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Web of Science-Based Green Infrastructure: A Bibliometric Analysis in CiteSpace

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Abstract: Many cities worldwide are using re-greening strategies to help reverse urbanization patterns that aggravate environmental issues. Green infrastructure (GI) has become a significant and effective strategy to address environmental problems. To better understand GI, this study uses CiteSpace to analyze 5420 published papers in the field of GI on the Web of Science database from 1990–2020. This bibliometric analysis will help new scholars and researchers to better understand the current status and trends in GI research, as well as identify further research needed in the field. This study evaluated research on GI trends according to publication amounts, keywords, journals, disciplines, countries, institutions, and authors. Results show that, first, GI research has experienced rapid growth since 2014. Second, GI, ecosystem services, and city are the top three keywords related to GI research, with green roof as the keyword with the strongest linkage. Third, *Sustainability*, *Urban Forestry and Urban Greening*, and *Landscape and Urban Planning* are the top three journals publishing GI research. Fourth, the top three disciplines researching GI are environmental science, engineering, and science and technology. Fifth, the USA is the top ranked country in terms of the number of published GI-related papers (1514 papers), followed by China (730 papers) and England (546 papers). Sixth, the US Environmental Protection Agency (84 papers) is the top institution in terms of publications, followed by the Chinese Academy of Science (83 papers) and the Swedish University of Agriculture (66 papers). Finally, D. Haase has the most published articles (29 papers), followed by S. Pauleit (28 papers) and P. Angelstam (26 papers). These findings indicate that GI has developed significantly in the last 30 years, with a high probability for increased growth in the future.

Keywords: green infrastructure; literature; bibliometric method; CiteSpace; visualization

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1. Introduction

Urbanization has drastically amplified the impacts of climate change, resulting in a series of environmental issues related to climate change adaptation, stormwater management, health and well-being, reductions in green space, lack of biodiversity, and unsustainable development; these circumstances had sparked a rebirth in the regreening of cities, nature-based solutions to flooding, and ecological planning [1–6]. Thus, urban scholars, city planners, and policymakers now emphasize sustainable development as a key approach to addressing these issues [7–9]. To ensure the adaptability to current environmental issues, many new concepts and approaches such as green infrastructure (GI) are being explored [10]. GI dates back to the 1880s when Frederick Law Olmsted was noted for his visions of designing with nature [11,12]. In 1999, the U.S. used GI as one of the tools that could help them attain future sustainable development [13]; the Environmental Protection Agency (EPA) also stresses the use of GI as a stormwater management tool and it also receives significant attention from international scholars, scientists, and politicians in regards to its urban services [14–16]. The number of scientific publications, books, and policy and planning documents referring to GI have rapidly increased in recent decades [17–21].

GI can be defined as a "strategically planned network of natural and semi-natural areas (with other environmental features) designed and managed to deliver a wide range of ecosystem services" [13]. It typically comprises a network of multi-functional green space of different types such as urban forests, urban parks, green streets, wetlands, green roofs, green ways, and bioswales [13,22,23]. Physical features, facilities, open air activities, and user preferences are key elements to gaining a more comprehensive understanding of GI [24]. As a system, GI fulfills its purposes by providing the following ecosystem services: regulating services (air quality, pollination, waste treatment, soil formation, biological control, water regulation, Carbon sequestration, CO2 emission regulation, runoff attenuation, pollution removal, etc.); supporting services (refugium function, primary production, nursery function, ecological diversity, animal habit, etc.); provisioning services (food production, water supply, raw materials, genetic resources, medicinal opportunities, etc.); and cultural services (recreation and eco-tourism, increased aesthetics, accessibility to green areas, etc.) [25,26].

GI also provides multiple benefits. First, environmental benefits include biodiversity and open space protection, enhancement of habitat and species (preservation of ecosystems, landscape restoration and regeneration, groundwater replenishment, pollutant filtration, and reduction of urban heat island) Second, economic benefits include sustainable water and flood risk management, efficient energy use, micro-climate heat lessening, and increased ability to adapt to climate change. Finally, GI also provides social benefits by increasing green space for citizens to recreate and communicate, improving community cohesion, increasing exposure to nature, and raising awareness of environmental issues [27–29].

Recently, there has been growing interest in GI-related research worldwide. Existing GI studies have covered a range of topics: climate change [29,30], air pollution [5,31], water management [32,33], urban heat island [34,35], carbon storage and emission [36,37], ecological services [38,39], human health and well-being [27,34], sustainable urban planning [7,40], food/regeneration [41,42], GI governance [43,44], GI policy [45,46], and evaluation of GI [42,47]. Researchers and policy makers have gradually established GI as an effective strategy and planning tool for sustainable development. This increases the demand for information about GI availability in urban areas, resulting in a need to examine the relevance of scientific bibliometric research in this field [48,49].

The literature mentions different methods to evaluate GI, with many researchers using statistical methods (classical, critical, and meta-analyses). For example, Seiwert and Rößler (2020) systematically reviewed and analyzed the term GI from contextual, geographical, and temporal origins, as well as assessed its rationale, semantic content, and primary purposes for spatial planning, based on the Web of Science (WOS) and Scopus databases [23]. In addition, based on the WOS, other researchers have analyzed the conceptualizations of GI, key research priorities, and thematic clusters within the existing literature, especially across European countries [50]. Wang and Banzhaf (2018) conducted a critical review for a better understanding of GI using statistical summaries based on WOS, Scopus, Google Scholar, and China National Knowledge (CNKI) databases [13]. Although these studies coupled statistical analyses with literature reviews, such statistical methods are generally labor-intensive and time-consuming. A large number of papers and academic documents must be collected for calculations and analyses. Moreover, several permissions from source data must be accurately processed. Thus, to obtain current and accurate information, more effort is required. Technological advancements in computer engineering have enabled the use of bibliometric analysis for literature review assessment [51–53]. Bibliometric methods were developed by Alan Pritchard in 1969 and can support analyses and examine the progress of any topic covered by several journals, institutions, countries, and authors [30]. Such approaches are qualitative descriptions of trends based on quantitative research based on a large number of publications; thus, researchers can more easily discover and assess research trends through the major impactful articles.

For example, Zhang and Chen (2020) used CiteSpace software to perform a bibliometric analysis to examine the trends and hotspots of Chinese loess plateau; this analysis was based on a review of the entire Science Citation Index-Expanded (SCI-E) database [54]. Zhang et al. (2020) used Citespace software for a scientometric analysis of sustainable urbanization based on WOS, Scopus, and CNKI databases to analyze the research status, development course, and potential trends of the topic. By adding Chinese literature databases (CNKI), summaries on global research can be more accurate and also allow for comparisons among the three databases [55]. Yang et al. (2019) used Citespace software scientometrics analysis to assess ecosystem health and highlighted the most relevant journals, articles, keywords, influential authors, and future research directions to readers based on the WOS database. The intent was to help researchers stay at the frontier in this field and to establish future research topics/directions [49]. In addition, Retno (2020) used the VOSviewer software's simple analysis to indicate the publication numbers, journals, countries, document types, authors, and research areas related to GI from 2009–2019 based on the Scopus metadata [56]. However, there is a gap in the current bibliometric research used to analyze these status, trends, and hotspots across different topics related to GI (functions of GI, ecosystem services of GI, benefits for the well-being of human beings, etc.). Contemporarily, GI-related issues and trends toward multidisciplinary cooperation appear to be increasing. Simultaneously, GI research has become increasingly complex and diverse [34,43,57].

This study analyzes the status, trends, and hotspots of GI using CiteSpace to conduct a comprehensive and systematic bibliometric review from 1990–2020. GI literature obtained from the WOS database was reviewed more specifically and accurately than previous research, focusing on revealing changes in research and indicating current its trends. From the results, the global publication patterns of GI were analyzed, including the distribution by time, keywords, journal published in, discipline publishing, country, institution, and authors. These characteristics were then linked to the research 'hotspots.' The results of this study can be used to inform scholars, researchers, and policy makers about the accurate and systematic descriptions of the GI literature, for supporting urban sustainability, improving environmental quality, and maintaining human health and well-being. By understanding these trends, new scholars and researchers can choose future research directions and issues through cooperation across different disciplines. From these results, this study then introduces future strategies for GI-based research.

2. Materials and Research Methods

2.1. Data Sources

The WOS Core Collection (formerly Institute for Scientific Information Web of Knowledge) is the most used and authoritative research literature search engine, providing comprehensive coverage of key research outputs from around the world. It is a multidisciplinary database with more than 100 subjects, including the major sciences, arts, humanities, and social sciences (e.g., political science, architecture, and philosophy). It is also the world's most trusted and famous scientific global citation database [57], containing all languages and documents (articles, conference papers and books, abstract of published items, etc.). Furthermore, its citation indexes include SCI-Expanded (Science Citation Index Expanded, 1900–present), SSCI (Social Science Citation Index, 1900–present), A&HCI (Arts and Humanities Citation Index, 1975–present), and ESCI (Emerging Sources Citation Index, 2015–present).

For this study, peer-reviewed scientific literature was retrieved from the bibliographic database (WOS). We use both the bibliographic basic and advanced searches to obtain bibliographic information, such as numbers of articles in subject areas, document types, authors, source titles, publication years, institutions, funding agencies, and countries. GI's concept and definition are gradually broadening, and multiple names and themes are being associated with the field [16,25,41,58], such as, not only "Green Infrastructure," but "Urban Green Infrastructure," "Blue Green Infrastructure," "Public Green Infrastructure," "Smart Green Infrastructure," "Coastal Green Infrastructure," and "Green stormwater Infrastructure." Consequently, the search topic (which includes title, abstract, author keywords, and keywords plus) used the term "Green Infrastructure." The search date was 15 January 2021.

2.2. Methodology

CiteSpace, an information visualization analysis software which is used to present the structure and distribution of scientific knowledge through visualization, is an emerging method in scientometrics and informatics. The visual map obtained by this method is called a "Science Knowledge Map," and reveals the knowledge sources and development level of a certain field [51,52,59–62]. In this sense, the approach can be used to scientifically and bibliometrically analyze the potential knowledge contained within the literature [63,64]. The WOS is the primary source of input data for CiteSpace; CiteSpace can select a particular field based on a time sequence and link both together to deduce the developmental trends and changes within a particular area [64].

Next, each article's database was downloaded, followed by a descriptive and quantitative analysis of each database using Citespace. Figure 1 shows how Citespace can, "project information as well as its ability to "time slice." The program can choose a particular time span, and "term source" the input database files (e.g. title, abstract, etc.) as (1) "node types," which are objects (author, institution, country, term, keywords, etc.) to be analyzed or (2) "links," which are the relational strength each network node. Links can be represented by shape (circle, cross, etc.), size (large or small), or color (dark or light). "Selection criteria," allocates is the quantity of information to be assessed and can be ordered from the most/important to least/unimportant. From these commands, first, the downloaded WOS database file was input, followed by selecting different objects for analysis. The relevant literature was then used to form a corresponding visualized knowledge map as well as analyze the knowledge base of GI. The output shows GI's developmental trends, latest related research, and hotpots within research categories. In addition, this analysis includes the key international conference papers and books focused on GI.

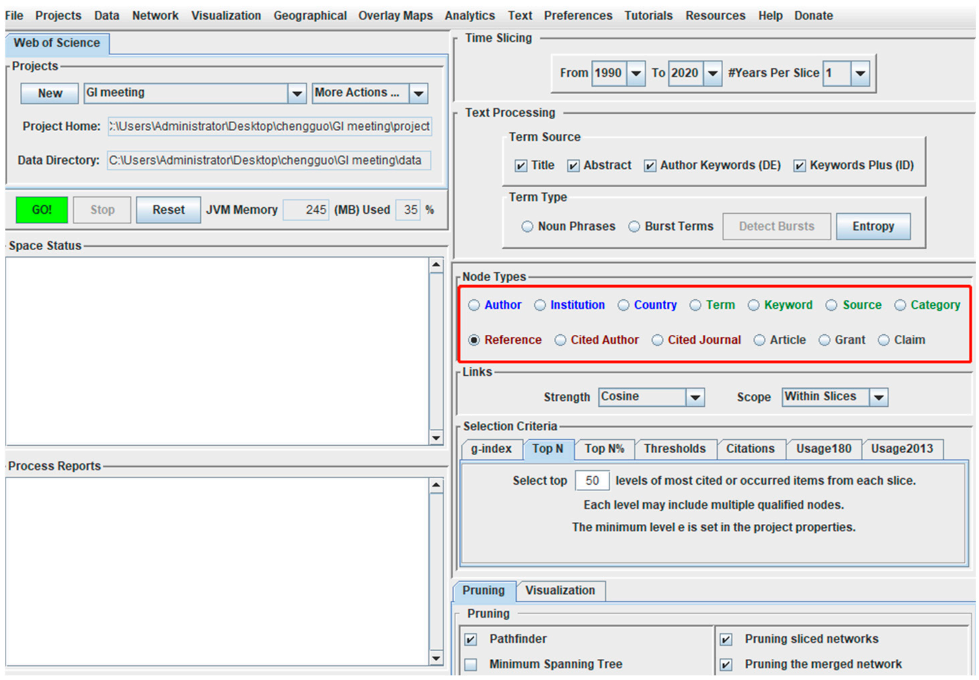

Figure 1. A descriptive, quantitative analysis of the database in Citespace.

3. Results

A total of 5420 papers were obtained from the WOS, followed by different terms and themes, such as Urban Green Infrastructure (2928), Blue Green Infrastructure (280), Public Green Infrastructure (938), Smart Green Infrastructure (267), Coastal Green Infrastructure (181), and Green Stormwater Infrastructure (752).

3.1. Trends in Publications by Stage

To obtain an overview of the research on GI, each year's (from 1990 to 2020) published papers and citation numbers were calculated and compiled (Figures 2 and 3) to reflect trends in publication and citation amounts.

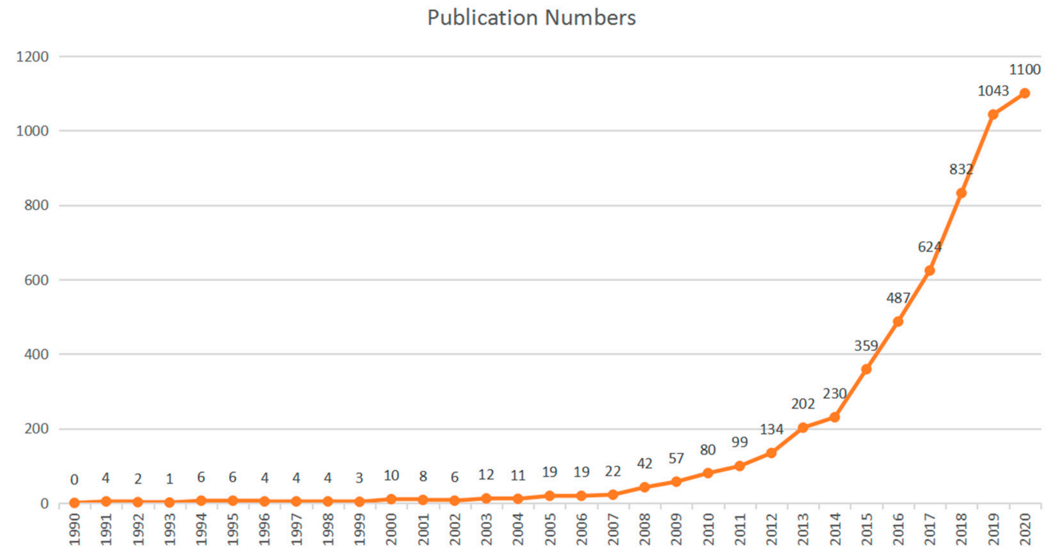

Figure 2. Line chart of publication trend from 1990 to 2020 (number of articles per year).

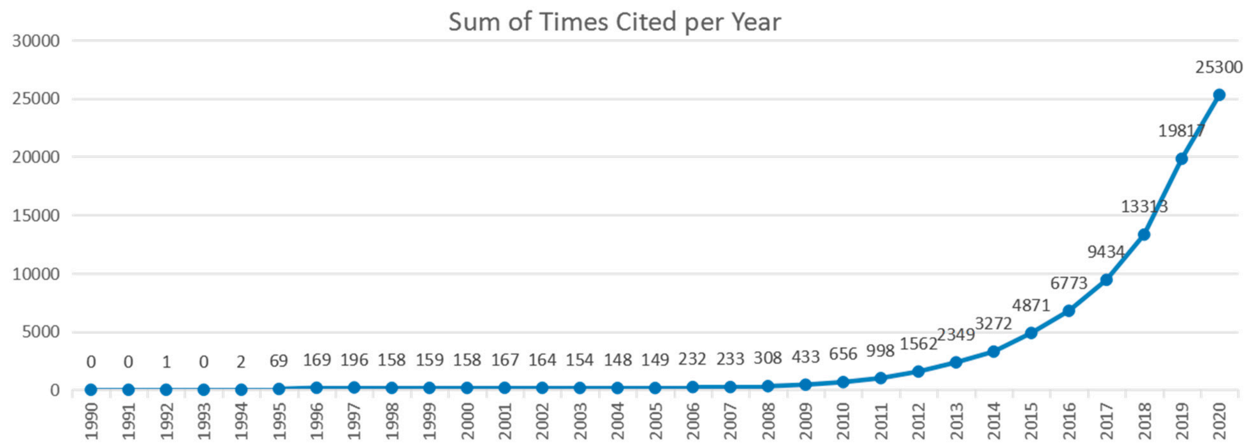

Figure 3. Line chart of citation trend from 1990 to 2020 (number of cited articles per year).

As shown in Figures 2 and 3, the annual changes in publication and citation amounts exhibit an upward trend. The first publication focused on GI was in 1991, with only four papers published in total. The first citation was in 1992 and the same growth trends have basically occurred in both measures. Specifically, based on the total number of publications, the GI research trends can be divided into three stages:

Initial development stage (1990–2007): In this stage, a slight increase can be observed in the number of publications and citations of GI (Figures 2 and 3). During these years, the total number of publications were a maximum of 22 per year, with an increase of several or a few publications each year. However, citation numbers were no more than 300 per year. This indicates that GI was at its initial stage, in terms of global research trends.

Slow development stage (2008–2013): In this stage, there appears to be a low increase in publications and citations related to GI with an overall upward trend. From 2008, the publications increased almost twice as much in 2007. From 2008 to 2013, there was an increase in published papers each year. The citation numbers increased from 308 to 2349 per year. An onslaught of new research articles and publications were continuously published during this period, thereby increasing the citation numbers. This indicates that the influence of articles/publications increased annually and the field of GI developed constantly, marked by the broadening of research and emergence of new hotspots.

Rapid development stage (2014–present): There was a significant increase in GI interest with a sharp upward trend in publications and citations within this stage. In this period, the total number of publications substantially increased from 230 publications in 2014 to 1100 in 2020, while the citation numbers increased to above 25,000 in 2020. Thus, GI's scope of influence continued to expand, the number of researchers increased, and the field entered a stage of vigorous development.

3.2. *Keyword Analysis*

3.2.1. Distribution of Publication by Keywords

Keywords are one of the most important elements of information regarding the research trends and topics within articles. In CiteSpace, the keyword co-occurrence analysis function can analyze the Descriptors (DE) and Identifiers (ID) fields in a document and generate a network view of these variables. Based on this, we summarized keywords in GI-based literature. The top 20 frequency keywords are visualized in Figure 4. The larger size of the cross corresponds to the keywords, and the larger size of the keywords' font indicates more frequency of the keywords' co-occurrence (Figure 4). Simultaneously, from the visualized graphs, the ticker of the line connected with different cross symbols; thus, the stronger the relationship between them, and the more the number of lines connected with a certain cross symbol, the closer the connection is between the keywords. As shown in Table 1, which lists the top 30 most frequently used keywords from 1990–2020, the top-ranking keyword is "green infrastructure" (because when we searched articles, the keywords were based on the GI), followed by ecosystem service, city, management, climate change, impact, infrastructure, sustainability, biodiversity, performance, and so on. From these top 30 keywords, the keywords indicating the primary terms are those that focus more on the urban ecosystem service, water management, sustainable and greening cities, urban environment, land use, and so on.

3.2.2. Timeline Analysis of Keywords

The keywords' timeline analysis focuses on revealing relationships between clusters and historical spans of keyword sets. As shown in Figure 5, the number at the top represents the time, and the words under the time are the keywords that appeared in this period; these could be used to analyze the time and relationships between the keyword clusters. The higher frequency of keywords indicates that these keywords are the GI-related hotspots within this period. The words with "# number" on the right represent the order/importance and the name of the keyword cluster. For example, to date, the timeline of clusters "#2 nature-based solutions" and "#9 infrastructure" are used, implying that research related to these clusters has been focused on and developing. By analyzing and summarizing the keywords of each cluster, 10 hotspot topics were found: stormwater runoff, urban development models and public administration, spatial planning, urban ecosystem, urban environment, human well beings, sustainable development, green city, urban development, and urban studies.

Figure 4. Distribution of top 50 keywords.

Table 1. Top 30 most frequently used keywords during 1990–2020.

NO.	Keywords	Frequency	NO.	Keywords	Frequency
1	green infrastructure	1225	16	landscape	234
2	ecosystem service	677	17	health	219
3	city	573	18	conservation	214
4	management	523	19	environment	210
5	climate change	456	20	design	209
6	impact	442	21	space	207
7	infrastructure	432	22	land use	205
8	sustainability	384	23	vegetation	199
9	biodiversity	359	24	energy	198
10	performance	318	25	area	193
11	system	300	26	benefit	190
12	model	282	27	green space	189
13	urban	262	28	quality	184
14	framework	251	29	policy	182
15	urbanization	240	30	green	180

The cluster title for stormwater runoff is "sponge city." This term primarily explores the sustainable hydrological cycle methods/strategies to improve urban water environment and build resilient cities. For urban development models and public administration, the cluster title is "optimization," which explores methods to identify the city's status of GI, create and improve the models and strategies to benefit the urban ecology, and fulfill a multifunctional function. For spatial planning, the cluster title is "nature-based solutions." This term mainly explores using GI as a greening design, improving the urban ecosystem, and assessing the environment. For urban ecosystem, the cluster title is "biodiversity," which explores how to increase ecosystem service, improve ecological functions, and create an ecological network through GI. For the urban environment, the cluster title is "climate change," which explores how to use GI to help cities adapt to climate change, find and improve the strategies to increase the city's sustainable growth, and provide suggestions to the planners and policy makers. For human well being, the cluster title is "physical activity," exploring how human activities impact the urban environment (urban heat island, etc.) and improving the benefits of GI for the well-being of human beings. For sustainable development, the cluster title is "ecological planning," which explores sustainable green habitats and environments, with an emphasis on increasing urban natural ecology. For the green city, the cluster title is "green infrastructure," which examines the methods of building a green city, as well as technologies and relevant policies associated with GI in different countries. For urban development, the cluster title is "urban planning," which explores the models, factors, and different methods used in urban planning and development. The cluster title for urban studies is "infrastructure," emphasizing the management of stormwater, increase of urban ecological carrying capacity, and achievement of sustainable development.

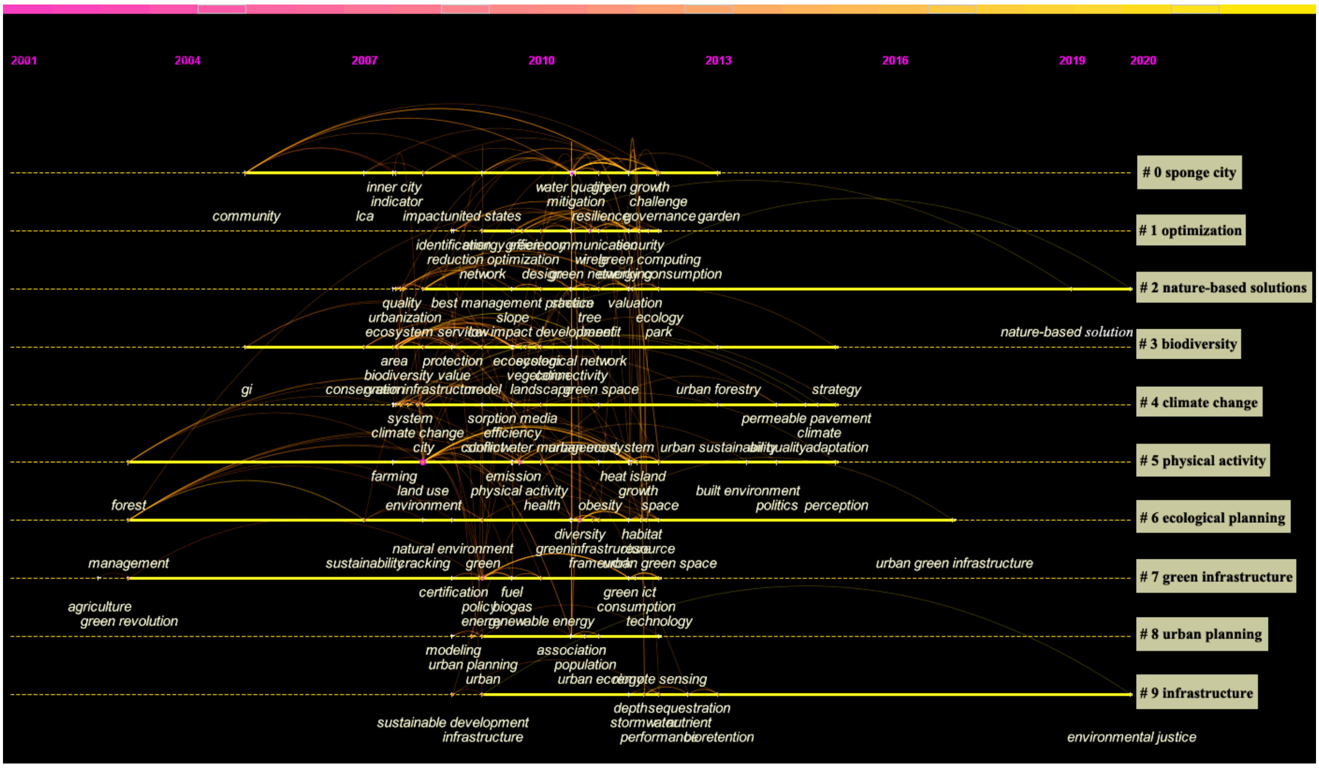

Figure 5. Keyword timeline in the literature on green infrastructure from Web of Science (WOS).

3.2.3. Keyword Bursts

Keyword bursts could reflect the changes in research topics and hotspots in a field. Figure 6 shows keywords with the strongest citation burst from 1990 to 2020. The earliest keyword burst is "green revolution" (began in 2003 and ended in 2009), and the latest keyword burst is "green roof" (began in 2016 and ended in 2018). The longest keyword is "community" (started in 2005 and ended in 2014), while the shortest keywords are "temperature," "energy efficiency," "heat island," and "climate." The top five keywords with the strongest burst are "green roof," "energy efficiency," "park," "heat island," and "power." These are research hotspots related to sustainable development, climate change, and urbanization. In addition, they indicate that while GI-related research topics can change fast, many research branches continue to exhibit vigorous development.

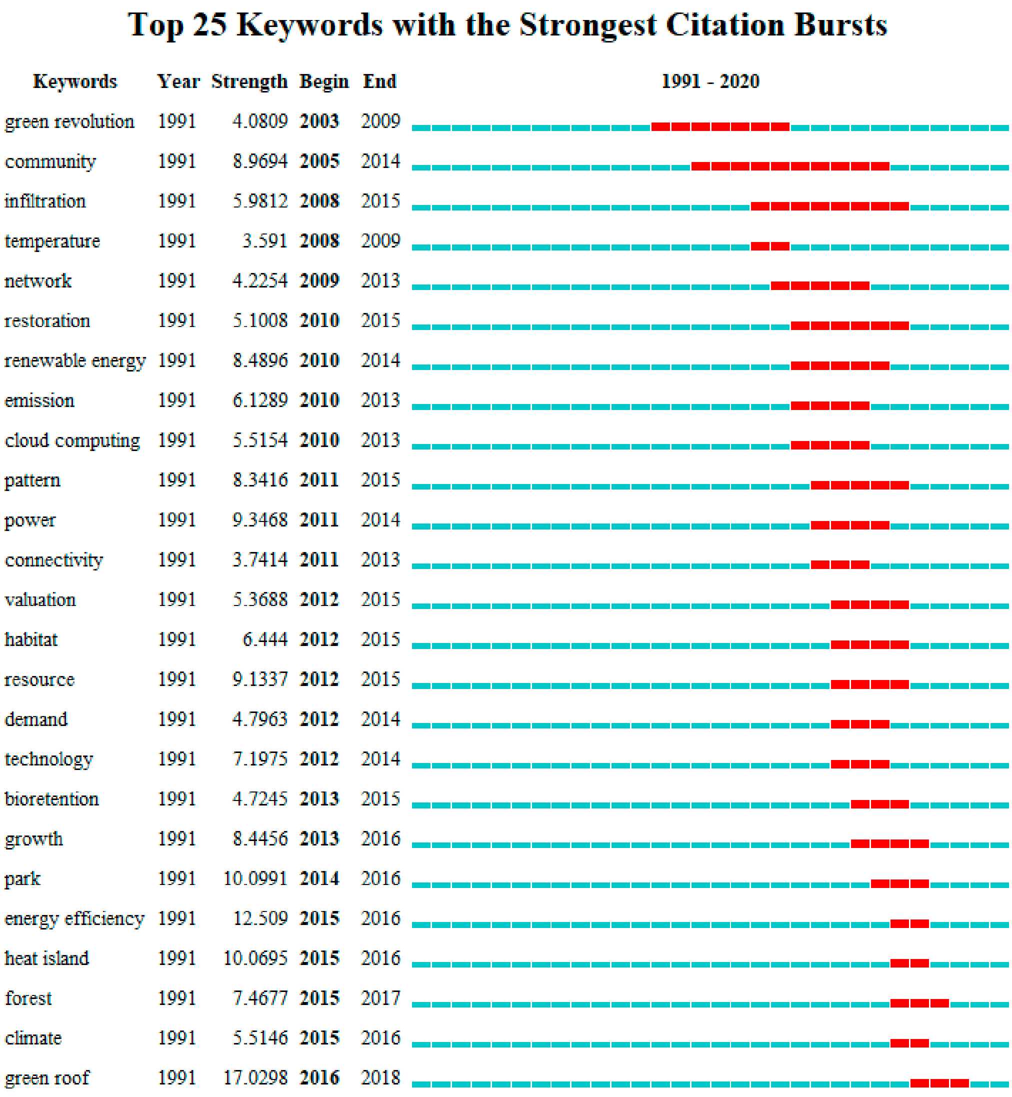

Figure 6. Time sequence of keywords.

3.3. Distribution of Publications by Journal

By analyzing the distribution of journals publishing material related to GI, the academic research can be accurately identified, helping scholars and authors choose suitable journals for future submissions. From the WOS database, the top 10 journals that published articles related to GI are listed in Table 2. These findings show that papers published in these journals could be more influential in regards to GI or more readily accepting GI-based article submissions. The higher impact factor (IF) with each journal, the greater the academic impact related to GI, and the larger the publication amount in journal, the greater the contribution of the journal to this field. The percentage of the number of publications across these 10 journals is 23.45%, and the total number of publications is 1275 papers. *Sustainability* is the largest published journal in this field, with 305 papers, and accounting for 5.61% of the total publications; the IF in 2020 was 2.567. Second largest is *Urban Forestry and Urban Greening*, with 235 papers, and accounting for 4.32%; in addition, it had an IF of 4.021 in 2020. The highest IF belongs to the *Journal of Cleaner Production*, followed by *Science of The Total Environment*, and *Landscape and Urban Planning*.

Table 2. Top 10 journals by number of publications.

Journal	PN	% Total PN	IF (2020)	Year *
Sustainability	305	5.61	2.576	2011
Urban Forestry & Urban Greening	235	4.32	4.021	2009
Landscape and Urban Planning	152	2.80	5.441	1986
Science of The Total Environment	124	2.28	6.551	1977
Journal of Cleaner Production	114	2.10	7.246	2002
Water	99	1.82	2.544	2009
Land Use Policy	66	1.21	3.682	1993
Sustainable Cites and Society	65	1.20	5.268	2011
Urban Ecosystems	58	1.07	2.547	2011
Journal of Environmental Management	57	1.05	5.647	1973

PN: Publication Numbers. Year * Earliest paper searched in the Web of Science.

3.4. Distribution of Publications by Disciplines

The discipline-based distribution of research on GI can be obtained by visualizing the papers published from the WOS, through "Category" in CiteSpace. The focus of scientific research related to GI can be accurately understood from the discipline-based analysis. Figure 7 presents the results of the top 10 disciplines researching GI; each node represents a certain discipline. The larger the size of the node, the greater the contribution of the discipline, and the thicker the connection line, the closer the cooperative relationship between the disciplines. The purple circles are used to highlight the importance of GI in each country, based on the analysis. The top three disciplines include environmental sciences and ecology (2547 papers), engineering (1054 papers), and science, technology, and other topics (772 papers), accounting for 46.81%, 19.37%, and 14.19% of the total publications, respectively. This accounts for 80.37% of the publications and indicates that such disciplines play a pivotal role in interdisciplinary collaboration and research. Urban studies, water resources, geography, public administration, computer science, and forestry also play a significant role in improving research.

3.5. Distribution of Publications by Country

The number of GI-related national/regional publications reflects the degree of the country or region's contribution to the research in this field. In CiteSpace, the literature published in 1990–2020 from the WOS database is analyzed (Figure 8). Each node represents a country; the larger the size of the nodes, the greater the contribution of the country, and the thicker the connection line, the closer the cooperative relationship between the countries. The purple circles highlight the importance of GI research related to each country. The USA ranked first (1514 papers), accounting for 27.83%, China ranked second (730 papers), accounting for 13.42%, and England ranked third (546 papers), accounting for 10.04% of the papers. The three countries covered 51.29% of the all publications, indicating that they occupy a dominant position in GI-based research. Italy, Germany, Australia, Canada, Spain, and Netherlands also play significant roles.

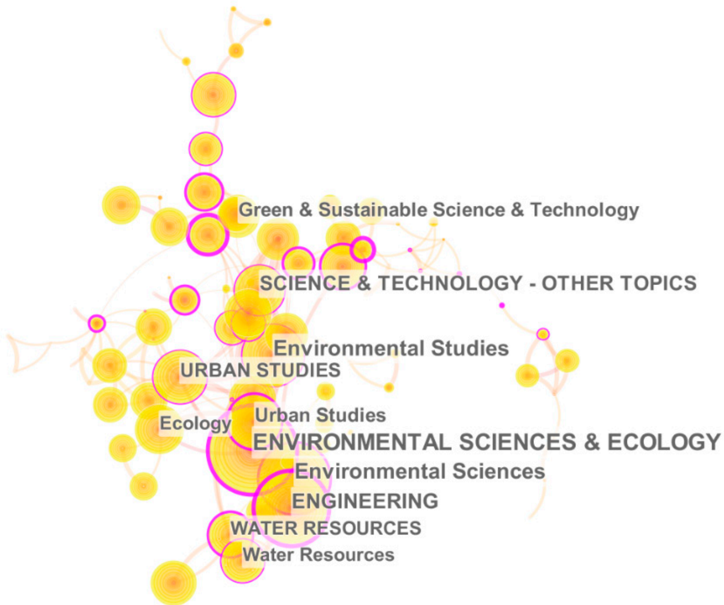

Figure 7. Distribution of main research disciplines.

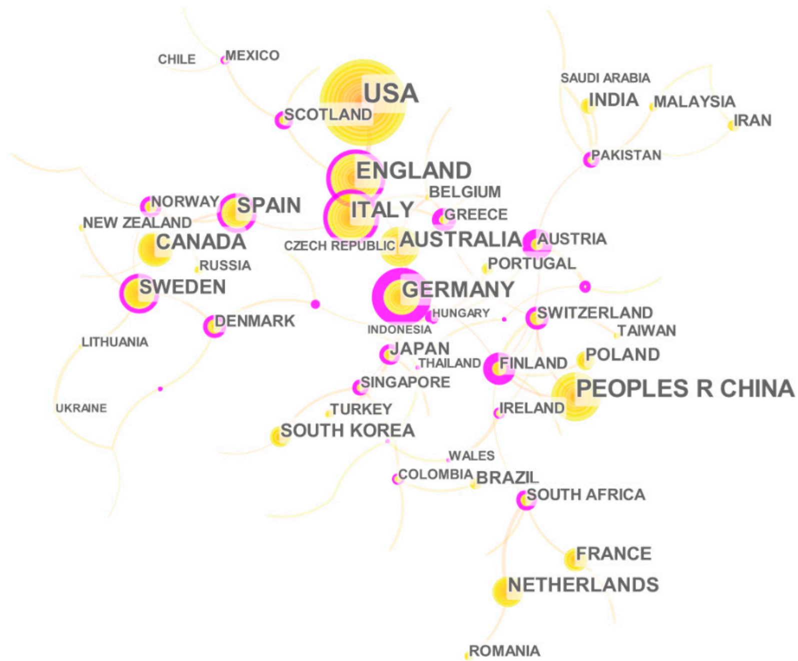

Figure 8. Distribution of main countries.

3.6. Distribution of Publications by Institution

CiteSpace was used to establish a network to reflect the contribution and cooperation degree of each institution related to GI research. Figure 9 shows the top 20 institutions that conduct GI research. Each node represents an institution; the larger the size of each node in the network, the greater the number of documents issued by the institutions, and the thicker the connection line, the closer the cooperative relationship between the institutions. As shown in Table 3, the top three institutions were US EPA (84 papers), Chinese Academy of Sciences (83 papers), and Swedish University of Agriculture Sciences (66 papers), accounting for 1.55%, 1.53%, and 1.21% of publications, respectively. The first papers published by these institutions were in 2001, 2005, and 2003, respectively. The University of Melbourne, Arizona State University, the University of Copenhagen, the

University of Hong Kong, and Texas A&M University are also strongly associated with GI research.

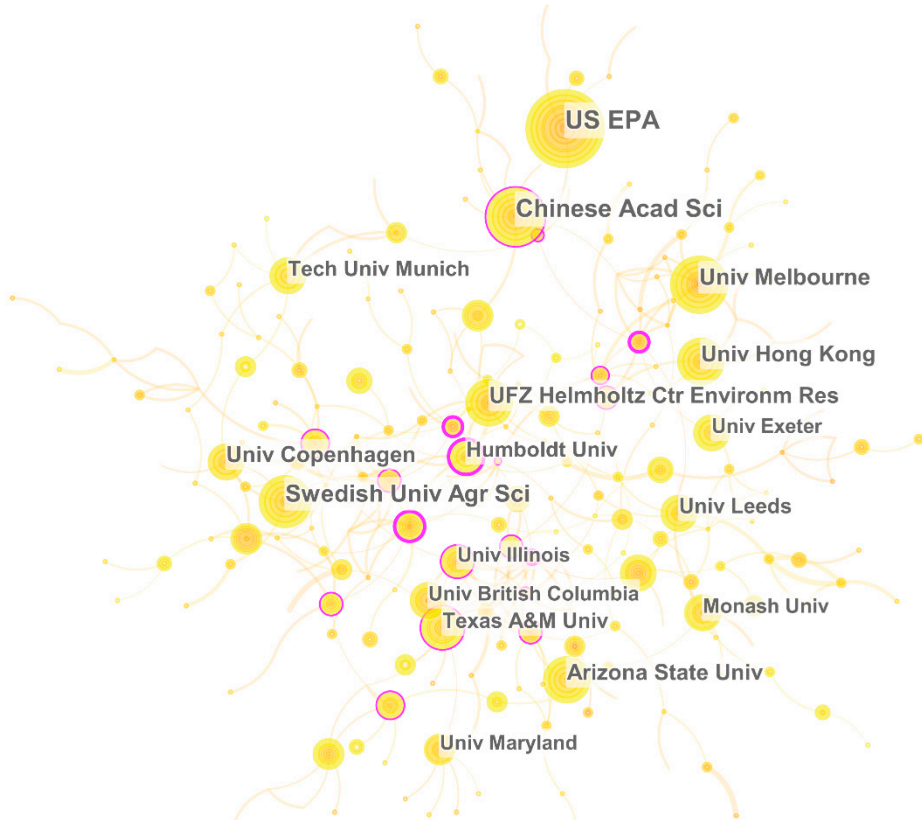

Figure 9. Distribution of top 20 institutions.

Table 3. Top 10 institutions by number of publications.

Institution	PN	% total PN	Year
US EPA	84	1.55	2001/2011
Chinese Acad SCI	83	1.53	2005
Swedish Univ Agr SCI	66	1.21	2003
Univ Melbourne	57	1.05	2008
Arizona State Univ	54	0.99	2007
Univ Copenhagen	52	0.96	2008
Univ Hong Kong	47	0.86	2014
Texas A&M Univ	46	0.85	2009
UFZ Helmholtz Ctr Environmental Research	46	0.85	2008
Univ British Columbia	45	0.83	1995

PN: Publication Numbers.

3.7. Distribution of Publications by Author

An analysis on the Authors' Cooperative Network helps reflect the core authors, authors' cooperative intensity, and mutual citations in this field and explore the influence of authors' and team cooperation. As shown in Figure 10, the top 50 author co-occurrence network was assessed and visualized. Each node in the author collaboration network represents the author; the larger the size of the nodes, the more the number of papers published, and the thicker the connection line, the closer the cooperative relationship between the authors. The results show that the top three authors are D. Haase (29 papers), S. Pauleit (28 papers), and P. Angelstam (26 papers), accounting for 0.53%, 0.51%, and 0.48% of the total GI-related published papers, respectively.

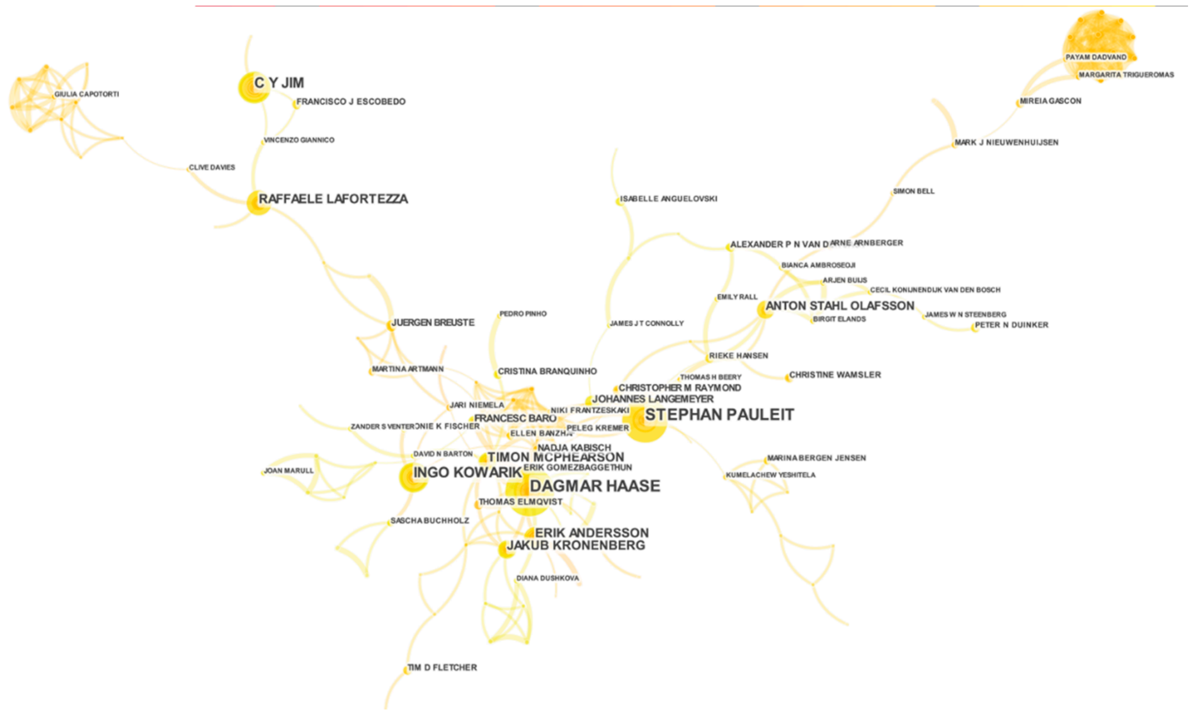

Figure 10. Author co-occurrence network.

3.8. Co-Citation Analysis of Literature

Co-citation analysis uses two documents appearing in the third bibliographic reference list. Through this analysis, the two documents form a co-citation relationship, which can reveal the development and evolution of a discipline. Co-citation analysis reflects the knowledge structure within a certain research field and explores the primary trends, directions, and terms utilized. Figure 11 shows a network of the highly cited papers in the field of GI. The size of the circle represents the citation frequency; the larger the size of nodes, the higher the frequently of papers cited, and the thicker the connection line, the closer the cooperative relationship between the papers. Table 4 shows the top 10 frequently cited papers in the field from 1990–2020 based on the WOS database. From the top 10 cited references, the most researched issue is ecosystem services, with four researchers focusing on this issue. This is followed by planning, urban environment, water management, and urban heat island.

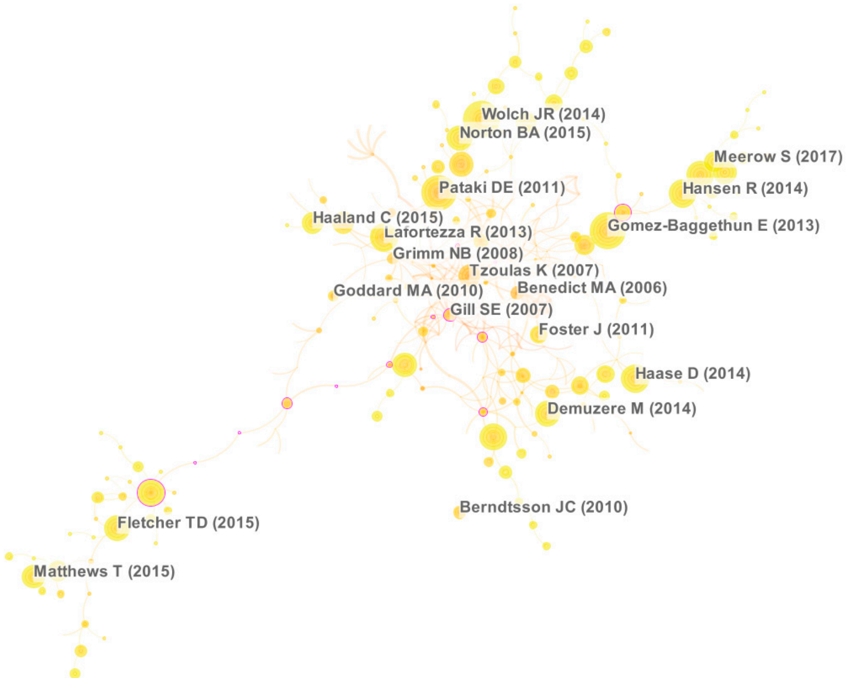

Figure 11. Co-citation of literature.

Table 4. Top 10 frequently cited literature papers in the green infrastructure area.

NO.	Citation Counts	Authors	Title	Journal	Year
1	213	Wolch J R, Byrne J, Newell J P.	Landscape and Urban Planning Urban green space, public health, and environmental justice	*Landscape and Urban Planning*	2014
2	168	Gómez-Baggethun E, Barton D N.	Classifying and valuing ecosystem services for urban planning	*Ecological Economics*	2013
3	135	Norton B A, Coutts A M, Livesley S J, et al.	Landscape and Urban Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes	*Landscape and Urban Planning*	2015
4	132	Fletcher T D, Shuster W, Hunt W F, et al.	SUDS, LID, BMPs, WSUD and more—The evolution and application of terminology surrounding urban drainage	*Urban Water Journal*	2015
5	130	Angelstam P, Boresjö-Bronge L, Mikusiński G, et al.	Assessing village authenticity with satellite images: a method to identify intact cultural landscapes in Europe	*AMBIO: A Journal of the Human Environment*	2003
6	126	Demuzere M, Orru K, Heidrich O, et al.	Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure	*Journal of Environmental Management*	2014
7	117	Meerow S, Newell J P.	Spatial planning for multifunctional green infrastructure: Growing resilience in Detroit	*Landscape and Urban Planning*	2017
8	113	Andersson E, Barthel S, Borgström S, et al.	Reconnecting cities to the biosphere: stewardship of green infrastructure and urban ecosystem services	*Ambio*	2014
9	106	Pataki D E, Carreiro M, Cherrier J, et al.	Coupling biogeochemical cycles in urban environments: ecosystem services, green solutions, and misconceptions	*Frontiers in Ecology and the Environment*	2011
10	103	Lovell S T, Taylor J R.	Supplying urban ecosystem services through multifunctional green infrastructure in the United States	*Landscape Ecology*	2013

4. Discussion

4.1. Advantages of Bibliometric Analysis and CiteSpace

The combination of bibliometrics and visual knowledge maps provides scholars and researchers with a reliable way to review the literature, helping them to comprehensively and systematically understand the development and evolution of hotspots within a certain field [55]. CiteSpace software provides a scientific, simple, and cost-effective alternative to the traditional literature reviews demanding a significant amount of time spent on reading and performing statistical analyses. Through this approach, a large number of the existing publications can be analyzed by using the WOS or other recognizable database, and scientific visualized graphs with different objects can be obtained (keywords, country, institution, author, etc.) for the benefit of scholars and researchers. Bibliometrics can comprehensively explore the research status, development stages, and potential trends of GI. Additionally, this approach can be used to analyze most of the English academic databases, such as Google Scholar and Scopus (among others), as well as non-English academic databases such as CNKI. Therefore, this methodology can provide a better approach for understanding global research frontiers and development trends [55]. Also in this study, we analyze the GI literature from 1990 to 2020 more comprehensively and systematically than previous research, and the GI themes involve all the related sub-themes. Compared with Ying et al. (2021), there is a richer and larger amount of literature evaluated, which is then analyzed according to research status, research trends, research hotspots, and research directions in the GI field more accurately and specifically [65]. Furthermore, this article also provides a detailed analysis and description of keywords (distribution, timeline, bursts), which more accurately reflect research themes and directions, the relationships between research themes and time spans covered, and the research topics across different time periods.

4.2. The Current and Future Trajectory of Green Infrastructure (GI) Research

The research areas of GI are gradually developing, with a potential for broadening the disciplinary sub-fields related to landscape architecture, urban planning, and other design related disciplines. The future of GI research should focus on being useful and beneficial for sustainable growth through the greening of cities, improving urban ecosystems, increasing ecological services and benefits, and ensuring the well-being of human beings or human health. Our results show that publication numbers have significantly increased from 2014; in 2020, the number of publications increased to 25,000. This indicates that more researchers are focused on or are interested in this field and using GI to help solve urban issues has become more important than ever.

From the analysis of the top 30 keywords, we found that the researchers focus more on ecosystem services in cities, the impacts of climate change, and urban sustainability and biodiversity. These issues require urgent solutions, of which GI can be a prominent option. The timeline of the keywords analysis reinforces this finding, showing that water management was one of the most important issues requiring more research. The strongest keyword bursts include "green roof," "energy efficiency," "park," "heat island," and "power," which means that, in these periods, more scholars focus on these urban issues (urban heat island, stormwater runoff, etc.). Due to urbanization and decreases in green space, impervious areas have increased and there has been an influx of people into the city. In addition, the identified bursts indicate that there are more important or useful methods such as GI to address urban issues.

The analysis of the top 10 journals indicates that GI researchers are more inclined to choose Elsevier and MDPI (Multidisciplinary Digital Publishing Institute) journals, focusing on sustainable urban planning, environmental issues, and hydrological circumstances. GI research has become increasingly multidisciplinary, including the more recent developments in engineering and technology. However, more useful and scientific methods are needed. Developed countries such as the USA and England also publish the most research on GI. China (ranked second in the world) is more focused than the other developing countries. The institutional analysis shows similar results through the country level analysis, indicating possible government and academic support. In this paper, we received government support from the US EPA, thus enabling the GI research. This may be because the government gives more financial support or has a stronger focus on GI than academic institutions. Authors are becoming increasingly cooperative in publishing GI-based papers, which can promote the development of this discipline. The co-citation analysis shows that the most common topics are urban planning and water management, indicating toward the relevant issues in this field.

4.3. Limitations of This Study

This study used CiteSpace to analyze GI publications from 1990–2020, based on the WOS database. While highly accurate, this approach also has some limitations. First, in this study, only the WOS research database was utilized and the first period available for analyzing this dataset was 1990. The first appearance of the GI in the literature was in the 1880s. In addition, some journals' publications were not obtained from the WOS database. For example, *Urban Forestry and Urban Greening* can only be searched from 2009, but the journal began publishing in 2002. Furthermore, some policy and social documents from governments or institutions, editorial materials, and book reviews are not included in the database. Thus, it requires a larger academic search database and more comprehensive documents within the item list. The search time was from 15 January, but some of the papers cannot be searched from the WOS, which can create a small error in interpreting the results. A few studies have tried to combine different approaches, such as combining VOSviewer and CiteSpace, as well as HistCite and CiteSpace, to improve the visual mapping and expression of System Analysis [48,54]. More related or similar research need to be found for effective application of bibliometric software to improve the accuracy of bibliometric analysis in the literature review.

Authors should discuss the results and how they can be interpreted from the perspective of previous studies and of the working hypotheses. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted.

5. Conclusions

This study used CiteSpace for a bibliometric analysis of GI related published papers (5420 papers) from the WOS database from 1990–2020. For the analysis, these published papers were downloaded as the initial database and input in CiteSpace. This was followed by visualization and marking of the research trends by stage, keyword timeline/burst, distribution of keywords, journals, disciplines, countries, institutions, authors, and co-citation of GI. This study found that GI, within this 30-year timeframe, has experienced intense development in research on theoretical (conceptualization, etc.) and methodological frameworks, quantification and modeling, ecosystem services, and functions to the urban environment. The research also exhibits a continued potential in methodological research, such as combining computer science using Geographic Information System (GIS), Remote Sensing (RS), and CiteSpace for quantitatively analyzing GI as well as using statistical methods or interdisciplinary cooperation to research a narrow/specific topic.

The results obtained from CiteSpace include show that GI had a significant increase from 2014 to present, and, in 2020, the publications elevated up to 1100. This indicates that more scholars now focus on GI to solve/ease urban issues, and this is expected to increase. The keywords analysis shows that the hotspots more focus on stormwater management, ecosystem service, sustainable and green urban development, and human well-being. Additionally, in regards to hotspots, the strongest burst was "green roof" and the longest burst was "community." The top 3 journals are *Sustainability*, *Urban Forestry and Urban Greening*, and *Landscape and Urban Planning*, from MDPI and Elsevier, with a focus on water, the environment, landscapes, and urban planning. The publications in these three disciplines include environmental science, ecology, engineering, science, and technology, accounting for 80.37% of the GI publications. This finding reveals a multidisciplinary cooperation is underway and that GI research is becoming more rational and complex. The USA (1514 papers) and England (546 papers) published more papers among developed countries, and China (730 papers) published a greater number of papers among the developing countries. Since the concept of GI first appeared in the USA in 1999, the country had a longer time to conduct GI-based research, comparatively speaking. The rapid urban development in China has also resulted in rigorous environmental issues; it has thus conducted more research in the field as a consequence. The distribution of institution is similar to the result of the country analysis. The three most frequently published authors are Haase (29 papers), Pauleit (28 papers), and Angelstam (26 papers) who used multidisciplinary knowledge and methods (e.g., geography, ecology, etc.) to conduct research on GI, with a greater focus on ecosystem services, climate change, and sustainability.

GI is a developing field and a comprehensive concept that is linked and integrated with ecology, environmental science, human well-being, and social and economic aspects. In addition, GI has multiple benefits for sustainable urban development. As a multidisciplinary field of research, it has significant functions in solving and easing urban issues. From this study, the research status, hotspots, and trends were obtained and marked. Consequently, new researchers can obtain this information more easily and accurately. They can identify the GI publication trends, the most important and frequently used keywords, countries prioritizing GI research, current authors, institutions, and suitable journals. However, more studies are required on GI using broader academic search databases or combinations of statistical methods. In conclusion, this bibliometric analysis will help new scholars conduct further research.

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