Research Hotspots and Evolution Paths Analysis of the Coordinated Development Between Water Resources Utilization and Industrial Structure Based on CiteSpace

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ABSTRACT

Based on 489 research papers on the theme of coordinated development of water resources utilization and industrial structure included in the WOS (Web of Science) kernel database from 1995 to 2022, this study uses CiteSpace visualization software to draw graphs of scholars' cooperation network, institutional cooperation network, keyword co-occurrence and clustering network, and keyword timeline, and systematically sort out the basic knowledge and cutting-edge hotspots in the field of international water resources utilization and industrial structure research, with the purpose of revealing the research progress in this field. Research has shown that the field received less academic attention before 2016; since 2016, research in the field has gradually become a research hotspot in the academic community; the cooperation between authors and institutions in this field is close, forming a relatively stable core cooperation team; the research in this field mainly focuses on the construction of indicator system for coordinated development of water resources and industrial structure and the selection of evaluation methods, sustainable development research, water footprint and virtual water research. By sorting out the evolution paths of research hotspots, it can be seen that keywords such as "energy consumption", "carbon emissions", and "ecosystem service" are at the forefront of research in this field.

Keywords: *Water resources utilization, Industrial structure, Coordinated development, Knowledge graph.*

1. INTRODUCTION

The report of the 20th CPC National Congress proposes that coordinating water resources, water environment, and water ecological governance is a key strategic deployment for obtaining green hills and clear waters. Optimizing the industrial water use structure is the only way to improve the efficiency of water resources utilization. While coordinating and promoting water-saving work, efforts should be made to upgrade the regional industrial structure to improve water use efficiency. Therefore, this study uses the WOS kernel database as the platform and SCI and SSCI core journals as literature sources. The search criteria are set as "year=1992-2022" and "theme=water resource utilization" and "theme=industrial structure or upgrading" and "theme=coordinated development or coupling coordination". A total of 489 pieces of English literature are obtained. Subsequently, with the help of CiteSpace visualization analysis software, visual analysis of international water resources utilization and coordinated development of industrial structure research is carried out, which has important guiding significance for grasping the research hotspots and future prospects of this academic field, enriching theoretical research in the field, and deepening practical exploration in the field.

2. RESEARCH METHODS AND DATA RESOURCES

CiteSpace is a visualization analysis software that can be used to draw knowledge graphs, which mainly conducts citation analysis and co-occurrence analysis through data mining technology, intuitively displays the structure, rules and distribution of scientific knowledge in the discipline field, and reveals the knowledge base and research frontiers in the discipline field.[1] Based on CiteSpace, this study processes retrieved literature data, draws knowledge graphs of key information such as authors, institutions, and keywords[2], and visualizes research hotspots and trends in the field of coordinated development of international waters resource utilization and industrial structure from 1995 to 2022. Firstly, in the WOS kernel database, the search criteria are set to "theme=water use efficiency" and "theme=industrial structure or industrial upgrading" and "theme=coordination". The literature sources are set to SSCI and SCI journals, and 489 pieces of English literature are obtained. Secondly, after appropriately deleting the retrieved literature, the data is prepared by importing it into CiteSpace 6.1R6 in plain text format, including full records and references. In CiteSpace 6.1R6 visualization software, after setting time slice values, selecting appropriate algorithms, and checking the corresponding graph options, the author cooperation network graph, institutional cooperation network graph, keyword co-occurrence network graph, keyword clustering graph, and keyword timeline graph are sequentially drawn to reveal the research progress in the field of coordinated development of international water resources utilization and industrial structure.

3. BIBLIOMETRIC ANALYSIS

Based on the data processed by CiteSpace, the basic characteristics of the field literature are summarised and analysed in terms of the trend changes in the number of articles published, and the tightness of cooperation between the authors of the articles and the publishing institutions.

3.1 Time Distribution of Number of Published Papers

The stage fluctuations in the number of published papers reveal the degree of attention that the field receives from the academic community. By analyzing the time distribution of number of published papers, the research period and future development potential of hotspots in the field can be obtained. Based on the analysis of the research on the WOS number of published papers in terms of coordinated development of water resources utilization and industrial structure from 1995 to 2022, it can be concluded that the field was still in its early stage from 1995 to 2008, with an average annual WOS number of published papers of 3, showing a slow fluctuation and upward trend; from 2009 to 2016, research in this field began to enter the right track, receiving a significant increase in academic attention, with an average annual WOS number of published papers of about 12; from 2017 to 2022, research in this field gradually matured, with an average annual WOS number of published papers of about 56, reaching its peak in 2021 (see "Figure 1"); although the WOS number of published papers in 2022 occasionally declined, it still far exceeded the average over the years. According to the fluctuation of number of published papers in recent years, this field still has rich academic research value in the future.

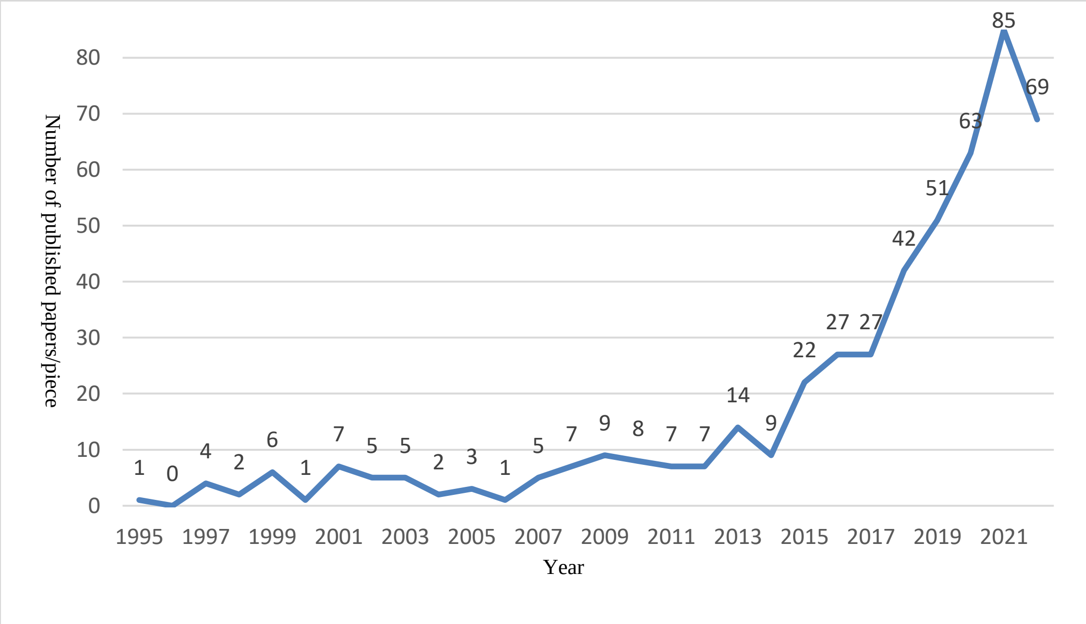

Figure 1 The kernel database's number of published papers in the coordinated development research field of WOS water resources utilization and industrial structure.

3.2 Analysis of Authors' Cooperation

By comparing the frequency and time of authors' published papers, core authors in the field can be identified. The size of the nodes in the figure is directly proportional to the frequency of the authors' published papers, and the connections between the nodes reflect the cooperative relationship between the authors. The thicker the connections, the closer the cooperation.[3] Based on the visualization graph of cooperative networks, it can be seen that there have been multiple stable collaborative teams of scholars in the research field of coordinated development of water resources utilization and industrial structure. Scholars in the research field of WOS collaborate closely, including the following collaborative teams: Zeng Chunfen-Wu Hao-Wei Yanan-Ma Xiaoxue-Wang Lachun-Li Na, Saxena Rani-Tiwari Atul-Joshi Suneel Kumar-Tripathi Shashi Kant, Huang Weichiao-Kan Daxue-Yao WenqingYang-Lyu Lianju, Zhao Yong-Gao Xuerui-An Tingli-Lin Lixing, Guoliang-Liu Kaidi-Yang Duogui, Cai Yanpeng-Zhou Ya, Wang Xiaojun-Zhang Jianyun, Deng Xiangzheng-Wang Zhan et al. (see "Figure 2"). According to the statistical analysis of the number and time of published papers, it can be seen that Deng Xiangzheng-Wang Zhang's research team entered the field early and achieved fruitful research results, making them a leading team in the field. According to the Price law [4], formula $m = 0.749\sqrt{n_{\max}}$ can be used to define the core author group in the field, where, according to calculation, m is the lower limit of the number of published papers by the core authors in the field, and n represents the maximum number of published papers by the scholars in the field. By substituting the data into the calculation, the minimum number of published papers by the core authors in the research field of WOS water resources utilization and industrial structure coordination development should be 2.

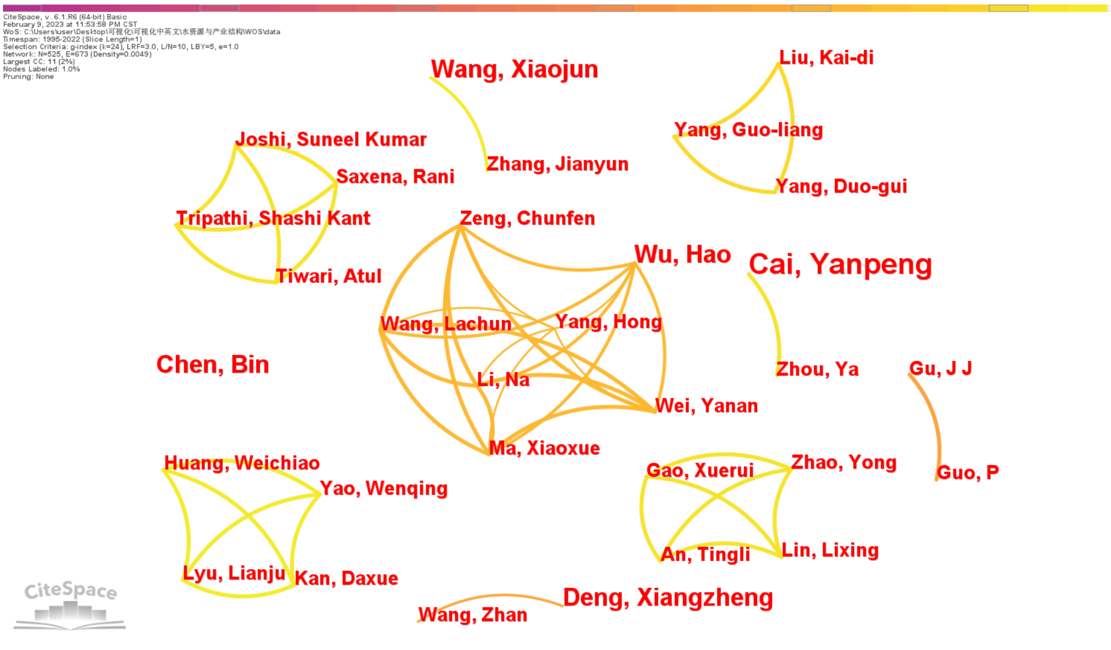

Figure 2 The author cooperation network graph in the research field of WOS water resources utilization and industrial structure coordinated development.

Based on the minimum number of published papers standard for core authors in the research field of WOS water resources utilization and industrial structure coordinated development, a table of the top 10 core author groups of number of published papers in the field can be obtained by sorting out the literature (see "Table 1"). The Price law [4] states that the total number of published papers of the core author groups should reach 50% or more of the total number of published papers in the field. According to calculations, the total number of published papers published by the WOS core author groups is 119, accounting for 24.34% of the total number of published papers in the field, which fails to meet the 50% judgment standard, indicating that a stable core author group has not yet formed in this research field, and that in the future, it is urgent to strengthen communication among scholars to enhance the influence of the field.

Table 1. Core author group

WOS core authors	Number of published papers
Cai, Yanpeng	5
Yang, Zhifeng	4
Wang, Xiaojun	3
Deng, Xiangzheng	3
Chen, Bin	3
Wu, Hao	3
Lyu, Lianju	2
Xie, Yulei	2
Liu, Kai-di	2
Zhao, Yong	2

3.3 Analysis of Cooperation Between Institutions

For the research on the coordinated development of water resources utilization and industrial structure, the top 10 universities and professional research institutes of WOS number of published papers are all located in China, with Beijing as the main area (see "Figure 3"), mainly including Chinese Acad Sci (Chinese Academy of Social Sciences), Beijing Normal Univ (Beijing Normal University), Hohai Univ (Hohai

University), Univ Chinese Acad Sci (University of Chinese Academy of Social Sciences), Tsinghua Univ (Tsinghua University), China Univ Geosci (China University of Geosciences), China Inst Water Resources & Hydropower Res (China Institute of Water Resources and Hydropower Research), Beijing Forestry Univ (Beijing Forestry University), Chinese Res Inst Environm Sci (Chinese Research Academy of Environmental Sciences), and Beijing Inst Technol (Beijing University of Technology). According to "Figure 3", the research institutions on WOS are closely linked, forming a core research team centered on the Chinese Academy of Social Sciences, Beijing Normal University and Hohai University.

Figure 3 The network graph of institutional cooperation in the research field of WOS water resources utilization and industrial structure coordinated development.

Based on the number of published papers as the standard, the top 10 research institutions are selected (see "Table 2"). Analysis shows that the research strength of research institutes and universities in this research field of WOS is evenly divided. Based on "Figure 3", it can be seen that various research institutions in the field of WOS water resources utilization and industrial structure coordinated development have close exchanges, forming a complex cooperative network system.

Table 2. Comparison of the number of published papers by research institutions

Ranking	Research institutions	Number of published papers
1	Chinese Acad Sci (Chinese Academy of Social Sciences)	57
2	Beijing Normal Univ (Beijing Normal University)	35
3	Hohai Univ (Hohai University)	26
4	Univ Chinese Acad Sci (University of Chinese Academy of Social Sciences)	19
5	Tsinghua Univ (Tsinghua University)	14
6	China Univ Geosci (China University of Geosciences)	11
7	China Inst Water Resources & Hydropower Res (China Institute of Water Resources and Hydropower Research)	9
8	Beijing Forestry Univ (Beijing Forestry University)	8
9	Chinese Res Inst Environm Sci (Chinese Research Academy of Environmental Sciences)	8
10	Beijing Inst Technol (Beijing University of Technology)	7

4. ANALYSIS OF RESEARCH HOTSPOTS

Based on an overview and analysis of the basic features of the field literature, CiteSpace software is used to explore the hot spots in the field in depth.

4.1 Keyword Co-occurrence Network

Analyzing the co-occurrence network graph of keywords is beneficial for identifying hot topics in the research field while exploring potential connections between major keywords. The thickness and font size of node rings are directly proportional to the frequency of the keyword's occurrence, the thickness of the connection is directly proportional to the frequency of keywords co-occurring in the same literature, and the color of the connection corresponds to the year range above the graph.[5] The color of a node ring is related to whether it is a burst keyword. If the node is centered around a red ring, it indicates that the keyword is a burst keyword. This study then uses CiteSpace to draw a WOS keyword co-occurrence network graph, as shown in "Figure 4". A total of 513 nodes and 2,236 connections are generated, with a network density of 0.017. It can be seen from "Figure 4" that the hot keywords on WOS in the field research from 1995 to 2022 are "model, water resource, climate change, industrial structure, water footprint, sustainable development, data envelopment analysis and input output analysis".

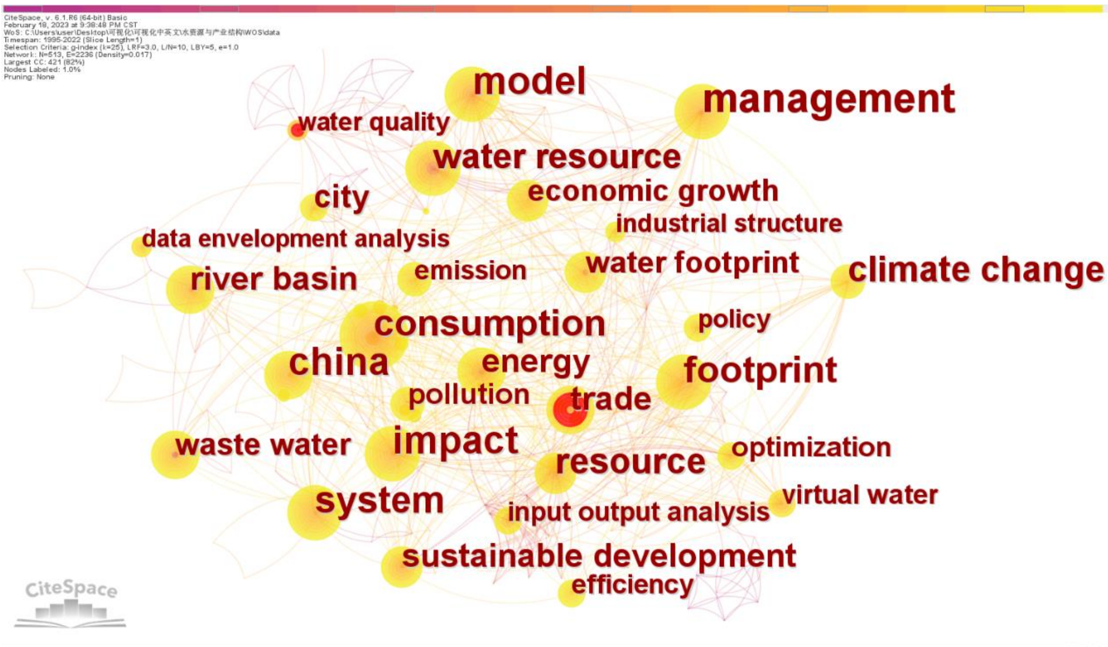

Figure 4 The keyword co-occurrence graph in the research field of WOS water resources utilization and industrial structure coordinated development.

It then organizes high-frequency keywords based on the keyword co-occurrence graph and selects the top 20 keywords on WOS with frequency rankings, as shown in "Table 3". The major keywords on WOS include model, system, footprint, consumption, climate change, water resource, sustainable development, trade, river basin, energy, city, sustainability, etc.

Table 3. Ranking of major keywords

Ranking	Major keywords on WOS	Frequency
1	management	49
2	impact	48
3	model	46
4	system	41
5	china	40
6	footprint	37
7	consumption	34
8	resource	31
9	climate change	30
10	water resource	29
11	water	25
12	sustainable development	24
13	trade	24
14	performance	22
15	river basin	22
16	energy	22
17	city	20
18	basin	19
19	growth	19
20	sustainability	18

It can be seen from the analysis that in the research field of coordinated development of WOS water resources utilization and industrial structure, the construction of indicator system for coordinated development of water resources and industrial structure and the selection of evaluation methods, sustainable development research, water footprint and virtual water research have attracted much attention.

4.1.1 Research on the Construction of Indicator System and Selection of Evaluation Methods

Scholars in this field often construct indicator systems from the perspective of input and output, for example, Chrysoula et al. [6] constructed an input-output indicator system from the perspectives of ecosystem function, water services, and agriculture, expanding the application of industrial ecology and functional model technology in watershed comprehensive management and water accounting; Hong Siyang et al. [7] constructed a comprehensive evaluation indicator system for each industry from the perspective of industrial structure, analyzed the water use characteristics of each industry, and provided suggestions for optimizing water resources allocation and management; Bo Yangsun et al. [8] introduced the principal component analysis method to accurately calculate the comprehensive water use efficiency of Jilin Province, reducing the 16 water resources input indicators and 14 water resources output indicators to 3 input principal components and 2 output principal components, respectively, and the multi-model data envelopment method was used to analyze the calculation results; Li Yuanjie et al. [9] constructed an input-output indicator system for the Beijing-Tianjin-Hebei intercity and used a multi-objective optimization model to study the sustainable development of water resources in multiple cities. The study showed that industrial structure optimization is of great significance for economic growth and water conservation, and that the optimization of agricultural water use in Hebei region plays a key role in improving the overall water efficiency of the Beijing-Tianjin-Hebei region.

4.1.2 Research on Sustainable Development

Different scholars explore sustainable development issues in the coordinated development of water resources utilization and industrial structure from different perspectives. For instance, Lu Shibao et al. [10] used the ecological network analysis method to analyze the agricultural, industrial, and domestic water use conditions in the northern basin of China based on the classification perspective of industrial structure. Based on this, they delved into how to ensure regional ecological water use; Kan Daxue et al. [11] used principal component analysis to calculate the level of water ecological civilization in various cities in Jiangxi Province based on the spatiotemporal dimension and deeply explored the influencing factors. The results showed that water resources endowment, advanced industrial structure, education investment, and government governance level significantly affect the level of water ecological civilization; Elshorbagy et al. [12] studied from the perspective of climate change about how the integrated system of water resources, energy, and cereal can reduce greenhouse gas emissions in a rapidly expanding economy.

4.1.3 Research on Water Footprint and Virtual Water

Most scholars provide suggestions for local economic development and industrial upgrading by measuring regional water footprint and virtual water. For example, Ge Liqiang et al. [13] concluded that China's water resources are unevenly distributed by measuring China's regional water footprint in 2007. It is urgent to adjust the industrial structure nationwide and reduce the virtual water content of unit product to improve water use efficiency; Dong Huijuan et al. [14] used the input-output analysis method to calculate the water footprint of Liaoning Province in China from the perspective of production and consumption, and found that the water footprint, water intensity, water exports and water trade balance of "agriculture" and "food and beverage production sectors" in Liaoning Province were the highest, so they put forward appropriate suggestions for regional industrial development and trade structure adjustment; Wang Ziyuan et al. [15] calculated the water footprint of Beijing in 2002 and 2007 based on the inter sectoral water flow and input-output model, and concluded that water shortage was the main problem in Beijing. After evaluating virtual water trade, it was concluded that Beijing was a virtual water net import area. Based on this, they proposed that the priority of Beijing's water-saving strategy is the adjustment of industrial structure and the import of virtual water; Wang Yun et al. [16] used spatial autocorrelation and spatial Durbin model to explore the temporal and spatial differences and influencing factors of agricultural water footprint in major grain producing areas. The results show that due to the spatial dependence and path locking characteristics of agricultural water footprint, socio-economic development, national policy adjustment, water-saving technology upgrading, and industrial structure adjustment are significantly negatively related to agricultural water footprint. In the future, it is necessary to optimize regional industrial structure, promote efficient water conservancy infrastructure technology, and strengthen water resources management.

4.2 Keyword Clustering Analysis

Based on the keyword co-occurrence network graph, this study then uses CiteSpace to perform clustering analysis on literature data, and WOS keyword clustering graph is obtained (see "Figure 5"). The clustering module value and the clustering average contour value can be used to judge the clustering effect. A clustering module value greater than 0.3 indicates that the clustering structure is significant and the boundaries are clear. An average contour value greater than 0.5 indicates that the clustering result is reasonable and a value greater than 0.7 indicates that the clustering result is convincing.[17] From "Figure 5", it can be seen that the clustering module value of the WOS keyword clustering graph is 0.7916, and the average contour value is 0.6246, indicating that the clustering structure is significant and the results are reasonable. The smaller the clustering number label, the more keywords the clustering contains. According to "Figure 5", the research hot keywords in the field of coordinated development of WOS water resources utilization and industrial structure can be divided into 8 clusters, mainly including: "#0 adsorption", "#1 water footprint", "#2 economic growth", "#3 catchment management", "#4 water use efficiency", "#5 multi-objective programming", "#6 system dynamics", and "#7 input-output analysis".

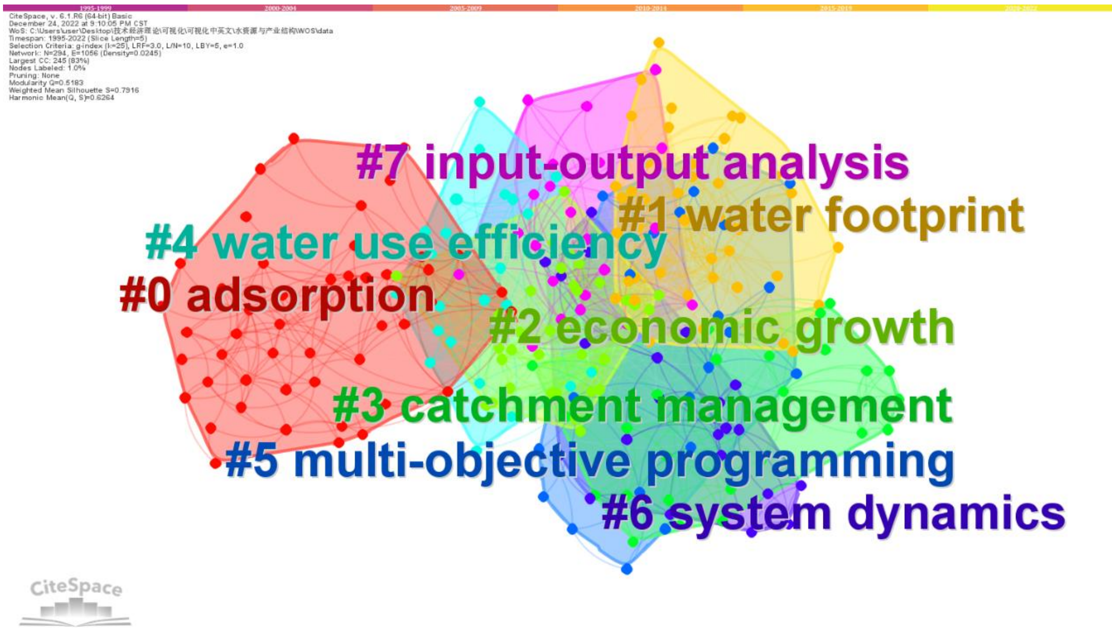

Figure 5 The keyword clustering graph in the research field of WOS water resources utilization and industrial structure coordinated development.

Based on the high-frequency keyword table and the clustering graph, it can be concluded that the hot research issues in the field of coordinated development of international water resources utilization and industrial structure are focused on the correlation between water resources utilization efficiency and industrial structure, comprehensive evaluation of coordination relationship, economic benefits, scientific and technological benefits, and ecological benefits and so on.

5. ANALYSIS OF THE EVOLUTION PATH OF RESEARCH

Based on the keyword co-occurrence graph and keyword clustering analysis, the temporal evolution trend of hot keywords in the field of international water resources utilization and industrial structure coordinated development can be deeply explored. By using CiteSpace visualization software, a timeline graph of keywords in the research field of WOS water resources utilization and industrial structure coordinated development is obtained (see "Figure 6").

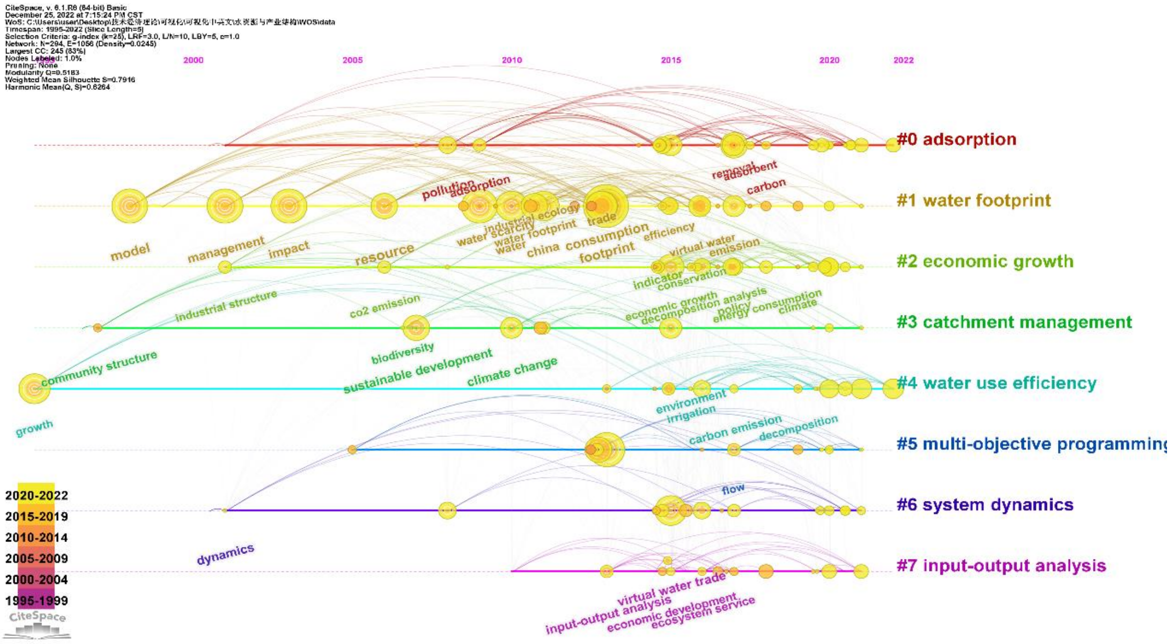

Figure 6 The keywords timeline in the research field of WOS water resources utilization and industrial structure coordinated development.

Based on the retrieved literature and analysis of "Figure 6", it can be seen that the research hotspots in the field of WOS water resources utilization and industrial structure coordinated development can be divided into the following 3 stages:

- The embryonic stage (1995-2005): The hot keywords in this stage included "model", "management", "industrial structure", "dynamics", etc. Dunglas [18] proposed that the rapid development of industrial economy has brought about a series of problems such as water resources shortage and water pollution. How to use technological development to improve water efficiency and optimize industrial structure has become a hot topic that urgently needs to be explored; Russo et al. [19] used the life cycle assessment method to evaluate the water use efficiency of greenhouse crops in order to study the environmental sustainability of greenhouse agricultural production; Liu Changming et al. [20] studied reasonable groundwater exploitation measures based on the observation data of water demand and groundwater level based on the overdevelopment of water resources in the North China Plain. The results show that accelerating industrial upgrading to reduce industrial wastewater discharge is one of the effective remedial measures.
- The growth stage (2006-2014): The hot keywords in this stage included "resource", "CO2 emission", "sustainable development", "pollution", "climate change", "industrial ecology", "water scarcity", "water footprint", etc. The field research in this stage focused on the coordinated sustainable development of water resources and industrial structure, as well as the theory of water footprint. Ge Liqiang et al. [13] estimated the per capita water footprint of China's provinces in 2007, and proposed that the government should speed up the pace of industrial restructuring nationwide in view of the obvious spatial differences in water resources utilization efficiency; Han Mengyao et al. [21] conducted input-output analysis on a system that combined economic data and natural resource data, while also analyzing in detail the intensity of virtual water use in Beijing. The study showed that in addition to improving technological and water efficiency, adjusting industrial structure and trade policies is also of great significance for water conservation; Zhu Hongli et al. [22] used the decoupling elasticity model to study the decoupling relation between water resources utilization and economic development in Yunnan and Guizhou provinces, and delved into the factors that affect the strength of decoupling relation. The results showed that the level of

economic development, water use efficiency, and water use structure were the main factors affecting the coupling and coordination of water resources utilization and economic development in Yunnan and Guizhou provinces; Pratibha Sapkota et al. [23] considered the impact of watershed climate changes, incorporated ecological water demand into the water resources allocation system, and applied a new watershed planning model to allocate watershed water resources. In addition, effective water management schemes were proposed for the predicted shortage of water resources to achieve the goal of sustainable development.

- The development stage (2015-2022): The hot keywords in this stage included "efficiency", "indicator", "virtual water", "economic growth", "decomposition analysis", "energy consumption", "input-output analysis", "ecosystem service", etc. From this, it can be seen that the research in this stage focused on the analysis method of the coupling system between water resources utilization and industrial structure. Chen Weiming et al. [24] used the input-output model to quantitatively estimate the water footprint and virtual water of various provinces in China, and concluded that there is a big difference between China's water footprint and virtual water among provinces. After in-depth exploration of the specific reasons, they proposed to accelerate industrial upgrading to alleviate the problem of water shortage; Zhong Shaozhuo et al. [25] built an emergy indicator framework to assess the sustainability of the Erhai basin, and research showed that adjusting the industrial structure, developing circular economy and green agriculture can help the sustainable development of the Erhai basin; Bao Chao et al. [26] used a complete decomposition model to quantitatively study the driving effects of urbanization on economic growth and water resources utilization in 31 provinces and regions of China from 1997 to 2011. The results showed that urbanization alleviated urban water pressure by optimizing industrial structure and improving water efficiency; Shi Qingling et al. [27] used input-output analysis to quantify the impact of industrial transformation on water efficiency, and empirical research found that industrial transformation in the northwest region has improved local water efficiency.

6. CONCLUSION

Through CiteSpace6.1R6 software, this paper conducts scientific visualization research on 489 pieces of English literature included in the WOS kernel database from 1995 to 2022. Combining with the retrieval literature system, it also combs out the bibliometric characteristics and the evolution of hotspots in this academic field, and reaches the following conclusions. First, from the perspective of number of published papers, the research field of WOS water resources utilization and industrial structure coordinated development received less academic attention before 2016. After 2016, research in this field gradually became a research hotspot in the academic community and began to mature. Second, from the perspective of authors and institutions, there is close cooperation between the field authors and institutions, forming a relatively stable core cooperation team. Third, by analyzing the keyword co-occurrence graph and clustering graph, it can be seen that the construction of indicator system for coordinated development of water resources and industrial structure and the selection of evaluation methods, sustainable development research, water footprint and virtual water research and other hot issues have attracted the attention of scholars in the field. Fourth, from the perspective of the evolution path of research hotspots, keywords such as "energy consumption", "carbon emissions", and "ecosystem service" are at the forefront of research in this field. Scholars in the field can deepen and expand related research based on these hot keywords in the future. Systematically sorting out the key hotspots and evolution trends in the coordinated development of international water resources and industrial structure can provide policy recommendations while promoting the deepening of research in this academic field.

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