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A bibliometric analysis for the research on river water quality assessment and simulation during 2000–2014

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Abstract Based on bibliometric analysis, this paper identified certain characteristics of literature related to river water quality assessment and simulation and consequently to assist researchers to establish future research directions. There were 3701 articles pertinent to river assessment and simulation published by SCIE and SSCI databases from 2000 to 2014. Various publication characteristics were analyzed, such as countries, research organizations, subject categories, journals and keywords. Results showed there was a significant growth in total publications over the past 15 years. The USA took a leading position out of 104 countries/territories, followed by China and the UK. Similarly, Chinese Academy of Sciences was the most significant contributor in this field of research. Environmental sciences and water resources were the top two most central subject categories and journal of hydrology was the most productive journal. Singh K. P ranked the first in terms of comprehensive index in all core authors. Five clusters were identified in terms of keywords networks. And temporal trend of keywords indicated nutrient and eutrophication is the hot topics and SWAT is widely accepted as the model to study water quality in the past 15 year.

Keywords Bibliometrics · River · Water quality · Research trend

Introduction

Water quality assessment and simulation plays a critical role in the field of river environmental management. An appropriate water quality evaluation contributes to water resource planning. A number of methods exist for water quality assessment. These include

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single-factor evaluation method, multi-index evaluation method, fuzzy mathematics evaluation method, grey system evaluation method, analytic hierarchy process method, artificial neural network evaluation method (Lu et al. 2010; Hurley et al. 2012; Chu et al. 2013; Yang et al. 2013; Bonansea et al. 2015). Results of water quality assessment reflect the temporal and spatial variations of water quality.

The simulation of water quality helps to establish corresponding models to describe the relationship between water pollution and water quality, and in turn assist the river water resource management (Sharma and Kansal 2013). The classic model was proposed by American engineers Streeter and Phelps in 1925 to analyze the coupling relationship between BOD and DO at one-dimension scale. Since then a large number of water quality models have been developed based on these equations. The last century has witnessed the significant development of water quality models from single factor to multi-factor model, from static to dynamic model, from point source to nonpoint sources model, and from one-dimensional to multi-dimensional models (Gao et al. 2014).

River water quality assessment and simulation play a crucial role in pollution control and management. And much attention has been paid to the corresponding research field. There is no lack of reviews of studies related to river water quality assessment and simulation. However, vast majority of these studies focused on methods and models. Very few of them attempted comprehensive analysis of various parameters such as author, country, journal, and hot topics. Indeed, a whole picture may not be obtained if the review purely focuses on methods and models.

Bibliometrics provides a useful tool which quantitatively analyzes development and growth of any specific research field (van Raan 2005; Mao et al. 2015). Mathematical and statistical methods can be employed to examine various characteristics of publications such as the distributed architecture and variation patterns, which in turn reflect the status quo of the underlying science and technology (Hou et al. 2015). Bibliometrics technique has been adopted in various environment-related fields such as wetlands (Zhi and Ji 2012), biosorption technology (Ho 2008), estuary pollution (Sun et al. 2012) and sediment-related research (Niu et al. 2014), but not on the assessment and simulation of river water quality.

This paper reports a comprehensive analysis of publications related to river water quality via bibliometrics technique. Hot topics are highlighted which provide useful inputs to the future research endeavor on water quality management.

Methods

Data sources

The data were retrieved from the databases of the Science Citation Index Expanded (SCIE) and the Social Sciences Citation Index (SSCI). These databases cover a wide range of research fields and are most common data sources for bibliometric related studies. SCI is an international index and mainly focuses on basic science including natural science, biology, medicine, agriculture, behavior science and so on. SCI was produced by the former Institute for Scientific Information in 1957. It is owned by Thomson Reuters now. SCIE, an extended version of SCI, is the most frequently employed source to evaluate the accomplishment in all scientific research fields (Niu et al. 2014). SCIE contains more than 6000 journals and adds average of 19,000 new records weekly. SCI's companion-SSCI is the world's most important index of social science journals. SSCI covers anthropology, law, economics, history, geography, psychology and so on.

Keywords used are: "water quality" and "river" and "assess*" and "simulat*". These keywords were used to search titles, abstracts and keywords of publications from three databases from 2000 to 2014. Initial screening was conducted to eliminate those publications not related to river water quality assessment and simulation.

Bibliometric analysis

Bibliometrics refers to a comprehensive technique which utilizes mathematical analysis and statistics to quantitatively describe literature distribution, variation and quantitative relationships which consequently reveals research trends of various research fields (Hou et al. 2015; Mao et al. 2015). In this study, bibliometric technique is employed to examine various publication characteristics such as authorships, citations, and the impact factor.

Social network analysis

Social network analysis is a useful tool for the representation and analysis of relational data (Butts 2008). It provides a quantitative relation assessment on casual acquaintances or bonds. Common software for social network analysis include Pajek and Gephi. In this study, Pajek was applied to show the cooperation networks among countries and institutes. Gephi was employed to analyze the co-occurrence of key-words to highlight the hot topics.

Comprehensive index

Comprehensive index method was used to the evaluate core authors. Both the quantity of publications and total citations of one author are weighted as half in the comprehensive index process. The higher the comprehensive index is, the more influential the author is. The comprehensive index as follows (Zhong 2012):

$$Z_i = \left(x_i/\bar{x} \times 100\right) \times 0.5 + \left(y_i/\bar{y} \times 100\right) \times 0.5$$

x_i—number of publications of one author; $\bar{x}$—average value of all publications; y_i—number of citations of one author; $\bar{y}$—average value of all citations.

Results

Characterization of publication outputs

A total of 4124 research papers related to river water quality assessment and simulation were retrieved from SCIE and SSCI from 2000 to 2014. There were six types of publications, of which journal article occupied the first, representing 97.19 % of the total, followed by proceedings, reviews, and others (e.g. editing material, book chapters and bibliography). Therefore, only 3701 journal articles were further analyzed in this study. The number of articles increased from 65 in 2000 to 446 in 2014 with an annual growth rate of 14.75 % on average. As shown in Fig. 1, the quantity of publications increased significantly in the past 15 years.

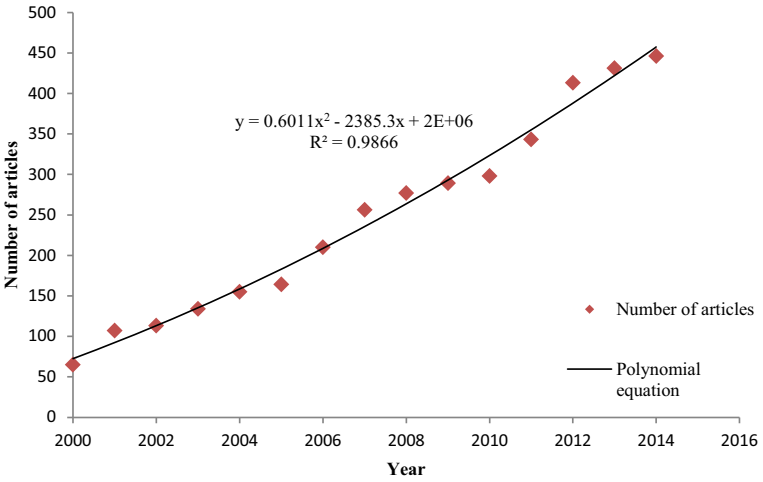

Fig. 1 The relationship between the number of articles and year

Subject categories and journals

After removing 22 articles that did not contain subject category information, 3679 articles were classified into 98 subject categories in this study. Environmental sciences had the most publications with 1802 records, almost half of the total number of publications (TP) followed by water resources and engineering environmental. Figure 2 describes the time trend of the top five productive subject categories. Environmental sciences and water resources maintained relatively consistent speed before 2005. Then, environmental sciences had faster growth, surpassing water resources. Interestingly, both categories experienced a decrease in 2013. The remaining categories held a stable increasing state in the past 15 years. Based on the category descriptions, Environmental sciences covers resources concerning many aspects of the study of the environment, among them environmental contamination and toxicology, environmental health, environmental monitoring, environmental geology, and environmental management. This category also includes soil science and conservation, water resources research and engineering and climate change. Water resources covers resources concerning a number of water-related topics. These include desalination, ground water monitoring and remediation, hydrology, irrigation and drainage science and technology, water quality, hydraulic engineering, ocean and coastal management, river research and management, waterways and ports (http://admin-apps.webofknowledge.com/JCR/static_html/scope_notes/SCIENCE/2012/SCOPE_SCI.htm). In sum, environmental sciences and water resources had gained more attention, which mainly focus on water resource, environment/river monitoring and management.

More than 500 journals have published articles related to assessment and simulation of river water quality. Table 1 displayed the top 10 most productive journals, accounting only 27.32 % of the total publications. The lower percentage indicated the breadth of article distribution as well as the broad interest in assessment and simulation of river water quality. The journal of hydrology was the most productive journal, with 139 articles, followed by science of the total environment and water science and technology. Water research ranked the first in IF^a and IF^b, which illustrates that water research is the most

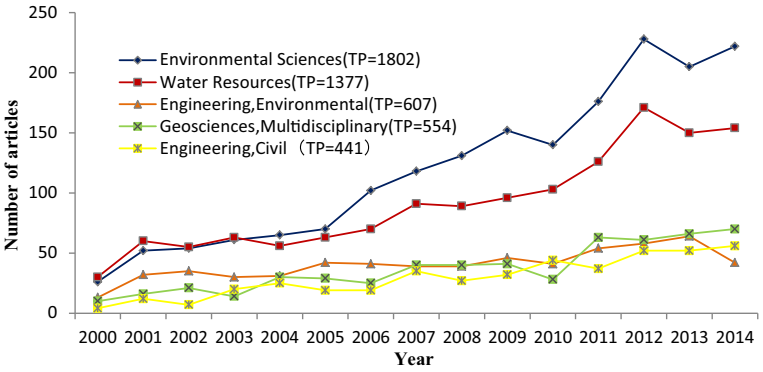

Fig. 2 Annual quantity of articles for the top five productive subject categories (2000–2014)

Table 1 The performance of top 10 most productive journals

SO	TP	Percent	IF[a]	IF[b]
Journal of hydrology	139	3.76	3.053	2.476
Science of the total environment	137	3.70	4.099	3.45
Water science and technology	128	3.46	1.106	0.987
Journal of the American water resources association	108	2.92	1.348	1.212
Ecological modelling	96	2.59	2.321	2.085
Environmental monitoring and assessment	94	2.54	1.679	1.487
Hydrological processes	81	2.19	2.677	2.414
Journal of environmental management	80	2.16	2.723	2.573
Water research	77	2.08	5.528	4.962
Water resources research	71	1.92	3.549	2.717

[a] IF presents journal impact factor in 2014

[b] IF is impact factor without journal self cites in 2014

influential journal on water quality control. It is worth noting that the difference between IF[a] and IF[b] of water resources research was largest, indicating higher journal self-citation in water resources research.

Core author(s)

A core author is the researcher who has contributed greatly to a specific subject of research. Based on comprehensive index methods, the top five core authors were identified on river water quality assessment and simulation. As shown in Table 2, two core authors are from the UK. Singh. K. P occupied first place with the highest comprehensive index (453.04), followed by Van Griensven. A and Neal. C. Thereafter is Alexander. R. B, who published comparatively small number of articles however with a high total citation.

Table 2 Top five core authors (2000–2014) with the quantity of publications (TP), total citations (TC), comprehensive index, country and institute information

AU	TP	TC	Comprehensive index	Country	Institute
Singh, K. P	9	622	453.04	India	Indian Institute of Toxicology Research
Van Griensven, A	8	498	371.86	Belgium	Free University of Brussels
Neal, C	11	254	269.20	UK	Centre Ecology & Hydrology
Alexander, R. B	3	339	258.74	USA	US Geological Survey
Wade, A. J	8	292	256.07	UK	University of Reading

Singh K. P has published 88 research articles, of which 64 were classified as environmental science. The most cited article on river water quality assessment and simulation was "Multivariate statistical techniques for the evaluation of spatial and temporal variations in water quality of Gomti River (India)—a case study" published in 2004. This paper demonstrated the multivariate statistical techniques provided effective tools to analyze and interpret complex data set on water quality. As a result, water resources can be managed effectively (Singh et al. 2004).

Country distributions

The quantity of authors determined how a country or region contributed to the developments in river water quality assessment and simulation. We could obtain information regarding countries from the corresponding author's address or affiliation. It was noted that the SCI had a policy of omitting certain addresses (Wang et al. 2014). The 3692 articles with related information from 104 countries/territories were used to analyze the distribution of countries. Results showed that only 23.86 % of articles involved international cooperation which indicated a lack of cooperation between countries.

The top 20 were graded in Table 3 by the quantity of journal articles, rank and the percentages of the quantity of one country's publication to the total quantity of publications, the h-index and 2014 country GDP. Eleven countries (USA, China, UK, Canada, Australia, Germany, France, South Korea, Spain, India and Italy) with the top 12 highest country GDP also ranked top 11 most productive countries in term of total publications. Generally speaking, large numbers of research publications from a country were correlated with the high economic level of the country (Zhou and Zhao 2015). Thus, with the highest GDP, the USA accounted for the largest number of high-quality publications, distantly followed by China and the UK. It is worth noting that China ranked second in terms of the total quantity of publications however as low as seventh in terms of the h-index. H-index was first proposed by Hirsch (2005) to measure the productivity and impact of published works. The large gap between total publications and the h-index indicates that China's academic influence could be further strengthened. Similar phenomenon also happened in other countries including South Korea, India, Japan, Taiwan, Spain and Turkey. Interestingly, most of these countries are located in Asia. On contrary, most European countries, such as Germany, France, Italy, Belgium, Netherlands, Portugal and Switzerland are comparatively consistent between total publications and h-index.

As shown in Fig. 3, total publications of UK, Canada and Australia increased slightly. By contrast, total publications from the USA and China experienced a rapid growth, indicating that improving water quality and controlling river pollution attracted wider

Table 3 Top 20 productive countries during 2000–2014

Country	TP	R (%)	h-index (R)	GDP (trillion, $)
USA	1296	1(35.1)	58(1)	17.42
China	491	2(13.3)	25(7)	10.35
UK	314	3(8.5)	36(2)	2.989
Canada	221	4(5.99)	26(5)	1.785
Australia	208	5(5.63)	30(3)	1.455
Germany	191	6(5.17)	27(4)	3.868
France	124	7(3.36)	26(5)	2.829
South Korea	118	8(3.2)	16(15)	1.410
Spain	108	9(2.93)	18(12)	1.381
India	107	10(2.9)	18(12)	2.049
Italy	101	11(2.74)	20(9)	2.141
Belgium	100	12(2.71)	25(7)	0.532
Netherlands	92	13(2.49)	20(9)	0.879
Japan	87	14(2.36)	14(17)	4.601
Taiwan	80	15(2.17)	13(19)	–
Iran	80	15(2.17)	14(17)	0.425
Turkey	69	17(1.87)	11(20)	0.798
Switzerland	59	18(1.6)	19(11)	0.701
New Zealand	57	19(1.54)	17(14)	0.166
Portugal	56	20(1.52)	16(15)	0.230

R(%): the rank and the ratio of the quantity of one country's publication to the total quantity of publications from 2000 to 2014; the h-index: this index was first proposed by Hirsch (2005) to measure the productivity and impact of published works; and GDP: gross domestic product (2014)

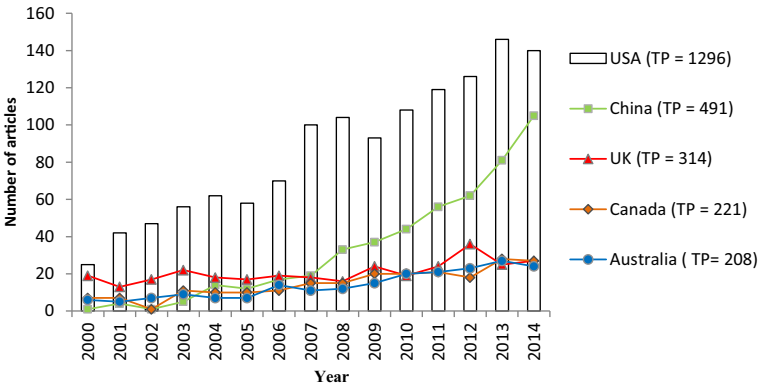

Fig. 3 Annual quantity of articles for the 5 most productive countries (2000–2014)

attention in these two countries. Notably, the quantity of articles published by Chinese scholars grew rapidly since 2007. "National medium and long-term plan for science and technology development" was introduced in 2006, which put forward the river pollution control. This arguably contributes to the significant growth of related publications since 2007. Indeed, policy plays a crucial role in facilitating transition to sustainable development (Yuan and Zuo 2011; Zhao et al. 2011; Zuo and Zhao 2014).

Based on the social network analysis, the collaborative relationships among the top 20 productive countries and regions are depicted in Fig. 4. The size of nodes presented publication volume while the thickness of connecting lines between countries demonstrated the intensity of cooperation. The thicker the connecting line is, the more frequently the two countries cooperate. As shown in Fig. 4, the USA has played a key role and has collaborated with all other countries, particularly with China, Canada, Australia, Germany and the UK. The partnership between the USA and China is notable, ranked the first in terms of intensity. There are many collaborative researches between these two countries. For example, the Sino-US Cooperation Forum Chongqing Declaration of Two Rivers was signed between two governments in 2010. The cooperation between the water resource management of Yangtze River and the Mississippi River is a typical example of governmental collaborations which aims to facilitate the communication and cooperation on river water quality research.

Characteristics of institutions

A total of 3692 articles provided author addresses. Analysis showed that more than 3000 institutions devoted to river quality control research. The top 21 institutions were ranked by the number of articles (Table 4). Among the top 21 institutions, 10 were in the USA, 3 in China, 2 in the UK, and 1 in Switzerland, Iran, Germany, Taiwan, Canada and Belgium each. Similarly, Chinese Academy of Sciences had the largest quantity of publications followed by the US Geological Survey and the US Environmental Protection Agency. It is

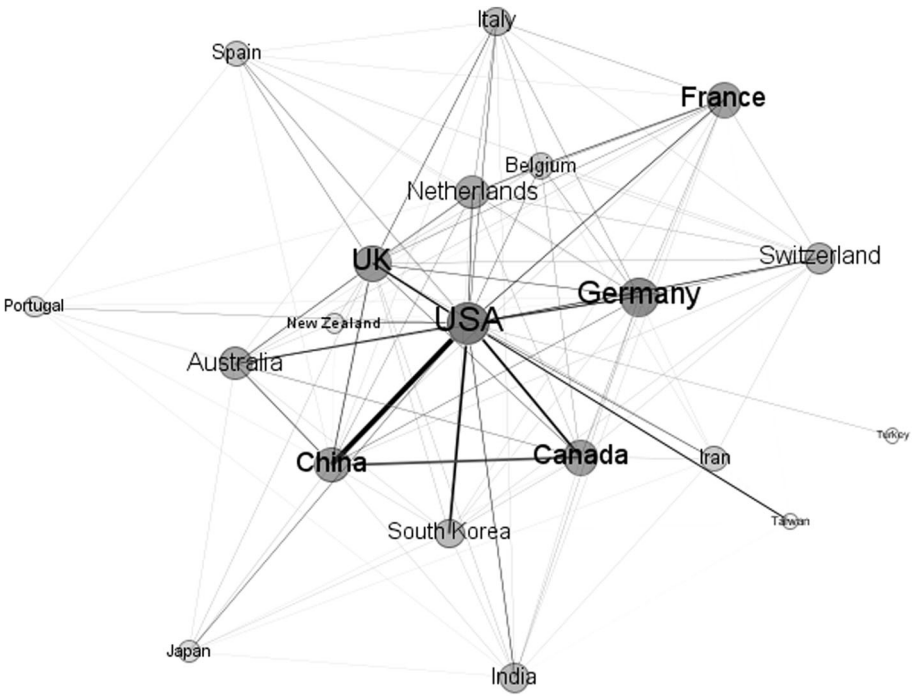

Fig. 4 The cooperation network of the top 20 productive countries

Table 4 Top 21 most productive research organizations from 2000 to 2014 in terms of published articles

Institute	TP	TP R (%)	h-index (Rank)
Chinese Acad Sci, China	105	1(2.84)	18(4)
US Geol Survey, USA	100	2(2.71)	24(1)
US EPA, USA	87	3(2.36)	21(2)
Beijing Normal Univ, China	62	4(1.68)	15(8)
Univ Ghent, Belgium	54	5(1.46)	16(7)
Ctr Ecol & Hydrol, UK	51	6(1.38)	17(6)
USDA ARS, USA	46	7(1.25)	15(8)
Natl Taiwan Univ, Taiwan	40	8(1.08)	10(20)
Univ Reading, UK	39	9(1.06)	19(3)
Univ Maryland, USA	39	9(1.06)	15(8)
Texas A&M Univ, USA	39	9(1.06)	12(16)
UFZ Helmholtz Ctr Environm Res, Germany	39	9(1.06)	15(8)
Univ Calif Davis, USA	36	13(0.98)	14(13)
Univ Tehran, Iran	35	14(0.95)	12(16)
Louisiana State Univ, USA	35	14(0.95)	18(4)
Univ Minnesota, USA	32	16(0.87)	11(19)
Duke Univ, USA	32	16(0.87)	14(13)
Eawag, Switzerland	30	18(0.81)	13(15)
Univ Georgia, USA	28	19(0.76)	12(16)
Zhejiang Univ, China	27	20(0.73)	9(21)
Univ Regina, Canada	27	20(0.73)	15(8)

worth noting that Louisiana State University ranked fourteenth in terms of the total quantity of articles however fourth in terms of the h-index. Similarly, University Regina ranked twentieth with 27 publications yet ranked eighth in terms of the h-index. By contrast, National Taiwan University and Texas A&M University ranked eighth and ninth, respectively, by the total quantity of publications, however ranked twentieth and sixteenth, respectively, in terms of the h-index. It presents opportunities for these two institutions to further improve their research profile on river water quality.

Similarly, a collaborative network of the top 21 productive institutions was drawn (Fig. 5). The network shows that the US Geological Survey and US Environmental Protection Agency, accompanied by other American institutions, played crucial roles among the top 21 institutions. As shown in Fig. 5, the cooperation between institutions was mainly within the same country. It can also be observed that the closest collaborative relationship was between University Reading and the Centre Ecology & Hydrology in UK. In China, Chinese Academy of Sciences and Beijing Normal University have the most intensive collaborative relationship. It presents opportunities for these institutions to strengthen international cooperation so that the productivity can be further enhanced.

Hot topics

The keyword is a noun or phrase that can reflect the full meaning or core content of a literature. Cluster analysis was undertaken in this study to identify the main research streams by using Gephi, an interactive visualization and exploration platform for all types

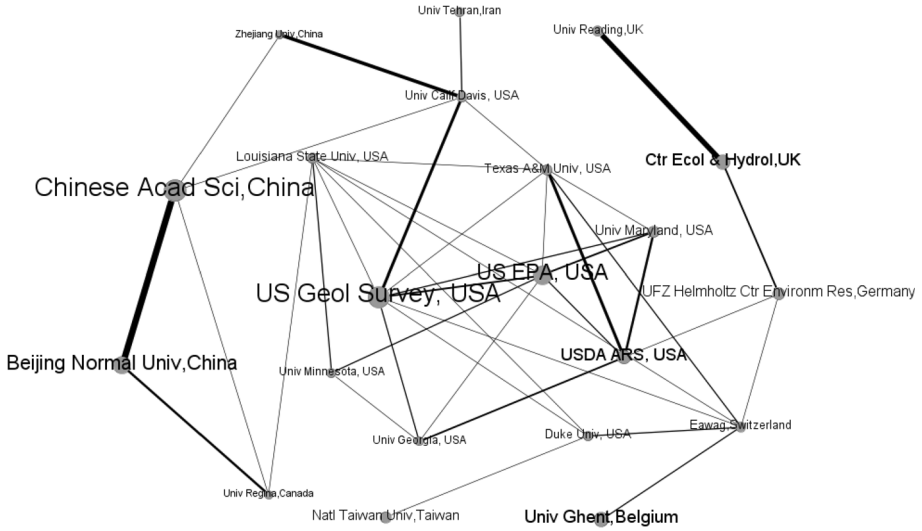

Fig. 5 The cooperation network of the top 21 productive institutions

of networks. During this process, keywords with the same meaning were combined, such as "nonpoint source pollution" and "non-point source pollution". In addition, generic words were eliminated for the keyword analysis, such as "river", "water quality" and "model". According to the Force Atlas2 Layout, the top 50 keywords were classified into five clusters.

As shown in Fig. 6, clusters I and V are slightly separated from other clusters with smaller size nodes. Cluster I mainly focuses on multi-index analysis method, such as "source apportionment", "cluster analysis", "factor analysis" and "principal component analysis". In cluster V, "monitor" is the largest node. Furthermore, water quality indexes, such as "salinity", "diatoms" and "suspended sediment" merged. However, these two clusters occupied a relatively smaller part of the diagram. This indicated that attention of scholars in the field of river water quality is gradually turned away from traditional research topics such as source apportionment, multi-index evaluation method and routine water quality monitoring. By contrast, clusters II, III and IV had much closer connection with each other and have become the hot topics in this research field. Clusters II and III focused on eutrophication. Similarly, there were many pertinent keywords such as "nitrogen", "nitrate", "phosphorus" and "nutrient". Furthermore, "agriculture" and "land use" occupied a large part of the diagram with larger nodes. This indicated that agriculture and land use had close relationships while eutrophication also became a hot topic. Meanwhile, GIS and RS were widely used in eutrophication monitoring and prediction. Cluster IV focused on "water quality management" and "SWAT". Other nodes exist such as "uncertainty analysis", "simulation" and "climate change".

The network analysis of keywords provided a useful indication of main topics within the field on river water quality assessment and simulation. To obtain a deeper understanding of these hot topics, temporal trends of certain main keywords were further analyzed.

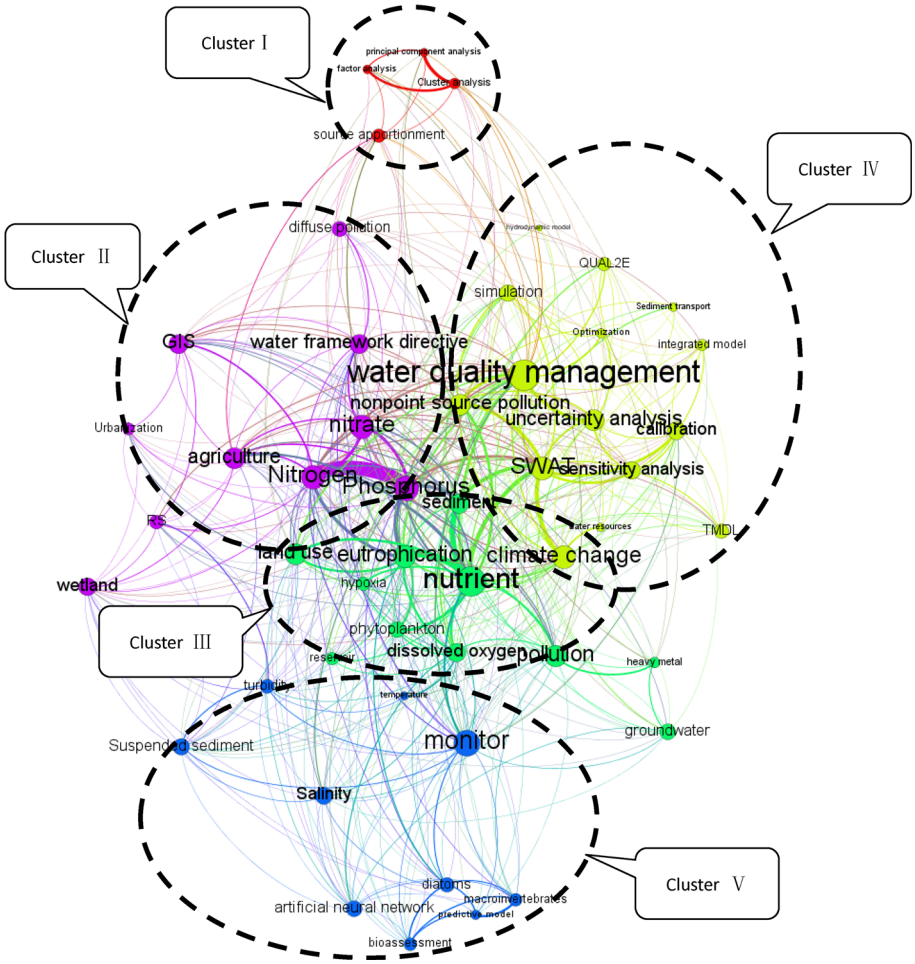

Fig. 6 The co-keywords' network of the top 50 keywords (except "water quality", "model" and "river")

Eutrophication related research: cluster II and cluster III

Nutrient ranked the first with 167 records in eutrophication related research publications, followed by eutrophication (135) and GIS (94). As shown in Fig. 7, the quantity of publications related to eutrophication maintained a steady growth over the past 15 years. This indicated that researchers paid a lot of attention to this area. Eutrophication is a global environmental issue derived from the excessive inputs of nitrogen and phosphorus as well as the overgrowth of algae in water. In general, the study of eutrophication needs to monitor nitrogen and phosphorus levels in the river. Because of the occurrence of eutrophication, attention was paid to identify causes and control measures. Recent years have seen various phosphorus or nitrogen model to predict the level of eutrophication so that appropriate decisions can be made. These include single nutrient load model, the phytoplankton and nutrient related model and the ecological dynamics model (Behrendt et al. 2002; Hofmann et al. 2010; Munawar and Fitzpatrick 2011; Afshar et al. 2012).

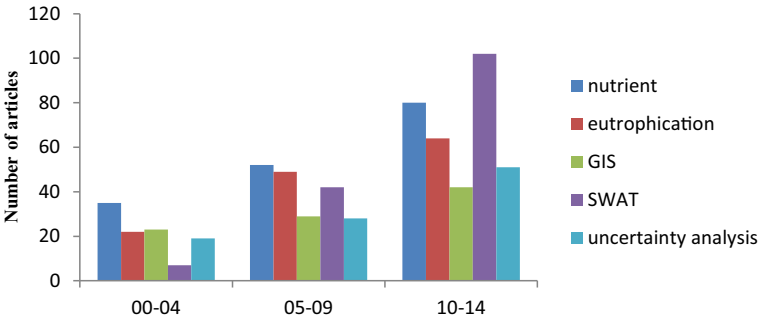

Fig. 7 The growth trend of main keywords

Water quality management: cluster IV

"SWAT" and "uncertainty analysis" were the key nodes in Cluster IV. First, Soil and Water Assessment Tool (SWAT), with 151 publications, was the largest role in water quality management. SWAT related literature experienced a sharp increase from 2010 to 2014 (see Fig. 7). Developed two decades ago, SWAT is a continuous time model to evaluate the mechanism of non-point pollution within large scale river systems such as basins (Arnold and Fohrer 2005). SWAT was introduced by the USA Agricultural Research Service (ARS). Since then SWAT has been widely adopted in water quality studies such as simulating and assessing the hydrological environment as well as non-point source pollution (Gassman et al. 2007). It is widely recognized that SWAT is highly flexible in addressing a wide range of water resource problems due to the comprehensive nature of the model, strong model support and open access status of the source code (Gassman et al. 2014).

With more models been introduced in the water quality management research, uncertainty analysis has become vitally important. In the past 15 years, there have been 98 publications related to uncertainty analysis. Based on randomness and contingency of water quality system, probability theory, mathematical statistics theory, grey system theory and stochastic differential theory have been established with the assistance of people's cognition improvement. Uncertainty model can simulate water quality system substantively and further provide a large amount of high reliable information for decision makers. Therefore, uncertainty analysis of water quality model will be a hot research topic for the future endeavor of water quality assessment and simulation.

Conclusions and discussion

This study offers a comprehensive statistical review of the literature related to river water quality assessment and simulation. Insights were obtained about the global publication outputs, subject categories, journals, core authors, countries/territories, institutions and hot topics. Results showed that number of research articles increased significantly in last 15 years. Environmental sciences and water resources were the top two most central subject categories which mainly focus on water resource, environment/river monitoring and management. And among all journals, journal of hydrology and water resource ranked

first in quantity and IF, respectively. USA accounted for the largest number of high-quality publications. By contrast, the gap between total publications and the h-index in some countries (China, South Korea, India, Japan, Taiwan, Spain and Turkey) was so large that those countries could strengthen their academic influence. In terms of institutes, Chinese Academy of Sciences came first, followed by the US Geological Survey and the US Environmental Protection Agency. It was noting the cooperation between institutions was mainly within the same country.

Previous review studies paid more attention to simulation methods, multivariate statistic models and water quality models. On contrary, this study attempts to identify hot topics and corresponding research methods in detail. Hot topic analysis indicated that future research on river water quality will likely focus on eutrophication such as monitoring, evaluation, simulation and prediction of nutrients (e.g. nitrogen and phosphorus). Eutrophication has close relationship with nonpoint source pollution in the agriculture sector. Therefore, SWAT model, which has been commonly adopted to simulate nonpoint source pollution and the impact of land use changes on the river water quality, will gain more applications in river water quality related research. Moreover, technologies such as ICT, on-line monitoring system as well as remote sensing have achieved notable development. As a result, the scale of river water research will be expanded, such as river basins. GIS is likely to become one of critical technologies for the larger scale river water quality assessment and simulation.

The bibliometric technique offers a quantitative perspective which provides a better understanding of the characteristics associated with river water quality research. This study provides a suite of indicators that can be combined to provide a useful picture of the development of river water quality assessment and simulation. It also offers a useful reference to researchers to identify the challenge which lie ahead for corresponding areas. Moreover, these results provide useful suggestions for water resource management via a close-loop feedback mechanism between academic research and policy making. This will be beneficial to policy making process. For instance, it could be an effictive policy to reduce eutrophication by investing more research funding on nonpoint source pollution in the agriculture sector.

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