Research on the Diagnosis of Initial Water Right Allocation Scheme in the River Basin

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ABSTRACT

The establishment of a set of perfect diagnosis methods for initial water right allocation scheme in the basin with strong practical operability can provide important support for promoting the coordinated and high-quality development of provinces and regions in the basin. In this paper, on the basis of systematically sorting out the design methods and diagnosis methods of the initial water rights allocation scheme of the basin, the diagnostic criteria of the initial water rights allocation scheme of the basin are constructed. Using the ELECTRE method, a diagnostic model based on diagnostic criteria is built to diagnose the rationality of the initial water rights allocation of each province in the basin. Combined with the empirical study, the feasibility of the diagnosis method of the initial water rights allocation scheme in the basin is further verified.

Keywords: *Basin, Initial water right allocation, Scheme diagnosis, Guidelines, Model.*

1. INTRODUCTION

In order to cope with the severe challenges of water resources and environment in river basins in China, the research on China's water rights system has been deepened since 2000. In 2005, the State Council took the construction of the national water rights system as the key content of deepening the economic system reform. In 2006, the "Outline of the National Medium and Long term Science and Technology Development Plan (2006-2020)" highlighted the priority theme of "optimal allocation and comprehensive development and utilization of water resources". The "Outline of the Eleventh Five Year Plan for National Economic and Social Development" proposed to "establish the national initial water right distribution system and water right transfer system". The "Decision of the Central Committee of the Communist Party of China and the State Council on Accelerating the Reform of Water Resources", No. 1 document of the Central Committee of the Communist Party of China, proposed to implement the strictest water resources management system, established three red line rigid constraints, and established "four systems" of total water consumption control, water efficiency control, water function area limitation and pollution acceptance, and water resources management responsibility assessment. Since 2012, the State Council has successively issued the "Opinions of the State Council on the Implementation of the Most Strict Water Resources Management System", the "Assessment Measures for the Implementation of the Most Strict Water Resources Management System", the "Action Plan for the Prevention and Control of Water Pollution", the "Overall Plan for the Reform of the Ecological Civilization System", the "Central Committee of the Communist Party of China's Suggestions on the Formulation of the 13th Five Year Plan for National Economic and Social Development "and other relevant policy documents, and put forward a series of policy measures to strengthen the rigid constraints on water resources, stipulated the control objectives of the total amount of water use, water use efficiency and water quality standard rate of important rivers and lakes in each province, city and autonomous region, and implemented the total amount and intensity control plan of water resources consumption to establish and improve the initial water rights allocation system. As an important part of the construction of the national initial water rights allocation system, carrying out diagnostic research on the initial water rights allocation scheme of the river basin to improve the fairness of the initial water rights allocation results of the river basin has aroused strong repercussions in the water conservancy and academic circles. Forming a set of perfect diagnosis methods for initial water right allocation scheme of river basin with strong operability in practice is a necessary means to establish and improve the national initial water right allocation system and solve the water use conflict among stakeholders related to water rights, and an effective way to improve the rational allocation and efficient utilization system of water resources.

2. LITERATURE REVIEW

At the same time, the practice of initial water rights allocation in the basin is affected by many factors, such as political stability, social equity, economic development, technical means, ecological environment protection, etc. Many scholars have made in-depth research on the design methods and diagnostic methods of initial water rights allocation scheme in the basin, drawing on international experience. From the perspective of the design method of initial water right allocation scheme in the basin, it mainly includes multi-objective coupling allocation method and multi-stage coupling allocation method involving stakeholders. Among them, multi-objective coupling allocation methods, such as basin water quantity and quality coupling water right allocation model [1], hydrology agriculture economy model, water resources economy hydrology model [2], Robust fuzzy stochastic programming model [3], multi objective dynamic equilibrium configuration model [4-5], analytic hierarchy process [6], ideal solution model [7], fuzzy optimization model [8], multi-objective optimization model [9], goal planning model [10], multi-level optimization model [11-12] and other models. There are also multi stage coupling allocation methods involving stakeholders, such as the comprehensive allocation model of surface water and groundwater involving stakeholders [13], economic power index allocation model simulating stakeholder negotiation process [14-15], two-stage cooperative allocation model to improve water user cooperation [2], interval two-stage planning model to cope with uncertain changes in complex water resources system [16-17], fuzzy alliance game model for transnational multi-agent cooperative water resources allocation [18], comprehensive discussion method [19], negotiation game model [20], two-stage optimal allocation model [21].

From the perspective of the diagnosis method of initial water right allocation scheme in the basin, on the one hand, Wu Fengping [22] established the diagnosis index system and semi structural multi-objective fuzzy optimization model of initial water right allocation system scheme in the basin for the diagnosis method of initial water right allocation scheme between regions in the basin, to diagnose the rationality of different regional allocation schemes in the basin, reflecting the fairness and efficiency of water use between regions in the basin. Chen Yanping et al. [23] built a harmony diagnosis method for the initial harmonious allocation of water rights in the basin, and built a multi round dynamic game model for the initial water rights allocation scheme that failed to pass the harmony diagnosis, and constantly adjusted the water rights allocation scheme of each region in the basin. At the same time, Chen Yanping et al. [24] proposed to construct a discrimination criterion from the dimension of direction and degree, and the configuration scheme that passed the harmony discrimination of the two dimensions is the harmonious configuration scheme of the initial water rights of the basin. Wu Fengping [25] et al. established a coupling and coordination criterion based on the "three red lines". According to the allocation scheme of provincial initial water rights and river basin level government reserved water, the coupling and coordination between the two are judged from the perspective of water quantity, water quality and water use efficiency. Wu Dan et al. [26] designed a set of evaluation index system and coupling evaluation model of initial water rights allocation practice effect from four dimensions of fairness, efficiency, sustainable development and government macro-control, and applied them to the Daling River basin, drawing on the evaluation index system of water resources allocation in the basin of China and combining the characteristics of the Daling River basin.

On the other hand, aiming at the diagnosis method of the initial water rights allocation scheme among industries in the region, Wu Fengping etc., [27] constructed the criteria for the harmony of the initial water rights allocation scheme, and proposed an interactive initial water rights allocation method that can fully absorb the "knowledge" of different regions and departments on the initial water rights allocation. Wu Dan et al. [28] built a diagnostic indicator system and an improved ideal solution model for the initial water rights allocation system in combination with the development goals of water use industries such as living, ecological environment and production in each region of the basin, and diagnosed the initial water rights allocation results of different water use industries in each region of the basin. Based on the interactive decision-making theory, the goal programming model is combined with the gradual compromise method to establish the initial water rights allocation system optimization model for water rights adjustment, so that the initial water rights allocation results of different industries can be diagnosed through the system.

In addition, Wu Dan et al. [29-31] built an evaluation index system for the effectiveness of regional coordinated development and a gray relational projection pursuit comprehensive evaluation model from the perspective of society, economy and ecological environment to diagnose the rationality of the initial water rights allocation scheme for each region and its water use industry in the basin. The evaluation criteria and index system of the initial two-dimensional water rights coupling allocation system of the basin were also constructed to evaluate the coupling and synergy effectiveness of the economic, social and ecological environment subsystems in each regional system unit, as well as the convergence development effectiveness of the economic, social and ecological environment and the whole among the regional system units. Guided by the practice of initial water rights allocation in the basin, and referring to the idea of initial allocation of existing water rights in accordance with the hierarchical structure of "basin province city industry", a multi-level hierarchical decision-making model for initial water rights allocation in the basin under the dual control action is established to diagnose the matching relationship between the water allocation proportion of each province and city and the comprehensive index of social and economic development, as well as the coupling and collaborative development effectiveness between provinces and cities.

It can be seen from the literature that, in view of the initial water right allocation process of the basin, the provinces and regions under the jurisdiction of the basin are in a cooperative development relationship of mutual competition and cooperation. The unreasonable amount of water rights allocated by any province will affect the balanced development among provinces. Therefore, the key to the initial allocation of water rights in the basin is to improve the acceptability of water diversion within the basin. Therefore, under the rigid constraint of water resources, this paper constructs a diagnosis method for the initial water rights allocation scheme of the basin, including the construction of diagnostic criteria and diagnostic model, to diagnose the rationality of the initial water rights allocation of each province.

3. CONSTRUCTION OF DIAGNOSTIC CRITERIA

W is set to be the initial water right allocation scheme of each province in the basin, that is, $W=\{W_1,W_2,\cdots,W_n\}$, in which the initial water right allocation amount of the i province/region, the k province/region, and the l province/region are W_i, W_k, and W_l respectively. It is assumed that the initial water rights allocation relationship among provinces in the basin can be expressed as $W_i \geq W_k \geq W_l$, that is, the initial water rights allocation amount of the l province/region is the largest, followed by the initial water rights allocation amount of the k province/region and the l province/region. Therefore, a set of diagnostic indicators is constructed for comparative analysis of diagnostic indicators between two provinces to diagnose the rationality of water division between provinces. It can be expressed as follows:

According to the comparative analysis of the diagnostic indicators between the i province/region and the k province/region, due to the differences between the two provinces in terms of economic development level, social security level, ecological environment construction level, etc., all the diagnostic indicators of the i province/region are not superior to the corresponding diagnostic indicators of the k province/region. It is possible that some of the diagnostic indicators of the i province/region are inferior to those corresponding to the k province/region. At the same time, all the diagnostic indicators of the k province/ region are not superior to those corresponding to the l province/region, and some of the diagnostic indicators of the k province/region may be inferior to those corresponding to the l province/region.

To this end, first of all, diagnostic criterion I is constructed, that is, the diagnostic indicators of a certain proportion of the i province/region are better than those of the k province/region, and then it is considered that the relatively good diagnostic indicators of the i province/region can compensate for the relatively poor diagnostic indicators compared with those of the k province/region. Secondly, the second diagnostic criterion is constructed, that is, compared with the k province/region in the mathematical formula, for the relatively inferior diagnostic indicators in the i province/region, the difference of diagnostic indicators between the two provinces and regions must be limited to the acceptable threshold range.

There is an important assumption implied in the diagnostic criteria: between the i province/region and the k province/region, the superior diagnostic indicators of the i province/region can compensate for their inferior diagnostic indicators. At the same time, although there are differences in the diagnostic indicators between the i province/region and the k province/region, they must be limited within the acceptable threshold range. Then it is considered that the water right allocation amount W_i of i province/region is more than or equal to water right allocation amount W_k of the k province/region.

When the diagnostic criterion I and the fairness diagnostic criterion II are met at the same time, the diagnostic result can be determined that the water right allocation between the i province/region and the k province/region is relatively reasonable, and $W_i \geq W_k$ is established. That is to say, the i province/region passed the diagnostic criteria compared with the k province/region.

In the same way, all the diagnostic indicators of the k province/region are compared and analyzed with those of the l province/region. If both diagnostic criteria I and diagnostic criteria II are met, the water right allocation amount W_k of the k province/region is greater than or equal to water right allocation amount W_l of the l province/region, which is relatively reasonable.

4. CONSTRUCTION OF DIAGNOSTIC MODEL

According to the diagnostic criteria, the diagnostic model based on the diagnostic criteria is established by using the ELECTRE method for the initial water right allocation scheme $W=\{W_1,W_2,\cdots,W_n\}$ of the provinces and autonomous regions under the jurisdiction of the basin, respectively to diagnose the rationality of water division between the i province/region and the k province/region and between the k province/region and the l province/region. The specific steps can be described as follows:

Step 1: Design diagnostic indicators. Under the rigid constraint of water resources, the researchers comprehensively investigated the river basin, and selected four indicators as diagnostic indicators, including the average annual water supply (H_1), water right demand (H_2), GDP (H_3), and cultivated land area (H_4), to measure the extent to which the initial water right allocation scheme reflects the current situation of water use, water demand, water benefit, and water sustainability, and comprehensively reflect the rationality of provincial water division.

Step 2: Ask basin management agencies or experts in the field of water resource management to assign the relative importance of diagnostic indicators, and use a group of weights to represent the relative importance of each diagnostic indicator. That is, $\omega_j\left(j=1,2,\cdots,4\right)$ is the weight of each diagnostic index of j.

Step 3: For the initial water right allocation scheme $W=\{W_1,W_2,\cdots,W_n\}$, if there is $W_i \geq W_k$, construct an index set:

$$\begin{cases} I^+(W_i,W_k)=\{j \mid 1\leq j\leq 4, H_{ij}>H_{kj}\} \\ I^=(W_i,W_k)=\{j \mid 1\leq j\leq 4, H_{ij}=H_{kj}\} \\ I^-(W_i,W_k)=\{j \mid 1\leq j\leq 4, H_{ij}<H_{kj}\} \end{cases} \tag{1}$$

In formula (1), H_{ij} is the reference value of the j diagnostic index of i province/region, and H_{kj} is the reference value of the j diagnostic index of k province/region.

Step 4: Construct the relative rationality index I_{ik}, $\hat{I}_{ik}$, and I_{kij}, respectively as follows:

$$\begin{cases} I_{ik} = (\sum_{j\in I^{+}(W_i,W_k)} \omega_j + \sum_{j\in I^{=}(W_i,W_k)} \omega_j) \Big/ \sum_{j=1}^{4}\omega_j \\ \hat{I}_{ik} = (\sum_{j\in I^{+}(W_i,W_k)} \omega_j) \Big/ (\sum_{j\in I^{-}(W_i,W_k)} \omega_j) \\ I_{kij} = \frac{H_{kj}-H_{ij}}{H_{ij}}\left(H_{ij} < H_{kj}\right) \end{cases} \tag{2}$$

In formula (2), I_{ik} is the weight proportion of the diagnostic index of the i province/region no less than that of the k province/region; $\hat{I}_{ik}$ is the ratio of good and bad diagnostic indicators between the i province/region and the k province/region; I_{kij} is the relative difference of the reference values of the diagnostic indicators of i province/region being inferior to those of k province/region.

Step 5: Set the threshold δ and ε_j for diagnosis. The threshold δ and ε_j can be determined according to the characteristics of the basin and the provinces and regions through the consultation of basin management institutions or experts in the field of water resources management. If they meet the following requirements:

$$\begin{cases} W_i \geq W_k \\ I_{ik} \geq \delta \\ \hat{I}_{ik} \geq 1 \\ I_{kij} \leq \varepsilon_j \end{cases} \tag{3}$$

That is, when equation (3) is established, it is considered that the i province/region has passed the diagnostic criteria compared with the k province/region.

Similarly, through the comparative analysis between the k province/region and the l province/region, the researchers can diagnose whether the initial water right allocation scheme passes the diagnostic criteria. When all provinces and regions under the jurisdiction of the basin have passed the diagnostic criteria, it is considered that the initial water right allocation scheme $W = \{W_1, W_2, \cdots, W_n\}$ has passed the diagnostic criteria. On the contrary, if one province fails to pass the diagnostic criteria, it is considered that the initial water right allocation scheme is unreasonable.

In conclusion, according to the initial water right allocation scheme $W = \{W_1, W_2, \cdots, W_n\}$ of the provinces and regions under the jurisdiction of the basin, based on the diagnostic criteria, the diagnostic model is established by using the ELECTRE method. The model can be expressed as

$$\begin{cases} W_i \geq W_k \\ I_{ik} = (\sum_{j\in I^{+}(W_i,W_k)} \omega_j + \sum_{j\in I^{=}(W_i,W_k)} \omega_j) \Big/ \sum_{j=1}^{4}\omega_j \geq \delta \\ \hat{I}_{ik} = (\sum_{j\in I^{+}(W_i,W_k)} \omega_j) \Big/ (\sum_{j\in I^{-}(W_i,W_k)} \omega_j) \geq 1 \\ I_{kij} = \frac{H_{kj}-H_{ij}}{H_{ij}} \leq \varepsilon_j \left(H_{ij} < H_{kj}\right) \\ i,k = 1,2,\cdots,n;\quad j = 1,2,\cdots,4 \end{cases} \tag{4}$$

When equation (4) is satisfied, it is considered that the initial water right allocation scheme of the basin has passed the diagnostic criteria, and the initial water right allocation scheme of the basin is reasonable and feasible.

5. EMPIRICAL RESEARCH

Taking the Yellow River basin as the research object, the researchers carried out a diagnosis study on the initial water rights allocation scheme of the Yellow River basin in the planning year 2030. The Yellow River basin involves nine provinces (regions) in Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi, Henan and Shandong. Without inter basin water transfer, it is estimated that the surface water supply of the Yellow River will be 39.0 billion m^3 and the water flow into the sea will be 18.58 billion m^3 in 2030, a normal water year. Among them, the surface water supply in the basin is 29.754 billion m^3. It is estimated that in 2030, the exploitation of shallow groundwater in the Yellow River will be 12.528 billion m^3, the reuse of sewage will be 1.88 billion m^3, and the utilization of rainwater will be 160 million m^3. The population, area, output value and water demand of each province in the Yellow River basin in 2030 need to be determined according to the initial water right allocation of each province in the Yellow River basin, as shown in "Table 1".

Table 1. Statistics of population, area, output value and water demand of each province in the Yellow River basin in 2030

Province (region)	Total population (10,000 persons)	Cultivated land area (10,000 mu)	Output value (100 million yuan)	Water demand (100 million m^3)
Qinghai	531.91	837	2127.68	27.67
Sichuan	9.96	9	17.88	0.36
Gansu	2097.37	5222	9323.78	62.61
Ningxia	758.99	1940	3568.61	91.16
Inner Mongolia	963.71	3267	10598.34	108.85
Shaanxi	3332.54	5841	18703.17	98.09
Shanxi	2638.24	4270	13697.31	69.87
Henan	1930.82	2140	9891.91	63.26
Shandong	830.32	836	8870.58	25.48
Yellow River basin	13093.86	24362	76799.25	547.33

Based on the comprehensive analysis of the economic and social development goals of the Yellow River basin in 2030, the initial water rights allocation scheme of the basin is set, as shown in "Table 2".

Table 2. Initial water rights allocation scheme of the Yellow River basin in 2030 Unit: 100 million m^3

Qinghai	Sichuan		Gansu	Ningxia	Inner Mongolia	Shaanxi	Shanxi	Henan	Shandong	Footing
21.73	0.36		52.24	67.5	84.23	80.52	60.82	53.27	22.5	443.18

According to "Table 2", the initial water right allocation scheme among provinces and regions in the Yellow River basin in 2030 is diagnosed. First, the researchers obtain the basic data of the four diagnostic indicators, as shown in "Table 3".

Table 3. Characteristic values of diagnostic indicators for 2030 initial water rights allocation scheme in the Yellow River basin

Province (region)	Average annual water supplyrovince H_1 (100 million m^3)	Water demand H_2 (100 million m^3)	GDP H_3 (100 million yuan)	Cultivated land area H_4 (10,000 mu)
Qinghai	17.38	27.67	2127.68	837
Sichuan	0.25	0.36	17.88	9
Gansu	40.77	62.61	9323.78	5222
Ningxia	66.63	91.16	3568.61	1940
Inner Mongolia	89.23	108.85	10598.34	3267
Shaanxi	56.96	98.09	18703.17	5841
Shanxi	43.87	69.87	13697.31	4270
Henan	51.90	63.26	9891.91	2140
Shandong	32.56	25.48	8870.58	836

According to the diagnostic criteria, the initial water right allocation scheme of the Yellow River basin is diagnosed as follows:

Step 1: Determine the weight of the four diagnostic indicators. According to the characteristics of the provinces and regions under the jurisdiction of the Yellow River basin, the weights of the four diagnostic indicators (H_1, H_2, H_3, H_4) were determined as (0.35, 0.25, 0.25, 0.15);

Step 2: find the provinces and regions with $W_i \geq W_k$ relationship, set the threshold $\delta = 0.6$, and calculate the relative rationality index I_{ik} and $\hat{I}_{ik}$ between different provinces and regions, as shown in "Table 4".

Table 4. Relative rationality index I_{ik} summation between different provinces and regions $\hat{I}_{ik}$

Province/region — Province/region	Relative fairness index I_{ik}	Relative fairness index $\hat{I}_{ik}$
Inner Mongolia — Shaanxi	0.60	1.50
Shaanxi — Ningxia	0.65	1.86
Ningxia — Shanxi	0.60	1.50
Shanxi — Henan	0.65	1.86
Henan — Gansu	0.85	5.67
Gansu — Shandong	0.75	3.00
Shandong — Qinghai	0.60	1.50

As the water right allocation in Sichuan meets its water right demand, Sichuan will not be diagnosed.

Step 3: Find the provinces and regions with $W_i \geq W_k$ relationship, set the threshold $\varepsilon_j = 3$, and calculate the relative rationality index I_{kij} between different provinces and regions of the Yellow River basin in 2030, as shown in "Table 5".

Table 5. Relative rationality index among provinces (regions) in the Yellow River basin in 2030 I_{kij}

Province/region — Province/region	I_{ki1}	I_{ki2}	I_{ki3}	I_{ki4}
Inner Mongolia — Shaanxi	—	—	0.765	0.788
Shaanxi — Ningxia	0.170	—	—	—
Ningxia — Shanxi	—	—	2.838	1.201
Shanxi — Henan	0.183	—	—	—
Henan — Gansu	—	—	—	1.440
Shandong — Qinghai	—	0.086	—	0.001

It can be seen from "Table 5" that all indicators have passed the diagnostic criteria. This shows that the initial water right allocation scheme of the Yellow River basin in "Table 2" is reasonable and feasible.

6. CONCLUSION

The research on the method of initial water rights allocation in river basin is the product of reflection and summary on the practice of initial water rights allocation in river basin. The practice of initial water rights allocation in river basins in China shows that the current practice of initial water rights allocation and management system reform in river basins in China conform to the international trend of water resources allocation and management. Facing the new situation of the green development concept of "water-based production" and the rigid constraints of water resources, the existing research on the allocation of initial water rights in river basins urgently needs to thoroughly implement the green development concept of "water based production", form a complete set of adaptive models for the optimization of initial water rights and industrial structure in river basins, and improve the adaptability of initial water rights and industrial structure optimization in river basins. In order to solve the problem of the optimization and adaptation of initial water rights and industrial structure in the basin, a framework for the optimization and adaptation of initial water rights and industrial structure in the basin is established based on the practice of initial water rights allocation in the basin. According to the "three-step" adaptive management idea of "adaptation scheme design based on adaptation mode - adaptation scheme diagnosis - adaptation scheme optimization", the study on the optimization and adaptation of initial water rights and industrial structure of the basin is carried out (see "Figure 1").

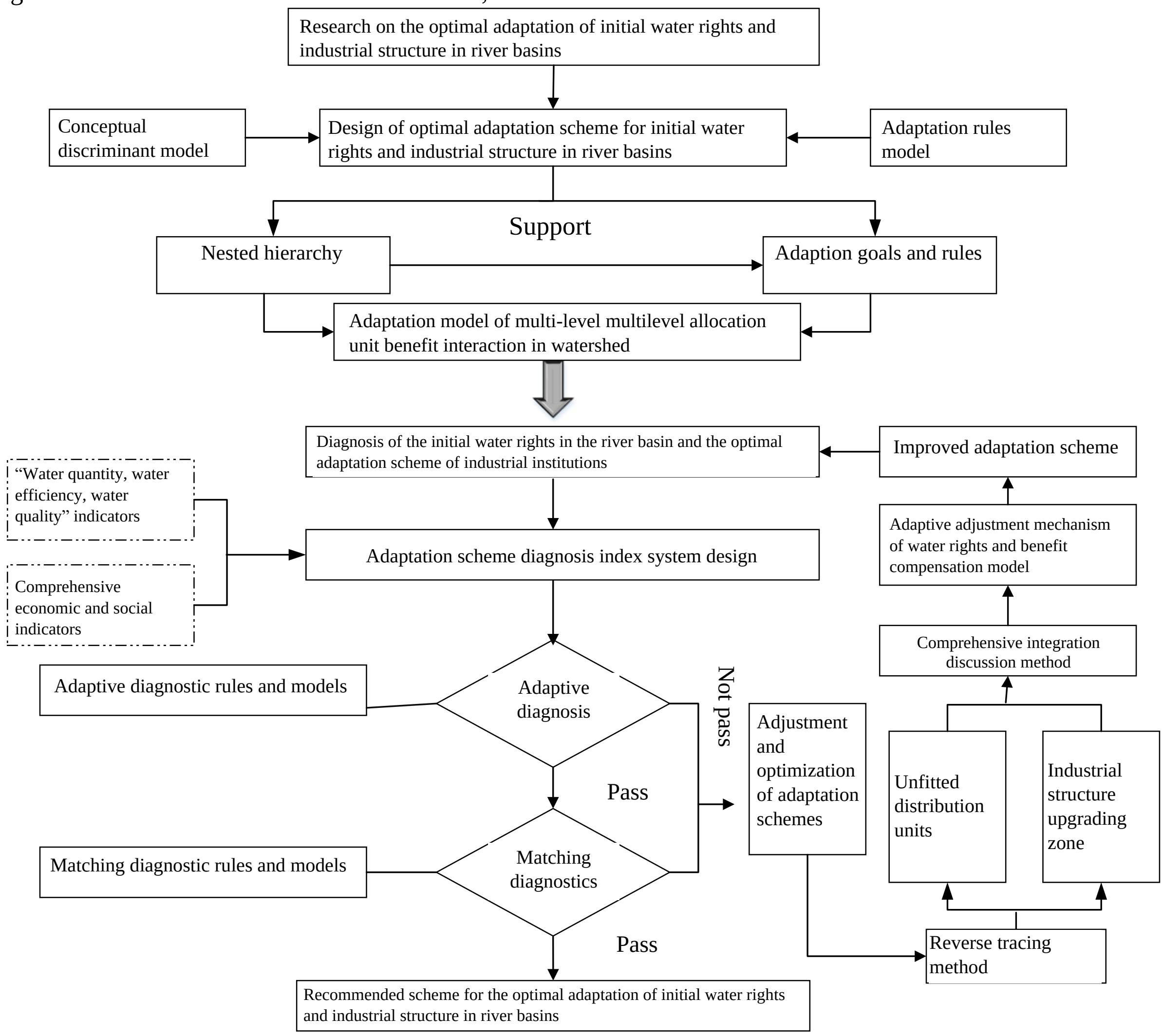

Figure 1 Research framework for the optimization and adaptation of initial water rights and industrial structure in the basin.

According to "Figure 1", the research on the optimization and adaptation of initial water rights and industrial structure of the basin is carried out according to the "three-step" adaptive management idea of "adaptation scheme design - adaptation scheme diagnosis - adaptation scheme optimization". First of all, it is quite necessary to implement the green development concept of "water-based production", build a conceptual discrimination model and rule model for the adaptation of initial water rights and industrial structure optimization, effectively determine the nested hierarchical structure and priority level for the adaptation of initial water rights and industrial structure optimization, determine the multi-level distribution units for the adaptation of initial water rights and industrial structure optimization according to local conditions, and define the adaptation mechanism and principle of multi-level and multi-layer allocation units in the watershed. It is also necessary to fully reflect the interest demands of multi-level and multi-level distribution units in the basin, establish an adaptation model for the benefit interaction of multi-level and multi-level distribution units in the basin, and design an optimal adaptation scheme for the initial water rights and industrial structure of the basin. Secondly, the "water quantity, water efficiency and water quality" indicators of the initial water right allocation of the basin cna be coupled with the comprehensive economic and social consideration indicators to construct a complete diagnosis system of the initial water right and industrial structure optimization adaptation scheme of the basin, including the adaptive diagnostic criteria of "basin region" level water rights allocation and high-quality economic development, and the matching diagnostic criteria of "region industry" level water rights allocation and economic and industrial structure optimization, to verify the feasibility and rationality of the initial water rights and industrial structure optimization adaptation scheme of the basin. Then, through the reverse tracking method, the root cause of the irrational diagnosis results of the adaptation scheme is explored. The circular coupling method of "adaptation scheme - diagnosis - adaptation adjustment - adaptation scheme" is adopted to establish the adaptive adjustment mechanism of water rights and benefit compensation model of multi-level distribution units in the basin, and adjust and optimize the designed initial water rights and industrial structure optimization adaptation scheme of the basin. Finally, by optimizing the existing initial water right allocation mode of the basin, the adaptability of the initial water right of the basin to the optimization of the industrial structure will be improved.

AUTHORS' CONTRIBUTIONS

Dan Wu is responsible for experimental design and writing the manuscript, and Mengyao Liu is responsible for data collection and writing the manuscript.

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