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A Systematic Literature Mining of Sponge City: Trends, Foci and Challenges Standing Ahead

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Abstract: Sponge City research has been attracting extensive attention both in practical and theoretical research field, as the increased threat of flood risk and environmental safety due to urbanization. Varies names of Sponge City prevalent in different countries, which leads to disconnection of literature in the same field of Sponge City. In this paper, a systematic literature mining of Sponge City is presented. A literature analysis system is created, which includes literature export from Web of Sciences and systematic analysis via NoteExpress and CiteSpace. Based on the final document storage which contains 962 articles, general trends are identified. Literature is classified into 9 theme types. Research foci of Sponge City are detected by citation and keywords burst detection. Further, some future research directions of Sponge City are anticipated, including trans-disciplinary approaches, a comprehensive design framework, application of information technology, and case studies of Sponge City in more parts of the world. The significance of this paper lies in summarizing past research, identifying research types, foci and anticipating some future research directions.

Keywords: integrated urban water management; trend analysis; citation analysis; research direction prediction; NoteExpress; CiteSpace

1. Introduction

Globally, there are more people live in cities than in rural areas and the trend of urbanization is irreversible [1]. Cities are relatively vulnerable to surface water flooding due to the increase in artificial surfaces and decrease in green space, preventing excessive rainfall from entering the ground [2,3]. Climate change makes the situation even worse by causing greater extreme weather, with more severe droughts, more intermittent, more intense storms, and higher coastal storm surges [4,5]. Such situation is especially true in China [6–8]. Most cities in China, using combination way of surface drainage and pipe drainage, are lacking of surface penetration because of the hard concrete [8,9]. Thus, not only the urban surface runoff raises, but also decreases in the groundwater recharge causing the shortage of domestic water supply for northern cities. What's more, the unfettered expansion of urbanization has increasingly exacerbated urban water resource issues [8].

In response to above situations, "Sponge City" was firstly introduced in "2012 Low-Carbon Urban Development and Technology Forum" in Shenzhen, April 2012 [10]. The construction of Sponge City in China was first formally proposed by Jinping Xi, the president of China, at Central Urbanization Working Conference in 2013 [11]. The Ministry of Housing and Urban-Rural Development proposed the construction guideline of Sponge City in 2015 [6–8]. On 2 April 2015, the first batch of pilot construction of Sponge City was announced, including 16 cities [10]. On 11 October 2015, the "Guiding Opinions on Promoting Sponge City Construction" specified that at least 70% of rainwater should be soaked into the underground instead of being discharged into the nearest rivers and lakes [12]. On 27 April 2016, another 14 cities were nominated as the second batch of pilot Sponge City [10,13].

It has been planned that the quantity of cities in China which have modern drainage systems and infrastructures that allow for efficient infiltration of rainfall should up to 20% by 2020, and rise to 80% by 2030 [14]. The construction of Sponge City became an important national strategy of China to achieve "new type urbanization" and building a moderately prosperous society in all aspects in 2020s [8].

There are some review papers about integrated urban water management. Some are focused on the conceptual comparisons or connotations interpretation. For example, Fletcher et al. [15] documented the history, scope, application and underlying principles of terms used in urban drainage and provided recommendations for clear communication of these principles. Wang et al. [6] summarized connotations, goals, and features of the Sponge City. Some review works are from the regional practice or case study angle. For example, the survey paper from Li et al. [13] was based on of all 30 pilot Sponge Cities construction projects in China. Zhou [16] presented the key elements and criteria of sustainable drainage design and introduced various devices and examples of sustainable drainage systems. Charlesworth [17] reviewed how vegetated Sustainable Urban Drainage System devices can sequester and store carbon, cool urban areas and increase perceptions of health and well-being in the populace by using case studies from around the world. Some review papers are focused on some specific technologies or approaches. For instance, Van Mechelen et al. [18] reviewed the green roof irrigation practices. Boyle et al. [19] reviewed intelligent metering for urban water. None of them is from a literature statistical analysis angle. It is still necessary to gather a comprehensive literature storage in the field of Sponge City, to summarize the research progress and predict future research directions through a systematic literature mining.

This rest of this section will introduce concepts of Sponge City and its synonyms, and clarify the motivations of literature mining in this field.

1.1. Sponge City and Its Synonyms

Although nowadays Sponge City research has been attracting extensive attention both in practical and theoretical research field, scholars have yet to reach a consensus on the definition of Sponge City. Wang et al. [6] offered a comprehensive definition of Sponge City in 2018 — "*The Sponge City is a strategy for integrated urban water management. It is scientific rooted in the laws of the natural and social water cycle and their associated processes. It aims to mitigate urban waterlogging, control urban water pollution, and utilize rainwater resources, as well as restore ecological degradation of urban water.*" The conceptual model is shown in the right side of Figure 1. Sponge City describes cities that are able to adapt flexibly, like sponges, to change in the environment, such that they absorb, store, permeate and purify rainwater, and are able to make use of the stored water when needed [20]. Sponge City construction contains the construction of big sponge infrastructures, including water pollution control projects, urban river restoration projects and waterlogging prevention projects, and also small sponge infrastructures, including construction of green infrastructures, sponge roads and sponge communities [6]. Sponge City handles 5 urban water problems (as shown in the middle of Figure 1), i.e., water shortage, waterlogging, water pollution, ecological degradation and city syndrome (e.g., heat islands, turbidity islands, and rain islands effects). Sponge City attempts to achieve 5 key objectives, as shown in the left side of Figure 1 [6,9].

In fact, there are many other terms which can be treated as synonyms of Sponge City in the sense of integrated urban water management strategy. These synonyms are introduced briefly in the following.

Sustainable Urban Water Management (SUWM) was initiated by Swedish Foundation for Strategic Environmental Research (MISTRA) in 1999 [21]. The vision of this program was defined as, "Every human being has a right to clean water. For urban areas, our vision is water management where water and its constituents can be safely used, reused and returned to nature." The primary objective of SUWM can be summarized as five concepts: moving towards a nontoxic environment; improving health and hygiene; saving human resources; conserving natural resources; saving financial resources [22]. SUWM reflects growing concerns over community well being, ecological health and sustainable development [23].

Its generalized target is to manage the urban water cycle to produce more benefits than traditional ways have delivered [24].

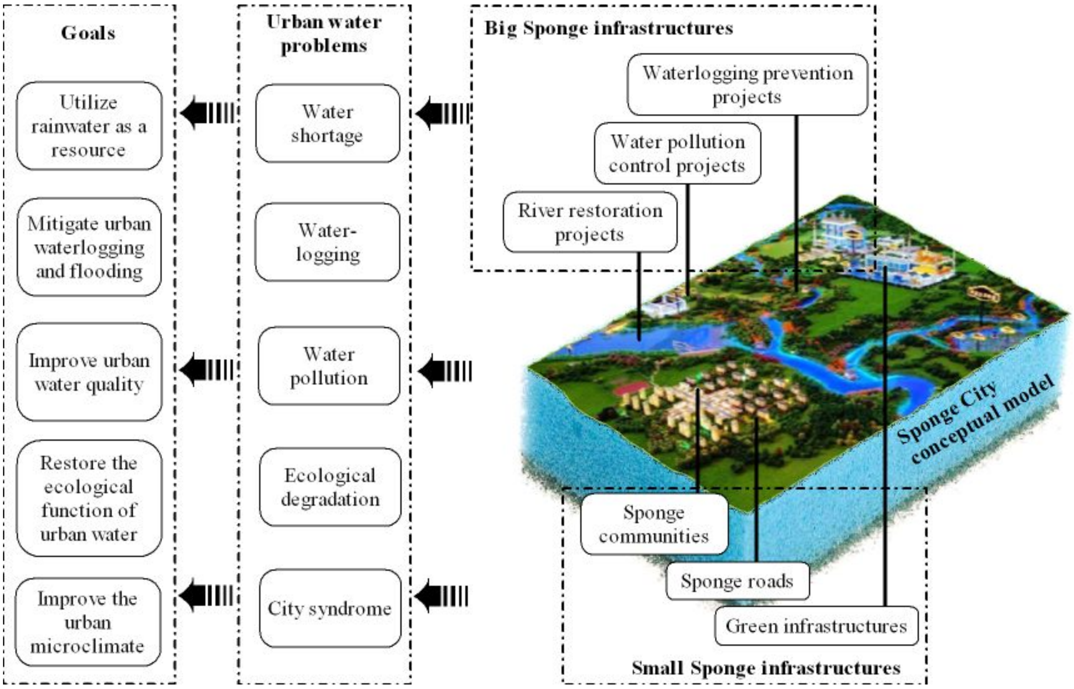


Figure 1. Goals and conceptual model of Sponge City.

Integrated Urban Drainage System (IUDS) originated in the late 1970s in Switzerland [25], aiming at developing an urban system. It has been defined as "modelling of interactions between two or more physical systems" by Rauch et al. [26]. IUDS is a combination of several components of water system (i.e., water treatment, distribution, sewerage, and storm drainage, wasterwater treatment, environmental compartments). It focuses on the integration of sewer, sewage water treatment plant, water receiving systems, and sustainable stormwater management, with economic factors taken into consideration [27].

Low Impact Development (LID) has been first introduced by Barlow et al. in 1977 [28] and most commonly used in North America and New Zealand. Its original intent was to achieve a 'natural' hydrology by use of site layout and integrated control measures. LID was characterised by smaller scale stormwater treatment devices such as bioretention systems, green roofs and swales, located at or near the source of runoff. The key point of LID implicates that specialists who develop and design systems are requested to minimise the impact on environment by the approaches of design and developing, and management process. During the practise of realizing LID, urban designers and developers must show their respect to water, surface soil, terrain, and vegetation, that is, to respect nature in a word, which marks the core value of LID [29]. The use of LID was codified in legislation throughout North America [30,31]. In the beginning of Sponge City Construction in China, LID was adopted to control waterlogging [9].

Water Sensitivity Urban Design (WSUD) was originated in Australia. It was first proposed by Mouritz in 1992 [32], and presented in a report for the Western Australian Government by Whelans et al. [33]. WSUD primarily targets at minimizing the adverse effects of urban development on surrounding hydrological environment [34]. WSUD is now increasingly used internationally, particularly in the UK and New Zealand [35].

Sustainable Urban Drainage System (SUDS) was started in 1990s and most adopted in UK. The term SUDS was formalized in 2000 in a set of similar but separate documents/manuals for Scotland and Northern Ireland, and England and Wales [36]. The most authoritative guide to SUDS is *The SUDS*

Manual [37], which aims to provide "comprehensive advice on the implementation of SUDS in the UK". SUDS is capable to improve urban flood and water contamination; also beautify the city, and provide a more livable environment for both human and wildlife [17,38,39]. In Scotland, SUDS have been mandatory in most new developments since 2003 [40].

Active Beautiful Clean (ABC) Waters Program was introduced in April 2006 by Singapore's water agency, Public Utilities Board [41]. The ABC Waters Programme is an initiative to transform Singapore's drains, canals and reservoirs beyond their traditional functions of drainage, flood control and water supply storage into beautiful streams, rivers and lakes that are well integrated with the surrounding landscapes. Compared with above concepts, ABC Waters design has a stronger focus on the cleansing function [42].

As introduced above, there is significant overlap between different terms, and their meanings are still under evolution [15]. The development of urban drainage management terminology is largely driven by local and regional perspectives, understandings and context [15] (Interested readers could refer to Fletcher et al. [15] for more details about the history and evolution of various terminologies around urban water management.). Sponge City was put forward by imitating, absorbing, and adapting all these concepts and strategies, and thereby incorporating special Chinese characteristics [6,9].

1.2. Motivations of Mining Sponge City Literature

There are two main motivations of literature mining of Sponge City studies.

First, although a large body of literature has touched on the theme of Sponge City, there has not yet been any systematic review article from the literature statistical analysis angle. The main reason may be due to the difficulty of collecting a relatively complete bibliography. In fact, it is quite important to make a systematic review of urban water management for the purpose of shedding some light on this field and provide insights for further studies.

Second, given the situation of China, urban water problems, such as water shortage, flooding, and water quality issues are so serious. Finding ways to solve low utilization ratio of rainfall resource and uncontrollable flood admits of no delay [13]. Sponge City provides a very promising strategy for integrated urban water management [6]. It is beneficial for us to look into what has been done and the challenges standing ahead in this field.

2. Method

Literature mining is a powerful method for elucidating major trends across time in published scientific literature and allows for topic maps to be built [43]. The rest of this section will introduce how to build a comprehensive literature storage and establish the literature analysis system.

2.1. Search Strategy and Selection Criteria

Literature mining was conducted in October 2017 using the academic resource retrieval website, Web of Science (WOS). WOS is the largest comprehensive academic database on global scale. It includes over 8700 core academic journals, seven databases containing information on nature science, engineering technology, biomedical and so on [44,45]. Owing to the broad scope of Sponge City, it is extremely difficult to gather all studies of it. Fortunately, WOS did provide us with relatively comprehensive, formats uniformed and academically quality references. Another advantage of WOS is that it has a nice compatibility to NoteExpress and CiteSpace.

To ensure no important articles are overlooked or duplicated, the searching methodology need be in accordance with procedures below.

- Step1: To ensure an accurate and efficient process, seven key words were used in searching by "theme", including "Sponge City" and its synonyms, i.e., "Sustainable Urban Water Management (SUWM)", "Integrated Urban Drainage System (IUDS)", "Water Sensitivity Urban Design (WSUD)", "Low Impact Development (LID)", "Active Beautiful Clean (ABC) Waters Program", and "Sustainable Urban Drainage System (SUDS)". This procedure guarantees that vary names of Sponge City were considered, the disconnection of literature was conquered and the literature identified were all relevant.

- Step2: Using the document management software "NoteExpress", repetitive articles were eliminated.
- Step3: Same keywords of records in different formats were unified by "finding" and "replacing" functions in NoteExpress. For example, "Sponge Urban" was replaced by "Sponge City", "ABC Waters Program" was replaced by "Active Beautiful Clean Waters Program". This procedure guarantees better performance of clustering and bursts identification.

A final document storage of Sponge City containing 962 articles was formed, ranging from 1960 to 2018 (Since some journals would publish issues online ahead of time, some papers with 2018 year information are included in the storage.).

2.2. Literature Analysis System

It should be noted that citations link literatures in a specific field formally and explicitly, which is stressed by Garfield—"father of academic literature citation indexing" [46]. The concept of indexing refers to assign the content identifiers (i.e., citations) to the documents, which has been developing rapidly [47]. Based on a given document storage which could be read by machine, computers are capable of make analysis based on scientometric analysis [47], forming proper content identifiers and attaching them to every stored document. Furthermore, it is easy to position a research using citation retrieving method on condition that it has significant influence on a specific field or cross-field disciplines [48].

Considering of the above, this paper established a data analysis system as shown in Figure 2. Records including information of publication years, countries, authors, journals, keywords, citations and abstracts were downloaded from WOS. By using the functions of NoteExpress (i.e., retrieval, selection, statistical analysis and browse), the finally database, growth trend and content types can be obtained step by step. Applying the visualization and bursts detection functions of CiteSpace, diagrams of research distribution, the dual-map overlay, co-citation network and citation bursts can be derived. Based on some representative literature from WOS and literature mining results from softwares, this paper discussed the future research directions of Sponge City.

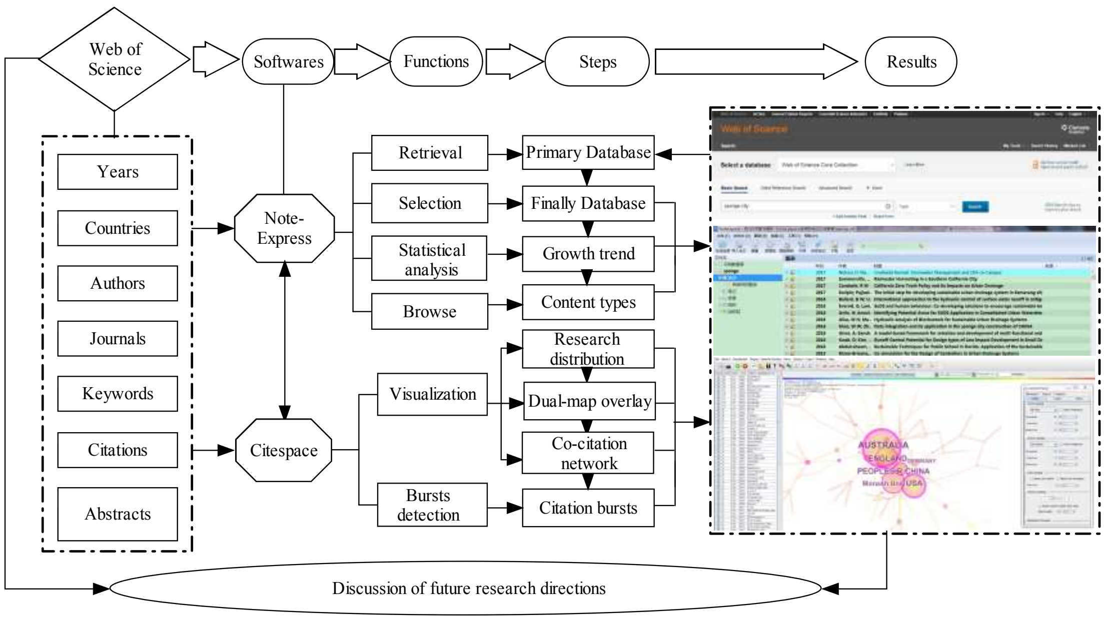


Figure 2. The framework of the literature analysis system.

NoteExpress is one of the most frequently used professional literature retrieving and management tools [49]. The core function of NoteExpress contains knowledge acquisition, management, application, and digging, covering all segments of knowledge management [50]. The bibliography downloaded from websites could be preserved through NoteExpress, thereby managed and cited easily. It can also be used to generate concise analysis of the researching trend and structure on a particular field. NoteExpress has been applied in many studies for literature mining [44,48,51]. This paper organized document storage and conducted a statistical analysis of Sponge City literature using NoteExpress.

CiteSpace, one of the most popular tools for knowledge mapping, is designed as a Java application for visualizing and analyzing process through producing co-citation networks [47]. CiteSpace visualizes the literature in the form of a co-citation network, which draws on article citations to reveal the structure of a field or fields [47]. Besides, it can also be used to show a particular research structure in a knowledge domain [52]. This paper will be the first attempt to analyze the research structure of Sponge City by CiteSpace.

3. Findings and Discussion

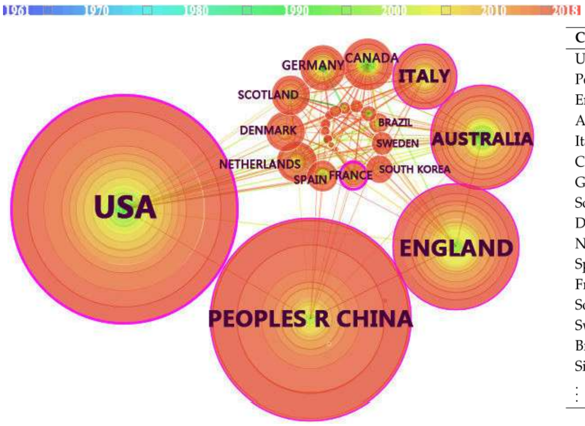
3.1. General Trends

As outlined in Table 1, there is a growing body of literature on Sponge City and similar concepts (SUWM, IUDS, WSUD, LID, ABC, SUDS) with more than 93% of all documents from 1960 to 2018 emerging in the final latest two decades. The literature is distributed on both proceeding papers and journal articles. The distribution of scholars is scattered, with only a few authors having more than 10 publications including the search terms. The journals of Sponge City research include a large range of academic journals from water science, water resource management, urban planning to a range of other journal topics. Among these, the most important journals are Water Science and Technology, Landscape and Urban Planning, Water, Journal of Hydrologic Engineering, Urban Water Journal, Environmental Modelling & Software, Journal of Hydrology, Water Resources Management and Water Research.

Table 1. The overall findings from the final document storage.

Theme	Results
Year of study	• 4 (0.42%) documents from 1960 to 1990; • 60 (6.24%) documents from 1991 to 2000; • 310 (32.22%) documents from 2001 to 2010; • 588 (61.12%) documents from 2011 to 2018.
Article Type	• 204 Conference proceedings papers (21.21%); • 758 Journal articles (78.79%).
Researchers	• Scholar distribution is scattered. • Authors who published more than 10 papers include: Rauch, W (16); Brown, RR (16); Mannina, G (15); Freni, G (12); Viviani, G(11); Scholz, M (10).
Journals	• Some important Sponge City studies journals include Water Science and Technology (125); Landscape and Urban Planning (48), Water (32), Journal of Hydrologic Engineering (21) Urban Water Journal (20), Environmental Modelling & Software (18), Journal of Hydrology (16), Water Resources Management (15), Water Research (15).

As shown in Figure 3, CiteSpace visualized the research distribution in different countries. The thickness of a ring in each circle is proportional to the number of papers in a given time slice. The colour of each ring represents the publication time corresponding to the time bar on top of the figure. The lines between different circles denotes co-authorship [47,53]. Although the first Sponge City papers from China is as recent as 2005, China publishes the second most papers, accounting for 15.7% of total studies. The top 4 countries (USA, China, England, Australia) generate almost 60% of Sponge City research, dominating the field in terms of number of publications.



Country	Count	Year	Percentage(%)
USA	217	1987	22.87
Peoples R China	149	2005	15.70
England	101	1994	10.64
Australia	86	2003	9.06
Italy	40	2004	4.21
Canada	33	2002	3.48
Germany	30	2000	3.16
Scotland	29	2006	3.06
Denmark	28	1998	2.95
Netherlands	28	1997	2.95
Spain	27	2010	2.85
France	22	2002	2.32
South Korea	22	2009	2.32
Sweden	19	2008	2.00
Brazil	14	2011	1.48
Singapore	10	2015	1.05
⋮	⋮	⋮	⋮

Figure 3. Sponge City research distribution in different countries (The color of a ring denotes the corresponding publication time. The thickness of a ring is proportional to the number of papers in a given time slice. The lines between different rings denotes co-authorship.)

Figure 4 shows a dual-map overlay of the final document storage. The dual-map overlay is designed by Chen and Leydesdorff to reveal patterns of a scientific portfolio with respect to a global map of scientific literature [54]. The so called "dual-map" refers to the citing and cited relationship in the overall visualization. Given 962 Sponge City papers, CiteSpace visualizes the disciplinary concentrations of these papers, and how these papers connect various regions according to their citation relationship. Each region is depicted by one colour to represent a academic field. Colored curves represent paths of references, originating from the citing map on the left and pointing to the cited map on the right. The nature of each area is determined by a set of journals that belong to the area, that is, a cluster. Each area is labeled by the most-common words in the titles of the corresponding journals. As shown in Figure 4, papers on Sponge City and its synonyms primarily appear in three broad areas on the citing map: the area in the top left corner in dark blue with the label of ecology/earth/marine; the area next to it in yellow with the label of veterinary/animal/science; and the area near the bottom in light blue with the label of economics/economic/political. Citation curves that originated from each of the three major regions point to regions in the cited maps on the right, among which the most primary links in yellow or dark blue are labeled with citing and cited journals. Citation paths in dark blue, for instance, indicate that publications in ecology-, earth-, and marine- related journals cite primarily three groups of journals, including earth/geology/geophisics, environmental/toxiology/nutrition, and economics/economic/political journals [47,55].

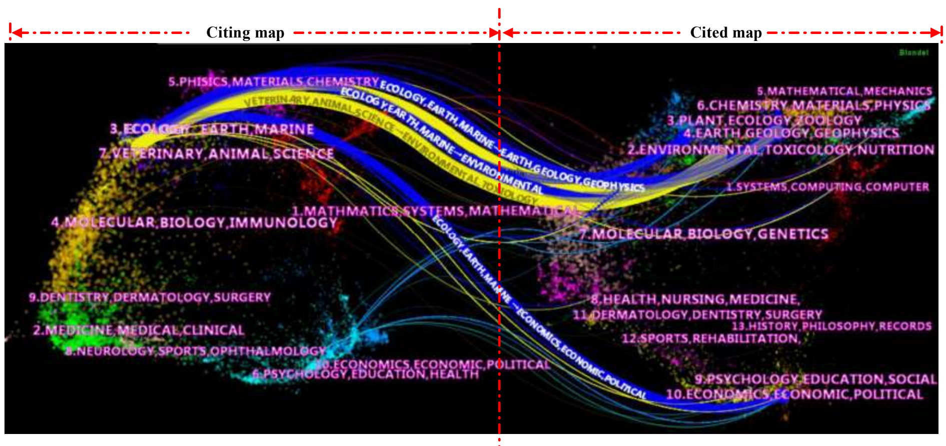


Figure 4. A dual-map overlay of the final document storage (Colored curves represent paths of references; Each area is labeled by the most-common words in the titles of the corresponding journals.)

3.2. Classification of Research Types

Scrutinizing the paper list in the NoteExpress, we classified 962 papers in the final document storage into 9 types research content as shown in Table 2. The number of papers, ratio and typical literature of each research type are shown in Table 3. It should be noted that content I, II, III, IV (namely, evaluation/prediction papers, modeling/planning/optimization papers, case studies and development of new technologies/tools/approaches papers) are mainstream research direction of Sponge City, occupying 80% of all studies. In addition, of all case studies (content III), there are most case studies from practice of China with the number of 66, far more than case studies from other backgrounds.

Table 2. Classification of research types based on topics.

Types	Description
Content I	• Effectiveness evaluation of Sponge City measures, evaluation/prediction of flood runoff reduction, risk/security evaluation;
Content II	• Modelling, planning or optimization of rainwater management system;
Content III	• Case study of Sponge City in various practical background;
Content IV	• Development of new technologies/tools/approaches, such as green roof, rain garden, urban hydrology;
Content V	• Review of Sponge City practices, effectiveness, technologies, and challenges in the background of climate change and urbanization;
Content VI	• Water quality/waste/pollution control or management;
Content VII	• Sustainability evaluation/analysis;
Content VIII	• Intelligent management or intelligent metering for urban water;
Content IX	• Policy analysis and recommendations.

Table 3. Details of research types.

Types	Number of Papers	Ratio	Typical Literature
Content I	288	29.938%	Li et al. [56], Yau et al. [42], Liao et al. [57], Viavattene and Ellis [58], Ouma and Tateishi [59], Ursino [60]
Content II	210	21.830%	Wang et al. [2]; Matteo et al. [61]; Hellmers et al. [62]
Content III	164	17.048%	Jia et al. [63], Gong et al. [64], Yao et al. [65], Xu et al. [66]
Content IV	109	11.331%	Cipolla et al. [67], Brunetti et al. [68], Mehring et al. [69], Guo and Luu [70], Alias et al. [71]
Content V	69	7.173%	Kuller et al. [72], Eggimann et al. [73], Tedoldi et al. [74], Vogel et al. [75], Xia et al. [8]
Content VI	45	4.678%	Morihama et al. [76], Freni et al. [77], Daigger [78]
Content VII	38	3.950%	Cettner et al. [79], Berndtsson and Jinno [80]
Content VIII	29	3.015%	Fernández et al. [81], Fuchs et al. [82]
Content IX	10	1.040%	Jasper et al. [83], Zheng et al. [84], Candaele [85]

Figure 5 shows the overview of a document co-citation network, reflecting classification of papers based on co-citation relationship. The largest cluster is in the center near the bottom of the figure, i.e., *#0 case study*. Each node depicts a cited reference. The citation history is visualized in terms of 'tree rings'. Nodes with citation bursts, which indicates the possibility that this scientific term has paid or is paying special attention to the potential contribution, are visualized by rings in red [47]. Similarly, the line between two nodes represents co-citation links [86], and the colour of it depicts the citation time corresponding with the time bar above. The largest cluster is *#0 case study*. The silhouette value of it, which measures the homogeneity of the cluster, is 0.802, close to 1, meaning the high reliability of this result. Case study has been identified with assistance in the problem of urban water management. It is available for scholars to do research basing on practical case and propose certain recommendations. Governments and communities are also capable of studying previous cases of practices, summarising their experiences, then selecting and utilising a set of appropriate plans. The second largest cluster is *#1 urban water management*, with a silhouette number of 0.942. It primarily concerns over public wastewater disposal and water supply management [87]. According to Citespace, the primary thermal investigation of this cluster are lowland area, non-point pollutant runoff, urban flood vulnerability, bioretention swale, mandatory urban rainwater harvesting, fossil energy, landscape fragmentation analysis, water recycling technologies and GIS water management system. The third largest cluster #2 *integrated urban drainage system (IUDS)*, which has been referred in the introduction, is an conception of integration of sewer, sewage water treatment plant, water receiving systems, and sustainable stormwater management, with economic factors taken into consideration [27].

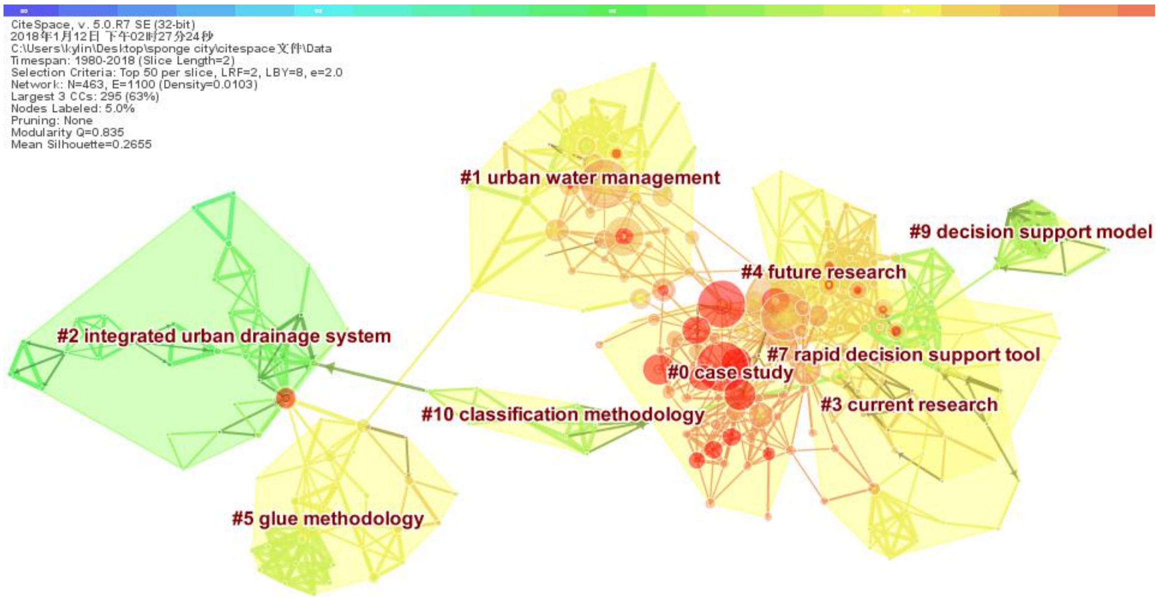


Figure 5. The overview of a document co-citation network (Each node depicts a cited reference; Nodes with citation bursts are visualized by rings in red.)

3.3. Research Foci Identification

Figure 6 shows the citation bursts of the dataset, which describes that the dynamics of a field can be characterized by articles that have received the steepest increase of citations. A citation burst represents the possibility that the research community has paid or is paying special attention towards the potential contribution, which is suitable to identify research foci [47]. CiteSpace separates citations into certain groups according to the time ranges of citations. In this way, literature cited in the same time range is gathered in one group, among which the article with the most citations indicates a study with the highest attention of focus. The number of blocks in light blue depicts the already published time of the paper, and red blocks depicts the burst periods. It shows the top 16 references with the strongest citation bursts, with strength to depict proportional citation numbers of each paper. Here select the strongest burst of groups beginning in different years, including 8 papers, which has been listed in Table 4.

The first strongest citation burst began in year 2005 was written by Hauger et al. in 2002 [27]. It presented and discussed a probabilistic approach to evaluating the performance of urban wastewater systems. The second strongest citation burst is also published in 2002 from Harremoes [88], which mainly summarized the status of urban storm drainage as an integrated professional discipline. The third paper presented an overview of current state of practising WSUD in Australia [89]. The fourth article was written by Scholz et al. It made a review about the wide-range literature on permeable pavement systems, summarised the research trend and put forward some recommendations for future study [90]. Next paper, written by Elliott et al. in 2007 focused on the low impact urban stormwater drainage technology and made a review of the LID models [91]. The sixth article, published in 2007, also belongs to review of LID practices, made a summary of temporary research, such as bioretention cells, porous pavement and grassed swales [92]. It has been cited 424 times in total, which represents the strongest citation burst among all the articles in the dataset. Ahiablame et al. [93] also made contributions on LID technology and assessed the performance of rain barrel/cistern and porous pavement [93]. The last paper in the list is from Qin et al. [94], which focused on LID and its effects on urban flooding under different rainfall characteristics. It can be figured out through examining the strongest citation burst that advanced technologies of LID practices has been paid the closest attention, followed by urban stormwater drainage, permeable pavement and urban flooding.

References	Year	Strength	Begin	End	1960 - 2017
RAUCH W, 2002, WATER SCI TECHNOL, V45, P81	2002	4.8234	**2005**	2010	
HARREMOES P, 2002, WATER SCI TECHNOL, V45, P1	2002	3.8863	**2006**	2010	
WONG THF, 2006, AUST J WATER RESOUR, V10, P213, DOI	2006	4.0026	**2009**	2011	
MITCHELL VG, 2006, ENVIRON MANAGE, V37, P589, DOI	2006	3.6921	**2009**	2011	
HUNT WF, 2006, J IRRIG DRAIN E-ASCE, V132, P600, DOI	2006	4.3948	**2010**	2013	
LI H, 2009, J HYDROL ENG, V14, P407, DOI	2009	4.0962	**2010**	2012	
SCHOLZ M, 2007, BUILD ENVIRON, V42, P3830, DOI	2007	5.2611	**2010**	2013	
ELLIOTT AH, 2007, ENVIRON MODELL SOFTW, V22, P394, DOI	2007	6.5237	**2012**	2015	
DIETZ ME, 2007, WATER AIR SOIL POLL, V186, P351, DOI	2007	7.8864	**2013**	2015	
GILL SE, 2007, BUILT ENV, V33, P115	2007	3.9149	**2013**	2014	
BURNS MJ, 2012, LANDSCAPE URBAN PLAN, V105, P230, DOI	2012	4.2707	**2015**	2017	
FLETCHER TD, 2013, ADV WATER RESOUR, V51, P261, DOI	2013	3.7686	**2015**	2017	
LIU YZ, 2015, J ENVIRON MANAGE, V147, P12, DOI	2015	3.7686	**2015**	2017	
AHIABLAME LM, 2013, J ENVIRON MANAGE, V119, P151, DOI	2013	5.127	**2015**	2017	
LIU YZ, 2015, SCI TOTAL ENVIRON, V511, P298, DOI	2015	3.9751	**2016**	2017	
QIN HP, 2013, J ENVIRON MANAGE, V129, P577, DOI	2013	7.587	**2016**	2017	

Figure 6. Top 16 references with strong citation bursts.

Table 4. Articles with the most citations in different time ranges.

Article	Strength	Time Range	Number of Citations
Hauger et al. [27]	4.8234	2005–2010	99
Harremoes [88]	3.8863	2006–2010	63
Wong [89]	4.0026	2009–2011	93
Scholz et al. [90]	5.2611	2010–2013	228
Elliott et al. [91]	6.5237	2012–2015	286
Dietz et al. [92]	7.8864	2013–2015	424
Ahiablame et al. [93]	5.127	2015–2017	44
Qin et al. [94]	7.587	2016–2017	57

Similar to the citation bursts, keywords burst detection is also available of depicting bursts keywords to indicating research foci. The time periods of bursts are depicted as blocks in red. As shown in Figure 7, top 11 strongest keywords bursts present during the period between 1960 to 2018. The strongest burst among ones began in the same year include source control (started in 1997), sustainable development (started in 1997), pollution (started in 2002), sewer (started in 2002), real time control (started in 2002), land use (started in 2008), calibration (started in 2008), soil (started in 2014), governance (started in 2014), performance (started in 2015), and green-roof (started in 2016). These results are close to the trend figured from Figure 8.

Figure 7. Top 11 keywords with the strongest citation bursts.

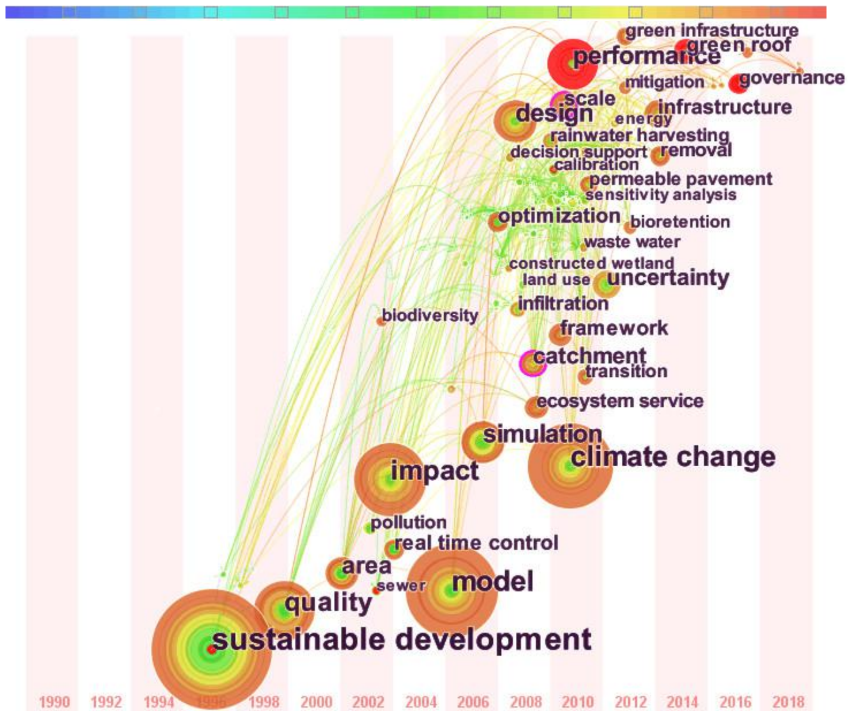


Figure 8. Appearance time of keywords (The color of a ring denotes the time of appearance; The thickness of a ring is proportional to the number of appearance frequency in a given time slice; The link between different keywords denotes co-occurrence in the same paper.)

Figure 8 depicts the appearance time of keywords. Each node represents a keyword. The repeating times of the keyword in the dataset are visualized in terms of 'tree rings'. The color of a ring denotes the time of appearance. The thickness of a ring is proportional to the number of appearance frequency in a given time slice. The link between different keywords denotes co-occurrence in the same paper. It can be concluded that sustainable development, model, water quality issues, impact research, climate change receive long and close attention in Sponge City research. Although the dark red nodes, including performance, governance and green roof are not stand out by size, they represent the recent hot topics in Sponge City.

4. Challenges Standing Ahead

As shown in the literature statistical results, there is a significant repository of literature that touches on the theme of Sponge City. It can be anticipated that Sponge City research is going to soar up in the future. As can be seen from Figure 9, there is a general increasing trend in all 9 content types.

Seen from many case studies of Sponge City, urban water management system built based on the concept of Sponge City works effectively in reducing surface flood risk [64,95], managing storm water runoff [63,65,66,96,97], improving economic feasibility [95]. Despite desirable technical performances of Sponge City, some case studies also show that some projects uptake in many places has been slow or has not reached its full potential [95,98,99]. It is mostly due to reasons beyond the engineering realm, and these directions call for further research:

(1) Trans-disciplinary approaches. Some review and evaluation studies show that trans-disciplinary are more and more important in successful urban water management [100–102]. As it is also shown in Figure 4, Sponge City papers are citing and cited in a wide range of disciplinary. Further in Figure 8, the keywords of Sponge City also come from an extensive areas including ecology, earth, engineering, environment, biology etc. There is a clear trend in Figure 8 that the research directions are becoming more and more diverse after 2010. These findings imply an integrated and trans-disciplinary approach are becoming indispensable to incorporate the many disciplines in a common platform to facilitate innovative and sustainable solutions.

(2) A design framework integrating leadership, technical support, government, legislation and institutions commitment. Usually local governments plan and regulate the bulk of public and private infrastructure and development, therefore they are key participants in the implementation of urban water management system [34]. Merely focusing on technical approaches would limit the implementation scale and effect of Sponge City. For example, Limthongsakul et al. [99] found a mismatch between limited authority and transboundary problems of stormwater management, which lead to the unsatisfactory results of a case study in Bangkok. Bahria et al. [98] identified the critical issues for improving uptake and scaling up, including strong leadership, the commitment of government and the institutions involved, and a formal programme of capacity building and technical assistance. Li et al. [13] summarized the challenges from the experience of 30 pilot Sponge Cities, and also highlighted the challenges of education/training, legal and regulatory, cooperation and data sharing etc. Although there are the least papers related to policy analysis and recommendations (Content IX), as shown in Figure 9, there is a growing trend and some studies begin to incorporate policy consideration into the decision making [103,104].

(3) Application of information technology. The promise of collecting and utilizing large amounts of data has never been greater in the history of urban water management [20,73]. It is very challenging that Sponge City needs to gather and monitor data in real time which allows mining these data for details that aid in day-to-day operations, regulatory compliance, and cost savings. Big amounts of data are generated and exchanged between departments, devices and regions. Some of the data exchanged are highly uncertain [20,105–107]. A typical case study is from Thorndahl et al. [108], who tried to simulate various types of flood events both historically and in real-time. The system of [108] was tested on the small town of Lystrup in Denmark. Results show it was possible to generate detailed flood maps in real-time with high resolution radar rainfall data, but rather limited forecast performance in predicting floods with leadtimes more than half an hour. Many papers pointed out that information technology has become a requisite part of municipal water management systems [73,109–111]. Many Content I, II, IV, VI, VIII papers are data-driven studies, such as application of weather radar data [108,112], urban data integration planning or database [20,113], urban storm water data processing [114], assessment of data and parameter uncertainties [77,105–107]. Some outstanding keywords in Figure 8 represent the focus of information technology, such as “real time control”, “simulation”, “uncertainty”. As it is shown in Figure 7, “real-time control” is one of the keywords with the strongest citation bursts. It can be noticed that the growth trend in content VIII “intelligent management or intelligent metering for urban water” is

remarkable as shown in Figure 9. It is also a proof of information technology and intelligent management becoming focus of frontier Sponge City research.

(4) Case studies of Sponge City in other parts of the world. Case studies (content III) grow rapidly as shown in Figure 9. However, there are the most case studies carried out in cities of Asia, North America, Australia and Europe. It could be a opportunity to carry out case studies in other parts of the world. For example, most of the urbanization in Africa over the next 30 years will occur in fast-growing small towns that lack mature infrastructure. This offers a unique opportunity to implement innovative solutions based on integrated urban water management [98]. There are some initial attempts of Sponge City in South Africa [115–117]. However, the successful experience in some places cannot be applied to other places. Local weather conditions and the degree of urbanization of different cities can vary considerably [7]. Plans and technology will need to be customized, and measures need to be adjusted according to the every actual circumstance, which can be a future research direction.

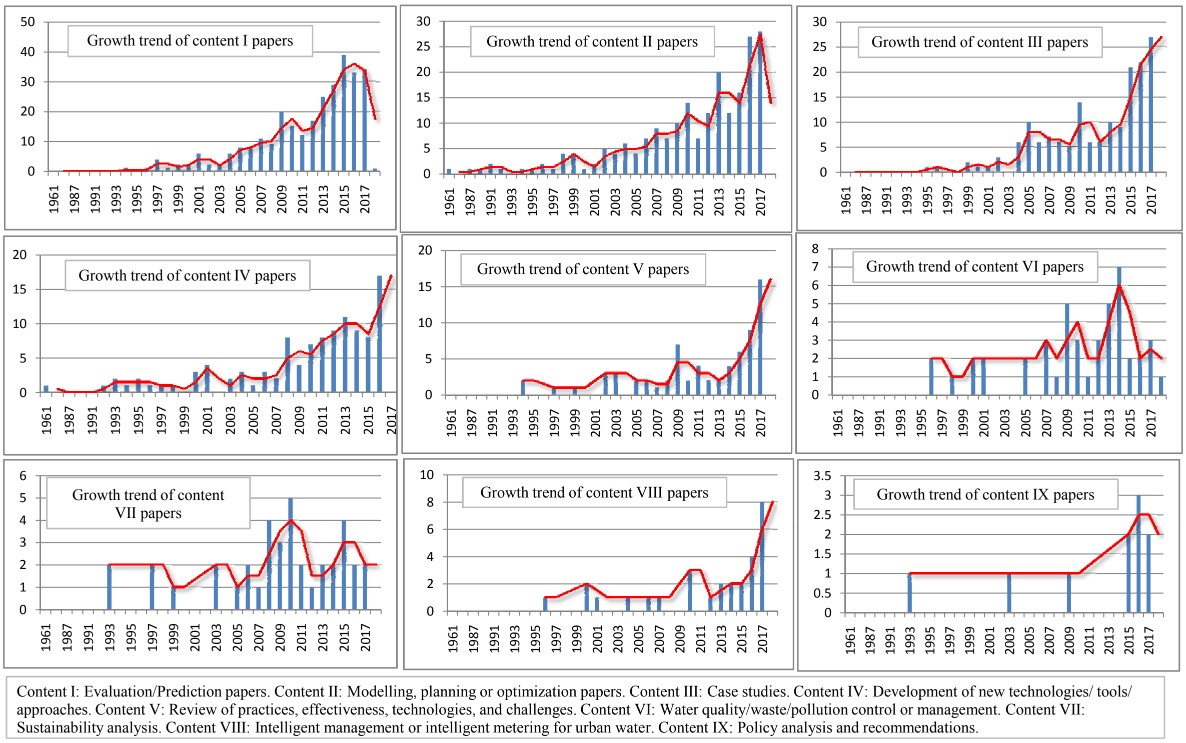


Figure 9. Growth trends of papers in different content types.

5. Conclusions

This paper conducted a systematic literature mining of Sponge City. The literature's disconnection caused by different names was conquered by using the following synonyms for Sponge City: SUWM, IUDS, WSUD, LID, ABC Waters Program, SUDS. Researchers of Sponge City could obtain a holistic picture about the research progress, trends and foci. The anticipated future research directions have certain guiding significance. The methodology introduced was also applicable in other disciplines.

This paper created a literature analysis system, which included literature export from WOS and systematic analysis via NoteExpress and CiteSpace. A final document storage of Sponge City containing 962 articles was formed. By applying the literature analysis system, we found that: (1) Literature of Sponge City has grown rapidly in last two decades; (2) USA, China, England and Australia generate almost 60% of Sponge City research; (3) Papers on Sponge City and its synonyms primarily cited papers in the areas of ecology/earth/marine, veterinary/animal/science and economics/economic/political. Meanwhile, Sponge City papers were primarily be cited by research in the areas of earth/geology/environmental/economic/political. (4) From examining the strongest citation burst that advanced technologies of LID practices has been paid the closest attention, followed by urban stormwater drainage, permeable pavement and urban flooding. (5) Sustainable development, model, water quality issues, impact research, climate change has received long and close attention in Sponge City research. Performance evaluation, governance and green roof represented the recent hot topics in Sponge City. (6) According to the theme, Sponge City literature can be classified into 9 theme types. Content I, II, III, IV (namely, evaluation/prediction papers, modeling/planning/optimization papers, case studies and development of new technologies/tools/approaches papers) were mainstream research directions of Sponge city, occupying 80% of all studies. (7) The following topics were anticipated as the future research directions: Trans-disciplinary approaches, a design framework integrating leadership, technical support, government and institutions commitment, application of information technology, case studies of Sponge City in other parts of the world.

Although we established a relatively comprehensive literature storage, a defect is that we cannot collect all Sponge City literature. The literature statistical results are based on the 962 articles, and could not illustrate all the research in this field. As the Sponge City research is increasingly abundant and mature, future literature mining can consider more keywords and databases in searching strategy. The analyzing tools can also be extended to find more effective information.

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Author Contributions: Zongmin Li established the framework of the literature analysis system, analyzed the literature by NoteExpress, and wrote parts of Sections 3–5. Shuyan Xu downloaded the bibliographical reference on WOS, analyzed the literature by CiteSpace, and wrote Sections 1 and 2 and parts of Section 3. Liming Yao critiqued the draft and the literature analysis system.

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Sample Availability: Samples of the compounds ...... are available from the authors.

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