Knowledge mapping of urban water resources management under changing environment

S M Wang¹, R G Jiang¹,², J C Xie¹, T Pan¹ and J C Liang¹

¹ State Key Laboratory of Eco-hydraulics in Northwest Arid Region of China, Xi’an University of Technology, Xi’an 710048, China
² E-mail: jrengui@163.com

Abstract. With climate change and inappropriate human behavior, the problem of urban water resources has become increasingly serious. The aim of this paper is to make insights into certain characteristics and landmark articles of urban water resources management (UWM) and to analyze the future trends of this field. Bibliometric software is used to explore the spatial and temporal distribution, research hotspots, research frontiers and representative literature in the field. The number of publications in the field shown a steady growth trend for past 12 years. Among all the countries, Australia has published the largest quantity of articles than other countries, and Netherlands has the closest connection to others. The reference co-citation analysis was carried out to obtain the representative references. Based on keyword co-occurrence analysis, research hotspots mainly include system, climate change, impact, sustainability. Emerging keywords were obtained using keyword burst detection analysis, indicating that reducing environment footprint and sustainable rainwater management are the research frontiers in the last few years, and are expected to continue.

1. Introduction

The comprehensive report of United Nations Educational, Scientific and Cultural Organization on water resources considers that water will be the most important resource to constrain human economic and social development in the 21st century. With the rapid development of cities and inappropriate wading behavior of human beings, the available water is rapidly reduced, and human beings are facing an increasingly serious and comprehensive water crisis [1]. 83 percent of people in developed countries and 53 percent of people in developing countries are expected to live in urban areas by 2030 [2]. Therefore, the research of USRM in the process of rapid urbanization is a hot issue in the field of global water resources.

Scholars from all over the world have studied the status quo of water resources, the actuality of USRM, and the methods of studying USRM from different angles. Water sensitive urban design is a concept developed in Australia that provides the possibility to maximize the value of water in urban areas and takes the resilience into account of urban flooding and drought. Carlos et al. [3] combined the existing knowledge of water sensitive cities with resilience to establish an elastic model. China has put forward "the sponge city", which is the first integrated USRM strategy implemented by developing countries. On the basis of USRM policy in China, Wang et al. [4] discussed the challenges, demands and future development direction. In consultation with stakeholders, Renouf et al. [5] developed quantitative indicators of the metabolic characteristics of USRM to bridge the gap between the vision of sustainable USRM and the performance indicators. Scientists and practitioners dealing with USRM
call for a transition to adaptive regimes. Bei et al. [6] provided a bibliometric approach to assess if there is a transition in social, cross-boundary interactions in the professional community and research publishing of the field of urban water science. Urban water cycle is one of the frontier issues in the field of water resources and the basis of USRM. By studying the differences and compatibility of urban hydrological process scales and methods, Wei et al. [7] highlighted the gaps in urban water cycle, including the development of a unique model to simulate the characteristics and process evolution of urban areas.

With the emergence of research hotspots, it is difficult to fully grasp the traditional methods for literature review in this field. Therefore, it is necessary to analyze the literature in the field of USRM using bibliometrics analysis. Bibliometrics emerged in the early 20th century and has developed into a visual analysis method which has been widely used to assess the maturity and vitality of a research field [8]. This paper investigates the network of co-countries, co-occurring keywords and co-citation reference using CiteSpace. The knowledge domains, quantified research patterns and trends about USRM are further explored, which provide references for study on the USRM.

2. Data and methods

2.1. Data acquisition
The data of this study are obtained from core database of Web of Science (WoS), which is a scientific and technological literature retrieval tool published by the institute for scientific intelligence (ISI). In order to ensure recall ratio, the retrieval formula of literature data was determined to be: TS="urban water resources management*" or "urban water resource management*". The time span was set from 2008 to 2019, the article type was set as "Article", and irrelevant items such as report, news and conference notification were removed. Ultimately, 487 search results were used in this study.

2.2. Methods
The concept of mapping knowledge domains originated at a conference organized by the National Academy of Sciences (NAS) in 2003 [9]. CiteSpace, the most popular knowledge mapping tool, is used for analysis in this study. It is mainly used for statistical analysis of scientific literature data and presenting the analysis results to readers in the form of mapping knowledge domains.

Based on bibliometrics and statistics theory, this study analyzes the hotspots, research frontiers evolution characteristics and landmark articles of USRM from the perspective of time series, country co-operation network, keyword co-word network and reference co-citation network. The process of USRM knowledge map analysis is shown in Figure 1.

![Figure 1. Process of USRM knowledge map analysis.](image-url)
3. Results and discussion

3.1. Time sequence analysis of articles

Based on the time sequence, the development and change of USRM research in different periods can be effectively analyzed. According to retrieval results in WoS, the annual distribution of the number of articles is obtained and the literature distribution curve is drawn, which is conducive to the prediction of its development trend. From 2008 to 2019, 487 articles were published in this field. The temporal distribution of the literature is shown in Figure 2.

Figure 2. Time sequence of relevant articles on USRM in WoS.

From 2008 to 2019, the annual number of papers published in the field of USRM shown an overall growth trend. With the development of urbanization, cities are facing increasingly prominent water problems, which has gradually increased the research enthusiasm in the field of USRM. The development process can be roughly divided into three stages. At first, the number of papers published in 2008-2009 increased rapidly and reached a small peak. This has a lot to do with the World Water Week forum held in Sweden in August 2008, where the Minister for International Development and Cooperation called on people around the world to work together to find a balance between water resources and economic development [10]. After 2009, the research on the USRM mode entered the exploration stage, and the number of papers published from 2009 to 2012 was generally stable. In March 2012, the 6th World Water Forum was held, which proposed that the world was facing an extremely serious water problem [11]. With the severe challenges brought by urbanization, population growth, global climate change and economic change, water resources management has become a major practical issue of global concern. The number of papers showed a steady increase from 2012 to 2019, indicating that with the increasingly severe water resources problems in cities around the world in recent years, the research in this field has developed booming. With the rapid development of society, USRM will still be a research hotspot, and the number of articles is expected to grow further.

3.2. Country co-operation network analysis

CiteSpace was used to analyze country co-operations network of papers on the USRM published from 2008 to 2019. In the function and parameter setting area of CiteSpace, the time slice was set to 1 year, the node type was set to "Country", and select Top 100 for the threshold value. Running CiteSpace can obtain the mapping knowledge domain of country co-operation network, as shown in Figure 3. In the
co-operation network obtained by CiteSpace, the size of the nodes represents the number of papers published by the country, and the color of the chronological ring represents the publication time of the papers, and the main nodes have been indicated in Figure 3.

According to the mapping knowledge domain of country co-operation network, "Australia" has the largest node, which means that the number of Australian publications in this field are more than that in other countries. Australia is one of the countries with severe water shortage around the world, rapid growth in demand and severe drought have increased the pressure on water supply [12]. Consequently, Australia attaches great importance to research in the field of USRM. The nodes, such as "USA", "China" and "Netherlands", are also prominent and of similar size, indicating that the USA, China and the Netherlands have the comparable amount of publications in the field and have significant positions.

The betweenness centrality is an index to measure the importance of nodes, which represents the influence of nodes on the information communication between others. When the centrality of the node exceeds 0.1, a purple ring will be added to the outermost layer of the node, and the thickness of the purple ring is proportional to the central value of the node. The purple ring of the "Netherlands" node is the thickest, indicating that the Netherlands has the highest betweenness centrality in the country co-operation network. Netherlands has a long history of integrated USRM, and Dutch cities such as Amsterdam consistently rank highly in international sustainable development rankings [13]. So, the Netherlands has extensive cooperation and exchanges with other countries. In general, most of countries have in-depth research on the USRM, and there are good cooperative relations among them.

3.3. Research hotspot and frontier analysis

3.3.1. Keywords co-word network analysis. Keywords are highly refined to the literature content, and the co-word analysis of keywords can reflect the hotspots in the research field to some extent. Consequently, Keywords co-word analysis was conducted on the articles. The time slice was selected as 1 year and selected the top 50 items that appeared the most in each time period, chose "Keyword" as node type. As shown in Figure 4, the knowledge mapping of keywords co-word network was obtained by running software and merging synonyms. The size of each node corresponds to the frequency of keyword occurrences. The lines represent the co-occurrence intensity between keywords, and the color of the line between keywords represents the first co-occurrence time.

In the mapping knowledge domain of keyword co-word network, the retrieval topic "urban water resources management" has the largest node. Furthermore, the most frequently used keywords include "system", "management", "city", "climate change", "sustainability", "impact", "model", "reuse", "drainage", representing the research hotspots from 2008 to 2019. Table 1 shows the high-frequency
keywords in detail. Traditional USRM aims to meet the demand for water and discharge wastewater and rainwater from the city. However, with the rapid development of urbanization and the increasing shortage of urban water resources, researchers began to explore the transformation of traditional water resources management methods into sustainable water resources management system. The research hotspots of the stage mainly included system, model, transformation, sustainable, climate change, urbanization, sustainability, frame. As time goes by, the scope of research in the stage was constantly expanded and the research hotspots gradually evolved, mainly including performance, policy, infrastructure, design, integrated USRM, stormwater management, runoff.

3.3.2. Keyword burst detection. A group of emerging concepts in a specific research field is defined as "research frontier", which can reveal hotspots and emerging trends in the research field. The burst detection in CiteSpace is used to determine whether the appearance of an entity increases sharply with reference to its peers [14]. Burst detection can identify bursts keywords as indicators of emerging trends. The burst detection results in the software are plotted in Table 1.

The algorithm proposed by Kleinberg is used to calculate the strength of burst in the software [15]. The keyword with the highest burst strength is "system", its burst strength is 8.3909. The duration of the burst from 2008 to 2013, indicating that the concept of system had been frequently applied in this stage of USRM. The keyword that burst started in 2008 is "China", its burst strength is 2.8117, indicating that China has significantly strengthened its emphasis on the USRM. The burst of the term "sustainable development" began in 2009, indicating that the concept of sustainable development has attracted intense attention from researchers as early as 2009. In recent years, because of frequent urban waterlogging, integrated and sustainable stormwater management has become a research hotspot. Compared with traditional methods, green infrastructure has been as a way of sustainable stormwater management and increasingly popular. "Green infrastructure" is the latest burst keyword and is expected to continue.

| keywords                      | Year | Strength  | Begin | End  |
|-------------------------------|------|-----------|-------|------|
| system                        | 2008 | 8.3909    | 2008  | 2013 |
| China                         | 2008 | 2.8117    | 2008  | 2010 |
| sustainable development       | 2008 | 2.1052    | 2009  | 2013 |
| management                    | 2008 | 2.5154    | 2009  | 2012 |
| drainage                      | 2008 | 2.3358    | 2009  | 2012 |
| urban water                   | 2008 | 2.67      | 2009  | 2010 |
| Australia                     | 2008 | 3.1628    | 2009  | 2013 |
| reuse                         | 2008 | 3.0672    | 2012  | 2015 |
| rainwater                     | 2008 | 1.9288    | 2012  | 2013 |
| impact                        | 2008 | 2.0102    | 2013  | 2014 |
| flow                          | 2008 | 2.6004    | 2014  | 2015 |
| consumption                   | 2008 | 2.5199    | 2015  | 2017 |
| footprint                     | 2008 | 2.1055    | 2016  | 2017 |
| green infrastructure           | 2008 | 2.0441    | 2017  | 2019 |

3.4. Reference co-citation network analysis
The main purpose of co-citation analysis is to determine the knowledge structure of the research field according to the groups formed by accumulated co-citation clues in the scientific literature [16]. The co-citation analysis of references in the field of USRM was initially conducted by selecting articles from 12 time slices from 2008 to 2019, and 50 references with the highest citation were selected from each time slice. These articles were combined into a reference co-citation network, and the combined
network was decomposed into certain clusters. Each co-citation cluster is summarized with a sentence selected from an article abstract that cites at least a member of the cluster. The timeline view of reference co-citation network is shown in Figure 5. Clusters are labeled on the right, and only the authors and years of the highly cited articles are shown in the figure.

The largest cluster #0 contains 55 members with an average citation year of 2007, and the cluster label is sustainable urban water management. By analyzing the articles on the USRM and other similar fields, Brown and Farrelly (2009) identified 12 types of obstacles, mainly of a social system [17]. This article is the most cited one in the largest cluster, followed by article published by Wong and Brown (2009) [18]. The average citation year of clustering #2 is 2010, and the cluster label is key driver. The most cited reference in the cluster is the article published by Brown and Keath (2009) [19]. The label of cluster #4 is household water demand, and the average citation year is 2013. The most cited reference in the cluster is the article published by Farrelly and Brown (2011) [20]. With the development of urbanization, centralized USRM systems are increasingly unable to adapt to the challenges posed by climate change, population growth and environmental pressures. Marlow et al. (2013) [21] critically evaluated the discussion around new approaches to USRM and infrastructure. This article is the most cited reference in cluster #6. The most cited paper in cluster #8 is the article published by Makropoulos et al. (2008) [22]. In addition, there is a small difference in citation frequency between members of the other clusters, and the outstanding article is not obvious. The average citation years of cluster #1 and #3 are both 2014, indicating that the two are latest clusters gradually formed in recent years and represent the development trend of this field.

Red rings of citation bursts appeared in the center of numerous nodes in the timeline view, which represents the citation burst detected in the corresponding time slice of. Burst detection can determine whether a given frequency function has a statistically significant fluctuation within a short interval and is of great value in determining when a particular citation burst. The articles with high citation bursts in each cluster are basically consistent with those with high citation frequency. These references represent the research hotspots in the field of USRM at a specific time.

4. Conclusions
This study conducts a bibliometrics based review of articles on the USRM. From the perspectives of time series, country co-operation network, keyword co-word network and reference co-citation network, the hotspots and evolution characteristics of USRM were analyzed.

The time series diagram shows that the publications still increase, indicating that the research field remains not stabilized, and the research profundity needs to be further deepened. According to the analysis of the country co-operation network, Australia has a leading position in the number of published articles in the field. Meanwhile, the international cooperation among these countries is relatively close. Netherlands is the country with the closest connection with other countries in the network.

Based on the co-word analysis of keywords, system, management, city, climate change, impact, sustainability, model, reuse and drainage are the most prominent research hotspots in this field. Based on keyword burst detection, footprint and green infrastructure are the research frontiers in recent years, indicating that reducing environmental footprint and sustainable rainwater management measures are the focus of attention in the last few years, and is expected to be continue. Based on the co-citation analysis of the references, the most frequently cited and representative articles in each cluster were obtained.

Acknowledgments
This paper was partly funded by the National Key Research and Development Program of China (Grant No. 2016YFC0401409), National Natural Science Foundation of China (Grant No. 51679188, 51509201), Young Technology Star in Shaanxi Province of China (Grant No. 2020KJXX-092). The authors thank the editor and anonymous reviewers for their valuable comments and suggestions.

References
[1] Vidyasagar D 2007 J. Perinatol. 27 56-8
[2] Barney C 2004 J. World Dev. 32 23-51
[3] Carlos N A, Richard A, Berry G, Jeroen R, Assela P and Chris Z 2014 J. WIREs Water. 1 173-86
[4] Wang H, Mei C, Liu J H and Shao W W 2018 J. Sci China Tech Sci. 61 317-29
[5] Renouf M A, Serrao N S and Kenway S J 2017 J. Water Res. 122 669-77
[6] Bei W, Marielle V D Z, Edwin H, Barend V D M and Wim V V 2015 J. Environ. Innov. Societal Trans. 15 123-39
[7] Wei H B, Wang Y M and Wang M N 2018 J. Desalin. Water Treat. 110 349-54
[8] Chen C M 2004 J. Proc. Natl. Acad. Sci. U. S. A. 101 5303-10
[9] Chen Y, Chen C M, Liu Z Y, Hu Z G and Wang X W 2015 J. Studies Sci. Sci. 33 242-53
[10] Qi R 2008 J. Ecological Economy. 11 12-5
[11] Chao L 2012 J. Ecolog. Econ. 05 8-13
[12] Andrew H, Ainsley A and Stefan H 2008 J. Water Resour. Manag. 22 1445-60
[13] Vanham D, Mak T N and Gawlik B M 2016 J. Sci. Total Environ. 565 232-39
[14] Chen C M, Dubin R and Kim M C 2014 J. Exp. Opin. Orphan Drugs. 2 709-24
[15] Kleinberg J 2002 Proc. ACM SIGKDD Int. Conf. Knowl. Discov. Data Min. (Edmonton) 61746 (Ithaca: New York) pp 91-101
[16] Gabe J, Trowsdale S and Vale R 2009 J. Water Sci. Technol. 10 1999-2008
[17] Chen C M, Fidelia I J and Hou J H 2010 J. Am. Soc. Inform. Sci. Techn. 61 1386-409
[18] Wong T H F and Brown R R 2009 J. Water Sci. Technol. 60 673-82
[19] Brown R R, Keath N and Wong T H F 2009 J. Water Sci. Technol. 59 847-55
[20] Farrelly M and Brown R 2011 J. Glob. Environ. Change-Human Policy Dimens. 21 721-32
[21] Marlow D R, Moglia M and Cook S 2013 J. Water Res. 47 7150-61
[22] Makropoulos C K, Natsis K and Liu S 2008 J. Environ. Modell. Softw. 23 1448-60