Spatial Correlation of Water Resource Consumption Intensity in the Yangtze River Economic Belt under the Dual-Control Action

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Abstract. This paper selected 11 provinces and cities in the Yangtze economic belt as research areas, and interregional differences & spatial correlations of their overall, industrial and agricultural water intensity were measured. The results show that the intensity of water resource consumption decreases significantly in all provinces and cities, but the intensity of water resource consumption decreases slightly. The variation coefficient of the total water resource consumption intensity of provinces and cities is relatively stable, while the inter-regional difference of agricultural water resource consumption intensity is increasing, and the industrial sector shows a trend of first increase and then decrease. The spatial correlation between total and agricultural water resource consumption intensity was significant but decreased year by year, while there was no significant spatial correlation between industrial water resource consumption intensity. The study suggests that the strictest water resource management system should be further implemented to strictly control the total amount and intensity of water resource consumption in the Yangtze river economic belt. China should promote industrial transformation and upgrading, encourage the development of advanced industries such as new and high technology industries, and establish a synergy mechanism and a reasonable compensation mechanism for the use of water resources in the Yangtze River economic belt.

1. Introduction

The state council issued “the guiding opinions on promoting the development of the Yangtze river economic belt by relying on the golden waterway”, which clearly proposed the effective protection and utilization of the water resources of the Yangtze river, implemented the most stringent water resource management system, and defined the red line of the development and utilization of the water resources of the Yangtze river and the water efficiency in September 2014. The Yangtze River economic belt, linked by the Yangtze River waterway, runs through the eastern and western regions of China, including nine provinces and two municipalities directly under the central government. Its population and economy accounted for 42.7% and 43.2% of the country's total in 2016. But in the same period, the Yangtze River economic belt accounted for 43.16% of the country's water consumption and 44.16% of its wastewater discharge. The Yangtze River economic belt has a slightly lower performance than the rest of the country in terms of water consumption and waste discharge, and its rapid economic growth
has led to a dual crisis of water shortage and water environment pollution. At the end of 2015, the Yangtze river basin that reached or exceeded III class section proportion was only 73.4%, the Yangtze river "double kidney" Dong Ting lake, lake Po Yang frequently drought bottom. It is also acting as a "water pollution shelter" in some developed countries or regions because of industrial transfer. The Yangtze River economic belt should carry out dual control actions of total and intensity water resource consumption, so as to promote the transformation of economic development mode and water consumption mode, and comprehensively promote the construction of water-saving society. It is of great practical value to explore the intensity and spatial difference of water resource consumption in the Yangtze River economic belt and analyze the regional difference and spatial correlation of water resource consumption intensity.

2. Literature Review

Domestic and foreign scholars mainly discussed from the perspective of regional differences in water consumption and driving factors, and also discussed the water footprint and water resource carrying capacity index, Willis and RM (2011) discussed the relationship between environmental or water resource conservation attitude and household water consumption [2]. Willis, RM (2013) investigated the effect of household water-saving devices and social demographic factors on the final household water consumption [3]. Chen Dabo et al. (2014) explored agricultural water use and its water-saving potential in arid regions through the study of intensity of agricultural water resource consumption in the Wei river basin [4]. Zhao (2010) used the grey correlation method to calculate the correlation degree of China's total water consumption and the allocation, and used the niche evaluation model to calculate the appropriateness of the allocation of total water consumption [5]. Liu Chenyue (2018) analyzed the spatiotemporal deductive characteristics of the economic effect, population effect and water efficiency effect through LMDI-I decomposition model [6]. Zhang Hongwei (2011) used input-output analysis to compare the direct, total and indirect consumption of water resources of various industries in the first and second industries, and studied the indirect pull of water resources consumption between different industries [7]. Liu Yifang (2014) constructed the structural deviation coefficient to calculate the correlation between industrial structure and water consumption structure, and measured the economic -- ecological benefit deviation [8]. However, relevant studies related to the economic belt did not discuss the convergence or divergence trend of regional differences in water resource consumption intensity, and did not involve the spatial correlation of water resource consumption intensity, which is also the problem to be solved in this paper.

3. Research Methods

3.1. Coefficient of variation

The coefficient of variation, also known as the discrete coefficient, is the ratio of the standard deviation of the variable to the mean value. As a relative number, the coefficient of variation has no unit and its size is affected by both the mean value and the standard deviation. Especially when two or more samples are compared, the coefficient of variation can be completely free from the influence of the mean value and the absolute value of standard deviation. CV is the coefficient of variation, S is the standard deviation of the observed variable, x is the average value of the observed feature, and n is the number of samples.

\[
CV = \frac{S}{\bar{x}} = \sqrt{\frac{\sum(x_i - \bar{x})^2}{n-1}} \div \frac{\sum x_i}{n}
\]

3.2. Moran's I Index

Moran's I index is used to explore the spatial pattern of the study area, to reflect the spatial correlation degree and spatial differentiation of the region, and to reflect the similarity degree of the specific attribute value of the adjacent region. The value of Moran's I index is between (-1,1), and is positive to
indicate positive correlation, the larger the space, the more aggregation. Negative means negative correlation; The larger the absolute value is, the more significant the spatial difference is. The value of zero indicates that the space is irrelevant [9]. The weight matrix of adjacent space is adopted here, that is, adjacent is 1 and non-adjacent is 0. The specific calculation is shown in formula (2). Here, \( n \) is the number of spatial samples; subscript \( i \) and \( j \) represent different regions; \( \bar{x} \) is the average value of the observed features of the spatial unit; \( S \) is its standard deviation; represents the spatial weight matrix.

\[
\text{Moran's } I = \frac{n \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}(x_i - \bar{x})^2}
\]

4. Empirical Test

4.1. The current analysis of water consumption intensity

| province   | 2006   | 2011   | 2016   |
|------------|--------|--------|--------|
|            | overall| industry| agriculture| overall| industry| agriculture| overall| industry| agriculture|
| Shanghai   | 114.38 | 166.98 | 1958.19 | 75.24 | 117.19 | 1896.87 | 44.11 | 76.17 | 2082.10 |
| Jiangsu    | 252.43 | 198.32 | 1752.01 | 140.61 | 93.17 | 1610.82 | 95.78 | 79.08 | 1242.01 |
| Zhejiang   | 132.29 | 82.64  | 1092.38 | 76.89 | 47.48 | 879.17 | 46.97 | 27.72 | 695.32 |
| Anhui      | 393.37 | 363.62 | 1326.39 | 252.89 | 185.50 | 1289.53 | 157.05 | 110.98 | 1003.26 |
| Jiangxi    | 440.37 | 279.99 | 1690.80 | 1690.80 | 145.61 | 1554.93 | 178.65 | 92.33 | 1280.16 |
| Hubei      | 341.36 | 296.77 | 1253.55 | 197.31 | 179.96 | 951.11 | 122.22 | 86.75 | 755.27 |
| Hunan      | 432.99 | 304.28 | 1489.22 | 226.31 | 146.82 | 1115.93 | 146.34 | 93.15 | 989.55 |
| Chongqing  | 209.65 | 311.39 | 425.58  | 119.56 | 153.16 | 338.58  | 61.73  | 54.21 | 345.27 |
| Sichuan    | 249.06 | 182.88 | 759.65  | 140.66 | 84.56 | 659.44  | 104.50 | 46.37 | 667.85 |
| Guizhou    | 438.11 | 319.08 | 1381.86 | 245.52 | 209.66 | 1047.00 | 140.14 | 84.65 | 852.79 |
| Yunnan     | 361.31 | 133.19 | 1408.02 | 205.92 | 90.87 | 963.76  | 129.67 | 44.12 | 786.31 |

From the perspective of the overall intensity of water consumption, the intensity of water consumption in all provinces and cities is decreasing year by year. In 2016, water consumption per 10,000 yuan of GDP in most provinces and cities dropped to only about 30-40% of that in 2006, especially in Chongqing, where the decrease was most obvious and only 29.4% of that in 2006. However, the intensity of water resource consumption in the Yangtze river economic belt has a significant spatial difference in the eastern, middle and western sections. In 2016, the intensity of water resource consumption in Jiangsu, Zhejiang and Shanghai was only 95.8, 47.0 and 44.1 cubic meters / 10,000, far lower than that in other provinces and regions except Chongqing. The water consumption intensity of Anhui, Jiangxi, Guizhou and Hunan provinces were higher than other provinces, while these provinces had a large proportion of agriculture and a lower level of urbanization. However, the intensity of industrial water resource consumption is slightly lower than the overall intensity of water resource consumption, and the decrease scope during the study period is greater than the intensity of total water resource consumption. The intensity of water resource consumption in central regions is much higher than that in eastern and western regions, and the intensity of water resource consumption in Zhejiang province was only 277 m³/10,000 yuan in 2016. However, the intensity of agricultural water resource consumption shows a stepped-down trend in the east, central and western regions. Due to the nature and regional structure of
agricultural production, the intensity of agricultural water resource consumption is limited and the absolute value is much higher than that of industrial water resource consumption. As a municipality directly under the central government, Chongqing had performed more prominently in terms of total water saving and waste water reduction. Shanghai had a higher agricultural water consumption intensity, probably because there existed a large proportion of aquatic products and vegetables in agriculture.

4.2. The variation coefficient of water consumption intensity
Figure 1 shows that from the inter-provincial difference of water resource consumption in the Yangtze river economic belt, the variation coefficient of overall water resource consumption intensity of provinces and cities is basically stable at 39-41% between 2006 and 2016. The variation coefficient of agricultural water resource consumption intensity is increasing, from 33.34% in 2006 to 46.64% in 2016. However, the regional difference of industrial water resource consumption intensity increases first and then decreases, because the decline in water resource intensity of these provinces were fast or slow variously. The variation coefficient of industrial water resource consumption intensity reached the maximum value in 2012, and then the economic belt started to promote coordinated development in water utilization. The increase of regional difference in agricultural water intensity was attributed to the obvious decrease of water intensity in Hunan, Hubei and Yungui during the research period. However, the water intensity in Shanghai and Sichuan only slightly decreased or increased instead, which led to the increase of variation coefficient of provinces and cities year by year. The variation coefficient of industrial water resource consumption intensity is related to the completion of the industrialization process in the eastern and western regions, and is also closely related to the transfer of high water consumption industry within the economic belt. Agricultural production is difficult to transfer between regions due to natural conditions and historical habits, and the development of service industry is conducive to reducing water consumption. With the continuous development of economy and society, the agricultural planting structure of various provinces had undergone great changes in 2006 to 2016, while some provinces still maintained original agricultural production structure and other provinces had fundamentally changed these years.

![Figure 1. Variation coefficient of overall, industrial and agricultural water intensity: 2006-2016](image)

4.3. The spatial correlation of water consumption intensity
As can be seen from table 2, the overall water resource consumption intensity has a significant positive spatial correlation. However, the positive spatial correlation showed a trend of gradual weakening from 2006 to 2016. The adjacent regions have relatively similar water resources conditions, agricultural
production structure and living production habits, but the spatial correlation is gradually weakened due to the rapid development of economic development and water saving and emission reduction in Chongqing, Shanghai and other municipalities directly under the central government. From 2006 to 2016, there was no significant spatial correlation between the intensity of industrial water resource consumption, industrial production has not shown the same high dependence on water resources as agricultural production. Provinces with high or low water resource consumption intensity do not show spatial agglomeration, while environmental regulation and technological innovation lead to excessive competition among local governments, and cities with relatively outstanding performance such as Chongqing and Zhejiang in decentralized layout are also presented, which were significantly different from the surrounding provinces. The intensity of agricultural water resource consumption showed a significant positive correlation between 2008 and 2016, but this positive correlation also showed a gradual weakening trend, while Shanghai may have a higher intensity of water resource consumption due to its possession of more abundant water resources and unique commodity agriculture types.

Because of the local GDP championship and the inter-governmental game, there is no spatial diffusion of technological innovation and environmental regulation between the upstream and downstream of the economic belt, and the "halo of pollution" or "refuge of pollution" brought by FDI and industrial transfer is also in dispute. Comparing with the water consumption in the Yangtze River economic belt, the waste water disposal showed the stronger spatial correlation between upstream and downstream, which would be further resolved.

### Table 2. Spatial correlation of water intensity of total, industry & agriculture: 2006-2016

| Type          | 2006  | 2007  | 2008  | 2009  | 2010  | 2011  | 2012  | 2013  | 2014  | 2015  | 2016  |
|---------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| overall water | 0.2291| 0.2149| 0.2067| 0.1958| 0.1921| 0.1791| 0.1948| 0.1693| 0.1651| 0.1843| 0.1554|
| (0.065)       | (0.084)| (0.070)| (0.084)| (0.099)| (0.090)| (0.092)| (0.098)| (0.087)| (0.075)| (0.116) |
| Industrial water | 0.1554| 0.1278| 0.0904| 0.0068| 0.0668| 0.0107| 0.0225| 0.0562| 0.0209| 0.0106| 0.1262|
| (0.101)       | (0.128)| (0.162)| (0.262)| (0.183)| (0.256)| (0.693)| (0.627)| (0.684)| (0.266)| (0.485) |
| Agricultural water | 0.1046| 0.0969| 0.1823| 0.2171| 0.2379| 0.2315| 0.1913| 0.2014| 0.1661| 0.1274| 0.0958|
| (0.128)       | (0.156)| (0.081)| (0.063)| (0.272)| (0.066)| (0.065)| (0.064)| (0.095)| (0.094)| (0.109) |

### 5. Conclusion

The Chinese government has proposed to reduce the water consumption of 10,000 yuan of GDP or industrial added value by 23% and 20% by 2020 compared with 2015. As the region with the most active economy and a large amount of water consumption, the Yangtze river economic belt should strictly control the total amount and intensity of water resource consumption, and force industrial transformation and upgrade to achieve high-quality development of the economic belt. Based on the variation coefficient and Moran index, this paper respectively measures the interregional difference and spatial correlation of the total, industrial and agricultural water resource consumption intensity in 11 provinces and cities of the Yangtze river economic belt. The results show that the intensity of agricultural water resource consumption in most provinces is much higher than the overall intensity of consumption and industrial intensity. The intensity of water resource consumption in all provinces and cities and the intensity of industrial and agricultural water resource consumption show a downward trend, but the intensity of agricultural water resource consumption declines slightly. From 2006 to 2016, the variation coefficient of overall water resource consumption intensity of provinces and cities was relatively stable, while the variation coefficient of agricultural water resource consumption intensity was increasing, while the inter-regional difference of industrial water resource consumption intensity was increasing first and then decreasing. During the study period, there was a significant spatial positive correlation between the total and agricultural water resource consumption intensity, but the spatial positive
correlation decreased year by year, while there was no significant spatial correlation between industrial water resource consumption intensity.

In view of this, the study suggests that the strictest water resource management system should be further implemented to strictly control the total consumption and intensity of water resources in the Yangtze river economic belt, improve the reuse rate of water resources and optimize the allocation of water resources. We should promote industrial transformation and upgrade in the Yangtze river economic belt, phase out backward production capacity, excess production capacity and low-end manufacturing, and encourage the development of advanced industries such as high-tech industries, modern services, water conservation and environmental protection. We should establish a coordination mechanism for the utilization of water resources in the Yangtze river economic belt, guide the Yangtze river economic belt to reasonably arrange industrial layout, strictly limit the competition among provinces and regions at the bottom level and take neighboring as the beggar-thy-neighbor as the target, and establish a joint solution and reasonable compensation mechanism for the utilization of water resources.

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References
[1] Hoekstra AY, Chapagain AK. Water footprints of nations: Water use by people as a function of their consumption pattern, Water Resources Management, Vol.21, 1, 2007, pp. 35-48.
[2] Willis RM, Stewart RA, Panuwatwanich K, et al. Quantifying the influence of environmental and water conservation attitudes on household end use water consumption, Journal of Environmental Management, Vol.98, No.8, 2011, pp. 1996-2009.
[3] Willis RM, Stewart RA, Giurco DP, et al. End use water consumption in households: impact of socio-demographic factors and efficient devices, Journal of Cleaner Production, Vol.60, S1, 2013, pp. 107-115.
[4] Chen Dabo, Yang Degang, Tang Hong, et al. Agricultural water consumption intensity and effecting factors in Ogan River Basin, Arid Land Geography, Vol.37, No. 3, 2014, pp. 509-519.
[5] Zhao Ao, Wu Chunyou. Grey Correlation Degree and Niche Measurement of Allocation of China’s Water Resources Consumption, China Population, Resources and Environment, Vol. 20, No. 9, 2010, pp. 65-69.
[6] Liu Chenyue, Xu Yingzhi. Spatial-temporal Decomposition of Water Resources Consumption in the Economic Growth Process of China, Journal of Dalian University of Technology(Social Sciences), Vol. 39, No. 2, 2018, pp. 40-46.
[7] Zhang Hongwei, He Xiabing, Wang Yuan. Analysis of Water Consumption of China’s Industries Based on the Input-Output Method, Resources Science, Vol.33, No.7, 2011, pp. 1218-1224.
[8] Liu YiFang, Liu Yanbing, Huang Shanshan. Study on the correlation between industrial structure and water resources consumption structure, Systems Engineering-Theory&Practice, Vol. 34, No. 4, 2014, pp. 861-869.
[9] Zang Zheng, Zou Xinqing, Song Qiaochu. Impacts of spatial weight on the analysis of spatial-temporal patterns of geographic factors: An empirical study on the intensity of water resource consumption in provinces of Chinese Mainland, Geographical Research, Vol. 36, No.5, 2017, pp. 872-886.