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Water Ecological Environment Protection under Changing Environment: A Systematic Review and Bibliometric Analysis

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ABSTRACT

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Systematic review is usually used to reveal the change characteristics of the quantity and law of the citations focus on one research theme. The paper investigated the research status, development trend and hotspots of water ecological environment protection using bibliometric analysis. Based on bibliometric, mathematics and statistics, articles related to the water ecological environment protection in Web of Science for the period of 2008-2019 were selected. CiteSpace software was used to conduct the annual frequency analysis of papers, countries and research institutions analysis, co-occurring keywords analysis, clustering analysis and research frontier. Results show that: (1) The number of published papers and cited papers have increased for the past 12 years. Especially, the number of published papers has increased sharply since 2015, indicating that the research on water ecological environment protection has been transferred from the exploration stage to rapid development stage, which needs to be analyzed from the aspects of national policy. (2) China has more publications than other countries. The research institutions are mainly concentrated on universities, the cooperation among them is not close. It shows the characteristics of small distribution and large concentration. Keywords such as "model" and "water quality" are research hotspots. (3) The results of clustering analysis show that water ecological environment quality assessment, water and soil conservation, ecosystem services and aquatic ecosystem are four main research directions of water ecological environment protection. (4) Using method of burst detection, nine keywords are obtained, which indicate that water ecological environment protection has rich research perspectives. The burst strength of land use is high, it will become the research hotspot of water ecological environment protection in future. The results should be beneficial to systematically understand research progress and future trends of water ecologic environment under changing environment, and therefore it promotes ecological civilization construction.

ADDITIONAL INDEX WORDS: *Water ecological environment protection, bibliometric, research hotspots, research frontiers, CiteSpace.*

INTRODUCTION

With the rapid development of the economy and the rapid population growth, people have neglected the protection of the ecological environment in order to satisfy the pursuit of material life, such as over-exploitation of land resources, serious pollution of water environment (Rasul *et al*., 2017; Xing *et al*., 2018), water eutrophication (Lalley *et al*., 2016; Xing *et al*., 2019) and extreme climate events (Jiang *et al.*, 2017; Jiang *et al.*, 2019). A variety of ecological and environmental problems frequently occur, aquatic ecosystems and environments are facing enormous threats. Many ecological and environmental problems related to water resources have restricted economic development (Jiang *et al.*, 2015; Zhu *et al*., 2010).

Many previous studies focused on the water ecological environment protection all over the world (Gao, Zhou, and Chen, 2014). For example, Zeng *et al*. (2016) developed a simulation-based water-environment management model with Laplace scenario analysis (SWML) for planning regional sustainability in compound wetland ecosystem. Kong *et al.* (2018) used the Haihe River Basin as an example to evaluate water quality using the eutrophication index (EI) and the potential ecological risk index (RI). The results indicate that water eutrophication and water pollution depend largely on the type of human activity. These findings have a great role in promoting the study of water ecological environment protection (Gurjar and Kaur, 2018). Relevant researches on water ecological environment protection keep emerging. Therefore, it is particularly important to analyze and summarize the current research and development of water ecological environment protection in a timely manner.

For water ecological environment protection, if the literature review is carried out, the literature data is very large and the

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individual research energy of researchers is limited, so it is difficult to fully grasp. Therefore, in order to effectively understand the research situation of water ecological environment protection in recent years, it is necessary to use scientific bibliometric methods. Based on the literatures obtained from the Web of Science Core Collection Database for the period of 2008-2019, the paper carry out the annual frequency analysis of papers, countries and research institutions analysis, co-occurring keywords analysis, clustering analysis and research frontier analysis, scientific and objective understanding of the research status and development trend of water ecological environment protection using bibliometric analysis and knowledge mapping, to promote the water ecological environment protection to the deepening of research.

METHODS

This section briefly introduces the data collection method of this study and the reasons for selecting CiteSpace software for data analysis.

Data

According to Law of Bradford, the core journals bring together the core literature of the discipline research field. Based on the perspective of water ecological environment protection, the sample data was collected from the Web of Science (WoS) Core Collection Database launched by the Institute for Scientific Information (ISI). Web of Science (WoS) Core Collection Database includes SCI-E, SSCI, CPCI-S, CPCI-SSH, CCR-E and IC, it is currently the most authoritative indexing tool for scientific and technical literature in the world. The searching term word in this study was "water ecological environment protection", the document type was set to article, and the time span was from 2008 till now. Finally, a total of 482 valid articles were retained for bibliometric analysis.

CiteSpace

With the development of information technology, information sources are becoming more and more huge, information visualization becomes very important. Big data software is widely used in various subject areas to understand the direction of scientific research within fields of study, ascertain the importance of particular groups, authors, or institutions (Vasudevan *et al*., 2016). Common data analysis software includes social network analysis (NetDraw), visualization tools (Ucient). Bibliometric analysis is a tool for statistical analysis and quantitative analysis of published literatures (Liang *et al*., 2017) and an important branch of information visualization. The document analysis tool used in this paper is CiteSpace, the version is CiteSpace V.5.2.R1 (64 bit).

CiteSpace software is developed by Dr. Chen Chaomei from Drexel University in the United States based on the Java platform. It is a new trend, new development and new progress in bibliometric analysis. CiteSpace is a multi-dimensional, time-sharing and dynamic visualization software. It combines social network analysis, association rule analysis and other methods. It has strong technical and functional advantages in drawing knowledge maps, analyzing developments trends of related fields, exploring the evolution trend of a subject field, research hotspots and the internal relations between different research hotspots in different periods.

Based on the principles of bibliometrics and statistical theory, the 482 papers retrieved are used as data sources. CiteSpace software is used in the Java environment to conduct countries and research institutions analysis, co-occurring keywords analysis, clustering analysis and research frontier analysis. In this way, the research progress, frontier hotspots and potential problems of water ecological environment protection are visually analyzed.

RESULTS AND DISCUSSION

The results and discussion section analyze the annual frequency, countries and institutions, co-occurring keywords, keyword clustering and research frontiers of water ecological environment protection.

Annual Frequency Analysis of Papers

To a certain extent, the number of articles represents the degree of academic concern and attention to this research field. In order to understand its trend more intuitively and accurately, by using the function of creating citation analysis report in the Web of Science, the frequency of published papers and cited papers from 2008 to 2018 were calculated. Because 2019 is still going on, only the years during 2008-2018 is considered in this section. The total number of published papers is 476, and the average number of publications is 43 per year. The total number of citations is 4,149, and the average number of citations per year is 377.

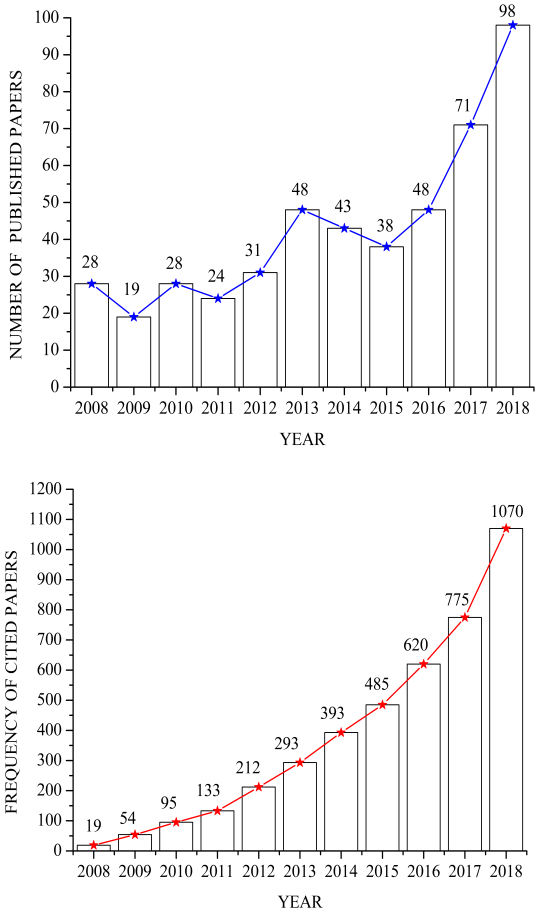

Figure 1. Time sequence of all articles on water ecological environment protection in WoS: the number of published papers and the frequency of cited papers.

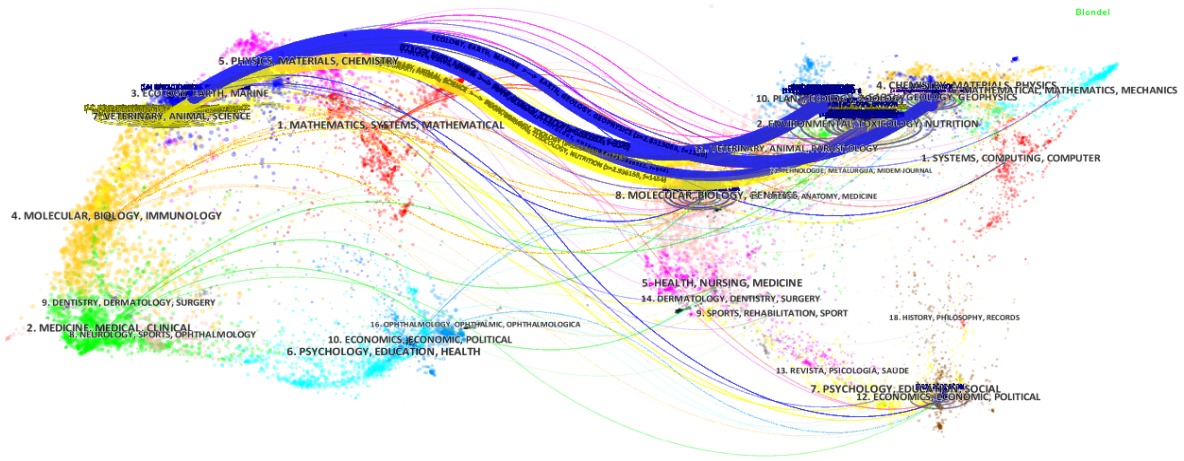

Figure 2. Dual-map overlays of journals.

Figure 1 shows that the number of published papers and the frequency of cited papers are generally rising from 2008 to 2018, it suggests that relevant research are increasing and the research system construction is advancing steadily. The number of published papers is in a fluctuating growth trend. In 2013, there was a small peak of water ecological environment protection, and the number of published papers reached 48. Taking 2015 as the turning point, before 2015, the water ecological environment protection presented a stable development trend with little inter-annual difference (Wang, Zhong, and Bo, 2018), the water ecological environment protection was in the exploration stage. After 2015, the number of published papers increased significantly. In 2015-1018, the number of papers issued increased by 61.22%. The research on water ecological environment protection has entered a stage of rapid development. From 2008 to 2018, the frequency of cited papers showed an obvious growth trend, with an increase of 98.22%. In summary, the field of water ecological environment protection is a flourishing research field, and still have high research value.

The dual-map overlays of journals are a method to obtain information such as distribution, citation trajectory and barycenter shift of papers in various disciplines, which can effectively grasp the rules and development of knowledge transfer among journals (Chen and Leydesdorff, 2014). The JCR Journal Maps function in CiteSpace was used to simplify the Journal Maps by z-score method, and the dual-map overlays of journals was obtained.

In Figure 2, the vertical axis of the ellipse represents the number of papers, the horizontal axis represents the number of authors, the left side represents the research field of citing journals, and the right side represents the research field of cited journals. Each spline curve starts from a citing journal in the base map on the left and points to a cited journal in the base map on the right. Figure 2 shows that there are five main routes for knowledge transfer in the field of water ecological environment protection. The citing journals focus on basic subject areas, such as ecology and systems. The cited journals cover a wide range of specific fields, including toxicology, nutrition and plant. More attention should be paid to journals in these fields in future studies.

Countries and Research Institutions Analysis

Based on the basic information of 482 articles, in the CiteSpace software, the Node Types was set to "country". The time slice was set to "2 years", so the 12 years were divided into 6 times segments for analysis. The top 20 most cited or occurred items from each slice were chosen. After running, the distribution map of the country where the number of articles is located, using the minimum spanning tree (MST) algorithm, as shown in Figure 3.

Figure 3 shows that there are 36 countries involved in water ecological environment protection research. We selected countries with frequencies greater than 10 from the Figure 3, and the results

Table 1. *Distribution of scientific research strength in various countries (part).*

Count	Centrality	Country	Count	Centrality	Country
205	0.33	CHINA	21	0	POLAND
61	0.18	USA	19	0.11	SPAIN
30	0.13	CANADA	16	0.01	ITALY
30	0.06	ENGLAND	15	0.03	NETHERLANDS
29	0.08	AUSTRALIA	14	0.12	FRANCE
23	0.15	GERMANY			

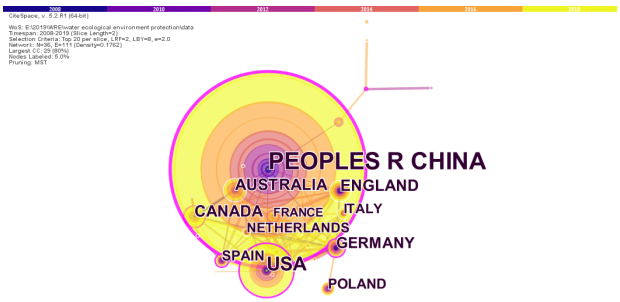

Figure 3. Distribution map of the countries.

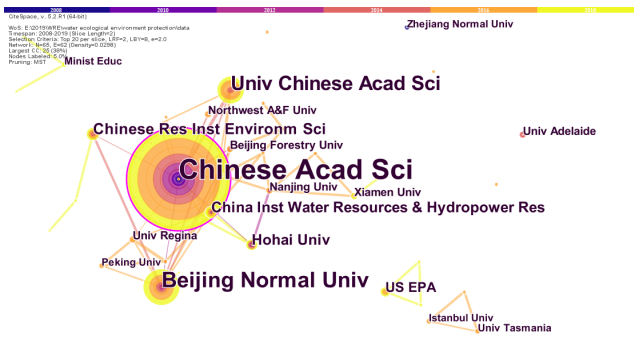

Figure 4. Distribution map of the institutions.

Table 2. *Important institutions in the top 20*.

Count	Centrality	Institution
59	0.1	Chinese Acad Sci
21	0.06	Beijing Normal Univ
16	0.01	Univ Chinese Acad Sci
8	0.04	Chinese Res Inst Environm Sci
7	0	China Univ Min & Technol
7	0.05	China Inst Water Resources & Hydropower Res
7	0.04	Hohai Univ
6	0	USEPA
4	0.02	Xiamen Univ
4	0	Univ Adelaide
4	0.01	Beijing Forestry Univ
4	0	Northwest A&F Univ
4	0.07	Nanjing Univ
4	0.01	Univ Regina
3	0	Peking Univ
3	0.01	Istanbul Univ
3	0	Zhejiang Normal Univ
3	0	Univ Tasmania
3	0	Zhengzhou Univ
3	0	Minist Educ

were shown in Table 1. Table 1 shows that China ranks first in research, with a frequency of 205, which has absolute advantages. The United States ranks second in the field, although far less than China, but far more than other countries. Canada and England are tied for third place with a frequency of 30. In fourth place is Australia. It can be seen that China plays an important role in the research field of water ecological environment protection.

In order to understand the research status and actual contribution of the research institutes in the study of water ecological environment protection, the publishing amounts of the research institutions were statistically analyzed. The data analysis in this section is limited to the research institution where the first author is located (Kang *et al*., 2018). Based on the retrieved papers, the network node was set to "institution", and the organization distribution map of the water ecological environment protection research was obtained, as shown in Figure 4.

Figure 4 shows that the institutions on water ecological environment protection research are mainly concentrated on colleges and universities. These institutions have a certain cooperative relationship, but the cooperation among research institutes is not close. It shows the characteristics of small distribution and large concentration (Li *et al*., 2017). We selected institutions with the amount of publications greater than 20 from Figure 4. The results were shown in Table 2. Table 2 shows that the institutions with more than 5 publications are "Chinese Acad Sci", "Normal Univ", "Univ Chinese Acad Sci", "China Univ Min & Technol", "China Inst Water Resources & Hydropower Res", "Hohai Univ" and "USEPA". Among them, the Chinese Academy of Sciences has published the most, with 59 articles. It is followed by Beijing Normal University, with a total of 21 articles. The third is the University of Chinese Academy of Sciences. The total number of published articles of the top three institutions is 96, accounting for 55.5% of the total number of published articles of institutions in the top 20, it suggests that the research institutions for water ecological environment protection are relatively concentrated and their scientific research capabilities are greatly different (Jusoh *et al*., 2014). In terms of geographical distribution, most publishing institutions are concentrated on China, followed by Australia.

Co-occurring Keywords Analysis

Keywords are highly concise to the content of literature research. The analysis of keywords co-occurring with CiteSpace can reveal the research direction and characteristics of this field. Similarly, it can be analogous to camera that capture snapshots of certain areas based on time series and links to deduce the research direction, trend changes and characteristics in the area (Li and Li, 2018). Centrality can reflect the relative importance and connectivity of keyword nodes in a certain research field. In CiteSpace software, the network node was set to "keyword", the rest were set the same as above. The keywords co-occurrence network obtained by running and merging synonyms is shown in Figure 5.

Figure 5 shows that the map density is 0.0522, the result shows that the co-occurring network of keywords is loose and the cohesive force is poor. There are 129 nodes and 125 links in Figure 5. By analyzing the keywords co-occurrence network, it can be seen that the outermost purple circle of nodes is thicker, such as "China", "environment", "pattern" and "model". It shows that the centrality of these words is higher. These keywords play an important role in the field of water ecological environment protection and are the bridge of research hotspots. It is explained

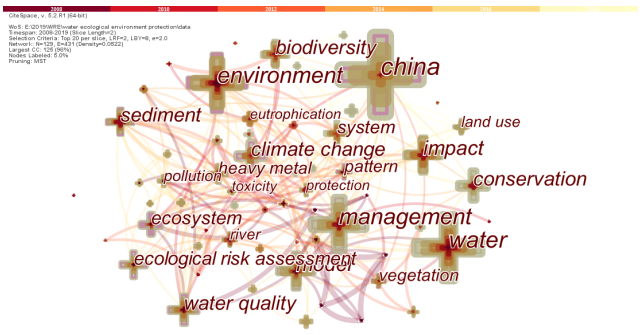

Figure 5. The co-occurring network of keywords.

Table 3. *Frequency of keywords (partial)*.

Count	Centrality	Year	Keyword
60	0.22	2010	China
52	0.06	2008	water
46	0.23	2008	environment
45	0.18	2008	management
32	0.08	2010	impact
31	0.19	2008	model
25	0.02	2010	conservation
25	0.12	2008	water quality
24	0.16	2010	climate change
24	0.12	2010	sediment
24	0.05	2010	biodiversity
22	0.11	2008	ecological risk assessment
21	0.31	2008	ecosystem
20	0.06	2012	system
16	0.14	2008	pattern
15	0.08	2010	heavy metal
15	0.11	2010	vegetation
12	0.03	2017	land use
12	0.02	2009	river
11	0.02	2009	pollution

that these nodes represent the strongest emerging trend in the research field of water ecological environment protection.

The keywords with a frequency greater than 10 times in the spectrum were selected, and the frequency and centrality values were shown in Table 3.

Table 3 shows that the highest frequency is "China". With the strengthening of research on water ecological environment and its awareness of water ecological environment, China's emphasis on water ecological environment protection is evident. Although the words such as "water" and "impact" are frequently used, their centrality is very low. Although the research on these keywords is very hot, the correlation with other research contents is weak. It also explains why the node of water in Figure 5 is very large while the outermost purple circle is almost invisible. With the passage of time and the development of society, the research hotspots of water ecological environment protection are different every year. Since 2008, the words such as "water", "environment", "water quality", "management" and "ecological assessment" have been frequently used (Wahi, Bhatia, and Bhadauria, 2018). It shows that the water ecological environment is always the research hotspot. In 2009, the words such as "rivers" and "pollution" appeared frequently, indicating that the river pollution was serious at that time. It was also the beginning of enhancing the research consciousness of water ecological environment protection. In 2010, the words such as "heavy metals", "protection", "ecosystem", "biodiversity" and "vegetation" appeared frequently, indicating that heavy metals were seriously polluted and the research heat of water ecological environment protection was high. At present, the problems of aquatic ecosystems, aquatic ecological environment quality and water pollution are important, and water ecological environment protection still needs to be highly valued.

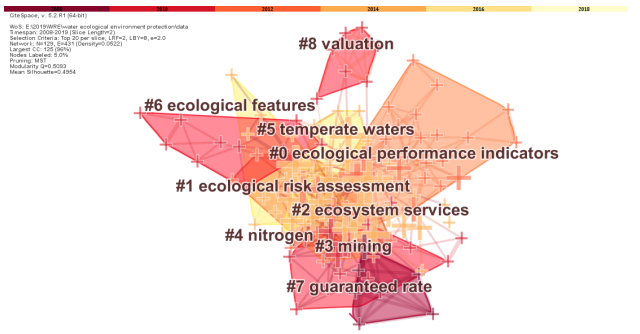

Figure 6. The keywords clustering map.

Clustering Analysis

Based on the co-occurring keywords analysis, the keywords of water ecological environment protection were clustered. The research method of clustering analysis is to classify multiple research variables (keywords) (Zhao and Zhang, 2019). According to the similarity among nodes, the clustering function of CiteSpace can cluster the nodes with obvious co-occurring relations into a category. Each category can be regarded as a basic topic composed of common themes or keywords. Then the research direction, structural characteristics and trend of these classifications are analyzed (Zhang and Qi, 2017).

According to the clustering modularity index Q and the clustering contouring index S, the clustering results are evaluated. Q>0.3 means that the network is significant and S>0.5 means that the clustering result is rational (Chen *et al*., 2015). Figure 6 shows that 10 main clusters are generated with a modularity Q of 0.5093. It proves that the network is significant.

The logarithmic likelihood method (LLR) was used to extract the keywords clustering labels, and a total of 9 clusters were generated. Clustering labels include: ecological performance indicators, ecological risk assessment, ecosystem services, mining, nitrogen, temperate waters, ecological features, guaranteed rate and valuation. According to the clustering results, it can be roughly divided into four categories. These four categories can be summarized as four research directions of water ecological environment protection: the first category is assessment of water eco-environmental quality, it includes ecological performance indicators, mining, guarantee rate and evaluation; the second category is water and soil conservation, it includes ecological risk assessment and nitrogen; the third category is ecosystem services; the fourth category is the aquatic ecosystem, it includes ecological features and temperate waters. As shown in Figure 6, the boundary of clustering is not very clear, and the concentration is strong and the overlap is high, forming a complex interdisciplinary network. A complex interdisciplinary network has been formed, and the disciplinary structure is advancing steadily.

Research Frontier Analysis

The concept of "research frontier" is used to reveal the dynamic evolution of the research field. Chaomei Chen defined a group of emergent concepts in a specific field as "research frontier" (Ma, Cao, and Shen, 2016). In CiteSpace software, burst detection can be used to reveal the sudden increase of keywords in the time series, this method can be used to analyze the frontiers of water

Table 4. *Top 9 keywords with the strongest citation bursts.*

Keyword	Strength	Begin	End	2008-2019
Ecology	2.6613	2010	2013	
Eutrophication	4.0457	2014	2015	
Climate Change	2.5799	2014	2015	
Environment	4.9645	2015	2016	
China	7.952	2015	2019	
Sustainability	3.6935	2016	2017	
Contamination	3.2267	2016	2017	
Conservation	2.6176	2017	2019	
Land Use	4.6254	2017	2019	

ecological environment protection research. Burst detection was carried out on keywords of water ecological environment protection from 2008 to 2019, and a total of 9 keywords were burst, as shown in Table 4.

The blue line in Table 4 represents the entire time span, the red line segment represents the duration of the burst of the keyword. The start time, end time and the burst strength of the corresponding keyword can be obtained from Table 4. Table 4 shows that the highest strength of the burst is "China". The strength is 7.952, and the period of emergence is from 2015 to 2019. It indicates that China's attention to water ecological environment protection research has been significantly enhanced during this period and will continue. Followed by "environment", this word started in 2015 and ended in 2016. The cycle is very short. The strength of "land use" is similar to "environment". Its burst period began in 2017. Soil and water conservation are an important aspect of water ecological environment protection, and it will become the research hotspot of water ecological environment protection in the future. "Eutrophication" is the last burst with a strength greater than 4. Its emergence period started in 2014 and ended in 2015. Overall, the research perspectives of water ecological environment protection during 2008-2019 are rich.

CONCLUSIONS

Based on the analysis of 482 articles on water ecological environment protection. The mainly results of the paper are summarized as follows:

(1) According to the number of publications, the research on water ecological environment protection can be roughly divided into two stages: the exploration stage before 2015 and the rapid development stage after 2015. The number of papers reached its peak in 2018. Therefore, 2015 is a landmark year for the study of water ecological environment protection. The journals focus on ecological pollution. It is expected that the research on water ecological environment protection will be in a state of blowout development.

(2) According to distribution of the countries and research institutions, the number of papers published by Chinese scholars is outstanding, presenting the trend of "a hundred flowers blossom, a hundred schools of thought contend", and then the United States. The research institutions of the first author of the literature are mostly concentrated in colleges and universities. Besides, the research ability of the research institutions varies greatly, the cooperation is not close, and research power dispersion. In the future, research institutions should strengthen cooperation and exchanges with each other to form more insightful academic research.

(3) According to research hotspots and frontiers, the academic research on water ecological environment protection covers a wide range. The keywords such as "pattern" and "model" are the bridge of research hotspots. The research directions of water ecological environment protection can be roughly divided into four categories: water ecological environment quality assessment, water and soil conservation, ecosystem services and aquatic ecosystem. The research perspective of water ecological environmental protection during 2008-2019 is relatively rich. Further analysis of the burst keywords shows that the problem of soil and water conservation is prominent. In the future, soil and water conservation will become the focus of research.

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