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Review

Review of River Basin Water Resource Management in China

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Abstract: Water resources are the basis for supporting the entire life system of the Earth. However, with the frequent global water crises—especially in the river basins of China—the issue of water resources has become a bottleneck that limits its development. Therefore, it is necessary to carry out relevant research. In this paper, we systematically analyzed different classification methods of the service functions of water ecosystems as well as factors that affect it. Results showed that climate, land cover, human activities, and their own endowment conditions were the main factors affecting the service functions of water ecosystems. Based on these, water resource management in China river basins was expounded from three aspects: water resources protection, allocation, and utilization. At the same time, the impacts of water resource management on land use in China were also summarized. Finally, the key trends of the next study were summarized as follows: improvement of the classification system of basin water ecosystem service functions, improvement of the mechanism of the basin water market; comprehensive tradeoff of water resource exploitation and protection in basins; and basin water resource management from the perspective of multidisciplinary crossing.

Keywords: water resource management; water ecosystem service functions; water crisis; China; basin

1. Introduction

Water is a fundamental natural resource and a strategic economic resource, and is an indispensable material foundation for human survival and social development [1]. Not only does the water ecosystem provide basic products for maintaining human life and production activities, but it also maintains the functions of natural ecosystem structure, ecological processes, and regional ecological environment, which play an important role in the development of human society [2]. However, in recent decades, due to the influence of climate change, land cover change, human activities, and its own vulnerabilities, the water ecosystem has been destroyed, its service functions have been threatened, and water resource problems have been increasingly prominent [3].

As basic units of the natural formation of water resources, river basins are facing increasingly serious problems. Owning the sevens basins of the Yangtze River, the Yellow River, the Yearl River, the Songhua River, the Huaihe River, the Haihe River and the Liaohe River, China is one of the earliest countries that developed and utilized water basin resources [4]. With rapid social economic development and population growth, the demand for basin water resources increases constantly, while the supply of water resources in basins is limited, thus exacerbating the contradiction between supply and demand of basin water resources in China. The contradiction is increasingly prominent, especially in northern basin regions of water shortages [5]. Moreover, the utilization rate of basin water resources is too high, and has exceeded the global average over the same period in recent years. Among them, the utilization rate of water resources of the three major basins of the Haihe River, the Yellow River,

and the Huaihe River is the highest—40% higher than the international standard. As a result, the sustainable development of basin water resources has been severely affected, causing serious problems in the basin water eco-environment and undermining the stability of the basin water ecosystems [6].

Water resources provide an important condition for the social and economic development of basins. However, the problems of water resources in basins become worse in China, which has seriously hampered the sustainable development of the economy and environment in basins [7]. As a relatively complete resource management unit and a concentrated area of human activities, a basin serves not only as a carrier for human needs and the survival of water ecosystems, but is also the crux of the problems to mitigate contradictions between supply and demand of resources, man and nature, the development and the protection of the water environment [8]. Integrated water resource management at the basin level is the basis for the nation's water resources allocation, so conducting water resource management in the basin is a significant object of study at the decision-making level in China [9]. However, China presently lacks a systematic and further study of the integrated management of basin water resources, resulting in less information on water resources management that can be provided as foundation for decision-making. Thus, we cannot effectively solve the problems of water resources and achieve their sustainable use. Therefore, exploring river basin management has become a hot and difficult point in current research on water resources in China. On the basis of summarizing the classifications and influencing factors of water ecosystem service functions, this paper summarizes China's progress in the management of water resources in river basins through the management of basin water ecosystem service functions. It also discusses the impact of water resource management on land use, in order to provide references for the solutions of water resource problems in Chinese basins.

2. Classifications of Basin Water Ecosystem Service Functions

"Ecosystem service functions" refers to the natural environment conditions and utilities that are formed and maintained by ecosystems and ecological processes, on which human beings depend [10]. They not only provide food, medicine, and other raw materials for human life, but also create and sustain the Earth's life support system and form the necessary environmental conditions for human existence [11]. Ecosystems can provide a variety of services to human beings, and different ecosystem services have different manifestations. Thus, classification of ecosystem service functions is the basis for understanding the functions of ecosystem services [12]. Currently, the internationally widely recognized method to classify ecosystem services was proposed by the MA (Millennium Assessment) Working Group. It integrates the ecosystem service functions into four major functional groups: provisioning, regulating, supporting, and culture. As a special ecological resource, water is the basis for supporting the entire system of life on Earth [5]. Besides, water ecosystems play an important role in the development of human society. However, with economic development and population increase, the problems of water resources in Chinese river basins are getting worse, the service functions of aquatic ecosystems are declining gradually, and people's lives and social development in basins are greatly restricted [13,14]. Therefore, it is of great significance to further understand the service functions of river basin aquatic ecosystems to conduct the integrated management of basin water resources [5].

There are many kinds of water ecosystem service functions. According to the literature analysis, there is no unified way to classify water ecosystem service functions at present. Different scholars have different divisions from individual perspectives. With the publication of the Daily's "*Nature's Services: Societal Dependence on Natural Ecosystems*" in 1997 and Costanza et al.'s research on global ecosystem services, ecosystem service functions have gradually become research hotspots [10,15]. The research on the service functions of aquatic ecosystems in China is also increasing. Moreover, the classification of water ecosystem service functions is the basis for studying water ecosystem services. Therefore, many scholars have studied the classifications of water ecosystem service functions.

Based on the study of Daily's research [10], Ouyang and others made a comprehensive use of ecological and economic methods to roughly divide ecosystem services into the provision of

ecosystem products and the environment that supports and sustains mankind's survival [16,17]. On the basis of this, Zhao et al. divided the water ecosystem service functions into product manufacturing with direct use value and life supporting with indirect use value, according to the characteristics of consumption and marketization of aquatic ecosystem services [18]. Considering the economic and ecological properties of water resources, Zhai et al. studied the 18 entire streams of Cangshan as a research area, dividing the functions into two types: economic and ecological service functions [17,19]. In addition, Wang et al. studied the Xiangxi River (the largest tributary of the Three Gorges Reservoir in Hubei Province), with references to the classifications of water ecosystem service functions at home and abroad. According to the compositional characteristics of the Xiangxi River water ecosystem, characteristics, ecological processes, and utilities, the service functions of aquatic ecosystems are divided into three categories: product functions, regulatory support functions, and cultural functions [20]. Li and others referred to the classifications of water ecosystem service functions by predecessors and combined the characteristics of the water system in the study area, divided water ecosystem service functions into five functions: water supply, regulation, product, recreation and entertainment, and human landscape [21].

As scholars continue to research the service functions of water ecosystems in China, their classifications are increasingly specific and more in line with the characteristics and research purposes of the study areas. However, these studies in China started late, and a unified classification system of water ecosystem service functions has not yet been set up. The relevant studies frequently directly refer to and use foreign classification methods, and how to establish a classification system of water ecosystem service functions in line with China's national conditions is still a problem to be solved [19,22].

3. The Influencing Factors of Basin Water Ecosystem Service Functions

Based on the classifications of the service functions of water ecosystems in Chinese basins, the factors that affect the service functions of the water ecosystems in basins determine different modes that different basin aquatic ecosystem services act on, which affects the stability of aquatic ecosystems in basins. The identification of influencing factors of the service functions of basin aquatic ecosystems can help to understand the mechanism of basin aquatic ecosystems and enhance the scientific basis for the integrated management of Chinese water resources in basins. In recent years, there have been more and more studies of the factors influencing the service functions of the aquatic ecosystems in basins. They have found that water ecosystem services in basins are affected by many factors, such as climate, land cover, human activities, and their own vulnerabilities.

The climate also impacts the service functions of water ecosystems in basins. Over the past 100 years, the global surface temperature has risen by 0.74 °C, and the climate will continue to change in the future. Heat and water resources are closely linked. In recent decades, the warming trend has led to changes in the hydrological cycle, and aquatic ecosystems are facing serious threats [23,24]. Global climate change will lead to significant changes in temperature regimes and rainfall patterns over the next 100 years. Temperature change will change water quality by altering heat balance and mixing dynamics of the water body [25]. Then, changes in temperature and rainfall will affect runoff, thus changing the total amount of water in basins, affecting water supply, erosion protection, purification of water bodies, hydroelectric power, and other service functions in river basin aquatic ecosystems [26–28]. In addition, climate change will change the water temperature in river basins, making water scarcity and flood more frequent [29]. At the same time, with the development of human society, the water resources of basins have been under increasing pressure and are thus extremely sensitive to climate change. Even the restoration of water bodies in basins may be hindered by climate change. In a word, climate change has a significant impact on aquatic ecosystems in basins and their service functions [30].

Land cover also impacts the service functions of basin aquatic ecosystems. With the continuous growth of the social economy and population, the pace, extent, and breadth of humanity's role in

the terrestrial surface systems of Earth are unprecedented. One of the most important changes in the terrestrial surface systems is the change in land cover, while land cover change has a significant impact on the hydrology water resources [31,32]. In the short term, land cover change is one of the main drivers of hydrological changes in basins [33]. The conversions of natural woodland and grassland into cultivated land are the most extensive land-based change processes. China is a populous country that relies on irrigated farmland to produce 70% of the food for its population of over one billion. Therefore, the changes of land cover characteristics in China are extensive and have a significant impact on the service functions of basin aquatic ecosystems [2,34]. The changes of land cover will change the interception of surface vegetation and surface evaporation, thus affecting the hydrological regime and the mechanism of confluence and drainage in river basins and increasing the frequency and intensity of flood disaster [35]. Changes in land cover will also change the soil structure, affecting soil hydraulic conductivities and water retention characteristics, thus affecting aquatic ecosystem functions such as carbon sequestration, soil erosion protection, and water cycle [32,36]. In addition, with the expansion of cultivated land, the demand for agricultural water is increasing, and the use of chemical fertilizers and pesticides is also increasing [34]. The loss of biodiversity is also on the rise, which all have important impacts on surface runoff, water quality, groundwater and water purification capacity, thus affecting water and soil conservation, supply of products, climate regulation, and other service functions of basin water ecosystems [37,38].

Human activities also have important impacts on the service functions of river basin aquatic ecosystems. In recent years, with humanity's increasing demand for industrial, domestic, and agricultural water, the imbalance between the supply of water ecosystem services and the demand for urbanization in river basins is becoming increasingly salient [2], and the pressure of water resources in basins has greatly increased. Especially, the basins in arid and semi-arid areas are facing greater challenges [39]. In order to meet the needs of production and life, China has carried out excessive exploitations and utilizations of water resources in many river basins, but it has neglected the ecosystem service value of basin aquatic ecosystems, leading to the interruption of rivers, the loss of wetlands, and threats to biodiversity; thus, the service functions of basin water ecosystems have degenerated. Among these exploitations, the construction of water conservancy facilities has a significant impact on basin aquatic ecosystems. The closure of upstream reservoirs and the construction of water conservancy projects degrades the biodiversity of the watershed and affects the erosion protection, hydropower generation, and other service functions of aquatic ecosystems, resulting in the severe degeneration of the service functions of the entire basin aquatic ecosystem [40]. Meanwhile, water conservancy projects also affect the service functions of river basin water ecosystems by affecting hydrological factors such as flow velocity, flow, and runoff in lower reaches [41].

There are many factors that affect the service functions of water ecosystems in basins—not only external factors such as climate, land cover, and human activities, but also the intrinsic endowment conditions of the river basin aquatic ecosystems, including water quality, water quantity, evaporation, and other factors (i.e., internal factors) [40]. The influence mechanism of watershed aquatic ecosystem service functions is a very complex system, which is usually the coupling effect of many factors to change the service functions of watershed aquatic ecosystems. Therefore, the related research in our country has also shifted from the early single factor studies to the present more comprehensive multi-factor studies, and the management of river basin water resources should also consider multiple factors that affect the service functions of river basin aquatic ecosystems.

4. Water Resource Management in Chinese Basins

Due to the impacts of global climate change, continuous population growth, urban expansion, and the fragility of aquatic ecosystems, the problems of production, living, and ecology caused by the shortage of water resources have become increasingly prominent. Many basins in China are facing different levels of water crisis—the water crisis is especially more severe in the arid and semi-arid basin areas [42]. Therefore, the integrated management of water resources in basins has become a

pressing task of the Chinese government, and more and more scholars are beginning to pay attention to the research of water resource management. Foreign research on water resource management originated from Masse's reservoir optimization and dispatch in the 1940s. Since the 1960s, with the introduction of system analysis theory and optimization techniques and the development of computer technology, research on water resource management moved into the rapid development stage. The research scopes have been continuously expanded and the depth further increased. In addition, the research is increasingly focused on multi-objective analysis. With the help of the combination of computer technologies and corresponding mathematical methods, multiple research methods have been exploited, including stochastic linear models, nonlinear models, static models, dynamic programming models, lumped parameter models, and so on [43,44]. Since the 1990s, the theoretical systems and research methods of water resource management have been gradually improved, focusing on water quality constraints and environmental benefits constraints [45–50]. Domestic research on water resource management started later. The studies on water resource allocation led by reservoir optimal operation began in the 1960s [51]. In the 1980s, the departments of geology, water conservancy, and transportation jointly carried out the investigation and evaluation of water resources in China, which laid a good foundation for water resource management research [52–56]. Since then, the research on water resource management in China has been developing rapidly.

4.1. Water Resources Protection

To manage the water resources of river basins, we should first protect the water resources. According to the 2016 China Bulletin on the State of the Environment, water pollution levels in the seven major river basins in China are varied, and the situation of water pollution is grim. Therefore, the protection of water resources in river basins is a prerequisite for their management. Water conservancy projects for the protection of water resources are of great significance. In response to the deteriorating water quality, floods during the rainy season, and lack of water during the dry season in the Taihu Lake basin, Yang et al. proposed the establishment of a Basic Peripheral Channel (BPC), which could divert low-quality water from the lake in dry season and bring better-quality water into the lake in the wet season so as to help solve the problems of water resources in the Taihu Lake [57]. Faced with the ecological problems caused by the over-exploitation of water resources in Heihe River Basin (e.g., river breakup, the drying up of lakes, and the degradation of vegetation cover), a national water transfer project was officially put into use in July 2000. Xi et al. found that this water transfer project had significantly increased the amount and frequency of water flowing into the lower reaches of the Heihe River Basin, and to some extent recharged the groundwater to improve the water quality in the Heihe River Basin and solve the problems of river shrinkage [58]. In view of the deterioration of the water environment in Xinjiang in the arid region, Hu put forward measures to transform plain reservoirs, build mountain reservoirs to accumulate floods and increase water sources, which will help to reduce ineffective evaporation of the water surface, improve the aquatic environment, and rehabilitate the service functions of aquatic ecosystems [59].

With the accelerating process of urbanization in China, land cover changes in the basin are becoming more extensive. The irrigated areas of cultivated land are expanding, and the discharge of sewage is increasing, resulting in the increased use of chemical fertilizers and pesticides in the watershed, deteriorating water quality in river basins, severe water and soil loss, and impaired services to the aquatic ecosystems. In order to protect the aquatic ecosystems in basins, Li and others took the Dongting Lake basin as a research area, and combined AHP and entropy methods to construct an evaluation index system and a response relation model of the comprehensive potential of urbanization and water resource development and utilization in the Dongting Lake Basin. Finally, they proposed the establishment of farmland irrigation water protection areas, the implementation of fertilizer and pesticide reduction, efficiency projects, and the promotion of ecological agriculture. Further, they suggested that small businesses whose water consumption and pollution are heavy should be rectified, and sewage charges should be imposed to promote the construction of sewage treatment facilities [60].

On the basis of monitoring the soil and water loss in the typical model of "Grain for Green" in the Three Gorges Reservoir area, Zeng et al. found that the implementation of "Grain for Green" and "Grain for Blue" could prevent soil erosion and significantly improve the water and soil conservation functions of aquatic ecosystems [61]. In addition, through the study of water resources in Xinjiang, Hu and others suggested that the implementation of biological systems engineering was also a powerful measure to protect water resources, which could improve the quality of water resources and improve the aquatic environment [59].

4.2. Water Resource Allocation

The rational allocation of water resources is an important part of water resource management [62]. In the course of developing and utilizing water resources, it is necessary to formulate a reasonable allocation plan in accordance with the various water needs of the economy and society under the guidance of the government administrative management system. Effective water resource management measures should be taken to deal with the contradiction between the various departments of water use, coordinate the relationship between development, utilization, governance, and the economic and social development of water resources, improve the overall efficiency of water resources, and realize the sustainable development of the social economy by relying on the sustainable utilization of water resources [60]. In recent years, the national government has also paid sufficient attention to the research of water resource management. In 2002, the new Water Law defined the system of total quantity control and quota management, emphasizing the strengthening of water management and implementing the permit system of water abstraction and the system of the paid use of water resources.

The price control system and the total amount control system are important measures for the Chinese government to allocate water resources in basins. Price control measures rely on market mechanisms. In the water resource utilization structures of all countries, agricultural irrigation water generally dominates. However, the low agricultural water price is considered to be the most important cause of the water shortage crisis in basins. Therefore, increasing the price of water is an important economic measure for the rational allocation of water resources [63]. Taking the Rachman Basin in Jordan as an example, Mahmoud et al. studied the water shortage crisis in the semi-arid area and proposed that the government must cope with the crisis of water resources by raising the price of water and recovering the used water resources [64]. Xia et al. studied the foreign water resource regulation and control measures and pointed out that China should use a price function to leverage the economic value of water resources to classify water resources [65]. Based on Chinese sustainable development strategy, Fu et al. put forward that China should rationally determine the water supply price and establish a scientific water price system [66]. Water volume control is another effective way to alleviate the pressure of water shortage; especially in water-shortage basins, reducing the water supply is the most fundamental and effective measure [67]. After the analysis of the utilization of water resources in the Dongting Lake Basin, Li et al. suggested that the formulation of a Dongting Lake water distribution plan should be formulated and implemented as soon as possible, and the control indexes of total water consumption should be decomposed layer-by-layer to determine the available or consumable water share of various industries, departments, irrigation districts, and enterprises [60].

However, the price control system and the total control system have their own shortcomings. Price control regimes often fail due to the low price elasticity of demand for water and difficulties in the detection and management of groundwater [68]. Compared with the price control system, the total amount control system has simple management and small transaction costs, and it can quickly adjust the supply of water resources. However, the cost of quantitative testing, supervision, and management of water resources is large [69], and the flexibility of the water control system is lacking [68]. As a developing country with a shortage of water resources, China is more likely to adopt a water control system to promote water rights trading through the establishment of a water market to enhance the flexibility of water control measures [70,71].

Under the government's institutional management, water resources can be further managed through specific water resource allocation measures. Water conservancy projects are an important measure to allocate water resources reasonably. Under the consciousness of protecting water resources, China's water conservancy projects have developed rapidly and can be used for flood control, water supply, soil and water conservation, ecological environment protection, power generation and other supporting projects and activities through the construction, expansion, reconstruction, enhancement, and restoration of water conservancy projects [72]. Based on the research on the rational allocation of water resources in Dongting Lake Basin, Li et al. proposed that water could be diverted from wet areas to dry areas through water diversion projects, mainly to meet the needs of residents and industry, but also for agricultural irrigation, to address the imbalance of spatial distribution of water resources [60]. It is also possible to meet the seasonal needs of agricultural production and increase the cultivated areas by constructing dams and reservoirs to change the distribution of water resources in basins [72].

For the allocation of water resources to the entire basin and to address the severe water and ecological problems in China's inland river areas, Cheng et al. took the Heihe River Basin as the research area to establish an integrated watershed model coupled with ecology, hydrology, and socioeconomics, and put forward the key period for determining the ecological water demand, during which the necessary amount of water should be guaranteed and the discharge of reservoirs and the runoff of the river should be reasonably adjusted [42]. Fu et al. discussed the issue of the coordinated distribution of water resources in the upper, middle, and lower reaches of river basins, and put forward that the upper reaches are mainly ecological protection, the middle reaches are farmland development, and the lower reaches are urban construction [73]. Measures like adjusting the industrial structure of basins, properly controlling the pace of industrial and agricultural development, and accelerating the development of tertiary industry are needed to allocate water resources [74]. In addition, Peng pointed out that the mutual conversion and compensation relationship of surface water and groundwater and constraints for the recoverable volume of groundwater during different periods in each node should be fully taken into account to realize the unified allocation and joint dispatch of surface water and groundwater by constructing a multi-objective programming model of water resource utilization in the Yellow River Basin [75]. Cheng et al. considered the impact of trade between basins and the outside on water resources, and proposed that the trade structure should be optimized to reduce the export of virtual water [42].

4.3. Water Resource Utilization

In the utilization of water resources, improving the use efficiency of water resources should be carried out simultaneously with water-saving measures. Firstly, the government needs to formulate water-saving policies, establish awareness of water conservation, promote water-saving technologies, and gradually establish a water-saving society. The research on the optimal utilization of local water resources are also being paid increasing attention by scholars. By analyzing the development of water resource utilization in Xinjiang, Hu found that the key to strengthening the management of Xinjiang's water resources lies in increasing revenue and reducing expenditure simultaneously, reducing waste, and increasing the rate of water resource utilization [59]. Cheng et al. took the Heihe River Basin as an example, and proposed improving the water transfer facilities to prevent leakage evaporation, improving irrigation technology and irrigation systems to promote the efficient use of irrigation water, and the cultivation of drought-resistant, water-saving, high-yielding varieties [42]. Peng et al. studied the utilization of water resources in the Yellow River Basin. The results showed that water saving methods included the adjustment of industrial structure and the improvement of water resource utilization, which was the main approach to solving the water problems in the Yellow River Basin [75]. Wang et al. studied the case of the Heihe River Basin and found that water-saving technologies can improve water efficiency but not reduce water demand. To further solve the contradiction between supply and demand of water resources in the arid basins of Northwest China, the demand for

agricultural water in basins needs to be reduced. Structural changes in water use were promoted, and authors stated that the efficiency of water utilization and the output benefit of limited water resources should be improved [76].

In short, the management of water resources in river basins needs to be carried out in three respects: water resource protection, allocation, and utilization. Only when these three factors are coordinated can the water resources be effectively managed. However, due to the large number of watersheds in our country and their complicated conditions, there are still some problems in our country's current water resource management: (1) The water price control measures of water resource management will lead to the increase of crop irrigation costs and the decrease of farmers' income; the amount control of water resource management measures will lead to the reduction of agricultural production scale, and farmers' income will also be reduced. (2) How to ensure the fairness of water allocation is a difficult problem when implementing water control measures. (3) There are obvious differences in the water resource areas in our country, and the economic development is not directly proportional to the supply of water resources. How to scientifically and effectively manage the differences between the two and make the coordination of water resources and economic development is a problem that current water resource management is faced with. (4) The water resource management support system needs to be strengthened. Auxiliary systems such as geographic information systems and management information systems are powerful technical tools for water resource management, and need to be used jointly.

In view of the current research's focus and deficiencies, it is necessary for our country's future basin water resource management to focus on the following aspects: (1) Water conservation. Basin water resource management needs to take the ecological water demand in river basins into account. When forecasting the demand of water, we should give priority to ensuring ecological water demand, and then allocate production and living needs rationally. (2) Water resource allocation. Water price should be considered as an important factor to establish the feedback relationship with other factors in the water resources system, and to enrich and perfect the water supply and demand system model in basins. Water resource management policies should be carried out based on water volume control measures, then the water market mechanism should be established and the water rights trading system improved. There is also a need to implement a virtual water strategy to mobilize social resources and import water-intensive agricultural products to ease the shortage of water resources in the afflicted areas. In addition, we should also explore the inter-basin resource combination and the comprehensive management of water resources. (3) Water resource utilization. The tapping and saving of water resources should be carried out simultaneously. Water conservation should be taken as a long-term hard measure to build a water-saving social system.

5. Impact of Basin Water Resource Management on Land Use in China

Through the water resource management of basins, the water ecosystem and its service functions in river basins can be improved, the comprehensive benefits of water resources can be improved, the sustainable utilization of water resources can be realized, the water resources crisis can be alleviated, and the land use efficiency can be improved [77]. Measures of water resource management are multifaceted, and their impacts on land use change are various. We mainly expound its impacts on land use from three aspects of water resource management:

(1) Impact of basin water resource protection on land use. In order to realize the protection of water resources, increasing attention has been paid to ecological land [78]. The projects of returning cropland to forest and grassland, grazing prohibition in mountains, increasing the area of low-water-consumption shrubbery, closed forest land, other forest land and other grassland, and reducing the sand area appropriately [79] are conducive to the promotion of water eco-environmental protection in river basins. They are particularly beneficial to ensure the construction of bioengineering and improve the service functions of water ecosystems for water conservation and climate regulation [60]. All of these measures can optimize land

use and promote ecological restoration, wetland expansion, and urban greening. In addition, the implementation of ecological water utilization will reduce the water consumption of other types of land, leaving other land use patterns limited, and the impact of ecological water on land use is very significant, especially in arid and semi-arid regions [77].

(2) Impact of basin water resource allocation on land use. As a whole, the allocation of water resources should emphasize the ecological use of water, guarantee the living water for residents, increase the industrial water, reduce the agricultural water, and realize the highly efficient use of water resources [80]. The construction of water conservancy projects in the allocation of water resources in river basins has an important impact on land use. According to a study conducted by Gan Hong et al., water resource allocation has allocated part of the water resources in the water-abundant areas to water-scarce areas through water diversion projects. Large-scale construction of water conservancy projects directly causes changes in the land use patterns and types, and the water resource regulation and distribution after the completion of water conservancy projects will indirectly cause changes in land use structures and layouts. Furthermore, the possible resettlement problems caused by water conservancy projects also have important effects on the land use of moving-out areas and moving-in areas [77]. Based on the study of the redistribution of water resources in the Heihe River Basin, Si Jianhua et al. proposed that the rational allocation of water resources in basins could improve the water volume and heighten the groundwater level downstream and repair the water ecosystems so as to optimize the land use structures [81]. In addition, through establishing a water pricing management system, China has accelerated the pace of water resource valuation and commercialization reform [82]. The commercialization of water resources is mainly reflected in the changes of water pricing with the changes of supply and demand in the market, and the changes of water pricing will inevitably lead to changes in land pricing [83]. Therefore, the water pricing management system can promote the optimal allocation of urban land use, and can also increase the intensive use of urban land. The intensive use of urban land can also reduce the impact of urban expansion on agricultural land—especially the occupation of high-quality cultivated land [77]. At the same time, the commercialization of water resources will also put our country's weak agriculture and food production in a disadvantaged situation in the future competition for water resources [84]. Therefore, farmland protection needs relevant agricultural laws and policies [85].

(3) The impact of basin water savings on land use. The implementation of water-saving measures will also profoundly affect the type and intensity of land use. The use of water-saving technologies in agriculture has not only promoted the improvement of land use efficiency but also enhanced the intensification of land use [77]. As water resources become more constrained, limited water resources can make more land available to agriculture in the process of production, and the output per unit of agricultural land will also increase greatly. The areas under high water consumption will be reduced, and drought-resistant crops planted areas will be increased. The agricultural planting structures will also be adjusted accordingly [84]. In terms of industrial water conservation, Huo comprehensively analyzed the characteristics of land and water resources in Shaanxi province. He pointed out that due to the classification of industrial water, ordinary factories and mines except for special industries all use poor-quality water or reclaimed water. Additionally, the uniform provisions made to water-taking, water using, and technical rules in industrial production processes through financial subsidies, relief, and other business-related fees to restrict some high-water-consuming industries [86], so that its land-use have to take the conversion due to high cost of water-saving input or water shortage [77].

6. Summary and Prospects of Basin Water Resource Management Research in China

Water resources are the foundation supporting the entire life system of the Earth. Especially for basins severely affected by water crisis, the integrated management of water resources is an important part of rehabilitating aquatic ecosystems and their service functions and ensuring the sustainable

development of basins. Although much research has been done on the management of water resources in river basins in China, it is not yet systematic and the information provided to the managers is extremely limited. In the future, the management of water resources in river basins in China may need to be focused on the following aspects:

The classification system of aquatic ecosystem service functions in basins needs to be improved. Ecosystem service functions are various and play an important role in human life. Different ecosystem service functions have different effects on humans, and therefore the classification of ecosystem service functions is the basis for understanding ecosystem services. As an important branch of ecosystem service functions, the study of classification systems of aquatic ecosystem service functions is an important foundation for further understanding aquatic ecosystems for water resource management. At present, the classification system of ecosystem service functions is more comprehensive and systematic, but the classification system for the service functions of watershed aquatic ecosystems is not yet accomplished, the basis of division is not yet clear, and the relevant research needs to be further strengthened.

The basin water market mechanism needs to be improved. In order to optimize the allocation of water resources, improve the water utilization rate, scientifically carry out water resource management, and solve the problems of water resources in basins, China has introduced and explored the water market. Taking the economic value of water resources for social development into account, the water market mainly refers to the water rights market and the water supply market. At the same time, the ecological value of water resources cannot be ignored. The appropriate emission rights, wastewater treatment, and wastewater reuse markets should be established. Practice has proved that China's current water market is not sufficient to deal with different water rights trading events in various regions. Therefore, it is necessary to clarify the rights to main bodies of water, establish and improve China's water right system, establish a water rights transfer mechanism that conforms to market rules, and improve the water market mechanism to better manage Chinese basin water resources.

In the allocation and utilization of water resources, synthetic tradeoff should be given to the development and protection. At present, the allocation and utilization of water resources mainly depend on the needs of the social development of river basins. However, the ecological needs of the river basins are often neglected, resulting in the duplication of efforts in the protection of water resources in basins. Therefore, in the allocation and utilization of water resources, comprehensive trade-off development, and protection are the focuses of most scholars.

Basin water resource management should be considered from a multidisciplinary perspective. The crossed and comprehensive utilization of knowledge from watershed management science, ecological science, geography science, and information science provides a powerful scientific support for basin water resource management, so as to comprehensively manage water resources in basins, repair basin water ecosystems and their service functions, and solve the basin water resource problems.

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