



OPEN ACCESS

EDITED BY
Chunhui Li,
Beijing Normal University, China

REVIEWED BY
Ying Zhu,
Xi'an University of Architecture and
Technology, China
Yongyong Zhang,
Institute of Geographic Sciences and
Natural Resources (CAS), China
Baohui Men,
North China Electric Power University,
China
Liu Liu,
China Agricultural University, China

*CORRESPONDENCE
Boyang Sun,
sunboyang@aliyun.com

SPECIALTY SECTION
This article was submitted to
Hydrosphere,
a section of the journal
Frontiers in Earth Science

RECEIVED 16 June 2022
ACCEPTED 25 July 2022
PUBLISHED 25 August 2022

CITATION
Yang X, Sun B, Lei S, Li F and Qu Y (2022),
A bibliometric analysis and review of
water resources carrying capacity using
rené descartes's discourse theory.
Front. Earth Sci. 10:970582.
doi: 10.3389/feart.2022.970582

COPYRIGHT
© 2022 Yang, Sun, Lei, Li and Qu. This is
an open-access article distributed
under the terms of the [Creative
Commons Attribution License \(CC BY\)](https://creativecommons.org/licenses/by/4.0/).
The use, distribution or reproduction in
other forums is permitted, provided the
original author(s) and the copyright
owner(s) are credited and that the
original publication in this journal is
cited, in accordance with accepted
academic practice. No use, distribution
or reproduction is permitted which does
not comply with these terms.

A bibliometric analysis and review of water resources carrying capacity using rené descartes's discourse theory

Xiaojing Yang¹, Boyang Sun^{2*}, Sheng Lei³, Fapeng Li² and Yanping Qu¹

¹Research Center on Flood and Drought Disaster Reduction, China Institute of Water Resources and Hydropower Research, Beijing, China, ²Development Research Center of the Ministry of Water Resources of P.R.China, Beijing, China, ³Jiangxi Academy of Water Science and Engineering, Nanchang, China

Water Resources Carrying Capacity is an important indicator of water sustainable and economic development, yet few studies investigated a bibliometric analysis of Water Resources Carrying Capacity research. In this research, we proposed a four-staged bibliometric analysis method for Water Resources Carrying Capacity studies following the René Descartes's *Discourse on the Method* guidelines which makes the bibliometric analysis process more systematic. Our four-staged bibliometric analysis method contains a refined screening process of the records, which can successfully delete poorly correlated data from tens of thousands of data within a short period of time and determined the subject-related data. The screening results shortlisted 271 records from an initial 16,769. We further conducted a complete bibliometric, statistical and meta-analysis of the 271 records. The results showed that China is the major country that conducts research on Water Resources Carrying Capacity. Modeling in various forms and system dynamics are the mainstream methods of Water Resources Carrying Capacity research. Water Resources Carrying Capacity is intrinsically linked to population carrying capacity, groundwater resources, urbanization and water shortage. Based on a comprehensive analysis of the research of Water Resources Carrying Capacity, we divided the research progress into five stages lastly. The method proposed in this research can provide reference for future bibliometric studies.

KEYWORDS

water resources carrying capacity, screening method, bibliometric analysis, water carrying state, VOSviewer

1 Introduction

1.1 Research background

Water resources are an important part of the natural environment and guarantee the development of the human society and economy. However, the distribution of water resources in space and time is often uneven. Rapidly developing and densely populated areas need more water resources but due to their uneven distribution, water resources in some areas cannot satisfy the local human population and economic demand for water (Yu et al., 2017). In this regard, it is important to pay attention to the relationship between the supply and consumption of water resources to be able to balance interaction between the two. Studying the relationship between water supply and consumption, that is, focusing on the water resources carrying capacity, is of great significance for the sustainable use of water resources within a certain region. Concern on sustainable use of water resources has increased due to the unprecedented growth and expansion of global economies within the last 3 decades that has placed an insatiable demand on water resources (Wu et al., 2020; Bian et al., 2022a). Hence, it is important to comprehensively study Water Resources Carrying Capacity (WRCC) to be able to achieve an efficient water related sustainable management.

1.2 Literature review and research gap

The concept of carrying capacity began in the study of physics and refers to the maximum load that an object can bear before any irreversible deformation occurs (Dhondt, 1988). Carrying capacity was however introduced from biology where it was applied in the study of wild animals (Young, 1998; Malthus, 1798). In 1921, Park and Burgess (Park and Burgess, 1921) re-invented the idea to calculate the maximum population that can be carried by a specific area from an ecological perspective based on the supply of objects and the state of natural and social resources in a specific period. From hence, carrying capacity has been applied in the field of ecology (Mcnaughton and Wolf, 1970; Kessler, 1994).

From early 1970, population and economic expansion, which sustained for 30 years, created a contradiction between social development and environmental sustainability and this triggered a worldwide exploration of the issue of Resources and Environmental Carrying Capacity (RECC). Afterwards, other concepts such as Land Carrying Capacity (Shi et al., 2013), Environmental Carrying Capacity (Li et al., 2019), and Resource Carrying Capacity (Wang et al., 2020) emerged, peaking research on carrying capacity.

In 1985, the United Nations Educational, Scientific and Cultural Organization (UNESCO) (UNESCO&FAO, 1985) proposed the definition of Resources Carrying Capacity.

Onwards, from then, carrying capacity has become one of the main contents of the concept of sustainable development (Bolis et al., 2017). In 1995, Arrow, the Nobel laureate in economics, and other well-known economists and ecologists (Arrow et al., 1995) published an article “Economic Growth, Carrying Capacity and Environment” in “Science”, which greatly improved the sustainable development and cataloged carrying capacity research in the scientific community.

WRCC is an extension of the concept of carrying capacity in the field of water resources, and belongs to a research aspect of Resources Carrying Capacity. WRCC research mainly originated in China. Though studied in other parts of the world at the time, scholars elsewhere regarded WRCC as part of the contents of sustainable development research and described it with terms such as available water and limits of river development (Falkemark and Lundqvist, 1998; Jonathan, 1999; Rijisberman and Frans, 2000; Gleick and Palaniappan, 2010; Zhu et al., 2010). An official scientific study of WRCC began in the late 1980's when the Xinjiang Water Resources Research Group met to discuss WRCC (XWRSSRG (Xinjiang Water Resources Soft Science Research Group), 1989). In 1990s, the concept of WRCC was clearly put forward by Shi Yafeng, an Academician of the Chinese Academy of Sciences (Shi and Qu, 1992). WRCC is about the relationship between the carrying “subjects” and the ‘objects’ in the “water resources-ecological environment-social economy” system, and whether the load generated by the objects exceeds the supporting capacity of the subjects.

After nearly 30 years of exploration and development, a large number of scientific research results have been discovered in the research of WRCC which has increasingly become a hot issue in regional water resources management. Early researches on WRCC mostly focused on cities (Yue et al., 2015; Dai et al., 2019; Yang et al., 2019), provinces (Huang et al., 2014; Yang and Ding, 2018; Deng et al., 2019; Zhu et al., 2019) and river basins (Yang et al., 2010; Wu et al., 2018a; Meng et al., 2018; Wang et al., 2018; Kang et al., 2019). With the continuous deepening of research on WRCC, especially in recent years, its research objects have also changed. More and more researches have begun to focus on the study of WRCC of some typical regions including arid and semi-arid areas (Wang et al., 2010; Xie et al., 2014; Li and Zhang, 2016; Qi et al., 2016; Xiao et al., 2017), urbanized regions (Gao, 2017), lake basins (Lei et al., 2013), water-deficient regions (Wang et al., 2014), karst regions (Bo et al., 2016; Yang et al., 2016; Li et al., 2018), mining areas (Chi et al., 2019), industrial park (Kang and Xu, 2012), islands (Cao et al., 2014; Kuspilić et al., 2018) and wetlands (Wang et al., 2017). While other studies have shown interest in WRCC research for certain specific periods, for example, some studies concentrate on WRCC of arid rangelands during the droughts (Accatino et al., 2017).

Calculation methods of WRCC have evolved over the study period. New methods including back propagation model (Yang

and Han, 2011), matter element analysis (Gao et al., 2013), grey clustering (Gao and Sun, 2018), state-space method (Tang et al., 2016), support vector machines (Zhang et al., 2008), analytic hierarchy process (Zhang et al., 2014; Chi et al., 2019), set pair analysis (Fu et al., 2008; Liu et al., 2018), multi-objective programming model (Wang and Zeng, 2013), metabolic theory (Ren et al., 2016), ecological footprint (Zhang and Li, 2012; Wang et al., 2017; Li et al., 2018; Dai et al., 2019; Yang et al., 2019), system dynamic model (Wang et al., 2014; Yang et al., 2015; Song, 2016; Fang, 2018; Sun and Yang, 2019), catastrophe theory (Chen et al., 2010; Song et al., 2020), cloud model (Cheng et al., 2018) and neural network (Lu et al., 2009; Wang, 2015) have been discovered. Some methods are a combination of two or three, such as, neural network and projection pursuit (Zhao, 2012); inexact fuzzy and multi-objective programming model (Wang and Zeng, 2013); analytic hierarchy process and fuzzy discrimination method (Chi et al., 2019); set pair analysis and entropy weight method (Cui et al., 2018); maximum entropy and entropy weight (Li et al., 2019); fuzzy set pair analysis model (Liu et al., 2018); combination weights and entropy principles (Zhou et al., 2017) and grey neural network model (Zheng et al., 2016).

The development and expansion of WRCC also witnessed the evolution of another concept of WRCC known as Water Resources Carrying State (WRCS) (Jiao and Liang, 2006; Ye et al., 2018). WRCC and WRCS are similar but differ slightly. Although the research on WRCC and WRCS both focus on the supply and demand of water resources within a certain area, WRCC tends to pay more attention on the larger economy and population that water resources in a certain area can support, making WRCC a threshold concept, while WRCS focuses on the balance between water supply and demand in a region.

1.3 The main work and innovations

Although the research on WRCC has increasingly become a hot topic in regional water resources management, bibliometric analysis of literature on it are still very limited (Zhang and Wang, 2012; Jin et al., 2019). Bibliometric analysis of the research on WRCC can clarify the development context and knowledge base, understand the development process, clarify the research progress, define research trends and provide scientific reference of WRCC studies.

To do a philosophical and scientific review of literature, we adopted René Descartes's (1596. 3. 31–1650. 2. 11) method of philosophical thinking expressed in his book, "*Discourse on the Method of Rightly Conducting One's Reason and of Seeking Truth in the Sciences*" (*Discourse on the Method*, in French: *Discours de la méthode pour bien conduire sa raison, et chercher la vérité dans les sciences*) (80). Based on his philosophical concept, René Descartes proposed a four-staged method of researching a problem which he categorized into the following: 1) The doubt stage, 2) The partition of problem stage, 3) Sequencing

of thoughts and problem-solving stage, and 4) The comprehensive inspection and review stage (Wikiquote contributors, 2020b). These four stages have important guiding significance for both scientific research and social practice, and thus have been widely researched and used in other studies, however, to our knowledge, no study has yet applied this thinking in bibliometric analysis. The basis of theoretical analysis is lacking in most bibliometric studies.

While conducting studies on bibliometric analysis, researchers often have to deal with thousands of records, some, not closely related with the topic under study. Some researchers perform manual screening of records directly (Tao et al., 2020), which consumes large quantities of time. And some of the studies even lack the process of screening (Huang et al., 2020; Mallawaarachchi et al., 2020; Secinaro et al., 2020), which will lead to less credibility of the results. Since finding out the subject-related records can be very time consuming, an efficient method that can quickly and precisely sort-out topic-related records within a short period of time is necessary. Consequently, we proposed a refined literature screening process to effectively and efficiently sort out relevant from irrelevant literature.

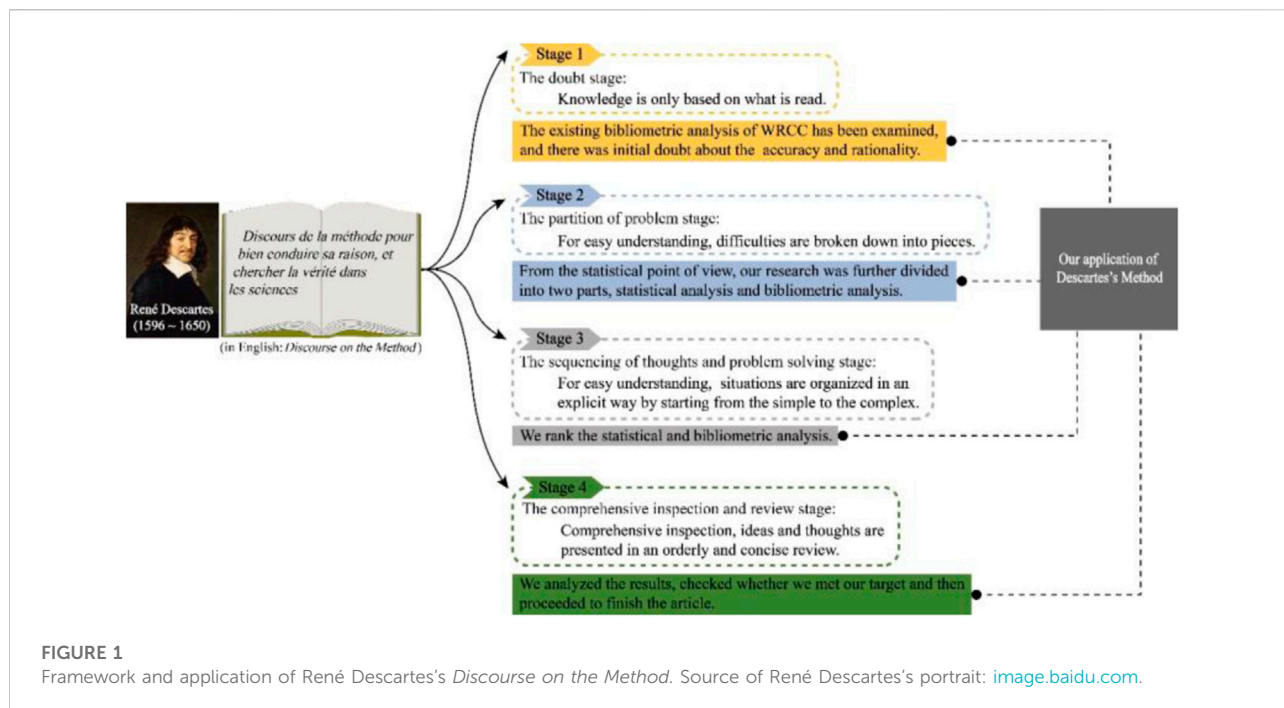
This article aims to sort out and summarize the research on WRCC through bibliometric analysis. The remaining parts of the article are structured as follows: the second part introduces the retrieval process, the records screening method and the analysis process; the third part analyzes and discusses the results of the bibliometric analysis and statistical analysis of WRCC; the fourth part summarizes the full text, and prospects for future development of research on WRCC.

2 A four-staged bibliometric analysis for WRCC

René Descartes's *Discourse on the Method* has been used as a general guideline, by which we build the framework of this research. Section 2.1 shows how we applied Descartes's four-staged methodology. Due to the macroscopic nature of Descartes's methodology, it is difficult to guide the specific steps (Wikiquote contributors, 2020b). According to the specific process of bibliometric analysis, and based on Descartes's methodology, we also divided the concrete steps of bibliometric analysis into four stages in this research (Section 2.2).

2.1 René descartes's *Discourse on the Method* and application

In Descartes's book *Discourse on the Method*, he proposed the true method by which to arrive at the knowledge of whatever lay within the compass of his powers, and he summarized this



method into four stages (Figure 1). These include: 1) The doubt stage in which ideas are scattered and uncoordinated, and knowledge is based only on what is read; 2) The partition of problem stage, where difficulties are broken down to pieces for easy understanding; 3) The sequencing of thoughts and problem solving stage, where by starting from the simple to the complex, difficult situations are organized in an explicit way for easy understanding and problem-solving; 4) The comprehensive inspection and review stage where enumerations are completed while ideas and thoughts are presented in an orderly and concise review (Wikiquote contributors, 2020b).

Putting René Descartes's study into perspective, in the first stage (Figure 1.) of this study where we examined the existing bibliometric analysis of WRCC, there was initial doubt about the rationality and accuracy of existing bibliometric research on WRCC. We found that the existing bibliometric analysis of WRCC were not systematic, lacked coherency and were not comprehensive. This confirmed our earlier assertion that bibliometric research on WRCC is limited. Only two studies by Zhang and Wang (2012) and Jin et al. (2019) have done a bibliometric analysis of WRCC. Zhang and Wang (2012) only conducted a bibliometric analysis of Chinese literature, and ignored the bibliometric analysis of English literature. Their paper is archaic ((Zhang and Wang, 2012), was published 8 years ago), and does not reflect the bibliometric analysis of current WRCC research. Even though Jin et al. (2019) was published recently, their work lacks a detailed screening process of the records (data) and also lacks rationality and

accuracy of the results. The above two scenarios are part of the foundations of this research.

In the second stage of applying René Descartes's philosophy, we broke the WRCC bibliometric analysis into several units consisting literature retrieval, records screening and analysis. From the statistical point of view, our research was further divided into two parts, statistical analysis and bibliometric analysis.

In the third stage, though we needed to rank the steps, since literature retrieval, records screen and records analysis cannot be re-ranked as literature retrieval should always come first followed by records screening and then analysis records, we chose rather to rank the statistical and bibliometric analysis. We found that statistical analysis was easier compared to bibliometric, so we finished the statistical analysis and then conducted a bibliometric analysis.

In the fourth stage, we analyzed the results, checked whether we met our target and then proceeded to finish the article.

2.2 Four stages of bibliometric analysis of WRCC

Because it can be better understood and thus can be widely used, staged method has attracted more researchers' attention in recent years (Wu et al., 2018b2018; Bian et al., 2022b). René Descartes's method can be concluded into four stages, therefore, we divide our research process also into four stages. Since each of

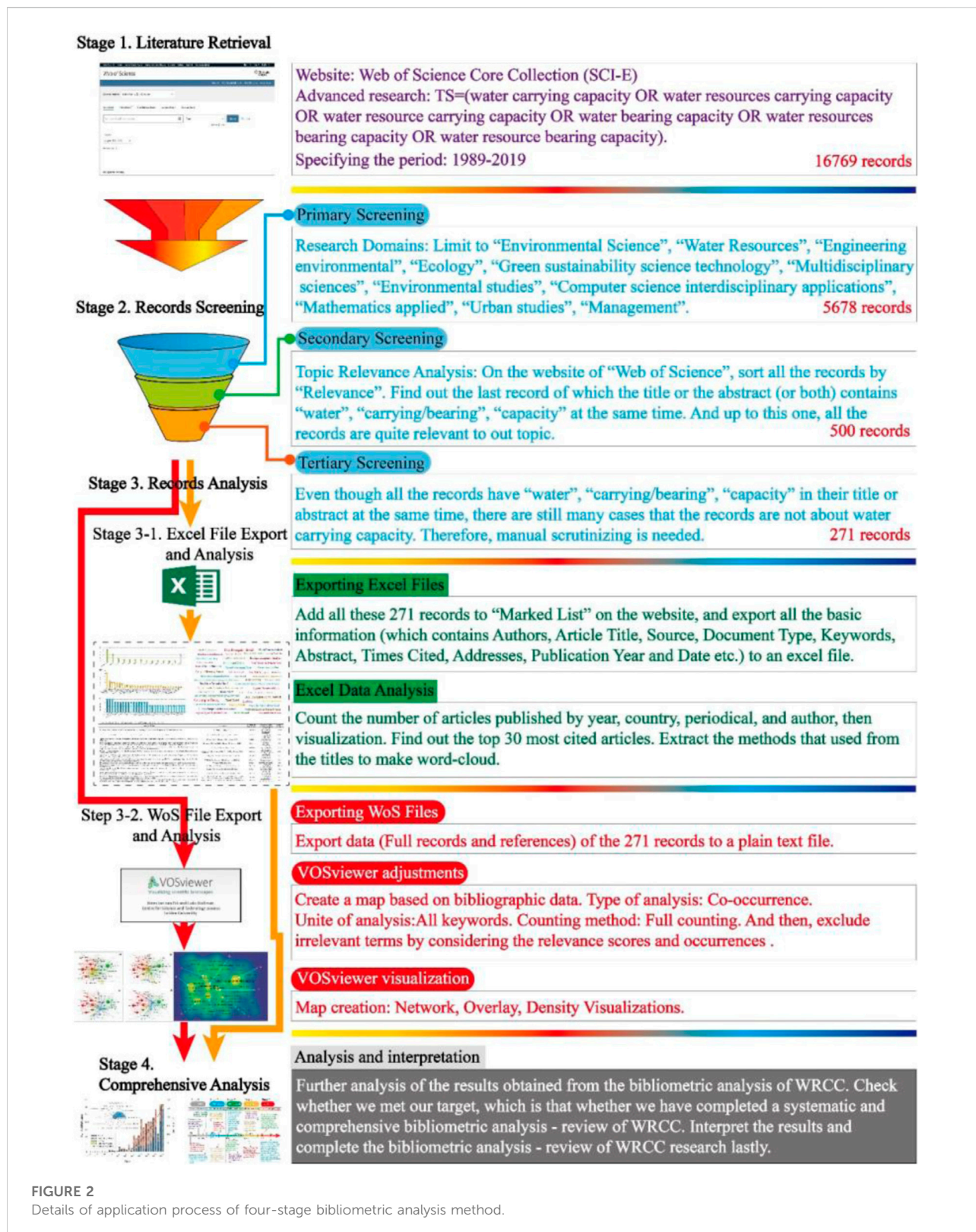


FIGURE 2
 Details of application process of four-stage bibliometric analysis method.

literature retrieval, records screening and records analysis stages are very complicated and contain several steps, we treated them separately. We further divide the concrete steps of bibliometric

analysis of WRCC into four stages. And the details of our four-staged bibliometric analysis proposed in this research is shown in Figure 2.

The four stages of bibliometric analysis are elaborated as follows:

- Stage 1: The choice of search terms and search strategies is very important, and directly determines whether the search results are comprehensive. Many terms can be used to express the meaning of WRCC, therefore, using a single term will not present comprehensive results. In order to acquire more comprehensive search results, in the first stage, multiple search terms should be selected.
- Stage 2: In the search process, files with poor relevance to the topic will inevitably be retrieved. The search results need to be accurately and carefully screened. In order to obtain more accurate topic-related results, this study proposed a refined literature screening process, which is a three-stepped screening method (Figure 2). Stage 2: The screening methods are done through records category, relevance, and manual. By adopting this three-stepped screening method, we can extract the topic-related records from even tens of thousands of records in a short period of time.
- Stage 3: We analyzed all the topic-related records by using both statistical analysis and bibliometric analysis at the same time.
- Stage 4: We analyzed all the results comprehensively, we checked whether we meet our target and finished this article.

2.2.1 Literature retrieval

In this study, the Web of Science Core Collection Database was explored in advanced search page, using Boolean Logic to search TS = (water carrying capacity OR water resources carrying capacity OR water bearing capacity OR water resources bearing capacity OR water resource bearing capacity) in which the subject contains “water carrying capacity”, “water resources/resource carrying capacity”, “water bearing capacity” or “water resources/resource bearing capacity”. The retrieval year ranges from 1989 to 2019 (in 1989, WRCC was discussed for the first time, but the concept of WRCC was not yet proposed). A total of 16769 records were obtained. The retrieval time is August 15, 2020.

2.2.2 Records screening

During the search process, some files irrelevant to the topic will inevitably be retrieved. Therefore, the search results need to be accurately and carefully screened. In order to obtain more accurate search results, this study adopted a three-stepped screening method. The specific screening steps were applied as follows: 1) The first screening explored 16769 results through Web of Science and selected the category that is related and similar to WRCC. For example, in this research, we click “Result Analysis” on the search results interface of Web of Science, and

selected “Environmental Science”, “Water Resources”, “Engineering environmental”, “Ecology”, “Green sustainability science” in the “Web of Science category on the result analysis interface technology”, “Multidisciplinary sciences”, “Environmental studies”, “Computer science interdisciplinary applications”, “Mathematics applied”, “Urban studies”, “Management”, 5678 records were obtained. 2) The second step is to screen 5678 search results through the relevance function of the Web of Science webpage. The 5678 search records obtained after screening were sorted in order of relevance, and it was found that the top 500 records all contained “water”, “carrying”, “capacity” or “water”, “bearing”, “capacity” in their topics. After the first 500, the records no longer contained, in relevant application, usage of the words “water”, “carrying”, “capacity” or “water”, “bearing”, “capacity”. Therefore, we concluded that the content after first 500 files does not contain relevant literature related to WRCC. 3) The third step of screening was to manually check the contents of the first 500 records one after the other. During the search, the fact that “water”, “carrying”, “capacity” or “water”, “bearing”, “capacity”, appears in the title of an article doesn’t necessarily mean its research content belongs to the research category of WRCC, therefore the 500 records need to be manually checked. For example, “tourism water resources carrying capacity”, “groundwater carrying capacity”, “water resources and water environment carrying capacity”, and “agricultural water resources carrying capacity” all belong to the research category of WRCC. However, though “soil water carrying capacity”, “sediment carrying capacity of river flow”, “carrying capacity of fishpond”, “stock carrying capacity”, “recreation carrying capacity”, “mineral resources carrying capacity”, all include the words “water”, “carrying”, “capacity” or “water”, “bearing”, “capacity” in their topics, they do not belong to the research of WRCC. We can see that due to the similarity of some research content, in order to obtain more accurate data in bibliometric research, it is very necessary to finely screen results. After the three-stepped screening process, a total of 271 records were obtained (Appendix A).

2.2.3 Records analysis

The data export of this study is divided into two parts: 1) In the first part, we added the 271 records to the Marked List on the Web of Science website, and then exported important information such as “title”, “author”, “source publication”, “cited frequency”, “document type” and “keywords” to an excel file. 2) In the second part, we directly exported the “full records and cited references” of 271 records on the Web of Science website to plain text files.

In processing of excel file data, we first sorted out the information in the exported excel file starting with the year, country, journal and number of author’s publications. We then sorted out the top 30 highly cited articles, extracted the methods

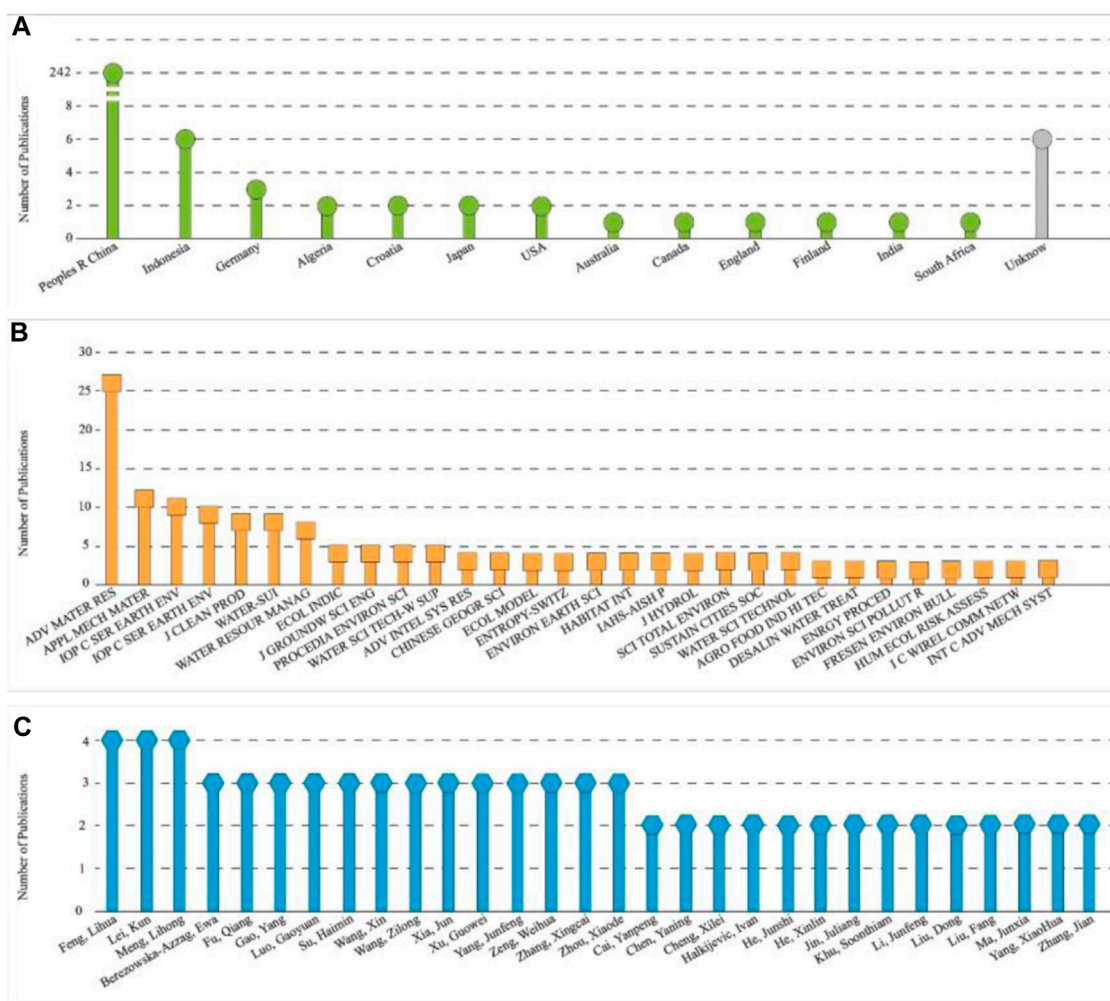


FIGURE 3 Number of articles published by countries, periodicals, and authors.

used in the articles and finally marked the time these methods were first used.

In dealing with the plain text files, we first analyzed the exported text file through the VOSviewer software. The results of keywords co-occurrence analysis, inter-year changes of keywords and heat maps were obtained. VOSviewer is a software tool for constructing and visualizing bibliometric networks, which has been developed by Nees Jan van Eck and Ludo Waltman at Leiden University’s Centre for Science and Technology Studies (CWTS) (<http://www.vosviewer.com/>).

2.2.4 Comprehensive analysis

In order to have a more comprehensive understanding of the nature of research progress and current research state of WRCC, we adopted the comprehensive analysis method to further analyze the results obtained from the bibliometric analysis of WRCC in this stage. We also checked whether we met our target,

which means that whether we have completed a systematic and comprehensive bibliometric analysis-review of WRCC in this stage. The volume of published literature and research progress have been analyzed, and stages of the development process of WRCC divided.

3 Results and discussion

In this section, both statistical and bibliometric results have been fully analyzed and discussed, and a comprehensive analysis has also been conducted lastly. 3.1 presented the number of articles published by country, periods and authors, and statistical analysis of methods; Section 3.2 analyzed the highly cited papers; 3.3 analyzed the keywords co-occurrence and research hotspots dynamics; and Section 3.4 analyzed WRCC development comprehensively.

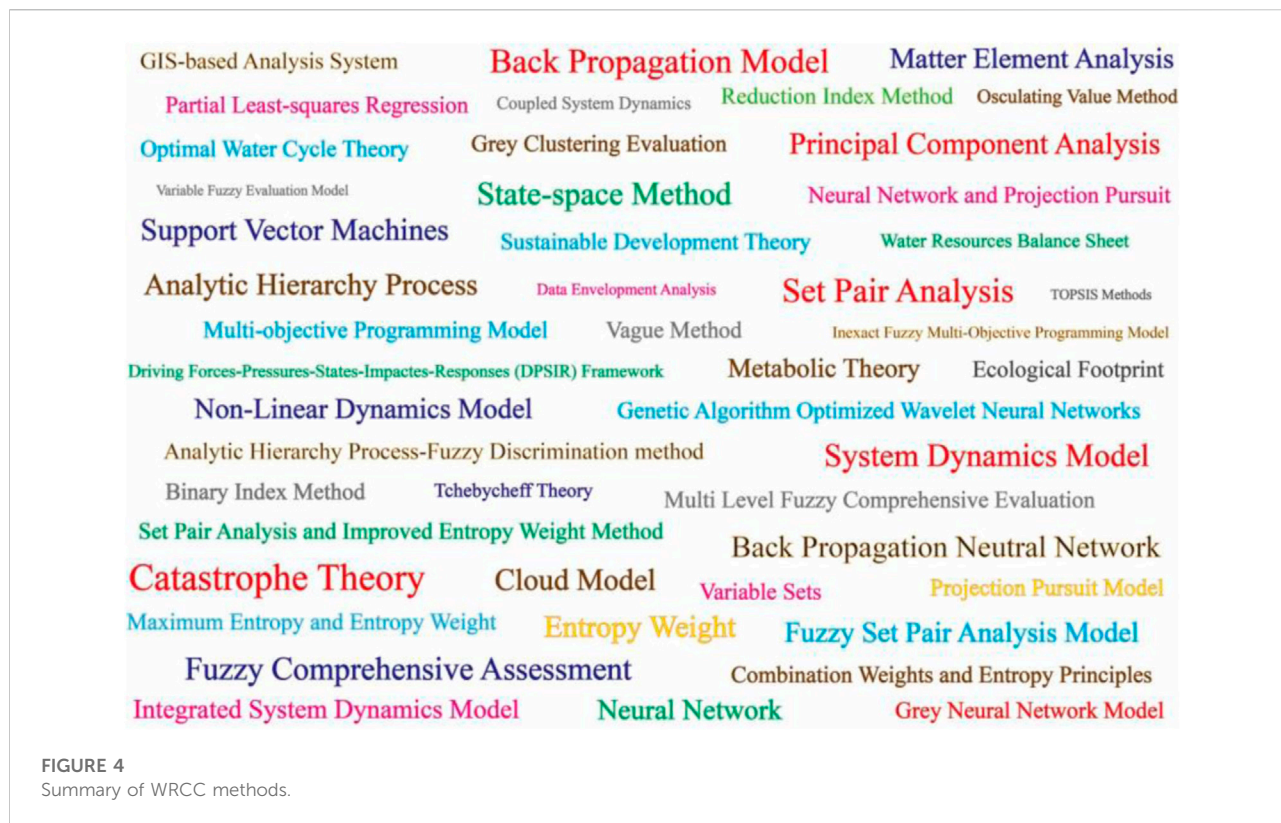


FIGURE 4
Summary of WRCC methods.

3.1 Statistical analysis of articles and methods

Number of articles by country, periods and authors are shown in Figure 3.

Number of publications by country indicates that China published the highest number of papers followed by Indonesia, Germany, Algeria and other (Figure 3A) in that order. China has the largest number of publications for two reasons: firstly, WRCC was put forward by the Chinese, and Chinese scholars have shown more research interest in this area. Secondly, due to rapid infrastructural and economic expansion witnessed by China in the last 30 years, demand for water resources has tripled and placed a huge deficit on water need. To avert this situation, the Chinese government attached great importance on WRCC research by setting up a number of National Natural Science Foundation Projects including “Innovative Research On Water Resources Carrying Capacity Based On Water Scarcity Risk Model” (approval number: 40771044), “Research On the Dynamic Mechanism And Sustainability Of the Evolution Of Water Resources Carrying Capacity Under the Framework Of Quality-Energy” (approval number: 41061053), “Risk Analysis Of Economic Development Planning Based On Water Resources Carrying Capacity Under Uncertain Conditions” (approval number: 41271536). The establishment of these National Natural Science Foundation

Projects directly and vigorously promoted the research and development of WRCC.

Results of number of papers published by journals indicated that, the top 30 journals with the most papers on WRCC research are in the order shown in (Figure 3B). They include ADV MATER RES, APPL MECH MATER, IOP C SER EARTH ENV, AER ADV ENG RES, J CLEAN PROD, WATER-SUI, WATER RESOUR MANAG, ECOL INDIC, J GROUNDW SCI ENG and PROCEDIA ENVIRON SCI. The number of articles published in the order in which the journals are listed above are: 26, 11, 10, 9, 8, 8, 7, 4, 4, and 4 respectively.

From number of articles published by authors perspective, the top 30 authors with the most articles and the number of articles published are shown in (Figure 3C). The top 10 authors with the most articles include Feng, Lihua, Lei, Kun, Meng, Lihong, Berezowska-Azzag, Ewa, Fu, Qiang, Gao, Yang, Luo, Gaoyuan, Su, Haimin, Wang, Xin, Wang, Zilong. Among them, Feng, Lihua, Lei, Kun, Meng, Lihong published 4 articles each while the remaining 7 authors published 3 articles each.

By analyzing the excel files exported from the Web of Science website, we discovered 47 methods from 271 articles used in WRCC calculation and evaluation (Figure 4).

In Figure 4, the methods include TOPSIS, system dynamics model, support vector machines, state-space, set pair analysis, neural network, ecological footprint, cloud model, analytic hierarchy process-fuzzy discrimination,

TABLE 1 TOP 30 highly cited papers (as of August 14, 2020).

Article title	Authors	Publication year	Source title abbreviation	Times cited
Fuzzy comprehensive evaluation for carrying capacity of regional water resources	Gong, L; Jin, CL	2009	WATER RESOUR MANAG	109
Assessment of water resources carrying capacity in tianjin city of China	Song, XM; Kong, FZ; Zhan, CS	2011	WATER RESOUR MANAG	91
Application of system dynamics in analyzing the carrying capacity of water resources in Yiwu City, China	Feng, LH; Zhang, XC; Luo, GY	2008	MATH COMPUT SIMULAT	76
Development tendency analysis and evaluation of the water ecological carrying capacity in the Siping area of Jilin Province in China based on system dynamics and analytic hierarchy process	Zhang, Z; Lu, WX; Zhao, Y; Song, WB	2014	ECOL MODEL	73
A risk assessment model of water shortage based on information diffusion technology and its application in analyzing carrying capacity of water resources	Feng, LH; Huang, CF	2008	WATER RESOUR MANAG	70
Fuzzy comprehensive evaluation model for water resources carrying capacity in Tarim River Basin, Xinjiang, China	Meng, LH; Chen, YN; Li, WH; Zhao, RF	2009	CHINESE GEOGR SCI	61
Analysis of temporal and spatial differences in eco-environmental carrying capacity related to water in the Haihe River Basins, China	Zhu, YH; Drake, S; Lu, HS; Xia, J	2010	WATER RESOUR MANAG	56
Assessment of water ecological carrying capacity under the two policies in Tieling City on the basis of the integrated system dynamics model	Wang, S; Xu, L; Yang, FL; Wang, H	2014	SCI TOTAL ENVIRON	49
Dynamic successive assessment method of water environment carrying capacity and its application	Wang, TX; Xu, SG	2015	ECOL INDIC	48
Multi-scale analysis of the water resources carrying capacity of the Liaohe Basin based on ecological footprints	Wang, S; Yang, FL; Xu, L; Du, J	2013	J CLEAN PROD	46
An innovative method for water resources carrying capacity research-Metabolic theory of regional water resources	Ren, CF; Guo, P; Li, M; Li, RH	2016	J ENVIRON MANAGE	43
Assessment of Water Resources Carrying Capacity for Sustainable Development Based on a System Dynamics Model: A Case Study of Tieling City, China	Yang, JF; Lei, K; Khu, S; Meng, W	2015	WATER RESOUR MANAG	42
Optimization of industry structure based on water environmental carrying capacity under uncertainty of the Huai River Basin within Shandong Province, China	Li, N; Yang, H; Wang, LC; Huang, XJ; Zeng, CF; Wu, H; Ma, XX; Song, XT; Wei, YN	2016	J CLEAN PROD	39
Assessment of water environmental carrying capacity for sustainable development using a coupled system dynamics approach applied to the Tieling of the Liao River Basin, China	Yang, JF; Lei, K; Khu, S; Meng, W; Qiao, F	2015	ENVIRON EARTH SCI	36
Water resources carrying capacity of wetlands in Beijing: Analysis of policy optimization for urban wetland water resources management	Wang, CH; Hou, YL; Xue, YJ	2017	J CLEAN PROD	34
Water Resources Carrying Capacity Evaluation and Diagnosis Based on Set Pair Analysis and Improved the Entropy Weight Method	Cui, Y; Feng, P; Jin, JL; Liu, L	2018	ENTROPY-SWITZ	33
Carrying capacities and standards as bases towards urban infrastructure planning in India: A case of urban water supply and sanitation	Joardar, SD	1998	HABITAT INT	33
Water ecological carrying capacity of urban lakes in the context of rapid urbanization: A case study of East Lake in Wuhan	Ding, L; Chen, KL; Cheng, SG; Wang, X	2015	PHYS CHEM EARTH	31
Comprehensive evaluation and scenario simulation for the water resources carrying capacity in Xi'an city, China	Yang, ZY; Song, JX; Cheng, DD; Xia, J; Li, Q; Ahamad, MI	2019	J ENVIRON MANAGE	26
Evaluating Beijing's human carrying capacity from the perspective of water resource constraints	Zhang, YX; Chen, M; Zhou, WH; Zhuang, CW; Ouyang, ZY	2010	J ENVIRON SCI	26
Water resources carrying capacity assessment: The case of Algeria's capital city	Ait-Aoudia, MN; Berezowska-Azzag, E	2016	HABITAT INT	25
Regionalization of water environmental carrying capacity for supporting the sustainable water resources management and development in China	Jia, ZM; Cai, YP; Chen, Y; Zeng, WH	2018	RESOUR CONSERV RECY	20

(Continued on following page)

TABLE 1 (Continued) TOP 30 highly cited papers (as of August 14, 2020).

Article title	Authors	Publication year	Source title abbreviation	Times cited
Advances in Study on Water Resources Carrying Capacity in China	Mei, H; Liuyuan; Duhuan; Yangxiaoyan	2010	PROCEDIA ENVIRON SCI	20
Water environment carrying capacity in Bosten Lake basin	Wang, YM; Zhou, XD; Engel, B	2018	J CLEAN PROD	17
Water Environmental Carrying Capacity Assessment of an Industrial Park	Kang, P; Xu, LY	2012	PROCEDIA ENVIRON SCI	17
Algiers carrying capacity with respect to per capita domestic water use	Naimi-Ait-Aoudia, M; Berezowska-Azzag, E	2014	SUSTAIN CITIES SOC	14
Integrated modeling framework for evaluating and predicting the water resources carrying capacity in a continental river basin of Northwest China	Wu, L; Su, XL; Ma, XY; Kang, Y; Jiang, YA	2018	J CLEAN PROD	13
Comprehensive Evaluation of Water Resources Carrying Capacity of Jining City	Du, M; Xu, ZH; Peng, LM; Zhu, YH; Xu, XF	2011	ENRGY PROCED	13
Research on the Risk of Water Shortages and the Carrying Capacity of Water Resources in Yiwu, China	Feng, LHH; Zhang, XC; Luo, GY	2009	HUM ECOL RISK ASSESS	13
Quantitative evaluation and optimized utilization of water resources-water environment carrying capacity based on nature-based solutions	Zhang, J; Zhang, CL; Shi, WL; Fu, YC	2019	J HYDROL	12

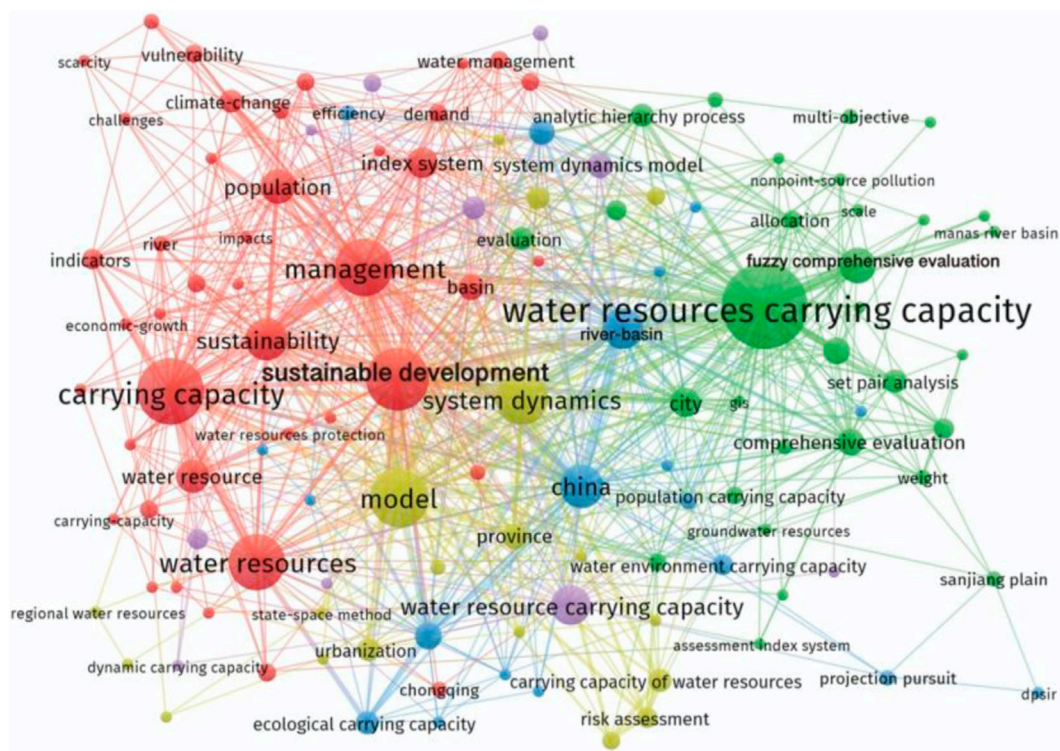
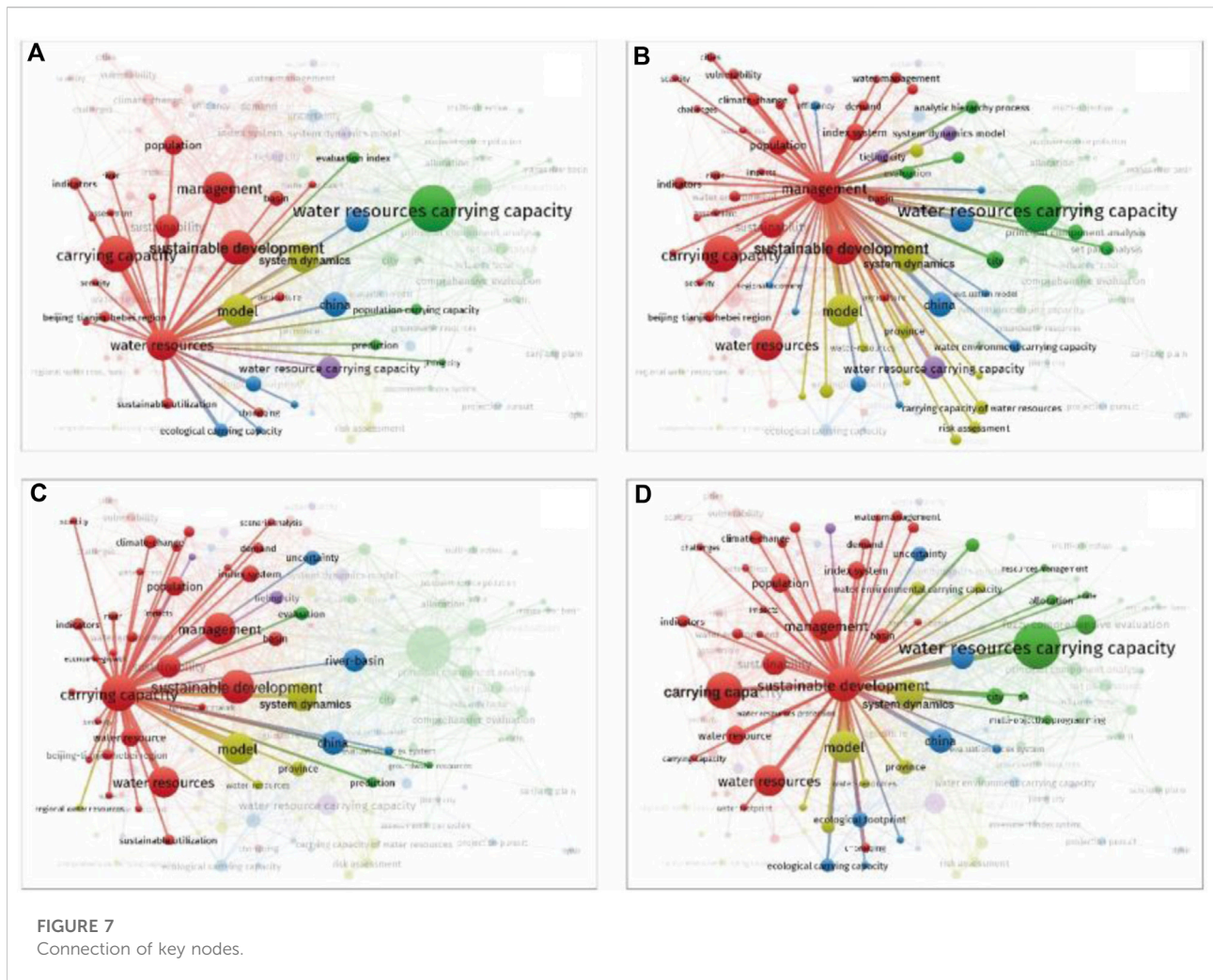


FIGURE 5
Keywords co-occurrence.



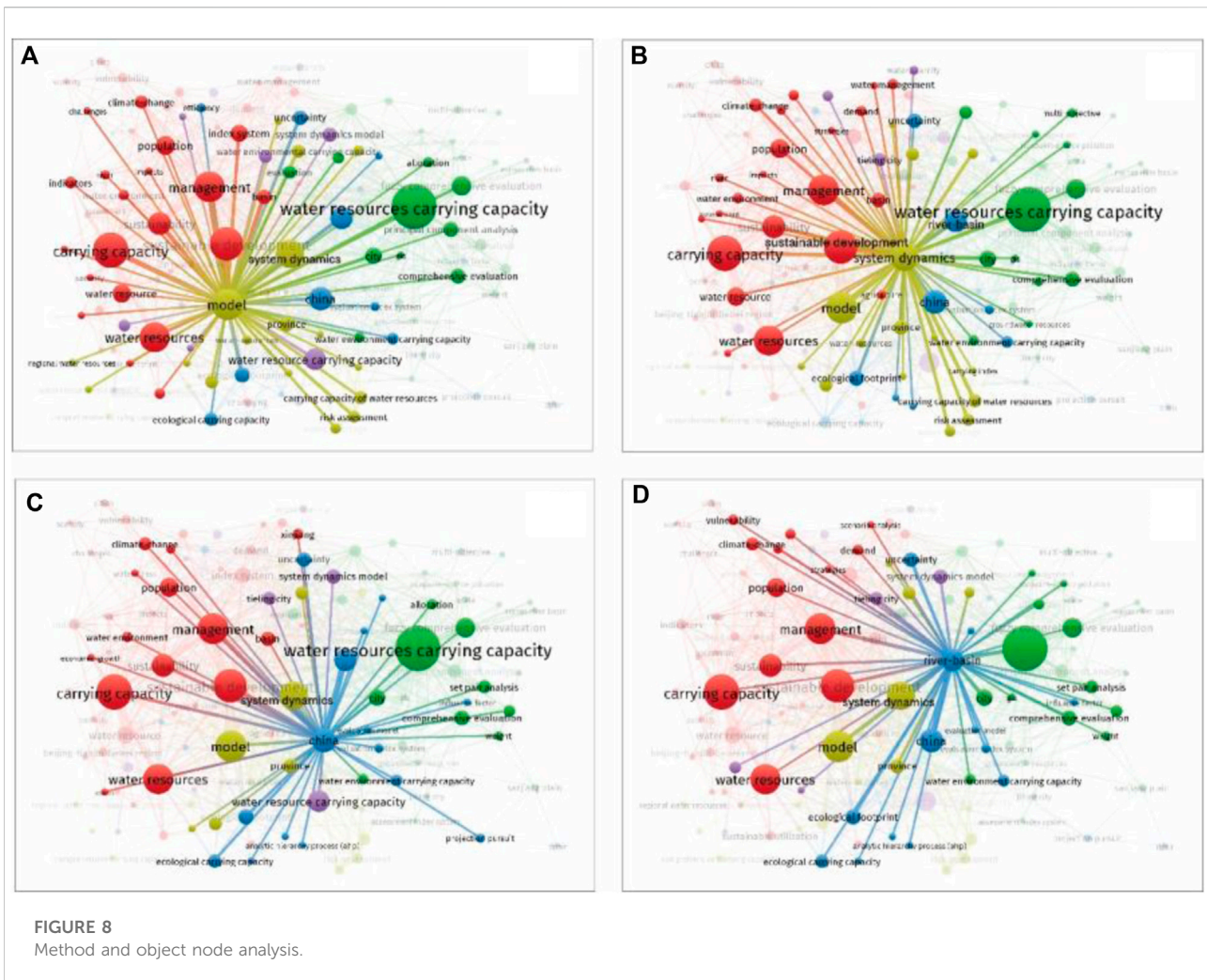
nodes, the connection between water resources carrying capacity and management and sustainable development is wider, and the connection between China and river-basin is wider. It shows that these two groups of keywords appear more frequently at the same time.

From the clustering results, the water resources carrying capacity node is the largest among all, which is shown in green. The yellow node emphasizes the methods, the main two yellow nodes are model and system dynamics. The blue node focuses on the research objects, and the two main blue nodes are China and river-basin. The red nodes focus on management, and the main red nodes are management, sustainability, sustainable development, carrying capacity and water resources.

In the analysis of keywords co-occurrence in papers related to water resources carrying capacity, the most frequently occurred keyword is “water resources carrying capacity”. Many nodes are directly connected to “water resources carrying capacity”, and other nodes are connected to this

node through intermediate nodes. The nodes that are most closely connected to the water resources carrying capacity node are the management node and the sustainable development node (Figure 6). The carrying capacity of water resources is an important means for water resources management and an important measure for achieving sustainable development of water resources.

From the results of cluster analysis, the red nodes emphasize water resources management. The number of nodes connected to the management node and the sustainable development node is greater than the number of nodes connected to the water resources node and the carrying capacity node (Figures 7A–D). This is because more nodes are connected to the water resources carrying capacity node, the number of nodes connected to the water resources node and the carrying capacity node is relatively reduced. It is worth noting that the largest node connected to the management node and the sustainable development node is the water resources carrying capacity node, and the width of the



connection with this node is the widest, indicating that they have the largest frequency of co-occurrence.

Analysis results of research methods indicates that the most frequently occurring research methods in the keyword co-occurrence graph are model and systems dynamics. This means that building various models and adopting system dynamics in the research process of WRCC are mainstream. Many nodes are closely connected to these two nodes (Figures 8A,B). Water resources carrying capacity, carrying capacity, and management are the nodes that are most closely connected to the model node and the system dynamics node. At the same time, the model node and the system dynamics node are also the most closely connected nodes to each other. This shows that these nodes appear more frequently at the same time. In the analysis of keywords co-occurrence, China is the only country that appeared. River basin is the only node closely connected to China (Figure 8C). Furthermore, China is the only node closely connected to the river-basin node (Figure 8D). It can be seen that the number of

nodes connected to the China node and the river-basin node is significantly less than the number of nodes connected to the model node and the system dynamics node, indicating that more research on WRCC tends to be methodological innovation and application, while research on WRCC in some specific areas is relatively lacking.

From the keywords co-occurrence density map, we can clearly find research hotspots in the field. The density map of WRCC keywords co-occurrence in this study is shown in Figure 9.

In Figure 9, apart from water resources carrying capacity, there is also carrying capacity, water resources, management, sustainable development, model, China, system dynamics, and other hot spots in the field of WRCC research. WRCC is an important method to realize the sustainable use of water resources and an important means to realize the effective management of water resources. Therefore, these three words, sustainable development, management, and water resources often appear in the keywords of research papers on WRCC.

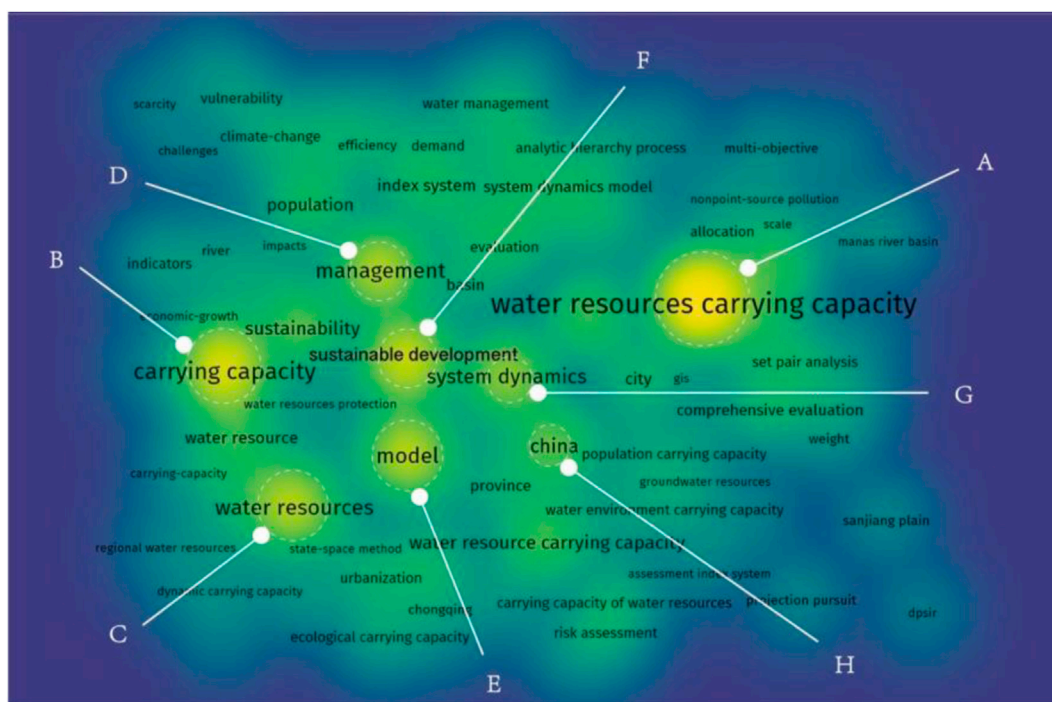


FIGURE 9
Hotspot analysis.

These three words are hot topics in the research of WRCC. WRCC and land resources carrying capacity belong to the research category of resources carrying capacity, therefore carrying capacity is also a hot vocabulary in the research scope of WRCC. China was the only count name of a country that appeared in Figure 9, which again confirms the assertion that China is the main country in the study of WRCC. It can also be seen from Figure 9 that model and system dynamics are the commonest vocabularies, meaning that a lot of research is carried out by building models or using system dynamics methods to study WRCC.

The time sequence analysis of keywords can reflect the changes of researchers’ interest in some aspects to a large extent. Therefore, time sequence analysis of keywords helps to clarify the development context and knowledge base of the concept. This study conducted a time series analysis on the keywords of WRCC. The analysis results are shown in Figure 10. The darker the color of the node, the longer the research time in this area. The lighter the color of the node means that the research in that area is the current hotspot.

From the perspective of time series analysis of the keywords of WRCC, WRCC is gradually generated and developed from scholars’ attention to population carrying capacity, groundwater resources, urbanization, water shortage, risk assessment, etc,

(Figure 10 regions A, B). From the perspective of the spatial scale of WRCC research, the evaluation of WRCC initially focused on the study of cities and provinces. As the research continued to deepen, scholars began to pay more attention to the impact of WRCC on regional water resources. The guiding significance of the deployment, is that the research scale of WRCC has begun to gradually shift to the basin scale (regions C and D in Figure 10).

3.4 Comprehensive analysis of WRCC development

The overall situation of the number of papers retrieved in the core database of Web of Science is shown in Figure 11.

From Figure 11, we can see that although the search period is set from 1989 to 2019, the search results indicated that the earliest literature on WRCC from Web of Science Core Database was published between 1997 and 1998. Within this period Joardar and other scholars comprehensively considered natural resources and social resources, established a set of index system for calculating water supply capacity, and used it for the calculation of urban carrying capacity to provide help for the formulation of urban development plans (Joardar, 1998). As

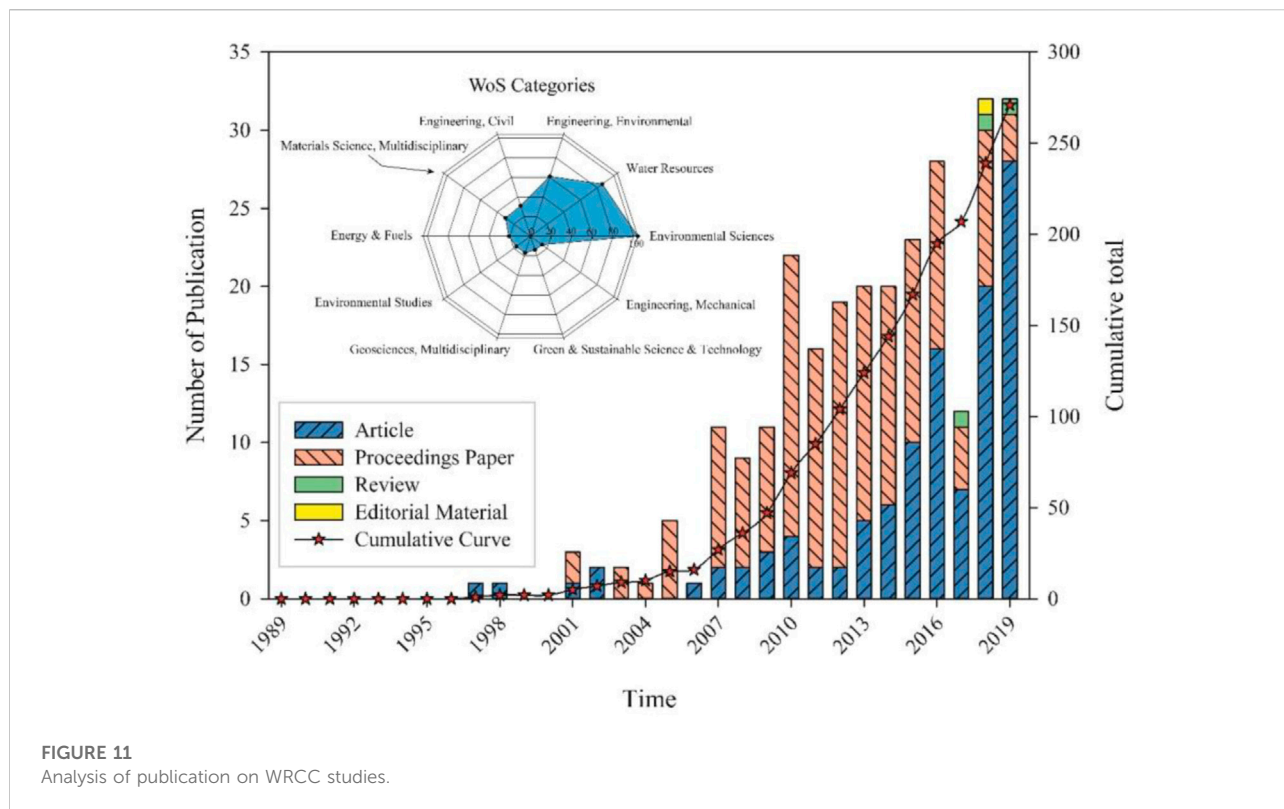
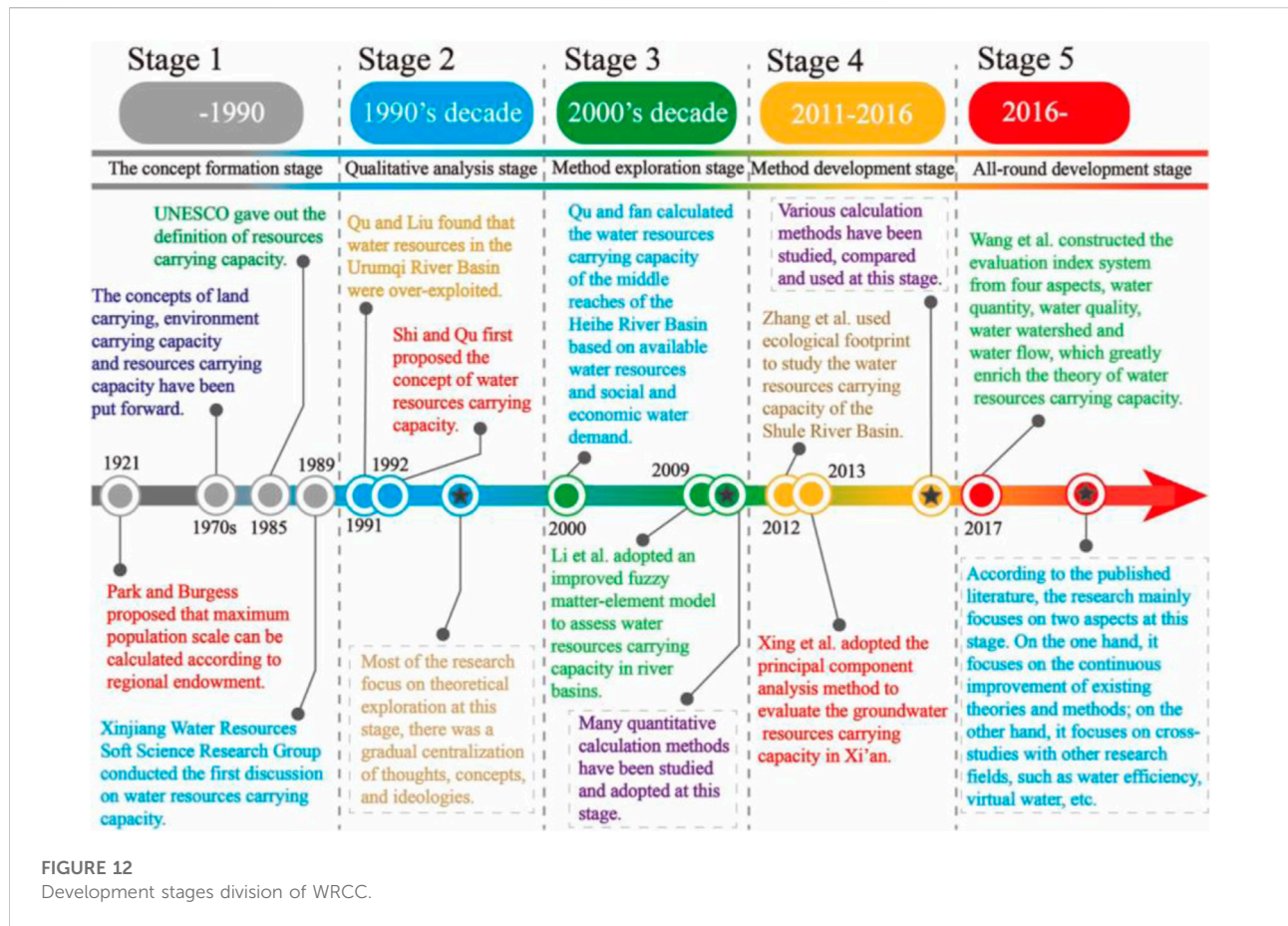


FIGURE 11
Analysis of publication on WRCC studies.

- The second stage is the qualitative analysis period (1990s decade). Most of the research in this period focused on the qualitative description stage, while the number of papers on quantitative research is relatively limited. Qualitative research mostly elaborates its theoretical basis and important significance. In 1992, Academician Shi Yafeng clearly put forward the concept of WRCC for the first time (Shi and Qu, 1992). Wang et al. (1999) conducted an in-depth discussion on the concept and theory of WRCC. Cai (1994) elaborated on the issues that needed attention in the study of WRCC in Xinjiang.
- At the methods exploration stage (2000s decade), many quantitative analysis methods have been proposed and applied. For example, Qu and Fan (2000) analyzed and calculated the WRCC in the middle reaches of the Heihe River Basin based on available water resources as well as social and economic water requirements. Li et al. (2009) used an improved fuzzy matter-element model to evaluate water resources carrying capacity. However, in the 10-year exploration stage of the method, only 9 of the 47 methods (47 methods extracted in Section 3.1) were proposed and applied at this stage.
- During the method development period (2011–2016), a large number of research methods have been introduced into the evaluation and research process of WRCC. For

example, Zhang et al. (2012) used the ecological footprint method to study the WRCC of the Shule River Basin; Xing et al. (2013) used the principal component analysis method to evaluate ground WRCC of Xi'an from 7 indicators. At this stage, which extends 6 years, 20 methods out of 47 methods have been proposed and applied. The speed of progress at this stage was much faster than the method exploration stage. This study defines this stage as the method development stage.

- The fifth stage is referred as the all-round development stage (2016-). On one hand theoretical system of WRCC has been further enriched and improved. For example, Wang et al. (2017) first constructed an evaluation index system for WRCC from the four aspects of “quantity, quality, region and flow”. At the other hand, application of the methods has also been expanded to a greater extent. Among the 47 methods, 18 methods have been proposed and applied at this stage, and the time limit from this stage to the study of this review is only 3 years. This explains that more methods were applied at this stage. At the same time, most of the subtle changes (Introduction paragraph 6) that occurred in the evaluation objects of WRCC all occurred at this stage. Based on this precept, this stage is defined as the all-round development stage of WRCC.



4 Conclusions and prospects

In this review, a four-staged bibliometric analysis method was used based on the René Descartes's *Discourse on the Method*. This makes the bibliometric research process more systematic and efficient compared to previous studies. The four-staged bibliometric analysis method proposed in this research is equipped with a records screening stage, in which we proposed a three-stepped screening method, that solved the problem of large file sorting. Through the three-stepped screening method proposed in this research, it was possible to finally determine the document records highly related to the research topic from tens of thousands of records within a short period of time.

The bibliometric analysis - review results show that a total of 47 methods including system dynamics, cloud model, set pair analysis, neural network and ecological footprint have been introduced into the evaluation process of WRCC. Through keyword co-occurrence analysis, we found that building various kinds of models and adopting system dynamics methods are the mainstream methods in the research of WRCC. We also found that China is the only country that appears in the keywords co-occurrence analysis chart, which shows that China is the main country in the study of WRCC.

Through time series analysis of keywords, we found that the research on WRCC originated from scholars'attention to population carrying capacity, groundwater resources, urbanization, water shortage and risk assessment. From the perspective of research objects, previous studies have focused more on some provinces and cities. In recent years, more and more scholars have begun to study the WRCC of some typical regions, such as arid and semi-arid regions, urbanized areas and water-deficient regions. Based on the research status, the amount of published literature over time, the analysis of the time when the method was first adopted, and our knowledge in this area, this study divided the development process of WRCC into the concept formation stage, qualitative analysis stage, method exploration stage, method development stage and all-round development stage.

Author contributions

XY contributed to conception and design of the study. FL organized the database. YQ performed the statistical analysis. BS, XY wrote the first draft of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

Acknowledgments

Thanks to the National Key Research And Development Program funded project 2021YFC3000203, and the Ministry of Water Resources' flood and drought disaster prevention strategy research talent innovation team project WH0145B042021. We also would like to extend special thanks to the editor and the reviewers for their insightful comments and constructive suggestions.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

- Accatino, F., Ward, D., Wiegand, K., and De Michele, C. (2017). Carrying capacity in arid rangelands during droughts: The role of temporal and spatial thresholds. *Animal* 11 (2), 309–317. doi:10.1017/S1751731116001531
- Arrow, K., Bolin-Costanza, R., Dasgupta, P., Folke, C., and Holling, C. S. (1995). Economic growth, carrying capacity, and the environment. *Science* 268, 520–521. doi:10.1126/science.268.5210.520
- Bian, D., Yang, X., Wu, F., Babuna, P., Luo, Y., Wang, B., et al. (2022). A three-stage hybrid model investigating regional evaluation, pattern analysis and obstruction factor analysis for water resource spatial equilibrium in China. *J. Clean. Prod.* 331, 129940. doi:10.1016/j.jclepro.2021.129940
- Bian, D., Yang, X., Xiang, W., Sun, B., Chen, Y., Babuna, P., et al. (2022). A new model to evaluate water resource spatial equilibrium based on the game theory coupling weight method and the coupling coordination degree. *J. Clean. Prod.* 366, 132907. doi:10.1016/j.jclepro.2022.132907
- Bo, L., Qiang, W., and Li-xia, C. (2016). An analytical method of regional water resources carrying capacity in karst area – A case study in guizhou province, China. *Water Pract. Tech* 11 (4), 796–805. doi:10.2166/wpt.2016.085
- Bolis, I., Morioka, S. N., and Szelwar, L. I. (2017). Are we making decisions in a sustainable way? A comprehensive literature review about rationalities for sustainable development. *J. Clean. Prod.* 145, 310–322. doi:10.1016/j.jclepro.2017.01.025
- Cai, A. (1994). A Brief Talk on Water Resources Carrying Capacity—A few issues that should be paid attention to in the study of appropriate water resources carrying capacity in Xinjiang. *Environ. Prot. Xinjiang* 04, 190.
- Cao, J. K., Zhang, J., and Ma, S. Q. (2014). “The analysis of water resource ecological carrying capacity of Hainan international island,” in *Ecosystem Assessment and fuzzy systems management* (Cham: Springer), 63–71. doi:10.1007/978-3-319-03449-2_7
- Chen, N. X., Qu, J. H., Xu, J. X., Li, Z. P., and Yang, L. (2010). “Evaluation of Groundwater Environment Carrying Capacity Based on Catastrophe Theory.” in 2010 4th International Conference on Bioinformatics and Biomedical Engineering, Chengdu, 18–20 June 2010, 1–4.
- Cheng, K., Fu, Q., Meng, J., Li, T. X., and Pei, W. (2018). Analysis of the spatial variation and identification of factors affecting the water resources carrying capacity based on the cloud model. *Water Resour. Manage.* 32 (8), 2767–2781. doi:10.1007/s11269-018-1957-x
- Chi, M., Zhang, D., Fan, G., Zhang, W., and Liu, H. (2019). Prediction of water resource carrying capacity by the analytic hierarchy process-fuzzy discrimination method in a mining area. *Ecol. Indic.* 96, 647–655. doi:10.1016/j.ecolind.2018.09.021
- Cui, Y., Feng, P., Jin, J., and Liu, L. (2018). Water resources carrying capacity evaluation and diagnosis based on set pair analysis and improved the entropy weight method. *Entropy* 20 (5), 359. doi:10.3390/e20050359
- Dai, D., Sun, M., Xu, X., and Lei, K. (2019). Assessment of the water resource carrying capacity based on the ecological footprint: A case study in zhangjiakou city, North China. *Environ. Sci. Pollut. Res.* 26 (11), 11000–11011. doi:10.1007/s11356-019-04414-9
- Deng, W., Yan, L., Wang, Y., Jin, X., and Hu, Y. (2019). A study on water resources carrying capacity based on water usage intensity in hainan province IOP

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/feart.2022.970582/full#supplementary-material>

- conference series: Earth and environmental science. *IOP Conf. Ser. Earth Environ. Sci.* 237 (3), 032090. doi:10.1088/1755-1315/237/3/032090
- Dhondt, A. A. (1988). Carrying capacity: A confusing concept. *Acta Oecol* 9 (4), 337–346.
- Falkemark, M., and Lundqvist, J. (1998). Towards water security: Political determination and human adaptation crucial. *Nat. Resour. Forum* 21 (1), 37–51. doi:10.1111/j.1477-8947.1998.tb00708.x
- Fang, H. (2018). “Application of system dynamics and WCCI in water resources evaluation: Taking Pakistan as an example,” in 2018 International Conference on Mechanical, Electronic, Control and Automation Engineering (MECAE 2018), Qingdao, March 30–31, 2018.
- Feng, L. H., and Huang, C. F. (2008). A risk assessment model of water shortage based on information diffusion technology and its application in analyzing carrying capacity of water resources. *Water Resour. Manage.* 22 (5), 621–633. doi:10.1007/s11269-007-9182-z
- Fu, Q., Liu, D., and Wang, Z. (2008). “Evaluation of region water resources carrying capacity based on set pair analysis technology,” in 2008 4th International Conference on Wireless Communications, Networking and Mobile Computing, South Korea, 12–14 Oct. 2008, 1–4.
- Gao, H., and Sun, L. (2018). Grey clustering evaluation of water resources carrying capacity based on triangle whitening weight function. *IOP Conf. Ser. Earth Environ. Sci.* 208, 012101. doi:10.1088/1755-1315/208/1/012101
- Gao, S. (2017). Study on the bearing capacity of water resources in urbanized area. *Agro Food Ind. Hi-Tech* 28 (1), 3026–3029.
- Gao, Y., Zhang, H. M., Xu, G. W., Su, H. M., and Zhang, Y. (2013). “Sustainable utilization evaluation on water resources base on matter element analysis in Huaibei City,” in *Advanced materials research* (Switzerland: Trans. Tech. Publications Ltd), 610, 2671–2674. doi:10.4028/www.scientific.net/AMR.610-613.2671
- Gleick, P. H., and Palaniappan, M. (2010). Peak water limits to freshwater withdrawal and use. *Proc. Natl. Acad. Sci. U. S. A.* 107, 11155–11162. doi:10.1073/pnas.1004812107
- Gong, L., and Jin, C. (2009). Fuzzy comprehensive evaluation for carrying capacity of regional water resources. *Water Resour. Manage.* 23 (12), 2505–2513. doi:10.1007/s11269-008-9393-y
- Huang, L., Zhou, M., Lv, J., and Chen, K. (2020). Trends in global research in forest carbon sequestration: A bibliometric analysis. *J. Clean. Prod.* 252, 119908. doi:10.1016/j.jclepro.2019.119908
- Huang, Q., Wang, W. P., and Deng, H. Y. (2014). “Agricultural restructuring based on the water resources carrying capacity in shandong province, China,” in *Applied mechanics and materials* (Switzerland: Trans Tech Publications Ltd), 675, 783–786. doi:10.4028/www.scientific.net/AMM.675-677.783
- Jiao, S., and Liang, H. (2006). *A research on spatio-temporal characteristics of the water resource carrying status in Guiyang City*. Guiyang: J. Guizhou Norm. Univ., 21–26. (in Chinese).04.

- Lin, J., Chen, P., Chen, M., Li, J., Xu, C., and Chang, T. (2019). Bibliometric analysis of research progress on water resources carrying capacity based on knowledge map. *Water Resour. Prot.* 35, 14.
- Joardar, S. D. (1998). Carrying capacities and standards as bases towards urban infrastructure planning in India: A case of urban water supply and sanitation. *Habitat Int.* 22 (3), 327–337. doi:10.1016/S0197-3975(98)00002-2
- Jonathan, H. M. (1999). Carrying capacity in agriculture: Globe and regional issue. *Ecol. Econ.* 29 (3), 443–461. doi:10.1016/S0921-8009(98)00089-5
- Kang, J., Zi, X., Wang, S., and He, L. (2019). Evaluation and optimization of agricultural water resources carrying capacity in haihe river basin, China. *Water* 11 (5), 999. doi:10.3390/w11050999
- Kang, P., and Xu, L. (2012). Water environmental carrying capacity assessment of an industrial park. *Procedia Environ. Sci.* 13, 879–890. doi:10.1016/j.proenv.2012.01.082
- Kessler, J. J. (1994). Usefulness of the human carrying capacity concept in assessing ecological sustainability of land-use in semi-arid regions. *Agric. Ecosyst. Environ.* 48 (3), 273–284. doi:10.1016/0167-8809(94)90109-0
- Kuspilić, M., Vuković, Ž., and Halkijević, I. (2018). Assessment of water resources carrying capacity for the Island of Cres. *Gradevinar* 70 (04), 305–313. doi:10.14256/JCE.2167.2017
- Lei, H. J., Yin, L., and Xi, B. D. (2013). “Scenario analysis on the water environment carrying capacity of wuliangshuai lake basin,” in *Advanced materials research* (Switzerland: Trans Tech Publications Ltd), 616, 1388–1393. doi:10.4028/www.scientific.net/AMR.616-618.1388
- Li, B., Wang, X., Wei, T., Zeng, Y., and Zhang, B. (2018). Analysis of sustainable utilization of water resources in karst region based on the ecological footprint model—Liupanshui city case. *J. Water Supply Res. Trans.* 67 (6), 566–575. doi:10.2166/aqua.2018.016
- Li, C., Li, H. J., Feng, S. D., Liu, X. Y., and Guo, S. (2019). A study on the spatiotemporal characteristics and change trend of the atmospheric environmental carrying capacity in the Jing-Jin-Ji region, China. *J. Clean. Prod.* 211, 27–35. doi:10.1016/j.jclepro.2018.11.045
- Li, J., Yang, X., and Lu, G. (2009). Fuzzy matter-element model based on improved membership degree for comprehensive assessment of water resources carrying capacity in river basins. *J. Hydroelectr. Eng.* 28, 78–83.
- Li, W. M., and Zhang, K. (2016). “Evaluation and analysis of water resources carrying capacity in arid zone—a case of manas basin,” in *Water Resources and Environment Proceedings of the 2015 International Conference on Water Resources and Environment*, Beijing, 25–28 July 2015 (Leiden, Netherlands: CRC Press/Balkema), 103–108.
- Liu, T., Yang, X., and Song, F. (2018). “Comprehensive evaluation for water resources carrying capacity in jilin province based on fuzzy set pair analysis model,” in *International Conference on Environmental and Water Resources Engineering (EWRE)*, South Korea, Oct 12–14, 2018.
- Lu, F., Xu, J., and Wang, Z. (2009). “Application of GA optimized wavelet neural networks for carrying capacity of water resources prediction,” in *2009 international conference on environmental science and information application technology*, Wuhan, China, July 4 2009 to July 5 2009, 308–311. doi:10.1109/ESIAT.2009.591
- Mallawaarachchi, H., Sandanayake, Y., Karunasena, G., and Liu, C. (2020). Unveiling the conceptual development of industrial symbiosis: Bibliometric analysis. *J. Clean. Prod.* 258, 120618. doi:10.1016/j.jclepro.2020.120618
- Malthus, T. R. (1798). *An essay on the principle of population*. Ann Arbor, Michigan, United States: University of Michigan Press.
- Mcnaughton, S. J., and Wolf, L. L. (1970). Dominance and the niche in ecological systems. *Science* 167 (39), 131–139. doi:10.1126/science.167.3915.131
- Meng, C., Wang, X., and Li, Y. (2018). An optimization model for water management based on water resources and environmental carrying capacities: A case study of the yinma river basin, northeast China. *Water* 10 (5), 565. doi:10.3390/w10050565
- Park, R. E., and Burgess, E. W. (1921). *Introduction to the science of sociology*. Chicago: University of Chicago Press.
- Qi, H., Jiang, J. Y., Ying, L. I., Shi, Z. G., and Yin, P. H. (2016). Current research status and perspective of water resources carrying capacity in the arid and semi-arid regions of northwest China. *DEStech Trans. Soc. Sci. Educ. Hum. Sci.* 2016, 383–390. doi:10.12783/dtssehs/icssd2016/4756
- Qu, G., and Fan, S. (2000). Water resources capacity and developing strategies in Heihe River Basin. *Chin. Desert* 20, 1–8.
- Ren, C., Guo, P., Li, M., and Li, R. (2016). An innovative method for water resources carrying capacity research—metabolic theory of regional water resources. *J. Environ. Manage.* 167, 139–146. doi:10.1016/j.jenvman.2015.11.033
- Rijsberman, M. A., and Frans, H. (2000). Different approaches to assessment of design and management of sustainable urban water system. *Environ. Impact Assess. Rev.* 129 (3), 333–345. doi:10.1016/S0195-9255(00)00045-7
- Secinaro, S., Brescia, V., Calandra, D., and Biancone, P. (2020). Employing bibliometric analysis to identify suitable business models for electric cars. *J. Clean. Prod.* 264, 121503. doi:10.1016/j.jclepro.2020.121503
- Shi, Y., and Qu, G. (1992). *Water resources carrying capacity and reasonable utilization of urumqi river basin*. Beijing: Science Press.
- Shi, Y. S., Wang, H. F., and Yin, C. Y. (2013). Evaluation method of urban land population carrying capacity based on gis—a case of shanghai, China. *Comput. Environ. Urban Syst.* 39, 27–38. doi:10.1016/j.compenvurbsys.2013.02.002
- Song, F., Yang, X., and Wu, F. (2020). Catastrophe progression method based on M-K test and correlation analysis for assessing water resources carrying capacity in Hubei province. *J. Water Clim. Chang.* 11 (2), 556–567. doi:10.2166/wcc.2018.114
- Song, X. (2016). “Evaluation of water resources carrying capacity based on system dynamics model,” in *3rd International Conference on Economic, Business Management and Education Innovation (EBMEI)*, Prague, Czech Republic, May 10–11, 2016.
- Sun, B., and Yang, X. (2019). Simulation of water resources carrying capacity in Xiong’an New Area based on system dynamics model. *Water* 11 (5), 1085. doi:10.3390/w11051085
- Tang, B., Hu, Y., Li, H., Yang, D., and Liu, J. (2016). Research on comprehensive carrying capacity of Beijing–Tianjin–Hebei region based on state-space method. *Nat. Hazards (Dordr.)* 84 (1), 113–128. doi:10.1007/s11069-015-1891-7
- Tao, J., Qiu, D., Yang, F., and Duan, Z. (2020). A bibliometric analysis of human reliability research. *J. Clean. Prod.* 260, 121041. doi:10.1016/j.jclepro.2020.121041
- UNESCO&FAO (1985). *Carrying capacity assessment with a pilot study of Kenya: A resource accounting methodology for sustainable development*. Paris and Roma: FAO.
- Wang, C., Hou, Y., and Xue, Y. (2017). Water resources carrying capacity of wetlands in Beijing: Analysis of policy optimization for urban wetland water resources management. *J. Clean. Prod.* 161, 1180–1191. doi:10.1016/j.jclepro.2017.03.204
- Wang, D. L., Shi, Y. H., and Wan, K. D. (2020). Integrated evaluation of the carrying capacities of mineral resource-based cities considering synergy between subsystems. *Ecol. Indic.* 108, 105701. doi:10.1016/j.ecolind.2019.105701
- Wang, J. (2015). “Comprehensive evaluation and analysis method for carrying capacity of water resource based on Neural Network,” in *8th International Conference on Intelligent Computation Technology and Automation (ICICTA)*, Nanchang, China, Jun 14–15, 2015. doi:10.1109/ICICTA.2015.84
- Wang, J., Jiang, D., Gu, Q., Qi, W., and Tang, Q. (1999). The concept and theory of the carrying capacity of regional water resources. *J. Gansu. Sci.* (02), 3–5. (in Chinese).
- Wang, S., Xu, L., Yang, F., and Wang, H. (2014). Assessment of water ecological carrying capacity under the two policies in Tieling City on the basis of the integrated system dynamics model. *Sci. Total Environ.* 472, 1070–1081. doi:10.1016/j.scitotenv.2013.11.115
- Wang, W., and Zeng, W. (2013). Optimizing the regional industrial structure based on the environmental carrying capacity: An inexact fuzzy multi-objective programming model. *Sustainability* 5 (12), 5391–5415. doi:10.3390/su5125391
- Wang, Y. J., Yang, G., and Xu, H. L. (2010). “Evaluation of water resources carrying capacity based on fuzzy comprehensive evaluation on river basin in Arid Zone,” in *Advanced materials research* (Switzerland: Trans Tech Publications Ltd), 113, 488–494. doi:10.4028/www.scientific.net/AMR.113-116.488
- Wang, Y., Zhou, X., and Engel, B. (2018). Water environment carrying capacity in Bosten Lake basin. *J. Clean. Prod.* 199, 574–583. doi:10.1016/j.jclepro.2018.07.202
- Wikiquote contributors, 2020b. Discourse on the method. Available at: https://en.wikiquote.org/w/index.php?title=Discourse_on_the_Method&oldid=2843135 (accessed Sep 18 2020).
- Wikiquote contributors, 2020a. René Descartes. Available at: https://en.wikiquote.org/w/index.php?title=Ren%C3%A9_Descartes&oldid=2825315 (accessed Sep 18 2020).
- Wu, C., Zhou, L., Jin, J., Ning, S., and Bai, L. (2020). Regional water resource carrying capacity evaluation based on multidimensional precondition cloud and risk matrix coupling model. *Sci. Total Environ.* 710, 136324. doi:10.1016/j.scitotenv.2019.136324
- Wu, F., Yang, X., and Shen, Z. (2018b2018). A three-stage hybrid model for regionalization, trends and sensitivity analyses of temperature anomalies in China from 1966 to 2015. *Atmos. Res.* 205, 80–92. doi:10.1016/j.atmosres.2018.02.008
- Wu, L., Su, X., Ma, X., Kang, Y., and Jiang, Y. (2018a). Integrated modeling framework for evaluating and predicting the water resources carrying capacity in a

continental river basin of Northwest China. *J. Clean. Prod.* 204, 366–379. doi:10.1016/j.jclepro.2018.08.319

Xiao, H., Zhang, L., and Chai, Z. (2017). *IOP Conference Series: Earth and Environmental Science*, 74, 012003. doi:10.1088/1755-1315/74/1/012003 Development of urbanization in arid and semi-arid regions based on the water resource carrying capacity—a case study of Changji, Xinjiang

Xie, Y., Li, X., Yang, C., and Yu, Y. (2014). Assessing water resources carrying capacity based on integrated system dynamics modeling in a semiarid river basin of northern China. *Water Sci. Tech-W sup.* 14 (6), 1057–1066. doi:10.2166/ws.2014.066

Xing, X., Shi, W., Zhang, Y., and Xie, J. (2013). Assessment of groundwater resources carrying capacity in Xi'an City based on principal component analysis. *J. Chin. Hydrol.* 33, 35–38.

XWRSSRG (Xinjiang Water Resources Soft Science Research Group) (1989). Xinjiang water resources and carrying capacity and development strategies. *Water Resour. Hydropower Tech.* (06), 2–9.

Yang, G., Wang, Y. J., He, X. L., and Li, J. F. (2010)., 113. Switzerland: Trans Tech Publications Ltd, 442–449. doi:10.4028/www.scientific.net/AMR.113-116.442 The study of three evaluation models of water resources carrying capacity in Manas river basin. *Adv. Mater. Res.*

Yang, J., and Ding, H. (2018). A quantitative assessment of sustainable development based on relative resource carrying capacity in Jiangsu Province of China. *Int. J. Environ. Res. Public Health* 15 (12), 2786. doi:10.3390/ijerph15122786

Yang, J., Lei, K., Khu, S., Meng, W., and Qiao, F. (2015). Assessment of water environmental carrying capacity for sustainable development using a coupled system dynamics approach applied to the Tieling of the Liao River Basin, China. *Environ. Earth Sci.* 73 (9), 5173–5183. doi:10.1007/s12665-015-4230-0

Yang, Q., Wang, H., Mu, H., Luo, J., Bao, X., Bian, J., et al. (2019). Risk assessment of water resources and environmental carrying capacity in Yinchuan city. *Hum. Ecol. Risk Assess. Int. J.* 25 (1-2), 120–131. doi:10.1080/10807039.2019.1573134

Yang, Q., Zhang, F., Jiang, Z., Yuan, D., and Jiang, Y. (2016). Assessment of water resource carrying capacity in karst area of Southwest China. *Environ. Earth Sci.* 75 (1), 37. doi:10.1007/s12665-015-4816-6

Yang, X., and Han, C. (2011). "Evaluation on water resource carrying capacity based on BP model-A case study," in Guanzhong District. International Conference on Ecological Protection of Lakes-Wetlands-Watershed and Application of 3S Technology (EPLWW3S 2011), Nanchang, China, Jun 25–26, 2011.

Ye, H., Dong, Z., Hang, Q., Liu, M., and Lu, X. (2018). Early warning of carrying status of water resources in Yancheng City. *J. Econ. Water Resour.* 36 (05), 31.

Young, C. C. (1998). Defining the range: The development of carrying capacity in management practice. *J. Hist. Biol.* 31, 61–83. doi:10.1023/A:1004205522191

Yu, M., Wang, C., Liu, Y., Olsson, G., and Wang, C. (2017). Sustainability of mega water diversion projects: Experience and lessons from China. *Sci. Total Environ.* 619–620, 721–731. doi:10.1016/j.scitotenv.2017.11.006

Yue, Q., Hou, L., Wang, T., Wang, L., Zhu, Y., Wang, X., et al. (2015). Optimization of industrial structure based on water environmental carrying capacity in Tieling City. *Water Sci. Technol.* 71 (8), 1255–1262. doi:10.2166/wst.2015.099

Zhang, J., Wang, C., Wang, X., and Yang, L. (2008). "The study of water resources carrying capacity in kaifeng city based on support vector machines," in International Conference on Informational Technology and Environmental System Science, Jiaozuo, China, May 15–17, 2008.

Zhang, J., Zhang, R., and Zhou, D. (2012). A study on water resource carrying capacity in the Shule river basin based on ecological footprints. *Acta Prataculturae Sin.* 21, 267–274.

Zhang, L., and Wang, J. (2012). Research progress and evaluation for water resources carrying capacity based on the Bibliometric method. *J. Water. Resour. Water Eng.* 23, 56–60.

Zhang, Y., and Li, S. S. (2012)., 518. Switzerland: Trans Tech Publications Ltd, 4362–4370. doi:10.4028/www.scientific.net/AMR.518-523.4362 The time-series study of xiangjiang river water carrying capacity based on the ecological footprint of water resource—The ChangZhuTan region, for example. *Adv. Mater. Res.*

Zhang, Z., Lu, W. X., Zhao, Y., and Song, W. B. (2014). Development tendency analysis and evaluation of the water ecological carrying capacity in the Siping area of Jilin Province in China based on system dynamics and analytic hierarchy process. *Ecol. Modell.* 275, 9–21. doi:10.1016/j.ecolmodel.2013.11.031

Zhao, X. Y., 2012. Application of coupling model with neural network and projection pursuit based on partial least-squares regression to water resources carrying capacity forecasting. In 2012 Fifth International Symposium on Computational Intelligence and Design (Vol. 2, pp. 446–449). NW Washington, DC United States: October 28 - 29, 2012. doi:10.1109/ISCID.2012.261

Zheng, Z., Wang, S., and Xing, J. (2016). "The complex index system of water scarcity based on the grey neural network model," in 2016 International Conference on Civil, Structure and Environmental Engineering, Guangzhou, China, March 12–13, 2016.

Zhou, R., Pan, Z., Jin, J., Li, C., and Ning, S. (2017). Forewarning model of regional water resources carrying capacity based on combination weights and entropy principles. *Entropy* 19 (11), 574. doi:10.3390/e19110574

Zhu, L., Li, X., Bai, Y., Yi, T., and Yao, L. (2019). Evaluation of water resources carrying capacity and its obstruction factor Analysis: A case study of hubei province, China. *Water* 11 (12), 2573. doi:10.3390/w11122573

Zhu, Y., Peng, L., Du, M., and Xu, X. (2010). On the evaluation of regional water resources carrying capacity. *Sci. Manage* 3, 21–24.