ISSN: 3082-8074 (O)
3082-8082 (P)

RESEARCH ARTICLE

Comprehensive assessment of China's water resources security based on AHP-CRITIC and research on influencing factors

Ziqin Guo

School of Statistics and Applied Mathematics，Anhui University of Finance & Economics，Bengbu 233030，China

ABSTRACT

In order to understand the level of China's water security, this paper selects 18 indicators from the aspects of natural endowment, economy, society and ecological environment to construct China's water resources security evaluation system. Firstly, the evaluation of China's water resource security from 2005 to 2020 shows that China's water resources were in a relatively dangerous state from 2005 to 2011, and the obstacles affecting water resource security were low economic development level and low natural endowment of water resources. After 2011, the level of water security gradually improved, and the transition to a relatively safe state was changed to a relatively safe state, and the obstacles at this stage were the level of social development and ecological environment. Secondly, the ARIMA (0, 1, 4) model is used to predict China's water security level from 2021 to 2025, and the results show that China's water security score increases year by year from 2021 to 2025. Finally, reasonable policy suggestions are put forward to further improve the level of China's water resources security.

Keywords: water security; AHP-CRITIC; ARIMA model; obstacle analysis

1. Introduction

Water resources are an indispensable natural resource for human survival and development, and an important resource for sustainable socio-economic development and healthy ecosystem development. In recent years, with the high-quality development of the economy and the deterioration of the ecological environment, the issue of water resource security has been raised to a new height. At present, the per capita water resources in China are relatively low, and there are still many provinces and cities whose per capita water resources are at an internationally recognized level of extreme water scarcity. It is urgent to clarify the factors affecting water resource security and improve the level of water resource security in China.

The evaluation of water resource security requires the selection of scientifically reasonable water resource security measurement indicators. In existing related research, the water resource security indicator system is mainly based on the water footprint theory and water poverty theory. Xing Xia et al. (2022) constructed a water resource security evaluation model for the Yellow River Basin based on the water footprint theory; Zhang Lili et al. (2022) analyzed and evaluated the water resource security status through water footprint intensity and water resource pressure indicators. Sun Caizhi and Zhang Zhixiong (2017) applied water ecological footprint and ecological carrying capacity to the field of water resource security evaluation, and calculated the water

ARTICLE INFO
Received: 3 March 2024 | Accepted: 26 March 2024 | Available online:

CITATION
Guo Z. Comprehensive assessment of China's water resources security based on AHP-CRITIC and research on influencing factors. . *Journal of Value Management* 2024; 1(1): XXXX. doi: 10.59429/jvm.v2i1.XXXX

pressure, water adaptation, and water security index of each province and city. Dai Wen et al. (2013) quantitatively evaluated the ecological security of water resources based on the ecological footprint theory, taking into account the ecological footprint of water resources, the ecological carrying capacity of water resources, and the ecological security of water resources. Chen Siyuan et al. (2021) and Cai Qingxin (2019) conducted research based on the theory of water poverty. In addition, some scholars have constructed an evaluation index system based on the comprehensive perspectives of water resources, ecological environment, and socio-economic factors, such as Jia Shou et al. (2022), Wu Lanzhen et al. (2022), Tang Lian et al. (2019), Huang Chuheng et al. (2019), and so on. In terms of evaluation methods, Chu Guihong (2020), Zhang Xiuyu et al. (2020), and Li Dan et al. (2022) used the Analytic Hierarchy Process to comprehensively evaluate water resource security. In order to make the indicator weights more objective, many scholars use a subjective and objective linear weighting method to comprehensively optimize the indicator weights and obtain more objective evaluation results. For example, Li Zhijun et al. (2021) used a fuzzy comprehensive evaluation method combining Analytic Hierarchy Process and Entropy Weight Method to comprehensively evaluate the water resource security in Jinan City; Wu Lanzhen et al. (2022) used a fuzzy matter element model based on entropy weight method and CRITIC coordinated weight to evaluate water resource security. In terms of research scope, most scholars have chosen a certain province or basin for water resource security research, such as Zhang Lili et al. (2022), Zhang Lifeng and Zhang Guoxing (2022), Zhang Yan et al. (2021), etc. The research scope is localized, and the research results cannot reflect the overall state of water resource security in China.

In summary, there have been certain research results on water resource security both domestically and internationally. However, most studies are based on a certain theory or indicators, and the selection of water resource security evaluation indicators is not comprehensive enough. Therefore, it is necessary to establish a more comprehensive water resource comprehensive security evaluation indicator system to evaluate the status and influencing factors of water resource security. This article comprehensively considers four aspects: natural endowment of water resources, economy, society, and ecological environment. It selects 18 indicators, including per capita total water resources, per capita GDP, and water consumption per 10000 yuan of GDP, to construct a water resource security evaluation index system and comprehensively evaluate China's water resource security. This article also conducts obstacle factor analysis on the factors that affect water resource security, providing policy ideas for further achieving sustainable development of water resources, enriching the research content of water resource security evaluation, and comprehensively understanding the status of water resource security in China.

2. Establishment of a comprehensive evluation system for water resource security in China

2.1. Establishment of evaluation index system

This article selects 18 evaluation indicators to construct a Chinese water resource security evaluation index system, as shown in **Table 1**. The data for each indicator is sourced from the China Statistical Yearbook from 2006 to 2021. Considering the impact of changes in GDP and industrial value added prices, the data related to GDP and industrial value added were processed at constant prices in 2005.

Table 1. 2005-2020 Descriptive statistics of China's water resources security evaluation index variables.

Variables	Mean	Standard deviation	Minimum value	Maximum value
Total water resources	27904.28	2557.72	23258.50	32466.40
Surface water resources	26826.08	2510.74	22215.20	31273.90
Groundwater resources	8035.45	456.15	7214.80	8854.80
Per capita water resources	2058.16	168.12	1730.40	2354.90
Per capita GDP	18238.73	2124.82	14006.53	20452.10
Industrial water use	1331.36	105.30	1030.40	1461.80
agricultural water	3733.16	106.75	3580.00	3921.50
Water consumption per 10000 yuan of GDP	243.10	20.45	217.37	284.80
10000 yuan industrial value-added water consumption	85.23	38.72	41.54	166.07
Total water supply	5981.06	149.41	5633.00	6183.40
Daily treatment capacity of urban sewage plants	14324.08	3522.78	7989.74	20405.10
Urban water usage penetration rate	94.52	6.83	71.90	98.78
Per capita domestic water consumption	57.09	5.96	47.81	66.32
Domestic water	776.05	61.42	675.10	871.70
Ecological environment water consumption	140.49	61.39	92.70	307.00
Green coverage rate in built-up areas	39.29	2.00	35.11	42.10
Completed investment in industrial wastewater treatment	1241911	421750	573852	1960722
Completed investment in industrial governance	6021129	1763216	3969768	9976511

From **Table 1**, it can be concluded that the average total water resources from 2005 to 2020 was 2790428 billion cubic meters. Among them, the surface water resources are relatively abundant, at 26826.08 billion cubic meters, while the groundwater resources are relatively scarce, at about 803.545 billion cubic meters. At the same time, the per capita water resources in China are relatively low, at about 205.816 billion cubic meters. The completed investment in industrial wastewater treatment is about 1241911 million yuan, accounting for about one-fifth of the completed investment in industrial treatment. In recent years, with the acceleration of the construction process of China's water supply network, the urban water use penetration rate has increased from 71.90% to 98.78%, and the urban water use penetration rate has rapidly increased.

Table 2. Comprehensive evaluation index system for water resources security in China.

Criterion layer	Indicator layer	Indicator properties
Natural endowment of water resources	Total water resources	Positive
	Per capita water resources	Positive
	Groundwater resources	Positive
	Surface water resources	Positive
Economic development	Per capita GDP	Positive
	Water consumption per 10000 yuan of GDP	Negative
	agricultural water	Negative
	Industrial water use	Negative
	Water consumption per 10000 yuan of IVA	Negative
Social development	Total water supply	Positive
	Domestic water	Negative
	Per capita domestic water consumption	Negative
	Urban water usage penetration rate	Positive
	Daily treatment capacity of urban sewage plants	Positive
Ecological environment	Ecological environment water use	Negative
	Green coverage rate in built-up areas	Positive
	Industrial pollution control completed investment	Positive
	Industrial wastewater completed investment	Positive
		Positive

2.2. Determination of weights

This article uses a combination of subjective and objective weighting methods to determine the final weight. The subjective weight is determined using the Analytic Hierarchy Process, while the objective weight is determined using the CRITIC objective weighting method.

Firstly, when determining the subjective weights, it is necessary to perform a consistency test on the weights of each evaluation indicator at each level. If the test result $CR \leq 0.1$, the judgment matrix passes the consistency test. At this time, the feature vector corresponding to the maximum eigenvalue is the weight vector, and normalization is performed to obtain the weights of each indicator. Secondly, considering the differences and correlations between indicators, the CRITIC method is selected to comprehensively measure the objective weights of the indicators. Finally, the subjective weights obtained from the Analytic Hierarchy Process and the objective weights obtained from the CRITIC method are linearly combined to obtain the final combined weights. (**Table 3**)

Table 3. AHP CRITIC evaluation index weights.

Target layer	Criterion layer	AHP weight	CRITIC weight	Combination weight	Evaluating indicator	AHP weight	CRITIC weight	Combination weight
Comprehensive evaluation of water resource security	Water resource endowment	0.4965	0.2696	0.3831	Total water resources	0.2720	0.0711	0.1716
					Per capita water resources	0.4829	0.0542	0.2686
					Groundwater resources	0.0882	0.0722	0.0802
					Surface water resources	0.1570	0.0721	0.1146
	Economic development system	0.2475	0.3641	0.3058	Per capita GDP	0.4192	0.0677	0.2435
					Water consumption per 10000 yuan of GDP	0.2571	0.0890	0.1731
					agricultural water	0.1521	0.0701	0.1111
					Industrial water use	0.1019	0.0676	0.0848
					Water consumption per 10000 yuan of IVA	0.0696	0.0697	0.0697
	Social development system	0.1052	0.1984	0.1518	Total water supply	0.4198	0.0518	0.2358
					Domestic water	0.1977	0.0516	0.1247
					Per capita domestic water consumption	0.2457	0.0174	0.1316
					Urban water usage penetration rate	0.0449	0.0167	0.0308
					Daily treatment capacity of urban sewage plants	0.0919	0.0609	0.0764
	Ecological Environment System	0.1509	0.1678	0.1594	Ecological environment water use	0.3022	0.0463	0.1743
					Green coverage rate in built-up areas	0.4005	0.0168	0.2087
					Industrial pollution control completed investment	0.1068	0.0597	0.0833
					Industrial wastewater completed investment	0.1905	0.0450	0.1178

The evaluation level of water resources is defined in **Table 4**.

Table 4. Water resource safety assessment levels.

Score	0-0.2	0.2-0.4	0.4-0.6	0.6-0.8	0.8-1.0
Security status	Very dangerous	Relatively dangerous	General	Relatively safe	Security

3. Research methods

3.1. Obstacle model

To better analyze the main factors affecting water resource security, identify the obstacle factors that cause lower levels of water resource security, and diagnose them. The main process of the obstacle model is:

(1) After determining the weights of each indicator, calculate the product of the weight of each evaluation indicator layer and the weight of the criterion layer, denoted as the F-value;

(2) According to the attribute of the indicators (positive or negative), standardize the original data (positive indicators: (X-min)/(max min), negative indicators: (max-X)/(max min)) to obtain the standardized value R';

(3) Calculate the obstacle level of the indicator layer:

$$P_j = \frac{F_j\left(1-R_j'\right)}{\sum_{j=1}^{n} F_j\left(1-R_j'\right)} \tag{1}$$

3.2. ARIMA prediction model

The ARIMA model is an autoregressive moving average model, and this article uses the ARIMA model to predict the trend of water resource security in China.

The modeling steps are shown in **Figure 1**.

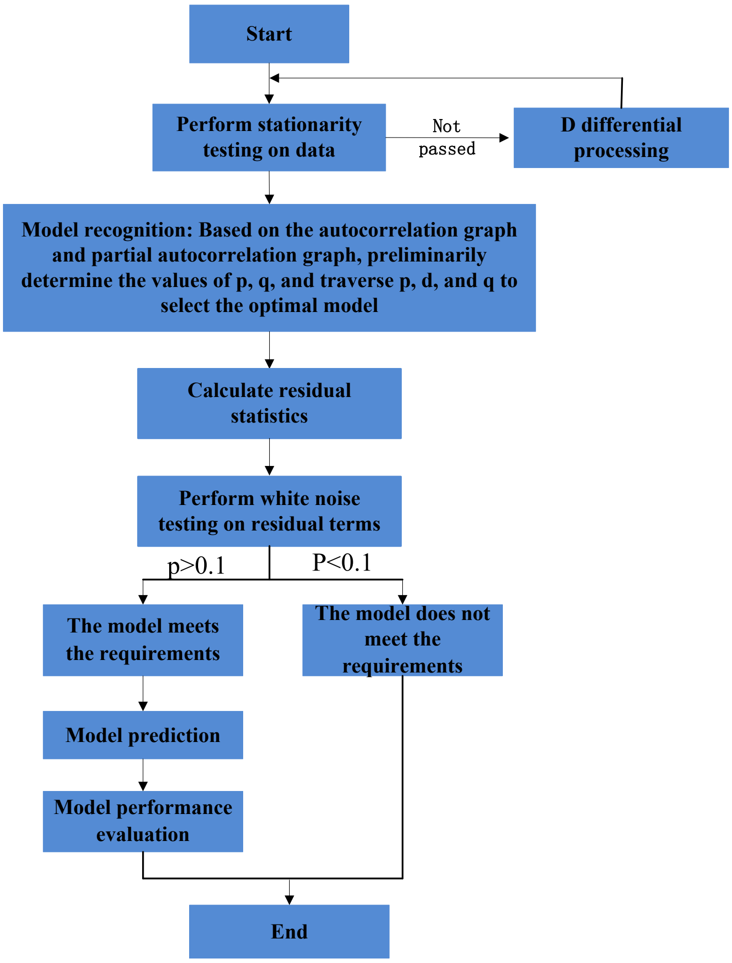

Figure 1. ARIMA modeling process.

4. Research results and analysis

4.1. Comprehensive evaluation results and analysis of water resource security in China

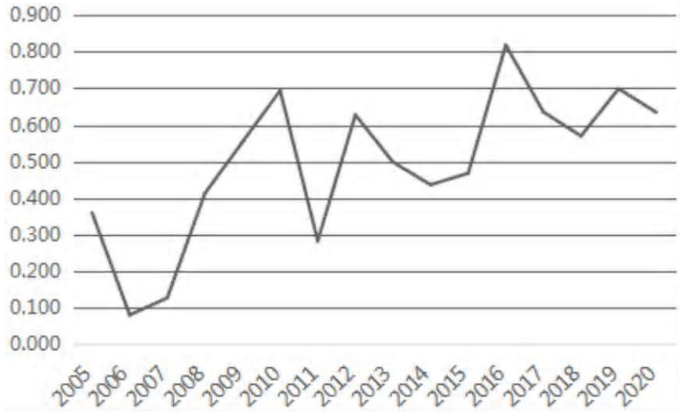

Figure 2. 2005-2020 Comprehensive evaluation score of water resources security in China.

From **Figure 2**, it can be seen that China's water resource security showed a constantly fluctuating state from 2005 to 2020. From 2006 to 2010, China's water resource security score increased year by year, but decreased in 2011. China's water resources were in a relatively dangerous state that year, and since 2011, the water resource security status has begun to improve, breaking away from the dangerous state and tending towards a general safe state. However, there is still some room for improvement from a relatively safe state. Below, an obstacle analysis will be conducted on China's water resource security status from 2005 to 2020. (**Table 5**)

Table 5. Score of comprehensive water resources security assessment in China from 2005 to 2020.

Year	Score	Security status	Year	Score	Security status
2005	0.359	Relatively dangerous	2013	0.498	Commonly
2006	0.080	Very dangerous	2014	0.436	Commonly
2007	0.127	Very dangerous	2015	0.468	Commonly
2008	0.413	Commonly	2016	0.818	Security
2009	0.554	Commonly	2017	0.635	Relatively safe
2010	0.694	Commonly	2018	0.570	Commonly
2011	0.283	Relatively dangerous	2019	0.699	Relatively safe
2012	0.627	Relatively safe	2020	0.634	Relatively safe

From **Figure 3**, it can be seen that the main obstacle factors affecting China's water resource security from 2005 to 2015 are the level of economic development and the natural endowment of water resources, while the impact of social development level and ecological environment status on water resource security is relatively low. Overall, from 2005 to 2015, China's water resource security value was relatively low and in a relatively dangerous state. From 2015 to 2020, social development and ecological environment were the main obstacles affecting water resource security.

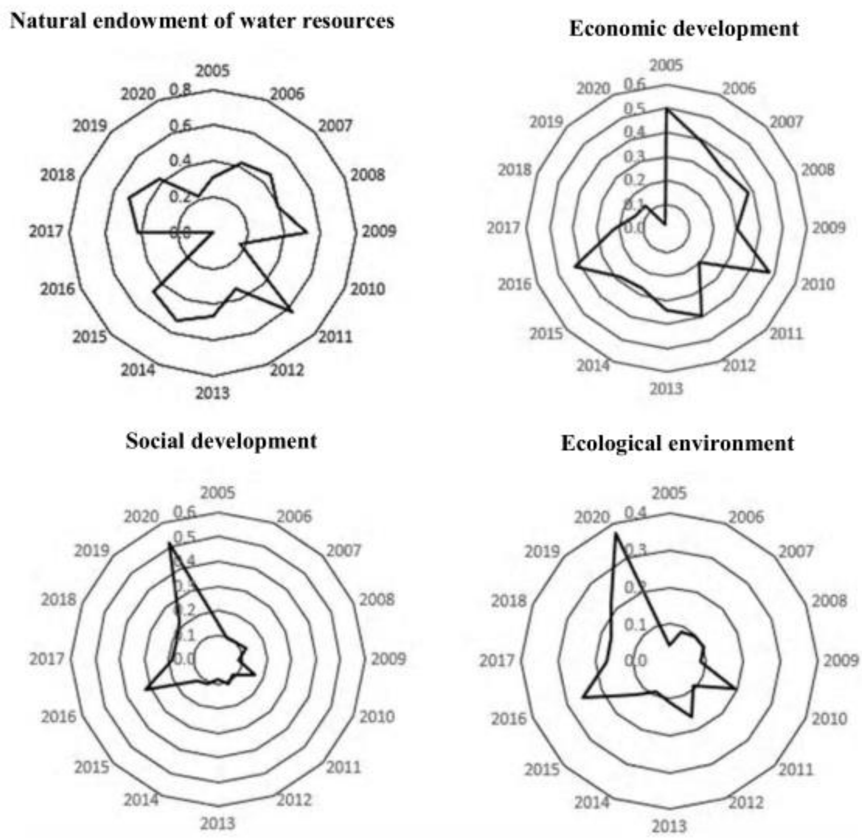

Figure 3. 2005-2020 Changes in barrier degree of comprehensive evaluation criteria for water resources security in China.

Table 6. 2005-2020 Obstacles to China's water resources security evaluation indicators.

Year	Natural endowment of water resources	Economic development	Social development	Ecological environment	Maximum obstacle factor in the criterion layer
2005	0.2168	0.4451	0.2665	0.0716	economic development
2006	0.3108	0.3600	0.1803	0.1489	economic development
2007	0.3320	0.3150	0.1868	0.1662	Natural resource endowment
2008	0.2782	0.3371	0.2159	0.1688	economic development
2009	0.3970	0.2873	0.1650	0.1507	Natural resource endowment
2010	0.0991	0.3642	0.2536	0.2832	economic development
2011	0.4765	0.1915	0.1645	0.1675	Natural resource endowment
2012	0.2240	0.3314	0.1826	0.2619	economic development
2013	0.3418	0.3099	0.1534	0.1949	Natural resource endowment
2014	0.3870	0.2489	0.2040	0.1601	Natural resource endowment
2015	0.3255	0.2469	0.2170	0.2106	Natural resource endowment
2016	0.0001	0.2715	0.4179	0.3107	social development
2017	0.2667	0.1750	0.2999	0.2583	social development
2018	0.3238	0.1150	0.3015	0.2597	Natural resource endowment
2019	0.2529	0.0986	0.3280	0.3205	social development
2020	0.1031	0.0119	0.4609	0.4241	social development

From **Table 6**, it can be seen that the criteria layers that have the greatest impact on China's water resource security from 2005 to 2020 are different. Among them, the maximum obstacle criteria layers from 2005 to 2006, 2008, 2010, and 2012 represent the level of economic development, while the maximum obstacle criteria layers from 2007, 2009, 2011, 2013 to 2015, and 2018 represent the natural endowment of water resources. The maximum obstacle criteria layers from 2016, 2017, and 2019 to 2020 represent the level of social development. Further research and analysis of Figure 2 reveals that the natural endowment of water resources and the level of economic development gradually reduce the obstacles to China's water resource security, while the level of social development and ecological environment system gradually increase the obstacles to China's water resource security. It can be seen that under a certain level of water resource endowment, with high-quality economic development, the demand and utilization of water resources by social development, as well as changes in the ecological environment, have an increasing impact on China's water resource security. It is necessary to implement policies and measures that are more conducive to water resource security for social development and ecological environment protection, and further improve the level of water resource security.

4.2. Prediction results and analysis of China's water resource security score

Firstly, it is determined that d=1. As the original time series is non-stationary, a first-order difference is applied to transform it into a stationary random sequence; Secondly, p and q are determined based on autocorrelation maps, partial autocorrelation maps, and information criterion values;

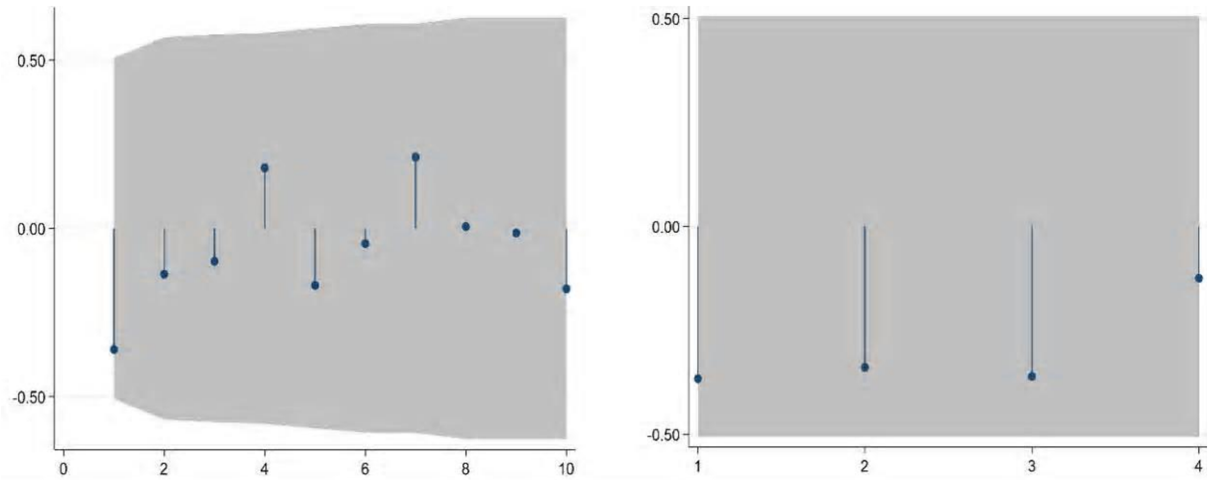

Figure 4. Autocorrelation (left) and partial autocorrelation (right).

From **Figure 4**, it can be seen that the ACF plot has tails in the 2nd and 4th orders, while the PACF plot has tails in the 4th order, so the p-value can be taken as 2 or 4; The q value can be taken as 4. In order to find the optimal prediction model, further judgments will be made based on information criteria below.

According to the information criterion values in **Table 7**, the final model is determined as ARIMA (0, 1, 4), and the calculated residual statistical value is 1.6476 (P=0.8002>0.1). The model meets the requirements and can be used to predict the water resource security status in China from 2021 to 2025.

Table 7. Information criteria for different p and q values.

（p，q）	AIC	BIC
（0，4）	-5.3921	2.5599
（2，0）	0.1162	2.9484
（4，0）	1.8216	6.0699

By comparing the predicted curve of the ARIMA (0, 1, 4) model with the actual curve, it can be seen that the trend of the predicted curve is the same as the actual curve. Overall, the curve shows an upward trend. Except for a few years, such as 2012, the error between the predicted and actual values is small, indicating that the predicted results of the model have a certain degree of credibility. Using the comprehensive evaluation scores of China's water resources security from 2005 to 2020, the water resources security scores for 2021-2025 are predicted. Combined with **Figure 5** and **Table 8**, it can be concluded that the predicted water resources security scores are increasing year by year, with the security scores mainly concentrated in the range of (0.6 to 0.8), showing an overall upward trend and being in a relatively safe state.

Table 8. 2021- Predictive scores for China's water resources security status in 2025.

Year	2021	2022	2023	2024	2025
Predicted score	0.661	0.687	0.713	0.740	0.766
The safety status is relatively safe	Relatively safe	Relatively safe	Relatively safe	Relatively safe	Relatively safe

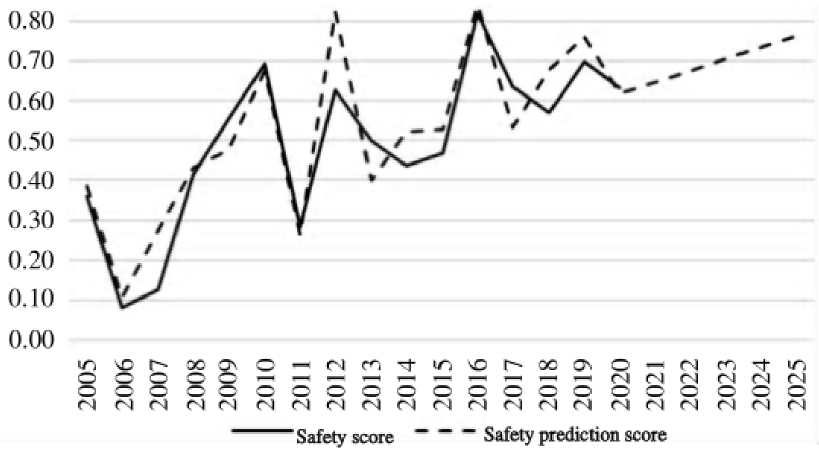

Figure 5. 2021- Prediction of China's water resources security status in 2025.

5. Conclusion and suggestions

5.1. Conclusion

This article constructs a comprehensive evaluation index system for water resource security in China from four aspects: water resource quantity, economic development, social development, and ecological environment. The evaluation results show that the water resource security level in China fluctuated continuously from 2005 to 2020, gradually transitioning from an early very dangerous state to a relatively safe state. From the perspective of the comprehensive evaluation criteria layer of water resource security, the criteria layer that has a significant impact on water resource security in the early stage is the natural endowment of water resources and the level of economic development. The per capita water resources, per capita GDP, and agricultural water use in the indicator layer are the obstacle factors affecting water resource security; The criterion layer that has a significant impact on water resource security in the later stage is the level of social development and the ecological environment system. Among them, the total water supply, per capita domestic water use, green coverage in built-up areas, and investment completion in industrial wastewater treatment in the indicator layer are the main obstacles affecting water resource security. Using the comprehensive evaluation scores of China's water resource security from 2005 to 2020, an ARIMA (0,1,4) model was established to predict the water resource security status in China from 2021 to 2025. The prediction results showed that China's water resources will be at a relatively safe level in the next five years, with an overall upward trend.

5.2. Suggestions

In order to further improve the level of water resource security and modern governance in China, and promote the construction of a beautiful ecological civilization in China, the following suggestions are proposed based on the research results of this article: to further strengthen the construction of the national water security guarantee and modern water governance system in the new era, and to focus on promoting precise and deep water conservation and balanced water resource allocation under the guidance of the central water control policy. In terms of natural endowment of water resources, we will comprehensively strengthen the management and protection of groundwater and surface water, and promote sustainable utilization of groundwater. In terms of ecological environment systems, we should follow natural laws, prioritize the maintenance of river ecological health, reduce the contradiction between regional water resource development and utilization and the carrying capacity of watershed water systems, clarify the boundaries and thresholds of various water activities, and build a "protection line" of green water and green mountains. In terms of economic development, it is necessary to adjust the structure of economic development, scientifically plan the layout of industries and productivity, and comprehensively solve the contradiction between economic development and water resource carrying capacity. In terms of social development, it is necessary to improve the supporting facilities for urban and rural water use, drainage, and other aspects, enhance the quality of urban functions, adhere to the concept of green development, and fully mobilize social forces to participate in the construction of a water-saving society.

Funding

Anhui University of Finance and Economics Graduate Research Innovation Fund Project (ACYC2020, 261).

References

1. Li Dan, Mao Yuxin, Chen Linlin, et al. Research on Comprehensive Evaluation of Water Resources Security in Linyi City [J]. China Rural Water Resources and Hydropower, 2022 (03): 75-79
2. Li Zhijun, Yao Rong, Wang Tao, et al. Evaluation of Water Resources Security in Xi'an City Based on AHP Entropy Weight Method and Fuzzy Model [J]. Water Resources Science and Economics, 2022, 28 (05): 1-5
3. Huang Dechun, Wu Xiaoqing, Li Jinqiu. Measurement and spatiotemporal evolution of inter provincial water resources energy food security in China [J]. Water Conservancy Economics, 2022, 40 (03): 48-53, 92, 94-95
4. Zhang Lifeng, Zhang Guoxing. Research on Water Resource Security Evaluation of Central Cities in the Yellow River Basin [J]. Hydroelectric Energy Science, 2022, 40 (03): 55-58
5. Ren Xiaoxiao, Niu Chengying. Evaluation of Water Resources Security and Diagnosis of Obstacle Factors in the Qilian Mountains Inland River Basin [J]. Journal of Hubei Normal University (Natural Science Edition), 2021, 41 (03): 42-49
6. Chu Guihong. Comprehensive evaluation of water security in Shanxi Province based on Analytic Hierarchy Process [J]. Water Resources Development and Management, 2020 (10): 76-80
7. Jing Jiangnan, Wu Lanzhen, Sun Dongyuan, et al. Research on Water Resources Security Evaluation in Tianshui City Based on Comprehensive Weights [J]. Water Resources Planning and Design, 2020 (09): 20-24
8. Wu Lanzhen, Sun Dongyuan, Zhao Xia, et al. Research on water resource security evaluation in the Shule River Basin [J]. China Rural Water Resources and Hydropower, 2020 (09): 84-89, 94
9. Tang Lian, Liu Zixi, Qi Yarong. Comprehensive Evaluation of Water Resources Security in Ningxia [J]. Journal of Safety and Environment, 2019, 19 (05): 1810-1816
10. Huang Chuheng, Jiang Zhiyun, Yang Zhiguang, et al. Water resource security evaluation and influencing factor analysis in Guangdong Province based on entropy method and analytic hierarchy process [J]. Journal of Water Resources and Water Engineering, 2019, 30 (05): 140-147
11. Liang Yuanyi, Lv Aifeng. Risk assessment of water resources security in China [J]. Resource Science, 2019, 41 (04): 775-789

12. Liu L. Assessment of water resource security in karst area of Guizhou Province, China[J]. Scientific Reports, 2021, 11(1).
13. Zhang Z Y, Hu A Y. Construction method and application of water environment security assessment system in Taizhou bay of Zhejiang province [J]. Journal of Environmental Protection and Ecology, 2018, 19(2):515-526.
14. Zhou F, Su W, Zhang F. Influencing Indicators and Quantitative Assessment of Water Resources Security in Karst Region Based on PSER Model-The Case of Guizhou. 2019.