation", "economic growth", and "energy consumption". Since 2010, the keywords have increased rapidly, especially in the past two years. This may be explained by the crisis of the 2007 sub-loan crisis, which tremendously impacted the global economy as it immediately went from prosperity to depression and panic; this was followed by the European debt crisis that broke out in 2010 and the COVID-19 pandemic that broke out in 2019, and global economic activities became chaotic.

The fifth major cluster, "#4 urban resource", focused on international habitats, environmental science, renewable energy, and urban and social sustainability. The main keywords were "water", "energy", "wastewater", "municipal solid waste", and "energy recovery". Research has grown rapidly since 2012. The 2012 World Water Conference was held in Busan, South Korea, and in 2018, 2019, and 2020, the International Solid Waste Management Summit may have contributed to this growth.

The sixth major cluster, "#5 urban technology and methods", started late and involved the latest technical methods and models of resilient city research; it was a special cluster. The main keywords were "networks", "models", "algorithms", "prediction", "machine learning", "remote sensing", "internet", "deep learning", and "big data". The keywords increased after 2010. In 2006, the concepts of deep learning and machine learning were proposed and gradually applied to various research fields. Deep learning and machine learning techniques for urban methods have been widely applied in resilient city traffic networks, urban planning, and power and electrical systems.

The seventh major cluster, "#6 environmental pollution", was mainly related to urban pollution, environmental pollution, and wastewater treatment. The main keywords were "environment pollution", "air quality", "pm2.5", and "black carbon". The number of keyword research hot spots has increased in recent years. This may be related to the fact that in 2012, Vancouver, Canada held the conference "Canada International Environmental Protection Exhibition", which proposed air quality management and environmental governance.

In 2012, the "6th International Conference on Environmental Science and Technology", which advanced air pollution and control, was held in Houston, TX, USA.

Generally, the evolution and development of "urban climate resilience" were relatively uniform from 2000 to 2022, and there were many high-frequency keywords at each stage. Because there have been many red squares related to keywords in recent years, this topic is currently a hot research field. Urban climate resilience is a core issue and hot topic in resilient city research, as well as a potential major direction and emerging field for future research. Policy makers and urban planners can gain insights and recommendations on how to increase urban resilience in order to develop more effective policies and measures accordingly. The high-frequency keywords in the clusters "social and demographic health" and "urban public health" first appeared from 2000 to 2010 and continued until 2022 (red chronology), indicating that research on these two topics started early and that they are important thematic themes. Comparatively, "urban economic resilience", "urban resources", and "urban technical methods" had fewer high-frequency keywords from 2000 to 2010 but more from 2010 to 2022 (red chronology), indicating that the three major clusters are hot areas or frontier technologies in recent research.

Finally, "environmental pollution" was one of the seven clusters with few keywords; however, its research scope was more concentrated on environmental pollution, which is a special research area in urban climate resilience and a focus of current research.

7. Country Cooperation Network

We conducted an analysis of country cooperation networks by mainly focusing on the number of publications and the betweenness centrality of the countries. The top 20 countries in terms of resilient city publications, including the total number of publications, country betweenness centrality, and year of first publication, were analyzed via CiteSpace, as shown in Table 3. The top five countries in terms of publications were the U.S. (7754), China (5388), the UK (2478), Australia (1573), and Canada (1376), whereas the top five countries in terms of centrality were France (0.24), the UK (0.21), Switzerland (0.16), Denmark (0.1), and the Netherlands (0.09). In addition to quantitative leadership, the U.S. had a greater degree of cooperation with other countries (as shown in Table 3, the betweenness centrality was 0.07, ranking in the top six).

Table 3. Analysis of countries' cooperative networks.

Country	Rank	Count	Centrality	First Year
USA	1	7754	0.07	2000
China	2	5388	0.01	2000
UK	3	2478	0.21	2000
Australia	4	1573	0.04	2000
Canada	5	1376	0.01	2000
Italy	6	1344	0.02	2000
Spain	7	1192	0.02	2000
Germany	8	1188	0.05	2000
Brazil	9	994	0.01	2000
The Netherlands	10	962	0.09	2000
India	11	879	0.02	2001
France	12	853	0.24	2000
Japan	13	787	0.02	2000
Sweden	14	604	0.06	2001
Republic of Korea	15	555	0.00	2000
Iran	16	536	0.01	2003
South Africa	17	469	0.05	2000
Switzerland	18	464	0.16	2000
Mexico	19	418	0.01	2000
Portugal	20	399	0.03	2000

Interestingly, the U.S. published the most papers (7754), yet the betweenness centrality value was not the highest (it was only 0.07). The number of publications in France was only 853, but its betweenness centrality value was the highest (0.24). Additionally, Switzerland, Denmark, The Netherlands, and Belgium did not publish many papers; however, their betweenness centrality values ranked high. That is, they preferred to cooperate with other countries.

To gain a deeper understanding of the regional distribution characteristics of the research themes, we further analyzed the country cooperation network and research themes of resilient city research, as shown in Figure 6. In general, we found a star-shaped network structure, with Europe at the center of the network, meaning all of the regions closely cooperate with Europe. As the birthplace of and an important research base for resilient city research, there is a deep research foundation in the European region. Additionally, the European region had a denser network of cooperation with other regions worldwide, which is also confirmed by Table 3. The betweenness centrality was higher in European countries, such as France, the UK, and Switzerland.

Figure 6. Country cooperation network. Source: prepared by the author.

We performed clustering of the country cooperation network according to CiteSpace, as shown in Figure 7. It shows five major regional clusters, "#0 Europe", "#1 Asia","#2 Africa", "#3 America", and "#4 Asia-Europe-Africa border".

Figure 7. Country cooperation network clustering. Source: prepared by the author.

In general, all of the regions were concerned with research on urban climate change planning and urban planning, as well as research on disasters. They also exhibited a preference for studying urban renewable energy and urban low carbon development in urban resources. Nevertheless, they focused on machine learning and deep learning. At the same time, they were interested in the health of older individuals and adolescents. Finally, they were also concerned with urban air quality, aerosols, and air pollution.

All of the regions exhibited a preference for cooperating with Europe. We found that Europe was at the center of a resilient urban research cooperation network. Importantly, in Asia, studies have focused on urban economic resilience, food resources, and food security.

Furthermore, in Asia, great importance has been given to technology and methods research. Similarly, in Africa, more attention was paid to urban economic development and the energy economy and food and nutrition security research because the climate characteristics of Africa include high temperatures, low precipitation, dryness, and frequent internal and external conflicts. Notably, in the U.S., coastal city resilience planning is preferred because it is related to the specific geographical characteristics and because the region is vulnerable to hurricanes, tsunamis, and other disasters. In contrast, the Asia–Europe–Africa border region focused more on the urban ecosystem and the dynamic urban environment, such as urban water resources, but not solid waste.

The horizontal axis of the keyword timeline map represents different time nodes, which are generally displayed from far to near according to the year, and the vertical axis represents different clusters; the smaller the cluster value, the greater the influence, and the higher the frequency of paper clustering.

The clustering horizontal axis represents different keyword nodes, and the influence size of the nodes is indicated by boxes; the larger the box, the higher the frequency of the nodes.

8. Dual-Map Overlay

Why has the resilient city become a research hot spot in recent years? Compared with the "urban emergency" and the "smart city", what is special about research on the resilient city? To understand this, two new databases were introduced: the "smart city" database and the "urban emergency" database. The dual-map overlays are shown in Figure 8B,C.

We conducted a CiteSpace journal dual-map overlay analysis for the 26,979 papers studying the resilient city we reviewed above, as is shown in Figure 8A. The citing journals are on the left, and the cited journals are on the right. The evolution of journals in different fields is represented in the dual-map overlay map using different colored curves, and for a clearer comparative analysis of the results, we used the z-score (see the "data and methods" chapter) option to convert the raw scores into standardized scores.

The urban emergency dataset was obtained by searching the WOSCC database using the keywords "city emergency" and "urban emergency". The search returned 17,959 papers, and 16,008 were retained after deduplication and deletion of irrelevant data.

For smart cities, the search was conducted using the following keywords: "smart city" and "intelligent city". The original results included 14,117 papers, and after deduplication and deletion of irrelevant data, 12,954 papers were retained.

The main evolution paths of resilient city, smart city, and urban emergency research from citing journal fields to cited journal fields are shown in Figure 8A–C, respectively (it is shown in a strong evolution curve in different colors). The citing and cited journal fields are shown in Table 4.

A comparison of Figure 8A–C clearly reveals that resilient city research is more concerned with environmental and ecological issues. According to the citing journals, the fields of the main journals of resilient city research covered the widest domain fields, involving six different knowledge fields (fields showing a strong evolution curve): ecology, earth, and marine (EEM) research; veterinary, animal, and science (VAS) research; mathematics, systems, and mathematical (MSM) research; medicine, medical, and clinical (MMC) research; economics, economic, and political (EEP) research; and psychology, education, and health (PEH) research. It was clear from the dual-map overlay of resilient city research that there were six major knowledge flows in resilient city research (shown in Figure 8): from PEZGG/CMP/EEP to EEM, from ENT to VAS, from EEP to MSM, from MBG/HNM to MMC, from EEP/PES to PEH, and from EEP/PES to EEP. The main fields in journals on smart city research were economics and economics and politics (EEP) and mathematics, systems, and mathematics (MSM). Urban emergencies in journals were covered by the following fields: medicine, medical, and clinical (MMC) research and psychology, education, and health (PEH) research. Resilient city research covered six main citing and cited journal areas, which was much more than urban emergencies and smart cities; therefore, re-

silient city research involves more fields, a broader research base, and more cross-sectional research.

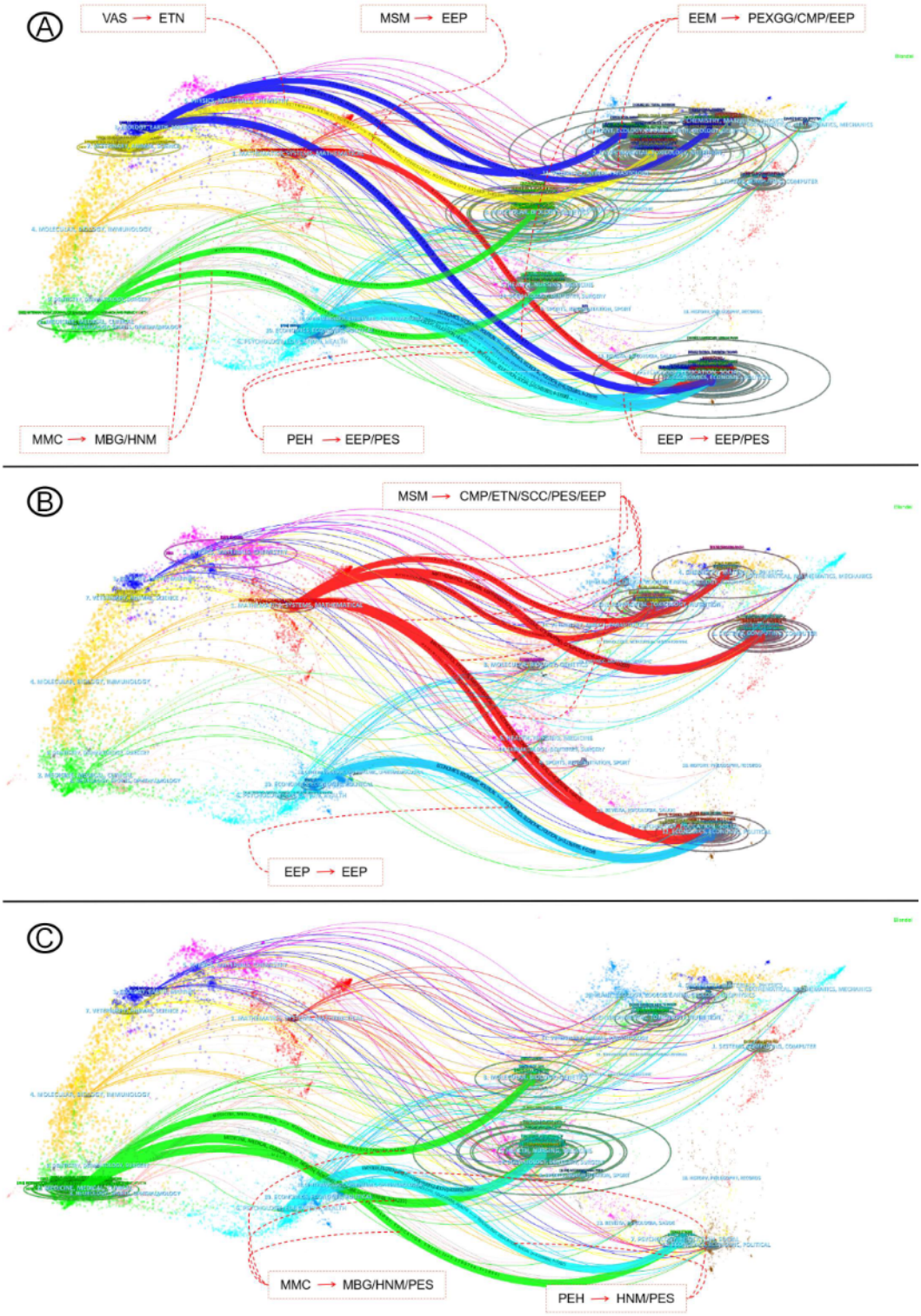

Figure 8. Citation dual-map overlays of resilient city, smart city, and urban emergency research. In the dual-map overlay, the longer the horizontal axis of the ellipse, the more papers are published in the corresponding journal; the longer the vertical axis of the ellipse, the more authors it represents [43]. The curves of different colors represent the citation links of citing and cited literature in different research fields. Source: prepared by the author.

Table 4. Dual-map overlay of resilient city, smart city, and urban emergency research.

City Type	Curve Color	Main Citing Journals' Fields	Main Cited Journals' Fields
Resilient city	Dark blue	Ecology, earth, marine (EEM)	Plant, ecology, zoology, geology, geophysics (PEZGG); chemistry, materials, physics (CMP); economics, economic, political (EEP)
	Yellow	Veterinary, animal, science (VAS)	Environment, toxicology, nutrition (ETN)
	Red	Mathematics, systems, mathematical (MSM)	Economics, economic, political (EEP)
	Green	Medicine, medical, clinical (MMC)	Molecular biology genetics (MBG); health nursing medicine (HNM)
	Cyan blue	Economics, economic, political (EEP)	Economics, economic, political (EEP); psychology, education, social (PES)
Smart city	Light blue	Psychology, education, health (PEH)	Economics, economic, political (EEP); psychology, education, social (PES)
	Red	Mathematics, systems, mathematical (MSM)	Chemistry, materials, physics (CMP); environment, toxicology, nutrition (ETN); systems, computing, computer (SCC); psychology, education, social (PES); economics, economic, political (EEP)
	Cyan blue	Economics, economic, political (EEP)	Economics, economic, political (EEP)
	Green	Medicine, medical, clinical (MMC)	Molecular, biology, genetics (MBG); health, nursing, medicine (HNM); psychology, education, social (PES);
Urban emergency	Light blue	Psychology, education, health (PEH)	health, nursing, medicine (HNM); psychology, education, social (PES)

Figure 8A–C shows that in terms of citation journal field research, two major journal fields of smart cities, MSM and EEP, and two important journal fields of urban emergencies, MMC and PEH, were within the major journal fields of resilient city research.

Therefore, research on these three areas promotes development in other areas. Additionally, in the evolution of the knowledge flow of major journal fields from cited journals to citing journals, the citation paths of two citations of resilient city research and smart city research were consistent. The first was from economics, economics, and politics (EEP) to mathematics, systems, and mathematics (MSM). The second was from economics, economic, and political (EEP) research to economics, economic, and politics (EEP). This shows that both resilient city research and smart city research are mutually reinforcing in terms of academic research.

In short, the research on resilient cities involved a wider range of citation fields than that on smart cities and urban emergencies. Compared with urban emergency and smart city research, resilient city research has focused more on citing fields like ecology, Earth science, marine science, psychology, education, and health. This is related to the fact that more attention has been given to urban ecology and urban public health, such as PM2.5 air pollution and urban water pollution, and the recent COVID-19 event, indicating that it is more concerned with hot social issues closely related to human life and the environment. Compared with research on urban emergencies, research on resilient cities focused more on journals related to science, economics, and politics, which cover social ecology, the environment, and governance. In other word, research on resilient cities, smart cities, and urban emergency response complements and promotes each other.

9. Disciplinary Burst Detection

To further understand the frontiers of research on resilient cities, we conducted a disciplinary burst detection analysis, as shown in Figure 9.

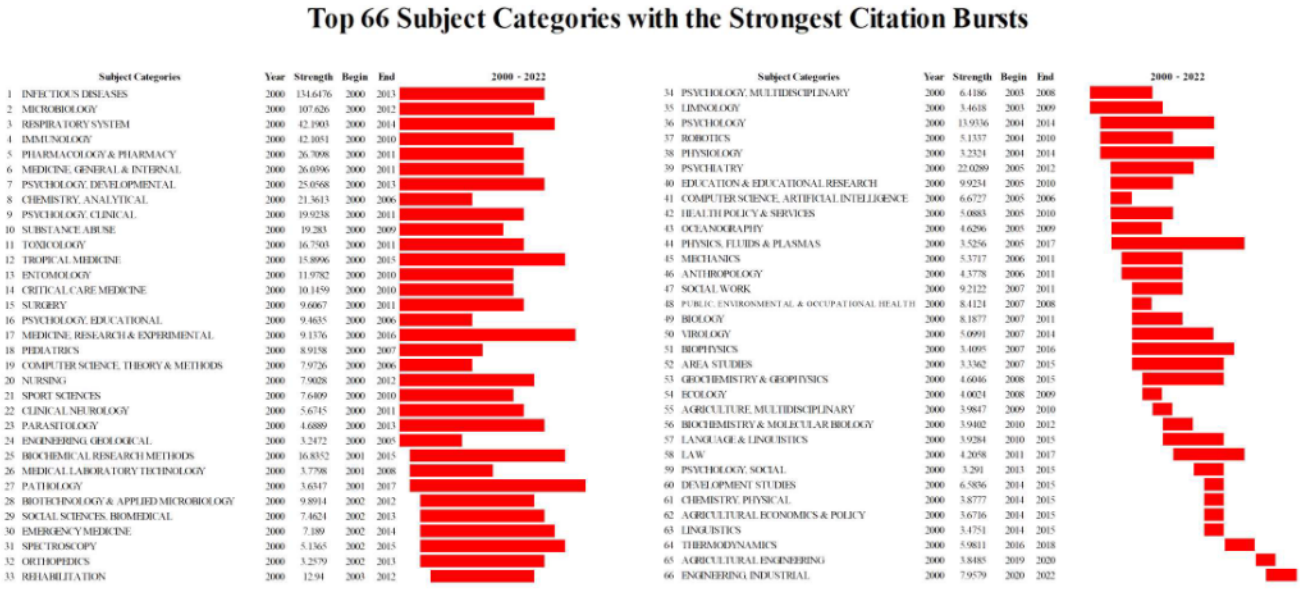

Figure 9. Disciplinary subject burst detection. Source: prepared by the author.

The research transitioned from "public health" to "computer, engineering" and then "ecology environment". More specifically, the dominant research ranges from the handling of emergencies in the field of public health to the study of people's psychological resilience and science, technology, and methods and then urban ecosystems and sustainable development.

As shown in Figure 1, after 2011, research on resilient cities began to show an explosive growth trend. Disciplinary burst detection also revealed that the focus of resilient city research shifted from the relatively single fields of public health and social psychology to the fields of computers, engineering, the ecological environment, etc., since 2011. That is, cross-disciplinary research gradually emerged, and disciplinary research shifted from the social science to the natural science area, especially in the fields of high-tech research and application. Furthermore, resilient city research has focused on the ecological environment, development studies, social sciences, geophysics, and engineering.

10. Keyword Burst Detection

Compared with disciplines, keyword burst detection can reflect research hot spots and trends involving resilient city research in greater detail. To analyze the research hot spots and trends of resilient city research in detail, we performed a keyword burst detection analysis, as shown in Figure 10. Chronologically, the 200 keywords were ranked according to burst strength according to Kleinberg's burst detection algorithm [50]. The analysis of keyword burst detection was divided into three phases at different periods.

Initially (keyword bursts starting from 2000 to 2002), researchers focused on urban public health; for example, the keyword "epidemiology" had a burst intensity of 68.76 from 2000 to 2014, and the term "infections" had a burst intensity of 42.34 from 2000 to 2014. Over a period of approximately 14 years, resilient-city-related papers attempted to study epidemiology and infections.

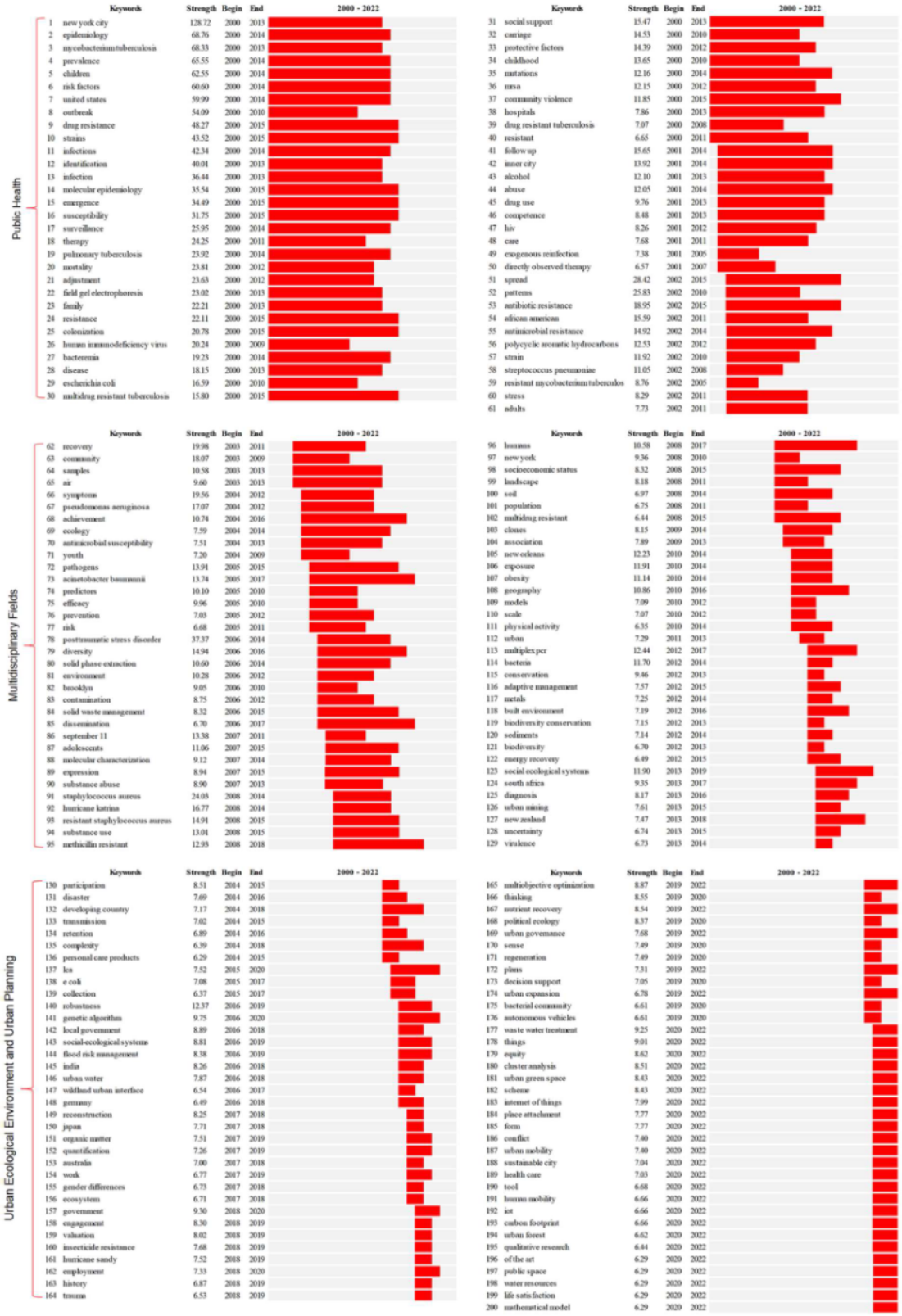

Figure 10. Keyword burst detection. Source: Prepared by the author.

During the multidisciplinary phase (keyword bursts start from 2003 to 2013), in addition to the field of urban public health, resilient city research expanded to new fields, such as urban ecology, urban public safety, and urban community recovery. The burst intensity of "recovery" in this phase (from 2003 to 2011) was 19.98, and the burst intensity

of "posttraumatic stress disorder" was 37.37 from 2006 to 2014, indicating that the studies in this stage focused more on urban recovery and people's posttraumatic psychological conditions after disasters.

During the professional development period (keyword bursts start from 2014 to 2022), urban ecology and environment keywords continued to be hot spots and research trends with higher burst intensities. Additionally, "urban planning" and "urban construction" had stronger bursts and became key research areas. The keyword "social ecological system" had a burst intensity of 8.81 from 2016 to 2019, and the keyword "urban green space" had a burst intensity of 9.25 from 2020 to 2022. Additionally, the burst intensity of many urban related keywords was high, such as "urban water", "urban governance", "urban expansion", "urban mobility", and "urban forest" was high. These findings demonstrate that urban ecology related researches are key areas in urban climate resilience research. Additionally, urban expansion, urban mobility, and urban economic development gradually became key research themes and trends.

Interestingly, there were two geographic terms with significant bursts in keyword burst detection. In the period from 2000 to 2014, the burst intensity of "New York City" (2000 to 2013) was 128.72, whereas that of the "United States" (2000–2014) was 59.99. The outbreak intensity for these two keywords was so high, which may be related to the disaster events that occurred in the United States between 2000 and 2013. Two major hurricane events in the United States in 2005 and 2012: Hurricane Katrina in August 2005 and Hurricane Sandy in October 2012, both of which resulted in significant loss of life and economic property. In the aftermath of hurricanes, much research on resilient city has addressed the mental health of disaster survivors. For example, researchers studied the health indices, health status, and causes of Hurricane Katrina urban survivors before and after the hurricane [68].

Interestingly, the hot spot study of resilient city was found to have a significant lag effect from the burst detection of keywords. For example, in the case of the "9.11" terrorist attacks in 2001, the emergence of the keyword "9.11" emerged from 2007 to 2014, lagging six years after the events occurred. In the case of Hurricane Katrina in 2005,the keyword "Hurricane Katrina" emerged from 2007 to 2014, a two-year delay.. The keyword "Hurricane Sandy" appeared in 2012 and became a research hot spot from 2016 to 2020, a lag of four years. Moreover, the duration of burst detection for keyword research decreased as time advanced.

Another interesting finding was that research on solid waste management developed from the emergence of the burst keyword "solid waste management" in 2005 to the keyword "energy recovery" in 2012 and then to the emergence of the keyword "electronic waste" in 2020. The evolution of solid waste management has shown that resilient city resources have changed with the development of technology, transferring from traditional waste to electronic waste. This indicates that current research focuses more on energy recovery and the sustainable development of global technology networks.

In terms of technology research, "cluster analysis" and "internet of things" had high bursts of 8.51 and 7.99 respectively. The "cluster analysis" technique has been applied mainly to social transportation and public health; for example, Frutos Bernal E studied the optimization and planning of subway networks [69]. The main application area of "internet of things" technology come to urban disaster monitoring, such as urban fire and heat wave video monitoring [70], However, there has also been research on intelligent transportation based on the internet of things, such as combining urban bus networks with subway networks and proposing a hybrid urban bus subway transportation network model [71]. The high burst detection of technological and methodological research in recent years indicates that advanced technologies have an important influence on resilient city research.

Currently, resilient city research has entered a stage of rapid development, yet urban social ecological systems, urban disasters and risk management, urban reconstruction, and adaptive urban management have become current research hot spots and trends. On the other hand, research on urban postdisaster reconstruction and its impact on the

socioeconomic structure has received attention; for example, after the tsunami, a significant proportion of people preferred to live further away from the coast. This has led to an increase in the price of inland real estate and the movement of poor families into coastal areas, inadvertently transferring disaster risk to the poor people [72]; there is also research on the housing resettlement of disaster victims in urban communities [73,74] and studies focusing on postdisaster reconstruction for the sustainable planning and development of urban systems and transportation [75]. Scholars are also interested in the impact of the epidemic on agroecology after COVID-19, proposing the territorialization of food production and consumption to avoid widespread food supply interruptions [76].

Keyword burst detection analysis emphasizes potential trends, hot spots and themes in resilient city during different periods. According to the above studies, resilient city research is divided into three stages: stage A (2000–2002) is the public health stage; in stage B (2003–2013), the research areas were expanded to multidisciplinary fields, such as urban ecology and environment, urban public safety, urban disaster impacts and recovery, and urban community organization; and in stage C (2014–2022), special disciplines, focused more on urban ecology and environment categories, urban planning and urban construction. Currently, urban ecology and environment, urban sprawl, urban mobility, and urban economic development have become key research themes and trends, and resilient city research is becoming systematic and specialized.

11. Conclusions

Resilient city studies are important for absorbing, recovering, and preparing for shocks caused by economic, social, health, environmental, disaster, and climate-related risks. Understanding the state of the art in research on and development of city resilience is therefore critical for promoting sustainable development, well-being, and inclusive growth of human society. In this review, we comprehensively examined the research themes, evolutionary history, and trends of resilient city research through advanced bibliometric and scientometric methods from various perspectives.

Research on resilient cities covers a wide range of topics, and we reveal seven main research themes of resilient city studies through a keyword clustering timeline analysis. It includes urban climate change, social and demographic health, urban public health, urban economic resilience, urban resources, environmental pollution, and technology and methods. Over time, the research topics have changed in terms of research hot spots; urban climate change was the most important research topic throughout the entire research period, whereas social psychological resilience and urban public health were hot spots in the early stage but have received less attention in recent years. However, urban economic resilience, urban resources, technology and methods, and environmental pollution have recently become research hot spots.

To gain a comprehensive understanding of current research on resilient cities, we conducted a descriptive analysis of research trends, author collaboration networks, national research status, and disciplinary evolution. The average yearly growth rate of resilient city research is substantially higher than the average scientific growth rate. Research on resilient cities has grown over the years and increased explosively since 2015, which may be related to the "Global 100 Resilient Cities" project launched by the Global Project Rockefeller Foundation in 2013. The author collaboration networks exhibited a heterogeneous network structure, and the European countries showed close cooperative networks with other countries worldwide. The betweenness centrality was higher for European countries, such as France, the UK, and Switzerland; at the same time, the United States and China ranked at the top in terms of the number of research papers. Currently, from the study of the discipline classification of resilient city research, urban ecology, urban economic development, urban sprawl, and urban mobility have become key research themes and new development trends, and the research presents a clear tendency toward multiple cross-disciplines.

Additionally, through the analysis of country cooperation networks, we found significant regional characteristics in resilient city research. In general, we found a star-shaped network structure, with Europe as the center of the network, and all of the regions closely cooperating with it. As the birthplace of and an important base for resilient city research, there is a deep research foundation in the European region. In Asia, attention has been given to research in the fields of technology and methods for building resilient cities. In Asia and Africa, more attention has been given to urban economic development and urban water resources, which is also applicable to research on urban food resources and nutritional security. This may be related to Asia being a subtropical monsoon region, and many areas are arid and prone to high temperatures, whereas the climate of Africa is characterized by high temperatures, low precipitation, dryness, and frequent internal and external conflicts. In the U.S., studies have focused on urban planning and resilience in coastal urban areas, which is related to specific geographical characteristics. Most developed cities in North America are in coastal areas that are easily affected by disasters, such as hurricanes and tsunamis. However, at the Asia—Europe—Africa border, more urban water resources and shortages were considered.

According to keyword burst detection and analysis, the outbreak of research on resilient cities may be related to some important climate events, disaster events, etc., and the study of the resilient city has a significant lag effect. As its evolution has advanced, it has gradually expanded from a single research field (urban public health) to multiple disciplines (e.g., the urban ecological environment, urban public safety, and urban disaster recovery) and specific disciplines (e.g., the urban ecological environment and the urban economy). From a broader perspective, we conducted a comparative evolution analysis of resilient city research, smart city research, and urban emergency research according to the journal dual-map overlay approach. Research on resilient cities has focused on a wider range of citation fields than smart city research and urban emergency research. Nevertheless, they complement and promote one another in the long term.

12. Research Limitations and Recommendations

It is important to acknowledge and account for several noteworthy limitations of this research. As the research field has expanded and the theoretical approach has gradually improved, resilient city research is becoming an important area in the fields of global climate change and ecological environment change and urban sustainability. The research in this paper provides new perspectives and constructive analysis for resilient city research. In this work, although comprehensive reviews have been conducted on resilient city research, we have considered only the WOSCC database as the sole source of data collection. WOSCC mainly includes high-impact international journals, mainly in the English language, and therefore it may overlook some regional or non-English journals [77,78]. This may lead to insufficient research coverage in certain fields or regions, thereby affecting the comprehensiveness and diversity of the results. In the future, it is necessary to also evaluate and survey other databases for a more comprehensive and systematic in-depth analysis of the research themes and trends in resilient city research.

This article provides important tools and insights for understanding the complex dynamics in resilient city research by comparing and analyzing the development trends of resilient city research, national cooperation networks, keyword timelines, keyword burst detection, and citation studies on resilient cities, smart cities, and urban emergency response. This will help researchers and policy makers understand current research priorities and future research directions. The study of the resilient city provides a systematic and data-driven analytical approach to help identify key research areas, promote international cooperation, and guide future research and policy making, providing a solid foundation for achieving sustainable urban development.

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

Appendix A

This study chose the Web of Science Core Collection and then chose all databases, including the following WoS sub-datasets:

Science Citation Index Expanded (SC-EXPANDED)—1999-present.

(1) Social Sciences Citation Index (SSCI)—1999-present.
(2) Arts and Humanities Citation Index (AHCI)—1999-present.
(3) Emerging Sources Citation Index (ESCI)—2019-present.
(4) Current Chemical Reactions CCR-EXPANDED—1985-present.
(5) Index Chemicus (IC)—1993-present.

The search query was as follows, including the select exact search.

TS = ((((((((((((TS = (city resilience)) OR TS = (resilient city)) OR TS = (city residen)) OR TS = (city robust)) OR TS = (city robustness)) OR TS = (city recovery)) OR TS = (city recoverability)) OR TS = (urban resilience)) OR TS = (resilient urban)) OR TS = (urban resident)) OR TS = (urban robust)) OR TS = (urban robustness)) OR TS = (urban recovery)) OR TS = (urban recoverability);

Publication date= "1 January 2000" to "31 December 2022";

Index = SCI-EXPANDED, SSCI, AHCI, ESCI, CCR-EXPANDED, IC.

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