Research Review of Basin Water Resource Allocation Methods Based on CiteSpace

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ABSTRACT

Based on 200 research literature on water resource allocation in river basins collected from the core collection of Web of Science from 1990 to 2022, CiteSpace software was used to visually analyze the published research institutions, teams, and keywords, and to summarize the methods of water resource allocation in river basins. The research results of water resource allocation in river basins indicate that from 1990 to 2005, the focus was on integrating and reflecting multidimensional goals such as social equity, economic benefits, and ecological protection. Water resource system simulation technology was applied for multi-objective coupling configuration. From 2005 to 2010, the research on multi-objective coupling configuration was deepened, focusing on promoting the coordinated development of water resources and economy, society and ecology, and "water allocation as the main focus" was shifted to "water quality coupling configuration" and interactive configuration of water resources stakeholders. From 2010 to 2015, research on the interaction and allocation of water resource stakeholders was deepened, focusing on strengthening the regulation of total water use, accelerating the optimization and upgrading of industrial structure through water rights trading, optimizing the allocation of industrial structure, optimizing industrial water use structure, and improving water efficiency. From 2015 to 2022, the research on optimizing the allocation of industrial structure was deepened, focusing on addressing the challenges of climate change, actively exploring methods for adaptive allocation of water resources, and enhancing the adaptive allocation capacity of water resources in river basins. In the future, it is urgent to implement the concept of "spatial balance", strengthen the rigid constraints of water resources, and promote the coordinated development of water resources and economic and social spatial balance in the basin.

Keywords: *Water resource allocation, Multi-objective coupling, Stakeholder, Industrial structure, Adaptability.*

1. INTRODUCTION

The study of basin water resource allocation began in 1953 with the operation and scheduling of reservoirs in the Missouri River Basin in the United States. Improving the system for rational allocation and efficient utilization of water resources, as well as the system for protecting water resources and ensuring the health of rivers and lakes, is conducive to promoting the ecological protection and high-quality development of river basins. The allocation of water resources in a watershed is an important regulatory means to ensure economic security, livelihood security, and ecological security in the watershed. The focus is on coordinating the relationship between water resources, economic and social factors, and ecological environment, promoting the sustainable use of water resources in the watershed and high-quality economic development. Mastering the research progress of basin water resource allocation methods is conducive to deepening the research on basin water resource allocation. To this end, based on CiteSpace visualization software and through data mining, a graph is drawn of key information such as research institutions and teams, keywords, etc. in English literature, visualizing the research on basin water resource allocation from 1990 to 2022, summarizing the research on basin water resource allocation methods, and providing reference for further theoretical research and practical exploration of basin water resource allocation.

2. RESEARCH METHODS AND DATA SOURCES

CiteSpace is one of the mainstream research tools for drawing knowledge graphs, which can present the evolution process of a knowledge field and the relationships between literature in the form of a scientific knowledge graph. It mainly generates knowledge graphs such as co-occurrence networks, keywords, and keyword timelines from five dimensions: annual publication volume of literature, main authors, main publication institutions, and keyword and keyword clustering. Based on CiteSpace software and bibliometric methods, a visual analysis was conducted on the 1990 to 2022 literature retrieved from the Web of Science (WOS) Core Collection. By using keyword co-occurrence graphs and keyword timeline graphs, the research ideas and stage evolution of watershed water resource allocation are clarified, and the methods of watershed water resource allocation are summarized.

To ensure the representativeness, reliability, and consistency of the data source literature, on the one hand, the search topics of WOS are "water resources allocation", "water resources configuration", and "basin". SCI, SSCI, and A&HCI journals are selected for indexing, and all abstracts are checked and irrelevant literature is removed, resulting in a total of 200 articles.

3. VISUALIZATION ANALYSIS OF BASIN WATER RESOURCE ALLOCATION RESEARCH

In 1992, the International Conference on Water and Environment was held in Dublin, proposing the principle of participation in water resource planning and implementation. Before 2000, research on water resource allocation in river basins did not receive widespread attention from the international community, and the annual publication volume of WOS and CNKI was relatively small. Since 2000, the annual publication volume of CNKI in this field has shown a rapid growth trend, but the annual publication volume of WOS is still relatively small, and the annual publication volume of CNKI is significantly higher than that of WOS (see "Figure 1").

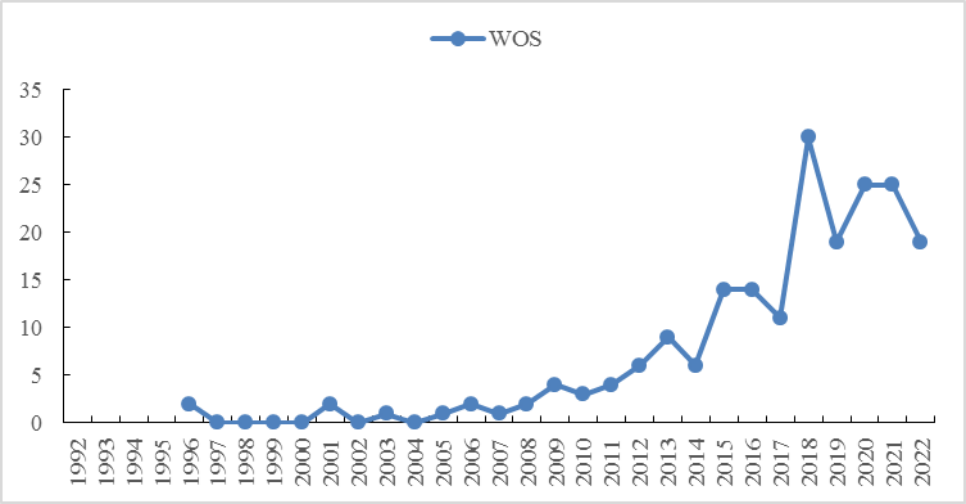

Figure 1 Annual publication volume of research on water resource allocation in river basins from 1990 to 2022.

According to "Figure 1", overall, from 1990 to 2022, the annual publication volume of WOS showed a gradually increasing trend, and research in this field has received continuous attention from scholars as a relatively hot topic. From 2012 to 2022, the annual publication volume of WOS research in this field increased significantly and showed a continuous upward trend. The annual publication volume can be mainly divided into four stages: the initial period (1990-2005), with relatively low publication volume; During the growth period (2005-2010), the number of publications increased rapidly; During the development period (2010-2015), the number of publications increased but gradually decreased; Maturity period (2016-2022), publication volume was relatively stable. In the future, research on basin water resource allocation will still become a global research hotspot.

3.1 Research Institutions and Teams

For the research on the basin water resource allocation, WOS core research institutions are mainly concentrated in China, including China Institute of Water Resources and Hydropower Research, Hohai University, Chinese Academy of Sciences, Wuhan University, Beijing Normal University, China Agricultural University and North China Electric Power University. At the same time, it involves a small number of foreign core research institutions, such as the University of Regina in Canada, Texas A&M University in the United States, University of Tehran in Iran, and Shahid Beheshti University in Iran (see "Figure 2").

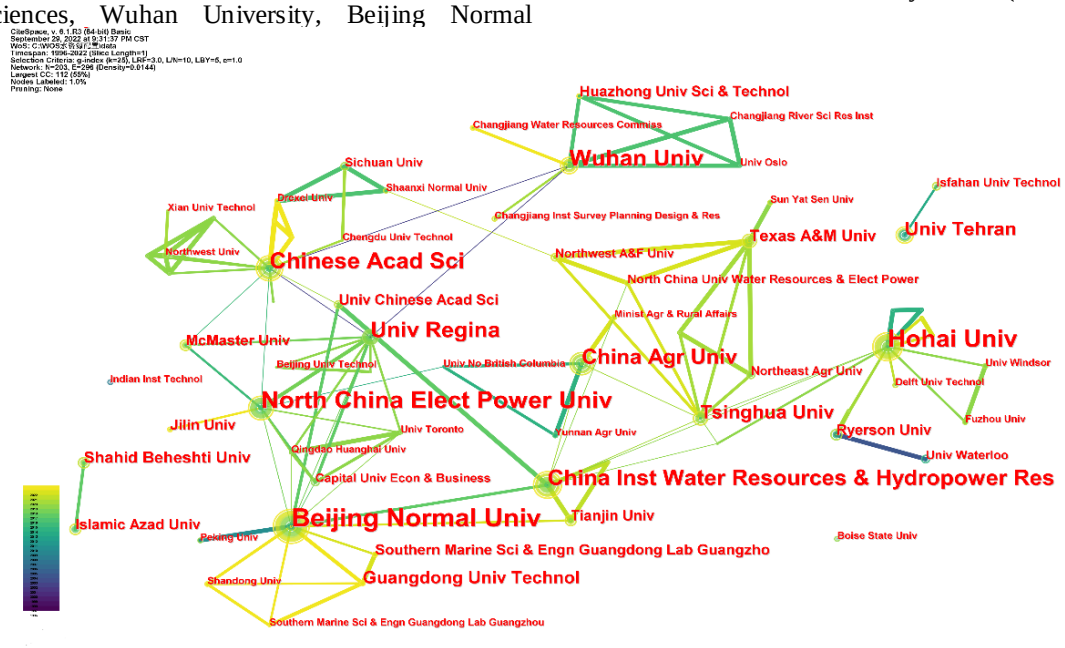

Figure 2 The co-occurrence graph of research institutions in the research of basin water resource allocation from 1990 to 2022.

Based on Cite space's pathfinding algorithm for optimizing collaborative networks [1], the core research team of WOS includes the HAW YEN and PRASAD DAGGUPATI teams at Texas A&M University, KERCHINA R and POORSEPAHY-SAMIAN teams at University of Tehran, H teams, HOUSIAN M and JARAL ATTARI teams at Shahid Beheshti University, Guo Shenglian teams at Wuhan University, Huang Guohe and Li Yongping teams at Beijing Normal University, Guo Ping's team from China Agricultural University and others (see "Figure 3"). According to "Figure 3", it can be seen that a relatively stable core research team has been formed in this field of research, forming a research group with intensive internal cooperation.

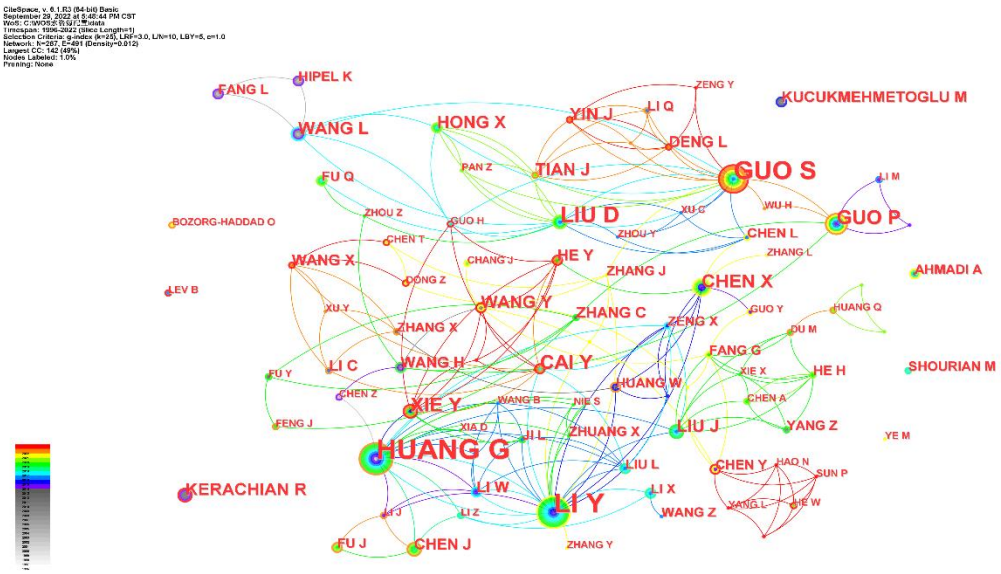

Figure 3 Team co-occurrence network graph of basin water resource allocation research from 1990 to 2022.

3.2 Keywords

According to the co-occurrence graph of WOS search results, the hot keywords in WOS include water resource allocation, management, model, optimization, climate change, system, river basin, uncertainty, simulation, and impact (see "Figure 4").

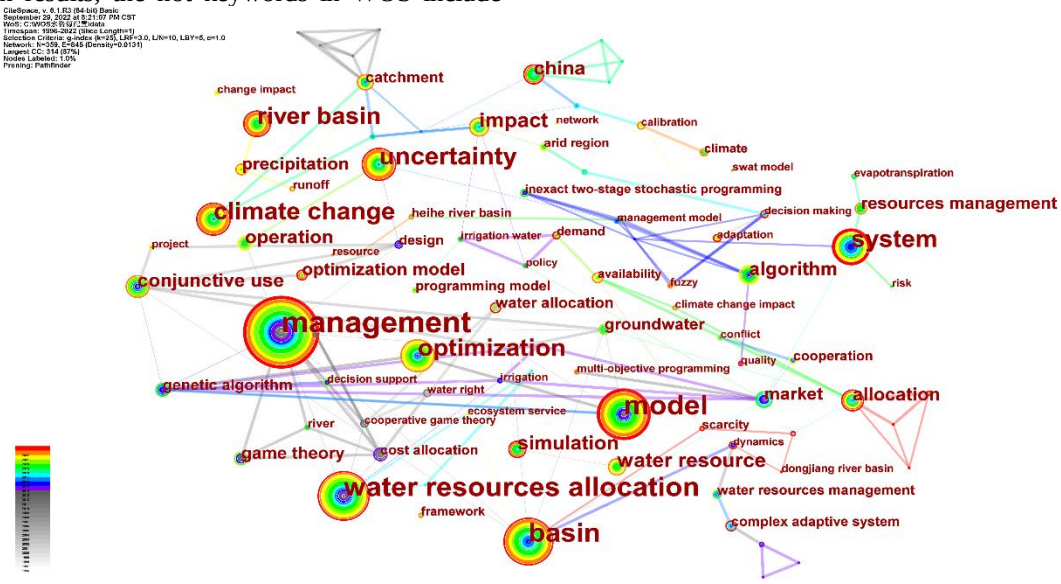

Figure 4 Keyword co-occurrence graph of basin water resource allocation research from 1990 to 2022.

According to the keyword timeline graph of WOS search results, the research focus of basin water resource allocation methods is on water resource allocation ideas and models, guiding water resource allocation practices. The concept of water resource allocation clarifies the goals and principles of water resource allocation, fully reflecting the interaction of interests among water resource stakeholders. The water resource allocation model is constructed based on the concept of water resource allocation [2] (see "Figure 5").

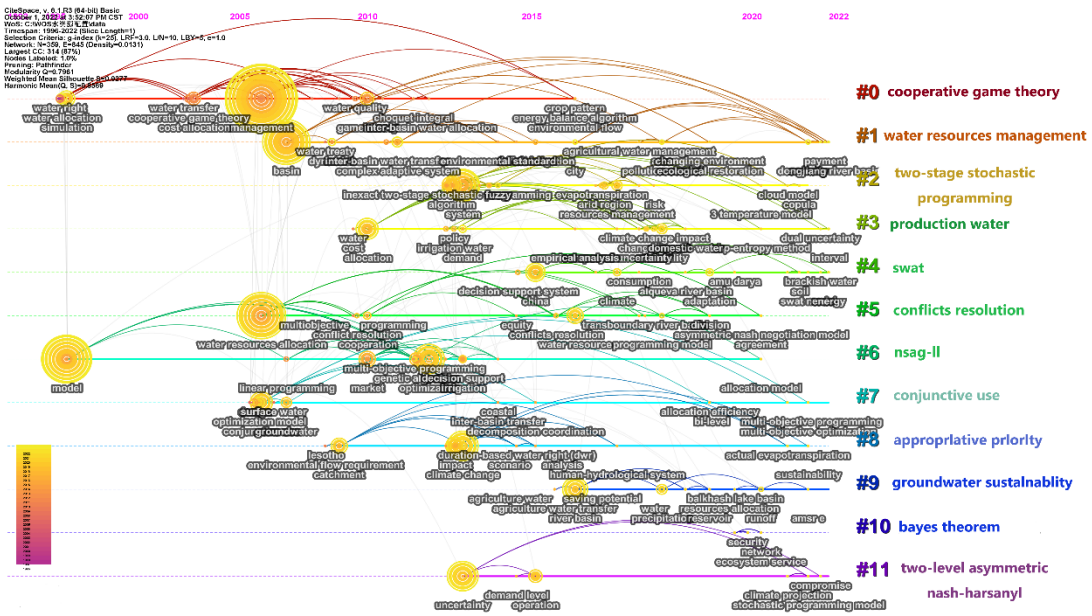

Figure 5 Keyword timeline graph of basin water resource allocation research from 1990 to 2022.

According to the annual publication volume in "Figure 1" and the keyword timeline graph in "Figure 5", the evolution of the research on basin water resource allocation can be expressed as follows: from 1990 to 2005, with a focus on integrating and reflecting multidimensional goals such as social equity, economic benefits, and ecological protection, and applying water resource system simulation technology for multi-objective coupling configuration. From 2005 to 2010, the research on multi-objective coupling configuration was deepened, focusing on promoting the coordinated development of water resources and economy, society and ecology, and "water allocation as the main focus" was shifted to "water quality coupling configuration" and interactive configuration of water resources stakeholders. From 2010 to 2015, research on the interaction and allocation of water resource stakeholders was deepened, focusing on strengthening the regulation of total water use, accelerating the optimization and upgrading of industrial structure through water rights trading, optimizing the allocation of industrial structure, optimizing industrial water use structure, and improving water efficiency. From 2015 to 2022, the research on optimizing the allocation of industrial structure was deepened, focusing on addressing the challenges of climate change, actively exploring methods for adaptive allocation of water resources, and enhancing the adaptive allocation capacity of water resources in river basins. Therefore, the methods of basin water resource allocation can be classified into four categories: multi-objective coupling system allocation methods for water resources, interactive allocation methods for water resource stakeholders, optimization allocation methods for industrial structure of water resource regulation, and adaptive allocation methods for water resources to address climate change challenges.

4. SUMMARY OF RESEARCH ON METHODS FOR BASIN WATER RESOURCE ALLOCATION

After a systematic combability of basin water resource allocation research and an in-depth exploration of the research priorities at each stage of the field, the basin water resource allocation methods can be summarized to four categories. The overview of basin water allocation methods will clarify the research thinking in the field and open up prospects for innovative research methods.

4.1 Configuration Method for Multi-objective Coupling System of Water Resources

The methods of basin water resource allocation originated from the operation and scheduling of basin reservoirs. The Missouri River Basin in the United States earlier applied water resource system simulation technology to carry out reservoir operation and scheduling [3]. Scholar Aristidis et al. [4] proposed using mathematical models to determine real-time scheduling rules for reservoir

systems. According to the keyword graph in "Figure 4" and "Figure 5", with the development and application of computer technology and system analysis theory, in order to comprehensively reflect social equity, economic benefits, and ecological protection goals, the international community has proposed coupling water resource system simulation technology with multi-objective optimization models, constructing a multi-objective coupling system configuration method for water resources, and conducting research on basin water resource allocation [7]. Haimes [5] used multi-level management technology to construct a joint operation configuration model for underground reservoirs; Condon et al. [6] coupled the water resource model with hydrological and economic model and built a water resource economy hydrology allocation model for the Maipo Basin in Chile; Campenhout et al. [8] established an optimal allocation model of water resources with Gini coefficient and conditional Value at risk to strengthen risk control and reflect social equity; Dadmand et al. [9] established a robust fuzzy stochastic programming model for optimizing the allocation of water resources in Mashhad City, northeastern Iran under water scarcity conditions, achieving the goals of minimizing water scarcity losses and maximizing profits for different consumer sectors.

4.2 Interactive Configuration Methods for Water Resource Stakeholders

According to the keyword graph in "Figure 4" and "Figure 5", with the deepening of research on basin water resource allocation, foreign countries have shifted from "water allocation as the main focus" to "water quantity and quality coupling configuration". Unlike the goal of maximizing economic benefits, the allocation method of basin water resource allocation more emphasis on the coordinated development of water resources and economic, social, and ecological aspects, taking into account the recycling and utilization of surface water, groundwater, and sewage, as well as the water quality requirements of different departments. Based on the concept of coordinated development between water resources and the economy, society, and ecology, the international community has constructed a basin water resource allocation method for the interaction of water resource stakeholders, reflecting the interests and demands of water resource stakeholders, fully reflecting social equity, and promoting the coordinated development of the basin's ecological environment and economy. For example, XEVI [10] constructed a configuration model that couples groundwater simulation with economic and social multi-objective optimization, coordinating the comprehensive goals of water supply, groundwater quality, and ecological economy in different time and space; WANG et al. [11] constructed a collaborative water resource allocation model for wasteland basins, achieving efficient water resource utilization and coordinated economic and ecological development; ZHANG et al. [12] constructed a model for coupling water quantity and quality in a watershed and coordinating economic and ecological allocation, ensuring the water cycle process and pollutant migration in the watershed; Xie et al. [13] established an interval two-stage planning model for stakeholder interaction to address changes in the water resource system; Read et al. [14] constructed an economic power index allocation model to simulate the negotiation process among water resource stakeholders and improve the stability and feasibility of water resource allocation plans; Liu et al. [15] established a fuzzy alliance game model for cross-border multi-agent cooperation in the Lancang Mekong River, reflecting the seasonal water demand characteristics and net utility differences among countries; FENG et al. [16] constructed a coupled allocation model of water resources, economy, society, and environment under uncertain conditions, achieving multi-objective dynamic equilibrium.

4.3 Industrial Structure Optimization and Allocation Methods for Water Resource Regulation

According to the keyword graph in "Figure 4" and "Figure 5", with the deepening of research on basin water resource allocation methods in academia, foreign countries have placed more emphasis on emphasizing the crucial role of market mechanisms in water resource allocation, stimulating water users to increase water resource value and achieve water resource redistribution, motivating enterprises to control sewage discharge, improve water quality, and protect the ecological environment [17]. However, due to the natural attributes of water resources, user demand characteristics and other factors, it is easy to cause "market failure" and "system failure" of water management [18]. To this end, relying on the integration of government and market water resource allocation ideas, the international community proposes to strengthen the regulation of

total water use, construct industrial structure optimization allocation methods, promote the bidirectional optimization and adaptation of water resources and industrial structure in river basins, promote industrial structure transformation and optimization upgrading, improve water resource allocation efficiency and protect the water environment while comprehensively reflecting multidimensional goals and stakeholder participation. Taskhiri et al. [19] established a simulation model for optimizing water use structure and industrial structure; Zhang et al. [20] constructed a multi-objective ITSP model for optimizing the allocation of water resources and industrial structure, achieving bidirectional optimization of regional industrial structure and water resource allocation structure.

4.4 Adaptive Allocation Methods for Water Resources

With the impact of climate change on the water resource system, the research on basin water resource allocation methods has been further deepened. According to the keyword graph in "Figure 4" and "Figure 5", it can be seen that the international community emphasizes actively conducting research on adaptive allocation methods for watershed water resources to address climate change and ecological environmental challenges while coordinating multidimensional goals, stakeholder interactions, and promoting industrial structure optimization and upgrading. On the one hand, scholars focus on the impact of factors such as climate change, uncertainty, and variability on the basin water resource allocation. In 2001, the International Committee on Rhine River Culture evaluated the impact of climate change on the runoff conditions of river basins [21]; Irmak et al. [22] proposed irrigation optimization strategies in climate changing environments by simulating the impact of environmental conditions on irrigation water demand patterns; Molina et al. [23] proposed to continuously adjust the direction of water resource management actions, enhance the water resource allocation capacity of the basin, and adapt to rapid changes in socio-economic conditions and the environment. On the other hand, in the face of a large number of uncertain factors, scholars have proposed the construction of a technical framework and model for adaptive allocation of water resources in river basins, effectively addressing the impact of climate change on water resources and improving the adaptability of water resource utilization to economic and social development. Using the SWAT model developed by Beleke E G [24], the impact of potential climate change on water resource allocation in the watershed was evaluated; Williams et al. [25] constructed an adaptive configuration model with adaptive mechanisms embedded in climate change and uncertain environments; Golfam et al. [26] constructed the AHP and TOPSIS methods to determine the optimal scenario for agricultural water resource allocation to adapt to climate change in the Garanghu Basin of northwestern Iran over a period of 30 years (2040-2069).

5. RESEARCH PROSPECTS

From the existing achievements, it can be seen that the basin water resource allocation has shifted from multi-objective coupling system allocation of water resources, stakeholder interaction of water resources, optimization of industrial structure, to adaptive allocation of water resources in response to climate change. At the same time, the basin water resource allocation model is continuously optimized. At present, the research on basin water resource allocation still needs to be deepened. On the one hand, the existing ideas on basin water resource allocation have not fully implemented the concept of "spatial balance" to guide the practice of water allocation in river basins. On the other hand, existing basin water resource allocation models pay more attention to technical design, which is too complex and does not fully reflect the spatial balance of basin water resource allocation. Therefore, there is an urgent need to form a comprehensive spatial balance oriented approach to basin water resource allocation, construct effective and practical spatial balance discrimination criteria and allocation models, and improve the spatial balance of basin water resource allocation. To this end, the concept of spatial balanced allocation of basin water resources and the construction of models are proposed.

5.1 The Concept of Spatial Balanced Allocation of Basin Water Resources

It is necessary to improve the existing ideas of basin water resource allocation, incorporate the water demand of each administrative region, industry, irrigation area, ecology and water users in the river basin into the same framework system, build a conceptual discriminative model for spatial balanced allocation of basin water resources, and effectively determine the "spatial balanced hierarchy system" of basin water resource

allocation (spatial balance at the basin level, spatial balance at the regional level within the river basin, spatial balance at the industrial level within the region), and determine the criteria for determining the "spatial equilibrium hierarchical system" of basin water resource allocation.

5.2 The Construction Idea of a Spatial Equilibrium Allocation Model for Basin Water Resources

Based on the concept of spatial balanced allocation of basin water resources, a model construction approach for designing, diagnosing, and optimizing spatial balanced allocation schemes of basin water resources is proposed.

5.2.1 Design of Spatial Balance Configuration Scheme

According to the configuration principle of the "spatial balance hierarchy system", fully reflecting the interests and demands of the "spatial balance hierarchy system", there is a necessity to establish a "spatial balance hierarchy system" allocation unit benefit interaction configuration model, design a basin water resource spatial balance configuration plan, and improve the water resource allocation efficiency of the "spatial balance hierarchy system" allocation unit.

5.2.2 Diagnosis and Optimization of Spatial Balance

Based on the designed spatial balance allocation plan for basin water resources, construct a complete set of "spatial balance hierarchy system" criteria to verify the feasibility of the plan. The plan should include the criterion of "spatial balance at the basin level" to diagnose the equilibrium and coordination of the coupling system of water resources, economy, society, and ecological environment in the basin, the criterion of "spatial balance at the regional level within a watershed" to diagnose the spatial balance of water resource allocation between regions within the watershed, the criterion of "spatial balance of industrial layers within a region" to diagnose the spatial balance between water resources and industrial structure layout within the region. Based on the diagnostic results of the plan, a "spatial equilibrium hierarchical system" water resource adaptability adjustment mechanism is established to adjust and optimize the water resource allocation of the allocation units of the "spatial equilibrium hierarchical system", in order to improve the spatial balance of basin water resource allocation through the "spatial equilibrium hierarchical system" discrimination criteria.

6. CONCLUSION

Based on 200 research literature on water resource allocation in river basins collected from the core collection of Web of Science from 1990 to 2022, CiteSpace software was used to process the literature data and map the research institutions, teams, and keywords to visualize the evolution of the field and the current status of the research, resulting in the following conclusions: (1) Research institutions and teams are closely linked and have now formed a stable core group, with most of the core research institutions concentrated in China and the core research teams evenly distributed domestic and international. (2) The evolution of the research on basin water resource allocation is clearly characterized, summarizing to four categories of basin water resource allocation methods: multi-objective coupling system allocation methods for water resources, interactive allocation methods for water resource stakeholders, optimization allocation methods for industrial structure of water resource regulation, and adaptive allocation methods for water resources to address climate change challenges. (3) The hotspot of basin water resources research allocation research has shifted to adaptive allocation of water resources in response to climate change. In order to meet the needs of continuous optimisation of basin water resources allocation models and deepening of water resources allocation research, the concept of spatial balanced allocation of basin water resources is proposed and relevant models are constructed, and future research in the field needs to implement the concept of "spatial balance", strengthen the rigid constraints on water resources, and promote the coordinated development of water resources and economic and social spatial balance in the basin.

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