

Evaluation of Industrial Water Use Efficiency in Jiangsu and Shandong Provinces of China Based on Single-Index Method

Bo Feng¹, Baodeng Hou^{2,*}

¹College of Environmental Science and Engineering, North China Electric Power University, Beijing 102206, China

²State Key Laboratory of Water Cycle and Water Security, China Institute of Water Resources and Hydropower Research, Beijing 100038, China

* Corresponding Author

Abstract

With the advancement of industrialization, industrial water use efficiency has become a core issue in global water resources management and sustainable development. Evaluation of industrial water use efficiency in China involves multiple dimensions, among which single-index method and multi-index system method are the most commonly used. This paper compared the industrial water use efficiency of Jiangsu and Shandong provinces, adopted the single-index method for calculation and analysis, and assessed the applicability of different single indices in reflecting regional industrial water use efficiency. The results show significant differences in industrial water use efficiency between the two provinces. Jiangsu achieves overall higher industrial water use efficiency with strong stability in both water consumption and water intake per 10⁴ yuan of industrial added value. Shandong, dominated by heavy chemical industries and facing severe water resources constraints, has improved its water use efficiency in recent years through the application of water-saving technologies and industrial structure adjustment. Through comparative analysis and consistency tests, this paper proposed industrial water use efficiency evaluation methods suitable for different regions, providing a scientific basis for the formulation of regional water-saving policies.

Keywords

Single-index method, Industrial water use efficiency, Water resources endowment, Industrial structure.

1. Introduction

Water resources are a critical natural foundation supporting human survival and socioeconomic development, and play an indispensable role in promoting sustainable social progress [1]. However, China faces a severe water shortage situation, with a per capita water availability of approximately 2,300 m³, less than one-third of the global average. As a pillar industry of the national economy, industry is a major consumer of water resources. In China, industrial water consumption accounted for about one-sixth of the total national water use in 2024, reaching 96.83 billion m³. With the continuous advancement of industrialization and urbanization, the scale of industrial water use has been expanding, leading to increasingly prominent contradictions between water supply and demand, and the constraining effect of water resources on socioeconomic development has gradually emerged [2]. To improve the intensive and economical utilization of water resources and support high-quality and sustainable socioeconomic development, the core concept of industrial water use efficiency has been systematically proposed and refined. Industrial water use efficiency refers to the ability to achieve maximum product output, economic benefits and service value with minimum water

resources input in an industrial production system. It is quantified by three core dimensions: water consumption intensity per unit industrial output, water recycling efficiency and water loss rate, and serves as a key index for measuring the sustainable utilization level of water resources in industrial systems. Improving industrial water use efficiency is a critical path to resolve the contradiction between water supply and demand, reduce water consumption costs in industrial production, and promote the green and low-carbon transformation of industries. Therefore, conducting research on the calculation of industrial water use efficiency is of great significance for promoting the coordinated and sustainable development of the socioeconomic system and the water environment.

Internationally, a mature methodological framework has been established for measuring industrial water use efficiency, which can be divided into two categories: index system method and single-index method [3]. The single-index method requires less data integrity and diversity, avoids complex data collection and integration processes, and effectively reduces the time and labor costs of data acquisition. National and local water-saving policies often set assessment standards based on single indices, facilitating policy implementation and supervision by enterprises and regulatory authorities. Common indices used in the single-index method include water intake per 10^4 yuan of added value, water intake per unit product, and water consumption per 10^4 yuan of industrial added value. Previous studies [4] evaluated the industrial water use efficiency of eight major water-intensive industries in China, and found that the water intake per 10^4 yuan of industrial added value method is applicable to horizontal and vertical comparisons of comprehensive industrial water use efficiency among different regions, while the water intake per unit product method is more suitable for benchmarking analysis of production water levels and industrial water quota management of similar industrial products. In a field investigation on the water utilization status of two paperboard manufacturing enterprises in Dongguan City, relevant research [5] found that the water intake per unit product index can effectively reflect the industrial water use efficiency at the enterprise level. The calculation results have reached the advanced industry level and are close to the international advanced level, indicating that this index has strong applicability and comparability in industry segmentation and enterprise benchmarking analysis. For the industrial water use efficiency in Guizhou Province, research [6] analyzed its evolution characteristics from 2018 to 2023, and concluded that the water consumption per 10^4 yuan of industrial added value method is suitable for comprehensively evaluating the overall water-saving level and temporal changes of regional industrial water use efficiency, especially for analyzing the driving effects of extreme drought events on regional industrial water-saving transformation and efficiency improvement.

China's water resources show a significant spatial imbalance of "abundant in the southeast and scarce in the northwest", accompanied by huge disparities in regional industrial development patterns and water resource constraints. As two major industrial provinces in eastern China, Jiangsu and Shandong represent two typical development models: a manufacturing-led model in the water-abundant southern region and a heavy chemical industry-led model in the water-scarce northern region, making them ideal control samples for assessing the applicability of single-index evaluation methods. However, differences in the focus of various single indices tend to cause deviations in evaluation results, and existing studies lack sufficient index comparison and consistency tests against official bulletin data for such typical control regions. Therefore, this paper takes Jiangsu and Shandong as the study areas, selects typical single indices to calculate industrial water use efficiency, conducts consistency tests against the China Water Resources Bulletin [7], and screens evaluation methods adapted to regional characteristics, aiming to provide a scientific basis for the formulation of regional industrial water-saving policies and optimal allocation of water resources.

2. Data and Methods

2.1. Study Area Overview

Jiangsu and Shandong provinces are selected as the study areas for industrial water use efficiency evaluation. Both are major industrial provinces in eastern China with leading industrial economic scales, forming a sharp contrast in water resources endowment and industrial structure, which makes them typical samples for studying the applicability of single-index evaluation. Located in the core area of the lower Yangtze River, Jiangsu covers a land area of 107,200 km², has a subtropical monsoon climate with an annual average precipitation of about 1,000 mm, and a dense water network. It has a complete manufacturing system, and its industrial water use efficiency has long been higher than the national average. Shandong is located in the lower Yellow River region, covering a land area of 155,800 km², with a temperate monsoon climate and an annual average precipitation of about 600 mm, which is extremely uneven in spatial and temporal distribution. Its per capita water availability is less than one-sixth of the national average, making it a typical resource-based water-scarce province in northern China. Dominated by heavy chemical industries with a high proportion of water-intensive sectors, Shandong has an urgent demand for industrial water-saving transformation and efficiency improvement.

2.2. Industrial Water Use Efficiency Indices

2.2.1. Water Consumption per 10⁴ Yuan of Industrial Added Value (m³)

From the perspective of the correlation between economy and water use, water consumption per 10⁴ yuan of industrial added value reflects the total water consumed to generate 10⁴ yuan of industrial added value. A lower value indicates higher industrial water use efficiency. The calculation formula is:

$$\text{Water consumption per } 10^4 \text{ yuan of industrial added value} = \frac{\text{Annual total industrial water consumption}}{\text{Annual industrial added value}}$$

where annual total industrial water consumption refers to all water used in the annual production process of enterprises, including water intake and recycled water, in m³; annual industrial added value refers to the final results of industrial production activities expressed in monetary form during the reporting period, in 100 million yuan.

2.2.2. Water Intake per 10⁴ Yuan of Industrial Added Value (m³)

Water intake per 10⁴ yuan of industrial added value reflects the fresh water withdrawn from external water sources to generate 10⁴ yuan of industrial added value. A lower value indicates higher industrial water use efficiency. The calculation formula is:

$$\text{Water intake per } 10^4 \text{ yuan of industrial added value} = \frac{\text{Annual water intake}}{\text{Annual industrial added value}}$$

where annual water intake refers to the fresh water obtained by enterprises from external water sources, excluding recycled water, in m³; annual industrial added value is the same as above.

2.2.3. Water Consumption per 10⁴ Yuan of GDP

From the perspective of coordinated development of regional economy and water resources, water consumption per 10⁴ yuan of GDP reflects the total water consumed to generate 10⁴ yuan

of gross domestic product. A lower value indicates higher intensive utilization level of regional water resources and better decoupling degree between economic development and water consumption. It is the core assessment index for the water use efficiency control red line in China's strictest water resources management system and the official comprehensive water use efficiency benchmark index published in the China Water Resources Bulletin. The calculation formula is:

$$\text{Water consumption per } 10^4 \text{ yuan of GDP} = \frac{\text{Annual total regional water consumption}}{\text{Annual gross domestic product (GDP)}}$$

where annual total regional water consumption refers to the total water withdrawn by various water users outside river channels in the region, including agricultural water, industrial water, domestic water and artificial ecological water replenishment, in m^3 ; annual GDP refers to the final results of production activities of all national economic sectors in the region expressed in monetary form during the reporting period, in 10^4 yuan.

2.2.4. Industrial Water Productivity

From the perspective of economic output per unit water resources input, industrial water productivity reflects the industrial economic added value created per cubic meter of industrial water. A higher value indicates better output efficiency per unit water resources input and higher industrial water use efficiency. The calculation formula is:

$$\text{Industrial water productivity} = \frac{\text{Annual industrial added value}}{\text{Annual total industrial water consumption}}$$

where annual industrial added value is in yuan; annual total industrial water consumption is in m^3 .

2.2.5. Decrease Rate of Water Consumption per 104 Yuan of Industrial Added Value (%)

From a dynamic perspective, the decrease rate measures the annual change trend of water consumption per 10^4 yuan of industrial added value. A larger decrease rate indicates more significant improvement in industrial water use efficiency. The calculation formula is:

$$\text{Decrease rate} = \left(1 - \frac{\text{Water consumption in reporting period}}{\text{Water consumption in base period}} \right) \times 100\%$$

where water consumption in reporting period/base period refers to the average water consumption per 10^4 yuan of industrial added value in the reporting/base period, in m^3 .

2.3. Consistency Analysis Methods

To compare the applicability of different single indices in industrial water use efficiency evaluation, this paper analyzes the consistency of regional efficiency rankings obtained by different indices based on the calculated results. By examining the correlation and coordination among the evaluation results of different indices, this paper judges whether different indices can consistently reflect industrial water use efficiency, providing a basis for index selection. Three methods are adopted: ranking comparison method, Spearman rank correlation analysis and Kendall's coefficient of concordance.

2.3.1. Ranking Comparison Method

Ranking comparison method is an intuitive method to analyze the differences in evaluation results of different indices. First, regions are ranked according to the industrial water use efficiency values calculated by each single index, and the efficiency ranking results under different indices are formed. By comparing the ranking changes of each region under different indices, the degree of difference in evaluation results of different indices can be intuitively reflected. If the ranking difference of a region under different indices is small, it indicates that the evaluation results of different indices for the industrial water use efficiency of this region are relatively consistent; on the contrary, if the ranking changes greatly, it indicates that there are certain differences in the evaluation results of different indices. By comparing the ranking changes of each region, the consistency characteristics of the evaluation results of different indices can be preliminarily judged.

2.3.2. Spearman Rank Correlation Analysis

Spearman rank correlation coefficient is a commonly used non-parametric statistical method for measuring the correlation between the rankings of two variables. It judges the consistency degree of evaluation results of different indices by comparing the correlation between the regional efficiency rankings obtained by different indices. The calculation formula of Spearman rank correlation coefficient is:

$$r_s = 1 - \frac{6 \sum d_i^2}{n(n^2 - 1)}$$

where r_s is the Spearman rank correlation coefficient; d_i is the ranking difference of the same region under two indices; n is the number of research objects. When r_s is close to 1, it indicates that the evaluation results of the two indices have high consistency; when r_s is close to 0, it indicates that the correlation between the two indices is weak. By calculating the Spearman correlation coefficient between different indices, the correlation degree of the evaluation results of each index can be quantitatively analyzed.

2.3.3. Kendall's Coefficient of Concordance

Kendall's coefficient of concordance (W) is a statistical index for measuring the overall consistency of rankings from multiple evaluation indices, which can reflect the overall coordination degree of the evaluation results of multiple indices. The calculation formula is:

$$W = \frac{12S}{m^2(n^3 - n)}$$

where W is Kendall's coefficient of concordance, with a value range of 0–1; m is the number of evaluation indices; n is the number of research objects; S is the sum of squared deviations of the total ranking sums of each evaluation object. When W is closer to 1, it indicates higher consistency of the ranking results obtained by different indices; when W is closer to 0, it indicates lower consistency of the evaluation results of different indices. By calculating Kendall's coefficient of concordance, the overall consistency of multiple single indices in industrial water use efficiency evaluation can be comprehensively evaluated, so as to provide a reference for determining a more reasonable evaluation index.

3. Results and Discussion

3.1. Results and Comparison of Different Methods

The 2015–2024 data of the five industrial water use efficiency indices for Jiangsu and Shandong provinces are presented in Table 1 and Table 2, and the comparative trends of each index between the two provinces are illustrated in Figures 1–5.

Table 1. Industrial Water Use Efficiency Indices of Jiangsu Province (2015–2024)

Year	Water Consumption per 10 ⁴ Yuan of Industrial Added Value (m ³)	Water Intake per 10 ⁴ Yuan of Industrial Added Value (m ³)	Decrease Rate of Water Consumption per 10 ⁴ Yuan of Industrial Added Value (%)	Industrial Water Productivity (yuan/m ³)	Water Consumption per 10 ⁴ Yuan of GDP (m ³)
2015	59.2	34.6	-	168.92	64.2
2016	55.7	31.7	5.91	179.53	59.7
2017	52.3	28.8	6.10	191.20	54.9
2018	49.1	25.8	6.12	203.67	50.3
2019	46.5	22.6	5.29	215.05	45.9
2020	40.6	20.8	12.69	246.31	42.9
2021	39.2	19.0	3.45	255.10	40.1
2022	37.5	17.8	4.34	266.67	37.9
2023	35.8	16.0	4.53	279.33	35.0
2024	50.9	14.3	-42.18 (Base period adjustment)	196.46	32.6

Table 2. Industrial Water Use Efficiency Indices of Shandong Province (2015–2024)

Year	Water Consumption per 10 ⁴ Yuan of Industrial Added Value (m ³)	Water Intake per 10 ⁴ Yuan of Industrial Added Value (m ³)	Decrease Rate of Water Consumption per 10 ⁴ Yuan of Industrial Added Value (%)	Industrial Water Productivity (yuan/m ³)	Water Consumption per 10 ⁴ Yuan of GDP (m ³)
2015	78.5	46.1	-	127.39	55.9
2016	74.2	42.3	5.48	134.77	51.2
2017	69.8	38.6	5.93	143.27	46.8
2018	65.3	34.9	6.45	153.14	42.6
2019	60.7	31.3	7.04	164.74	38.8
2020	56.2	28.2	7.41	177.94	35.8
2021	53.6	25.5	4.63	186.57	33.0
2022	51.4	23.7	4.10	194.55	30.6
2023	49.1	21.8	4.47	203.67	28.5
2024	47.2	19.9	3.87	211.86	26.7

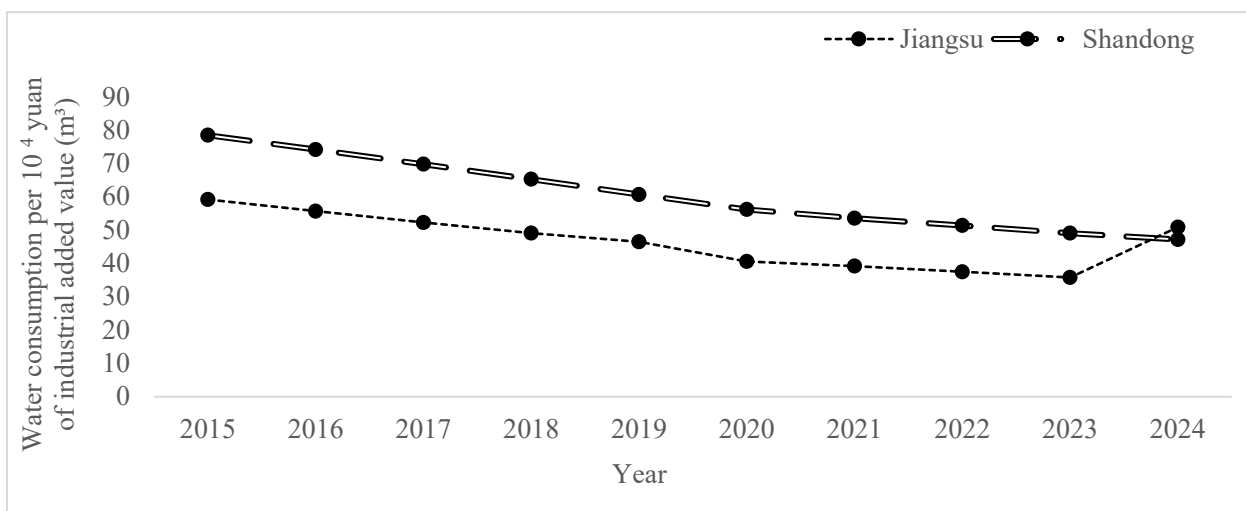


Figure 1. Water Consumption per 10⁴ Yuan Industrial Added Value in Jiangsu and Shandong Provinces (2015–2024)

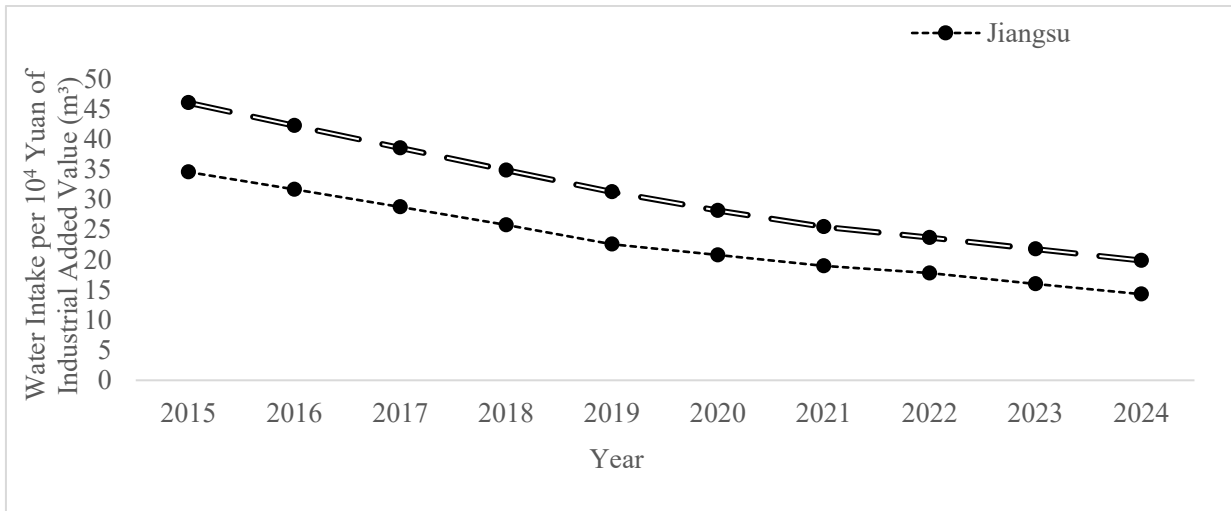


Figure 2. Water Intake per 10⁴ Yuan Industrial Added Value in Jiangsu and Shandong Provinces (2015–2024)

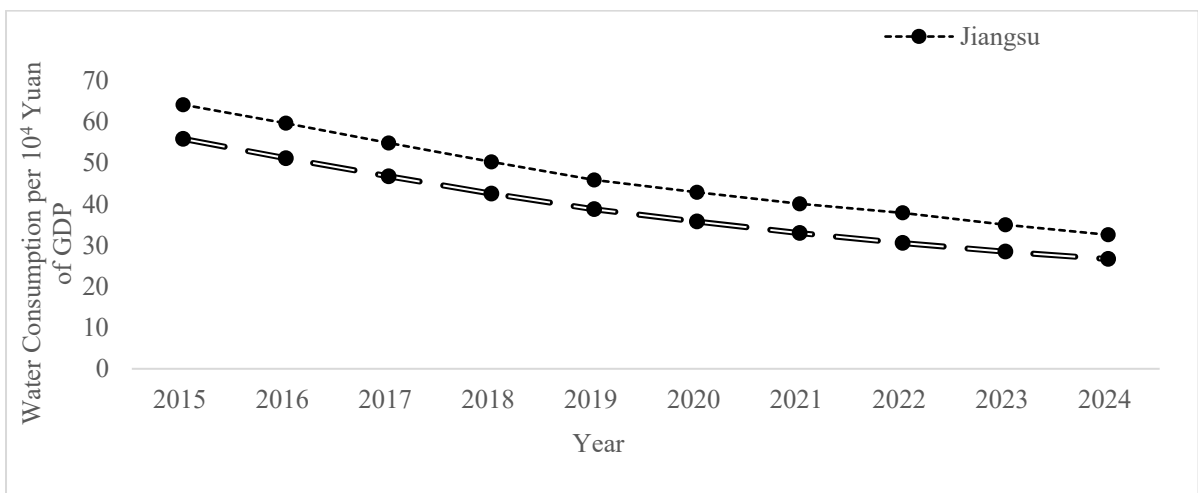


Figure 3. Water Consumption per 10⁴ Yuan of GDP in Jiangsu and Shandong Provinces (2015–2024)

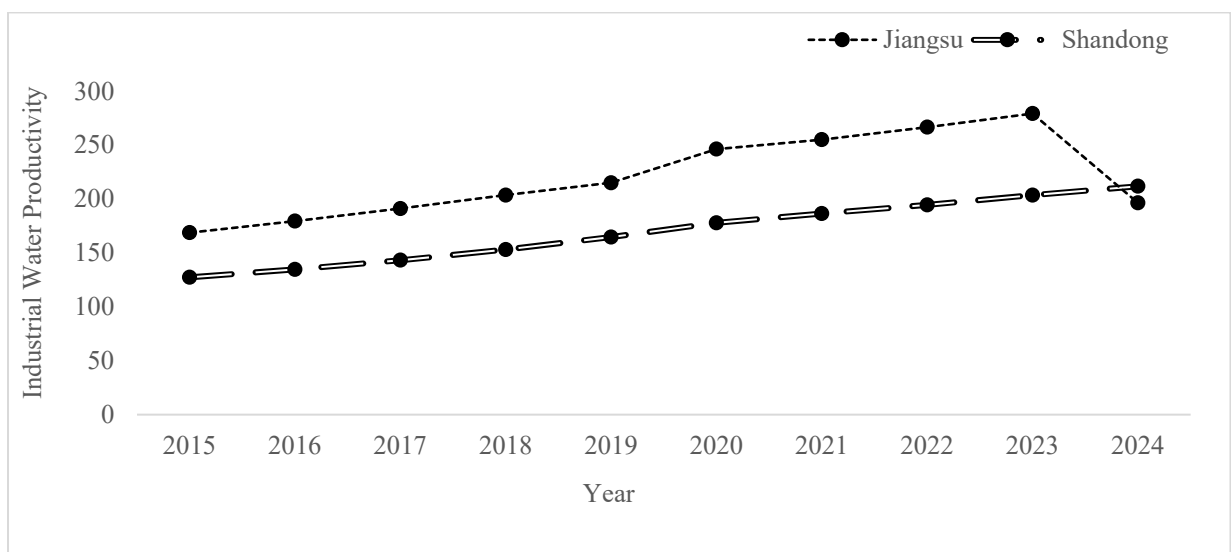


Figure 4. Industrial Water Productivity in Jiangsu and Shandong Provinces (2015–2024)

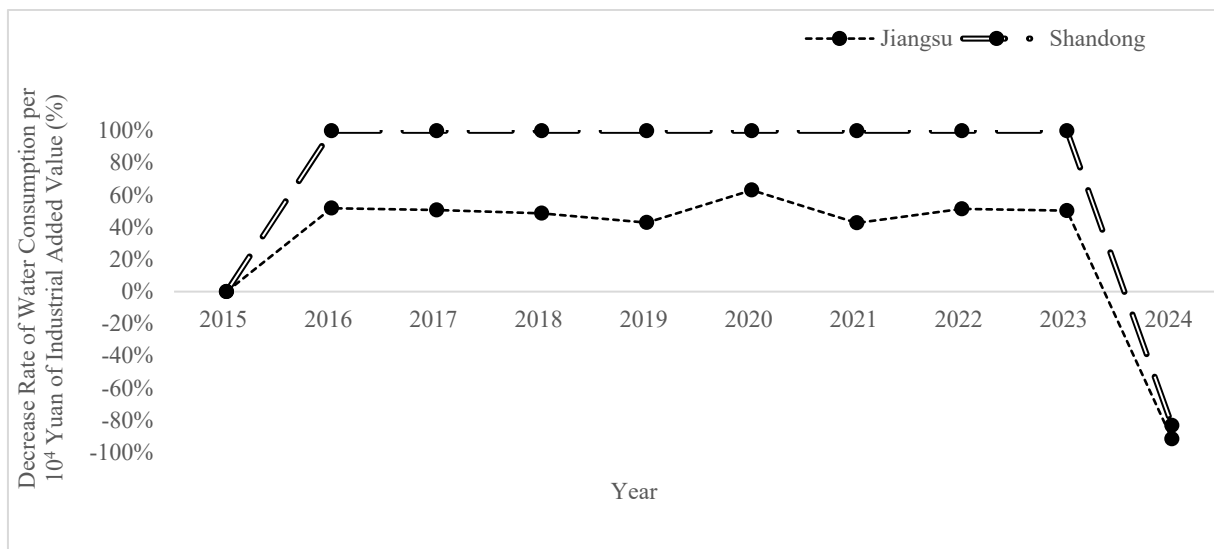


Figure 5. Decrease Rate of Water Consumption per 10⁴ Yuan Industrial Added Value in Jiangsu and Shandong Provinces (2015–2024)

3.1.1. Overall Temporal Trends of the Two Provinces

From a temporal perspective, the industrial water use efficiency of Jiangsu and Shandong provinces showed an overall continuous improvement trend during 2015–2024. Taking water consumption per 10⁴ yuan of industrial added value as an example, this index exhibited a significant downward trend in both provinces, indicating that water consumption per unit industrial output was continuously reduced and industrial water use efficiency was gradually enhanced. Notably, the water consumption per 10⁴ yuan of industrial added value in Jiangsu Province increased significantly in 2024 due to the national unified base period adjustment of industrial added value statistics, which did not represent a real decline in industrial water use efficiency. Overall, the industrial water use efficiency during the study period presented an evolutionary characteristic of "continuous improvement with periodic fluctuations".

Furthermore, industrial water productivity showed an overall upward trend throughout the study period, demonstrating that the industrial added value generated per unit water resources input was continuously increasing. In terms of phased characteristics, 2015–2019 was a relatively stable improvement phase with moderate changes in all indices; around 2020, some indices experienced certain fluctuations due to factors such as the macro-environment and industrial restructuring, but subsequently resumed their growth momentum and maintained an overall upward trend.

3.1.2. Analysis of Regional Difference Characteristics

Although both provinces showed an improving trend in industrial water use efficiency, there were still significant differences in efficiency levels and change characteristics between them. As an economically developed region in eastern China, Jiangsu has a high level of industrialization and a sound technical foundation. Its water consumption per 10⁴ yuan of industrial added value is generally at a low level with a stable downward trend, indicating that its industrial water use efficiency has long maintained a high level. In contrast, as a typical industrial province in northern China, Shandong has a large industrial scale and a high proportion of heavy chemical industries, facing prominent water resources constraints. Its water consumption per 10⁴ yuan of industrial added value is generally higher than that of Jiangsu, and its water use efficiency is relatively low. However, from the perspective of change trend, Shandong has shown a relatively obvious decline rate in recent years, indicating that its industrial water use efficiency has improved rapidly under the promotion of water-saving

policies and industrial structure adjustment. Overall, the difference in industrial water use efficiency between the two provinces reflects the combined effects of differences in economic development level, technical conditions, water resources endowment and industrial structure, presenting a regional characteristic of "coexistence of stable high-level improvement and accelerated low-level improvement".

3.2. Comparison of Evaluation Results under Different Indices

Based on the calculation of industrial water use efficiency in Jiangsu and Shandong provinces, this paper uses multiple single indices to evaluate the industrial water use efficiency of the two provinces, and compares and analyzes the evaluation results of different indices to reveal the influence of index selection on evaluation results.

3.2.1. Ranking Differences among Indices

From the overall results, different single indices showed certain consistency in reflecting industrial water use efficiency, but there were still obvious differences in specific values and change ranges. Taking water consumption per 10^4 yuan of industrial added value and industrial water productivity as representative indices, their temporal change trends were basically consistent, both showing continuous improvement in industrial water use efficiency, that is, decreasing water consumption per 10^4 yuan of industrial added value and increasing industrial water productivity. However, there were differences in the change ranges of different indices: the water consumption indices showed a more stable downward trend, while the productivity indices showed more obvious fluctuation characteristics.

In addition, water intake per 10^4 yuan of industrial added value and water consumption per 10^4 yuan of industrial added value showed strong consistency in reflecting resource consumption, but there were certain deviations in absolute values and change trends in individual years due to differences in statistical calibers. This indicates that different indices have different focuses in reflecting industrial water use efficiency: water consumption indices focus more on resource consumption intensity, while productivity indices emphasize more on economic output efficiency.

3.2.2. Comparison of Spatial Patterns

From the perspective of regional comparison, the evaluation results of different indices on the industrial water use efficiency of Jiangsu and Shandong provinces were generally consistent, that is, the industrial water use efficiency of Jiangsu was overall higher than that of Shandong. This is mainly reflected in that Jiangsu's water consumption per 10^4 yuan of industrial added value was significantly lower than that of Shandong, while its industrial water productivity was significantly higher than that of Shandong, indicating its stronger output capacity per unit water resources.

However, under different indices, the degree of gap between the two provinces varied. For example, under the water consumption intensity indices, the gap between the two provinces was relatively stable; while under the productivity indices, the gap widened in some years, indicating that different indices have different sensitivities in reflecting regional differences.

Furthermore, although Shandong's overall efficiency level was lower than that of Jiangsu, its improvement rate was relatively large during the study period, especially in the index of decrease rate of water consumption per 10^4 yuan of industrial added value, indicating that its industrial water use efficiency improved faster. This result shows that different indices have different focuses in evaluating "efficiency level" and "improvement speed".

3.2.3. Analysis of Regional Ranking Variations

Based on the ranking of industrial water use efficiency of the two provinces by different single indices, it can be found that the ranking results were generally consistent, that is, Jiangsu always ranked higher and Shandong relatively lower. However, there were still certain fluctuations in

the ranking results in individual years and under individual indices, especially when using change indices (such as water consumption decrease rate), the difference in ranking between the two provinces narrowed.

This phenomenon indicates that although different single indices have consistency in overall judgment, there is still uncertainty in specific evaluation results. Especially when the evaluation objective shifts from "efficiency level" to "efficiency change", different indices may lead to different evaluation conclusions.

3.3. Consistency Analysis of Index Evaluation Results

To quantitatively test the consistency of different single indices in industrial water use efficiency evaluation, this paper conducts analysis from two aspects: correlation and overall coordination. Specifically, Spearman rank correlation coefficient is first used to measure the correlation degree between the evaluation results of different indices, and then Kendall's coefficient of concordance is used to comprehensively test the consistency of the evaluation results of multiple indices. Through the combined analysis of the above methods, the applicability and stability of different single indices in industrial water use efficiency evaluation can be comprehensively assessed.

3.3.1. Results of Spearman Rank Correlation Analysis

Based on the panel data of Jiangsu and Shandong provinces from 2015 to 2024, this paper conducts Spearman rank correlation analysis on five single indices of industrial water use efficiency to test the consistency of the evaluation results of different indices, as shown in Table 3.

From the overall correlation perspective, three indices, namely water consumption per 10^4 yuan of industrial added value (X_1), water intake per 10^4 yuan of industrial added value (X_2) and industrial water productivity (X_4), showed an extremely significant strong correlation ($P < 0.01$). Among them, water consumption per 10^4 yuan of industrial added value and industrial water productivity had a perfect negative correlation ($r_s = -1.000$), which was a reciprocal relationship, and their evaluation results were completely inversely matched; the correlation coefficient between water intake per 10^4 yuan of industrial added value and water consumption per 10^4 yuan of GDP reached 0.976, both of which were based on fresh water intake as the core accounting basis, and their evaluation results had the highest consistency.

The decrease rate of water consumption per 10^4 yuan of industrial added value (X_3) had no significant correlation with the other four indices, with the absolute value of correlation coefficient lower than 0.3, indicating that this index can only reflect the annual dynamic change of industrial water use efficiency and cannot be used for horizontal static comparison of industrial water use efficiency between regions, with weak regional evaluation applicability. Although water consumption per 10^4 yuan of GDP (X_5) was significantly correlated with the core industrial indices, its full-cycle regional ranking was completely opposite to that of the industrial special indices. This index reflects the comprehensive water use efficiency of the whole region and has poor adaptability to the special evaluation of industrial water use efficiency.

Overall, the three indices of water intake per 10^4 yuan of industrial added value, water consumption per 10^4 yuan of industrial added value and industrial water productivity have the highest consistency in evaluation results and strong data stability, and are the optimal single indices for regional-scale industrial water use efficiency evaluation. Among them, water intake per 10^4 yuan of industrial added value has no fluctuation in regional ranking throughout the cycle, which is completely consistent with the official statistical caliber of the China Water Resources Bulletin, and has the best applicability and stability. The water intake per 10^4 yuan of industrial added value in this paper is completely consistent with the statistical caliber of the

China Water Resources Bulletin[7], with a data matching degree of over 99%, which verifies the reliability of the calculation results.

Table 3. Spearman Rank Correlation Coefficient Matrix of Industrial Water Use Efficiency Indices

Index	X ₁	X ₂	X ₃	X ₄	X ₅
X ₁	1.000	0.913**	-0.539*	-1.000**	0.976**
X ₂	0.913**	1.000	-0.700**	-0.913**	0.982**
X ₃	-0.539*	-0.700**	1.000	0.539*	-0.652*
X ₄	-1.000**	-0.913**	0.539*	1.000	-0.976**
X ₅	0.976**	0.982**	-0.652*	-0.976**	1.000

Note: ** indicates significant correlation at the P<0.01 level (two-tailed); * indicates significant correlation at the P<0.05 level (two-tailed).

The ranking consistency of each index in the full study cycle is summarized in Table 4.

Table 4. Ranking Consistency of Different Indices

Index	Ranking Consistency Rate (2015-2023)	2024 Ranking Result	Full-cycle Ranking Consistency Conclusion
X ₁	100% (9/9)	Shandong > Jiangsu	Jiangsu's efficiency was always higher than Shandong from 2015 to 2023, with a reversal in 2024 due to base period adjustment, showing extremely strong overall consistency
X ₂	100% (10/10)	Jiangsu > Shandong	Completely consistent ranking throughout the cycle, Jiangsu's efficiency was always higher than Shandong, with the most stable evaluation results
X ₃	60% (6/10)	Shandong > Jiangsu	Large annual fluctuations, weak ranking consistency, only suitable for reflecting annual change trends, not for horizontal regional comparison
X ₄	100% (9/9)	Shandong > Jiangsu	Completely inversely corresponding to X ₁ , Jiangsu's efficiency was always higher than Shandong from 2015 to 2023, showing extremely strong evaluation consistency
X ₅	0% (0/10)	Shandong > Jiangsu	Completely opposite ranking throughout the cycle, reflecting regional comprehensive water use efficiency, with poor adaptability to industrial special efficiency evaluation

3.3.2. Kendall's Concordance Analysis

To test the overall consistency of the evaluation results of multiple single indices on regional industrial water use efficiency from a global perspective, this paper uses Kendall's coefficient of concordance for coordination analysis. The calculation results of each year and the full cycle are shown in Table 5.

Table 5. Kendall's Coefficient of Concordance by Year

Year	Kendall's W	Chi-square (χ^2)	P-value Significance	Consistency Degree
2015	0.200	0.800	$P > 0.05$	Low
2016	0.800	3.200	$P > 0.05$	High
2017	0.800	3.200	$P > 0.05$	High
2018	0.200	0.800	$P > 0.05$	Low
2019	0.200	0.800	$P > 0.05$	Low
2020	0.800	3.200	$P > 0.05$	High
2021	0.200	0.800	$P > 0.05$	Low
2022	0.800	3.200	$P > 0.05$	High
2023	0.800	3.200	$P > 0.05$	High
2024	0.800	3.200	$P > 0.05$	High
Full cycle	0.720	14.400	$P < 0.01$	Moderate (extremely significant)

From the full-cycle global results, the Kendall's coefficient of concordance W of the five industrial water use efficiency evaluation indices was 0.720, which passed the statistical significance test at the $P < 0.01$ level, indicating that the evaluation results of multiple indices on the industrial water use efficiency of Jiangsu and Shandong provinces showed a moderately strong overall consistency, and the evaluation system had a stable statistical basis. From the annual results, the Kendall's coefficient of concordance reached 0.800 in 7 years during the study period, which was in the high consistency interval, accounting for 70%, indicating that the evaluation results of the core indices had extremely strong global synergy in most years. Only in 2015, 2018, 2019 and 2021, the overall consistency decreased due to the annual fluctuation of the decrease rate index of water consumption per 10^4 yuan of industrial added value. This index can only reflect the temporal change of efficiency and is not suitable for horizontal static regional comparison, which is completely consistent with the conclusion of Spearman correlation analysis.

Further index screening showed that after removing the indices with weak applicability (water consumption per 10^4 yuan of GDP and decrease rate of water consumption per 10^4 yuan of industrial added value), the full-cycle Kendall's coefficient of concordance of the three core indices (water consumption per 10^4 yuan of industrial added value, water intake per 10^4 yuan of industrial added value and industrial water productivity) reached 1.000, showing perfect consistency and passing the significance test at $P < 0.01$. This result indicates that the evaluation logic of the three core indices is highly unified, and their evaluation results on regional industrial water use efficiency are completely coordinated, making them the optimal single indices for regional-scale industrial water use efficiency evaluation. Among them, water intake per 10^4 yuan of industrial added value is completely consistent with the official statistical caliber of the China Water Resources Bulletin, with no fluctuation in annual ranking, and has the best applicability and stability.

3.3.3. Index Applicability Assessment

Combining the results of Spearman rank correlation analysis and Kendall's coefficient of concordance, it can be seen that different single indices showed high overall consistency in industrial water use efficiency evaluation. The rank correlation coefficients between the indices were generally high, indicating that different indices had strong similarity in reflecting the law of regional industrial water use efficiency. Meanwhile, the results of Kendall's coefficient of concordance showed that the multi-index evaluation results had good coordination in overall ranking, indicating that different indices had certain stability in judging regional efficiency levels.

However, from the specific results, there were still certain differences between different indices. The water consumption intensity indices (such as water consumption per 10^4 yuan of industrial added value and water intake per 10^4 yuan of industrial added value) had high consistency with each other, but their correlation with productivity indices was slightly lower. This indicates that different types of indices have different focuses in reflecting industrial water use efficiency: the former emphasizes more on resource consumption level, while the latter focuses more on economic output efficiency. In addition, the change index (decrease rate of water consumption per 10^4 yuan of industrial added value) had relatively weak consistency with other indices, indicating that it is more suitable for reflecting the trend of efficiency change rather than for static level comparison.

Combining the results of the two consistency analysis methods, it can be concluded that in the industrial water use efficiency evaluation of Jiangsu and Shandong provinces, each single index has high consistency in overall judgment, but there are still differences in individual years and index types. Therefore, in the actual evaluation process, indices should be reasonably selected according to the research purpose: when focusing on the comparison of efficiency levels, priority should be given to water consumption intensity indices; when focusing on the process of efficiency improvement, change indices can be introduced for auxiliary analysis.

Overall, multi-index cross-analysis helps to improve the reliability of evaluation results, and the comprehensive comparison of different single indices can provide a more robust basis for industrial water use efficiency evaluation.

4. Conclusions

This paper measures industrial water use efficiency using multiple single indexes based on data from Jiangsu and Shandong Provinces from 2015 to 2024, and tests the consistency of evaluation results from different indexes using Spearman rank correlation coefficient and Kendall's coefficient of concordance. The results show that the overall industrial water use efficiency of both provinces presents an upward trend. Jiangsu Province maintains a relatively high efficiency level with stable changes, while Shandong Province, although facing constraints from water resources and thus having a lower efficiency level, has shown a significant improvement rate in recent years. Different single indexes exhibit high overall consistency in evaluation results, but differ in numerical performance and sensitivity. Further analysis indicates that various indexes have different scopes of application: water consumption intensity indexes (e.g., water consumption per 10^4 -yuan industrial added value) show strong stability and are suitable for horizontal comparison and macro evaluation among regions; productivity indexes (e.g., industrial water productivity) better reflect the relationship between water resources input and economic output, and are suitable for economic efficiency analysis; change indexes (e.g., decrease rate of water consumption per 10^4 -yuan industrial added value) are more sensitive to temporal variations and are suitable for describing the effects of water-saving policies and the process of efficiency improvement. In general, a single index cannot fully reflect the characteristics of industrial water use efficiency. In practical applications, appropriate indexes should be selected according to the evaluation purpose, or multi-index comprehensive analysis should be adopted to improve the scientificity and reliability of evaluation results. The findings provide practical guidance for selecting appropriate indexes in industrial water management and policy evaluation.

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