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Agricultural Total Water Consumption Coefficient and Its Spatial Correlation Network in Yangtze River Economic Belt

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Abstract: Agriculture contributes extensively to the economic development of countries; however, it is one of the main water-consuming industries. Revealing the characteristics and network structure of agricultural water use efficiency (AWUE) is conducive to green and coordinated development of agriculture. Considering that analyzing the variation of AWUE is helpful to calculating the AWUE, this study aims to calculate the total water consumption coefficient of the agricultural sector in the Yangtze River Economic Belt (YEB) by using the China interregional input-output tables in 2012 and 2017. The gravity model was modified to deduce the spatial correlation network of agricultural total water consumption coefficient (ATWCC), and the social network analysis method was used to analyze the network structural characteristics. The results show that: (1) compared to 2012, the AWUE of YEB in 2017 improved, with a decrease of ATWCC from 532.5 to 387.5 m^3/10,000-yuan, account for 27.2%; (2) The network relevance of ATWCC of YEB's 11 provinces (cities) enhanced, the rank relationship within the network and the network structure was relatively stable; (3) The spatial correlation network formed several network centers, Zhejiang and Jiangsu in the eastern coastal area were the main destinations of the spatial spillover of the spatial correlation network.

Keywords: agricultural water use efficiency; agricultural total water consumption coefficient; input-output analysis; spatial correlation network; modified gravity model; social network analysis; Yangtze River Economic Belt

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1. Introduction

Agriculture is an irreplaceable important sector that highly relies on water resources [1]. However, the global risk of water shortages poses a severe challenge to the sustainable development of agriculture [2]. Thus, it is of great significance to analyze the agricultural water use efficiency (AWUE) and put forward the countermeasures.

At present, the research on AWUE mainly focuses on two aspects: the technical research on improving AWUE [3–7], and the measurement and analysis of AWUE [8–11]. While the latter reveals existing problems and identifies directions for improvement, the former is aimed at specific implementation.

Measurement and analysis of AWUE have frequently used the data envelopment analysis (DEA) method based on input-output tables [7,9,12]. Recently, combining DEA with other analysis methods has become an important research direction. Shi et al. coupled the DEA model and Social Network Analysis (SNA) to evaluate the AWUE of YEB from 2010 to 2019 [11]. Zhang et al. adopted a slacked-based model to measure China's AWUE [13], etc.

As the economy and society developed, the relationship among regions or sectors becomes increasingly interconnected, and water flow becomes more frequent. However, current AWUE research primarily focuses on direct water use in the agricultural sector, neglecting the virtual water consumption of other sector products used by the agricultural sector. Xu et al. put forward the calculation method of direct water consumption coefficient (DWCC) and total water consumption coefficient (TWCC) [14], which provides a solution to deal with this issue.

According to Xu et al. [14], the water resources calculated in DWCC are mainly natural forms, but water resources involved both the virtual form and the real form. In actual production, not only are a large number of natural form water resources consumed by the different sectors, but tons of virtual water are also consumed through the exchange of products and services. The two parts of water resource constitute TWCC, which refers to the total water resource consumed by the whole economic system to increase one unit of products in a sector. TWCC has become an important tool to account for the virtual water and optimize the industrial structure [15–18]. It is worth emphasizing that the characteristics of TWCC mentioned above make it a more objective indicator for measuring AWUE. Specifically, the larger the TWCC value, the lower the AWUE of the agricultural sector. Therefore, the agricultural total water consumption coefficient (ATWCC) is a crucial tool for objectively and comprehensively assessing AWUE, which has received limited attention in current research. Furthermore, with the advancement of regional coordinated development strategies, the flow of labor, capital, technology, products, and virtual resources among regions has accelerated [19]. The spatial correlation between regional industries and consumption has surpassed geographical proximity limitations, forming a spatial correlation network. At present, spatial association network analysis has become one of the important research contents for regional coordination and sustainable development [20–22]. Therefore, revealing the spatial correlation network of AWUE is helpful for the formulation and implementation of relevant policies and measures.

As an important component of social and economic activities, the spatial effects of agricultural water use may also exceed geographical proximity and create a spatial correlation network. However, few studies have been conducted within this field. As one of China's important strategic development areas, the Yangtze River Economic Belt (YEB), which spans the East, middle, and west of China, covers six of 13 major grain-producing areas. YEB plays a crucial role in China's agricultural production and coordinated development. Therefore, based on the above analysis, considering YEB as the research area, this study aims to explore ATWCC and its spatial correlation network, and provide support for YEB's agricultural sector water resources utilization and management.

2. Materials and Methods

2.1. Study Area

YEB is a major strategic development area in China, including 11 provinces (cities) (Figure 1) (Sichuan, Guizhou, Yunnan and Chongqing; Hubei, Hunan and Jiangxi; Shanghai, Jiangsu, Zhejiang and Anhui). The total area of YEB is about 2.05 × 106 km^2, accounting for 21.4% of China [23]. YEB has abundant water resources, which account for more than 40% of China's total. YEB is the largest food production and processing base in China, which has six provinces (cities) in China, namely Jiangsu and Anhui in the upper reaches, three provincial administrative regions in the middle reaches, and Sichuan in the lower reaches [24]. YEB plays an important role in ensuring China's food security. However, agricultural water use efficiency in YEB is low. In 2017, the food-sowing area of YEB accounted for 36.5% of China, while the water-saving irrigation area accounted for only 27.3%. The water-saving irrigation area was 9.38 × 10^6 hm^2, accounting for only 21.75% of the food sowing area. Therefore, studying AWUE and its network structure in YEB is of great practical significance.

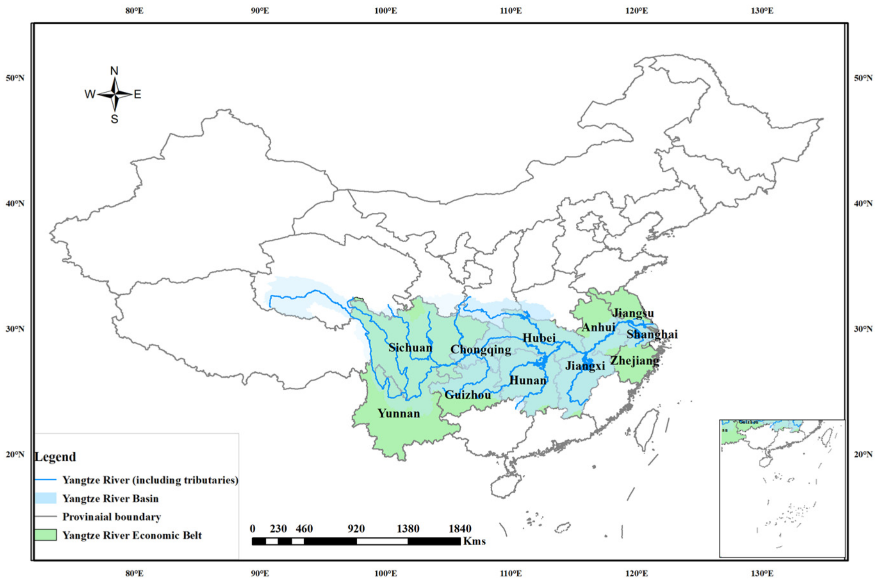


Figure 1. Geographical location of YEB.

2.2. Data Preparation

To account for water consumption in the agricultural sector (Agriculture, forestry, animal husbandry, and fishery), the interregional input-output table of 31 provinces (cities, autonomous regions) in China was utilized.

The areas outside YEB were aggregated as "China outside YEB". The balance rule was applied to verify the Input-Output table, ensuring that the total input equals the total output [25], as shown in Table 1.

All the data involved in this study are from the water resources bulletin and statistical yearbook of China and each province (city) in YEB (2012 and 2017); Economic census yearbook, energy statistical yearbook, wine sector yearbook, agricultural products processing sector yearbook of China (2013 and 2018) and EPS data platform.

2.3. Agricultural Total Water Consumption Coefficient (ATWCC)

The input–output analysis is a common analysis method in Econometrics [26], since 1960, it has been widely used in the research of leading sectors and industrial linkages [14,25], resource circulation and environmental impact [27]. To quantify the agricultural water consumption in the 11 provinces (cities) of YEB, the inter provincial circulation relations must be considered. Therefore, it is necessary to use the Multi-Regional Input–Output (MRIO) model for accounting.

The MRIO table of water consumption for YEB was constructed (Table 1). The monetary unit is 10,000-RMB yuan. There are 12 regions, $R_1, R_2, \cdots, R_{12}$, representing Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, Hunan, Chongqing, Sichuan, Guizhou, Yunnan and the areas outside YEB in China. Each region has n sectors, $n = 27$. The row balance relationship is as follows [26].

$$X_i^{R_r} = \sum_{s=1}^{12} \sum_{j=1}^{27} x_{ij}^{R_r R_s} + \sum_{s=1}^{12} y_i^{R_r R_s} + e_i^{R_r} \tag{1}$$

where, R_r and R_s are any two regions. $X_i^{R_r}$ is the total output of sector i in the region R_r. $x_{ij}^{R_r R_s}$ is the intermediate input provided by sector i of region R_r to sector j of region R_s; $y_i^{R_r R_s}$ is the input of sector i in region R_r to the final demand of region R_s. $e_i^{R_r}$ is the output of sector i in region R_r.

Table 1. Multi-regional input and output table of YEB.

			Intermediate Consumption											**Final Consumption**				**Export**	**Total Output**
			Shanghai			…	**Yunnan**			**China Outside YEB**				**Shanghai**	…	**Yunnan**	**China Outside YEB**		
			S1	…	**Sn**	…	**S1**	…	**Sn**	**S1**	…	**Sn**							
Intermediate input	Shanghai	S1	$x_{11}^{R_1R_1}$	…	$x_{1n}^{R_1R_1}$	…	…	…	…	$x_{11}^{R_1R_{12}}$	…	$x_{1n}^{R_1R_{12}}$		$y_1^{R_1R_1}$	…	$y_1^{R_1R_{11}}$	$y_1^{R_1R_{12}}$	$e_1^{R_1}$	$x_1^{R_1}$
		…	…	…	…	…	…	…	…	…	…	…		…	…	…	…	…	…
		Sn	$x_{n1}^{R_1R_1}$	…	$x_{nn}^{R_1R_1}$	…	…	…	…	$x_{n1}^{R_1R_{12}}$	…	$x_{nn}^{R_1R_{12}}$		$y_n^{R_1R_1}$	…	$y_n^{R_1R_{11}}$	$y_n^{R_1R_{12}}$	$e_n^{R_1}$	$x_n^{R_1}$
	……	……	…	…	…	…	…	…	…	…	…	…		…	…	…	…	…	…
	Yunnan	S1	$x_{11}^{R_{11}R_1}$	…	$x_{1n}^{R_{11}R_1}$	…	…	…	…	$x_{11}^{R_{11}R_{12}}$	…	$x_{1n}^{R_{11}R_{12}}$		$y_1^{R_{11}R_1}$	…	$y_1^{R_{11}R_{11}}$	$y_1^{R_{11}R_{12}}$	$e_1^{R_{11}}$	$x_1^{R_{11}}$
		…	…	…	…	…	…	…	…	…	…	…		…	…	…	…	…	…
		Sn	$x_{n1}^{R_{11}R_1}$	…	$x_{nn}^{R_{11}R_1}$	…	…	…	…	$x_{n1}^{R_{11}R_{12}}$	…	$x_{nn}^{R_{11}R_{12}}$		$y_n^{R_{11}R_1}$	…	$y_n^{R_{11}R_{11}}$	$y_n^{R_{11}R_{12}}$	$e_n^{R_{11}}$	$x_n^{R_{11}}$
	China outside YEB	S1	$x_{11}^{R_{12}R_1}$	…	$x_{1n}^{R_{12}R_1}$	…	…	…	…	$x_{11}^{R_{12}R_{12}}$	…	$x_{1n}^{R_{12}R_{12}}$		$y_1^{R_{12}R_1}$	…	$y_1^{R_{12}R_{11}}$	$y_1^{R_{12}R_{12}}$	$e_1^{R_{12}}$	$x_1^{R_{12}}$
		…	…	…	…	…	…	…	…	…	…	…		…	…	…	…	…	…
		Sn	$x_{n1}^{R_{12}R_1}$	…	$x_{nn}^{R_{12}R_1}$	…	…	…	…	$x_{n1}^{R_{12}R_{12}}$	…	$x_{nn}^{R_{12}R_{12}}$		$y_n^{R_{12}R_1}$	…	$y_n^{R_{12}R_{11}}$	$y_n^{R_{12}R_{12}}$	$e_n^{R_{12}}$	$x_n^{R_{12}}$
Import input			$I_1^{R_1}$	…	$I_n^{R_1}$	…	…	…	…	$I_1^{R_{12}}$	…	$I_n^{R_{12}}$							
Added value			$V_1^{R_1}$	…	$V_n^{R_1}$	…	…	…	…	$V_1^{R_{12}}$	…	$V_n^{R_{12}}$							
Total investment			$x_1^{R_1}$	…	$x_n^{R_1}$	…	…	…	…	$x_1^{R_{12}}$	…	$x_n^{R_{12}}$							
Water consumption			$W_1^{R_1}$	…	$W_n^{R_1}$	…	…	…	…	$W_1^{R_{12}}$	…	$W_n^{R_{12}}$							

The direct water consumption coefficient (DWCC) is as follows:

$$a_{ij}^{R_r R_s} = x_{ij}^{R_r R_s} / x_j^{R_s} \tag{2}$$

Bring Formula (2) into Formula (1):

$$X_i^{R_r} = \sum_{s=1}^{12} \sum_{j=1}^{27} a_{ij}^{R_r R_s} x_i^{R_r} + \sum_{s=1}^{12} y_i^{R_r R_s} + e_i^{R_r} \tag{3}$$

Expressed as the matrix form:

$$X^{R_r} = A^{R_r R_s} X^{R_r} + Y^{R_r R_s} + E^{R_r} \tag{4}$$

Further,

$$X^{R_r} = \left(1 - A^{R_r R_s}\right)^{-1} \left(Y^{R_r R_s} + E^{R_r}\right) \tag{5}$$

where, $L = \left(1 - A^{R_r R_s}\right)^{-1} = \left[l^{R_r R_s}\right]$ is Leontief inverse matrix. $\left[l^{R_r R_s}\right]$ is the input of sector i to meet the production needs of a unit product of sector j in region R_s.

To establish the connection between economic and water resources data, water resource consumption $W_j^{R_r}$ was introduced into the MRIO table. The DWCC represents the total amount of water resources invested by each sector in the process of producing a unit of product [14], and the formula is:

$$R_j^{R_r} = r_j^{R_r} / x_j^{R_r} \tag{6}$$

where, $R_j^{R_r}$ refers to the total amount of the water resource to be consumed in unit products or services of sector j in region R_r. $r_j^{R_r}$ refers to the amount of water resources consumed by sector j in region R_r; $x_j^{R_r}$ is the total output of sector j in region R_r.

According to DWCC, the TWCC can be calculated as follows:

$$\text{TWCC} = RL = R(1 - A)^{-1} = \begin{bmatrix} q^{R_1} & q^{R_2} & \cdots & q^{R_z} \end{bmatrix} \tag{7}$$

2.4. Modified Gravity Model

To identify whether the ATWCC of 11 provinces (cities) in YEB has spatial correlation network characteristics, it is necessary to construct the gravity matrix in the first place. According to the relative research works [20,28], a modified gravity model to measure the spatial correlation gravity intensity of ATWCC was constructed as follow:

$$Q_{ij} = \frac{AG_i}{AG_i + AG_j} \times \frac{\text{ATWCC}_i \cdot \text{ATWCC}_j}{\left(d_{ij} / (ag_i - ag_j)\right)^2} \tag{8}$$

where, Q_{ij} refers to the gravity of ATWCC between the ith and jth provinces (cities) of YEB. ATWCC_i, ATWCC_j, AG_i, AG_j, ag_i and ag_j respectively refers to the ATWCC, agricultural GDP and agricultural GDP per agricultural worker in the ith and jth provinces (cities). d_{ij} refers to the geographical distance obtained by the ArcGIS distance tool between the ith and jth provinces (cities).

After calculating gravity, the spatial correlation network matrix can be constructed. Here, taking the mean value of gravitation in each row as the comparison value, those greater than the average level are recorded as 1, otherwise as 0.

2.5. Social Network Analysis (SNA)

SNA is a scientific method to analyze the correlation networks based on "relationship data", which has been widely used in many fields [29–33]. This study uses SNA to analyze the structural characteristics of the ATWCC spatial correlation network in YEB.

This characteristic is mainly analyzed by five indicators: network relationships number, density, correlation, rank and efficiency. The network relationships number refers to the actual relationships number between different provinces (cities). When the network relationships number is greater, the network density is greater, indicating that the ATWCC of 11 provinces (cities) is more closely related, and the impact of ATWCC among provinces (cities) is also stronger. The network density can be calculated as follows:

$$D = L/[N(N-1)] \tag{9}$$

where, N and L represent the number of provinces (cities) and the network relationships respectively.

The network correlation reflects the robustness of the network. When it is 1, it indicates that the ATWCC of 11 provinces (cities) has a spatial network effect, and the network is robust. The calculation formula is:

$$C = 1 - 2V/[N(N-1)] \tag{10}$$

where, V refers to the number of unreachable point pairs.

The network rank reflects the status difference of ATWCC in 11 provinces (cities). The higher the rank, the greater the rank difference formed in the spatial correlation network. The calculation formula of network rank is:

$$H = 1 - K/\max K \tag{11}$$

where, K and $\max K$ denote the number of symmetric reachable point pairs and the number of maximum symmetric reachable point pairs respectively.

The network efficiency reflects the stability of the network. A lower network efficiency indicates a more stable spatial correlation network. The calculation formula for network efficiency is:

$$E = 1 - M/\max M \tag{12}$$

where, M and $\max M$ represent the number of redundant links between provinces(cities) and the number of maximum possible redundant links, respectively.

The individual characteristic of spatial correlation networks is mainly analyzed by three indicators: point center degree (PCD), closeness center degree (CCD) and intermediation center degree (ICD). PCD is used to measure the number of other provinces connected to a province in the network, which can be divided into point-out degrees and point-in degrees. In this study, the higher the PCD, the closer the province (city) is to the network center, and the stronger its effect on other network nodes. There are two measurement methods: absolute and relative.

Relative PCD is the most commonly used, which can be expressed as:

$$C_{RD} = n/(N-1) \tag{13}$$

CCD is used to describe the degree to which a province(city) is not controlled by others. If the distance between a province(city) and others is short, it has more obvious advantages in transmitting information, and its closeness to the center will be higher. When a province (city) is closer to the center, it indicates that it is closer to others in the network. The CCD can be expressed as:

$$C_{AP} = \left(\sum_{j=1}^{n} p_{ij}\right)/(N-1) \tag{14}$$

where, p_{ij} refers to the shortcut distance between the ith and jth province (city).

ICD is used to measure the intermediary role of a province (city) in other point pairs. If a province (city) is on many other points to point shortcuts, it has a high ICD. When a province (city)'s ICD is higher, it plays a stronger role in controlling and regulating the ATWCC of others in the network. ICD can be expressed as:

$$C_{RB} = 2\left(\sum_{j=1}^{N}\sum_{k=1}^{N} b_{jk}(i)\right) / (N^2 - 3N + 2) \tag{15}$$

where, $j \neq k \neq i$, and $j < k$; $b_{jk}(i) = g_{jk}(i)/g_{jk}$ indicates the ratio of the number of shortcuts ($g_{jk}(i)$) passing through the ith province (city) and connecting the jth and the kth to the total number of shortcuts between the jth and kth (g_{jk}).

Using the plate model analysis method, this paper discusses the role of each plate in the ATWCC spatial correlation network in 11 provinces (cities) of YEB. Referring to the research of WASSERMAN and FAUST [34], the spatial association network is divided into four attributes. The attributes of the plate are judged according to the number of received and issued relationships inside and outside the plate, and the number of members inside the plate (Table 2), revealing the position and role of each plate in the spatial network, as well as the connection and interaction between the internal and external of the plate, in which g_k and g represent the number of members in the plate and in the whole network relationship.

Table 2. Classification of ATWCC plate attributes in the plate model.

Proportion of Relationships within the Location	Proportion of Relationships Received by This Position	
	≈0	**>0**
$\geq (g_k - 1)/(g - 1)$	Two-way overflow plate	Net benefit plate
$< (g_k - 1)/(g - 1)$	Net overflow plate	Broker plate

Here, the CONCOR algorithm of UCINET 6.0 was used to cluster the ATWCC spatial association network.

3. Results

3.1. ATWCC in YEB in 2012 and 2017

Based on the MRIO model and Equations (2), (6), and (7), the ADWCC and ATWCC of YEB in 2012 and 2017 were calculated, as shown in Figure 2.

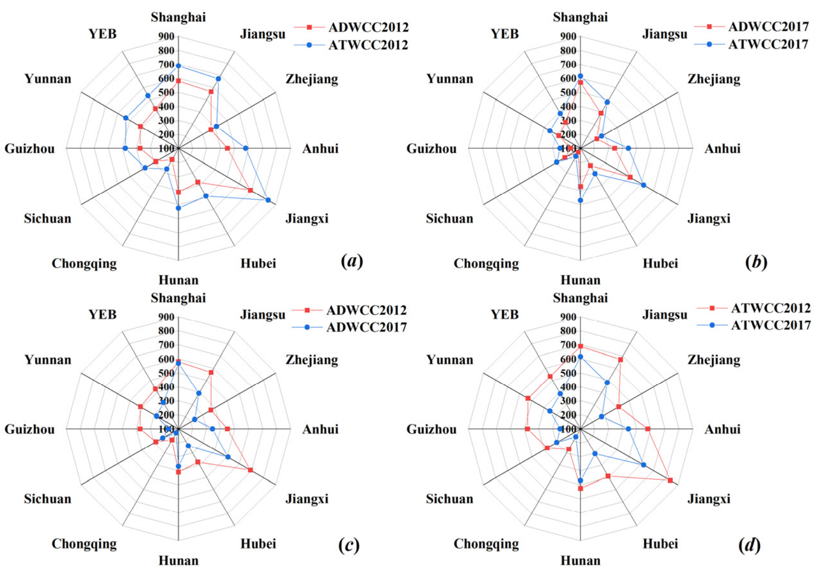


Figure 2. ATWCCs of 11 provinces (cities) in YEB (2012 and 2017). (**a**) Comparison of ADWCC and ATWCC in 2012; (**b**) Comparison of ADWCC and ATWCC in 2017. (**c**) Comparison of ADWCC between 2012 and 2017; (**d**) Comparison of ATWCC between 2012 and 2017.

Figure 2a,b indicates that the proportion of ADWCC in ATWCC in YEB was relatively high, 80.29% (2012) and 81.30% (2017), which remained basically unchanged. Among them, the proportion in Shanghai in 2017 was as high as 92.51%, which may indicate that the agricultural modernization level in this region is relatively high and it is less dependent on other sectors. Figure 2c,d shows that from 2012 to 2017, both ADWCC and ATWCC in YEB have decreased to a certain extent. Among them, the average value of ADWCC decreased from 427.4 to 315.1 kg/10,000 yuan, with a decrease rate is 26.27%, while the average value of ATWCC decreased from 532.5 to 387.5 kg/10,000-yuan, with a decrease rate is 27.2%.

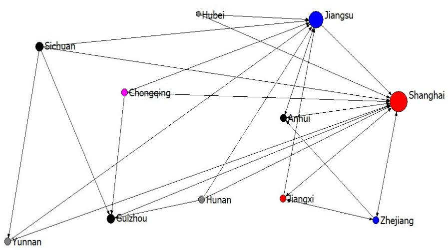
Regarding sector-wide consumption, Figure 2d shows that the AWUE of YEB has improved in the past five years, and the same agricultural input has obtained more economic output. On the one hand, agricultural production efficiency has been improved under the development of agricultural science and technology. The application of agricultural information technology and new irrigation equipment has improved the AWUE. On the other hand, the awareness of water conservation among agricultural employees has increased with the in-depth promotion of high-quality development and green development strategy, leading to a transformation from extensive water use to intensive water conservation, which has achieved remarkable results.

Based on the data from different provinces and cities in YEB, it was found that ATWCC decreased to varying degrees over the past five years. Guizhou showed the largest decrease, with a downtrend of 48.4%, followed by Chongqing and Hubei with 37.9% and 37.7%, respectively. In 2017, Chongqing had the lowest ATWCC, only 166 kg/10,000-yuan, while Shanghai had the highest, reaching 614.1 kg/10,000 yuan. The main reason for this difference is that Shanghai has a highly developed economy with a low proportion of primary industry, whereas Chongqing has a reasonable industrial structure and relatively high agricultural water technology, being an economically developed municipality directly under the central government and adjacent to three of China's major grain-producing areas. On the other hand, Jiangxi's agricultural production is relatively backward compared to Hunan and Hubei and the developed coastal areas in the East, resulting in the largest ATWCC of 619.4 kg/10,000 yuan. Overall, the ATWCC in YEB has been effectively controlled, and the AWUE has been greatly improved. However, there is still room for improvement in the region.

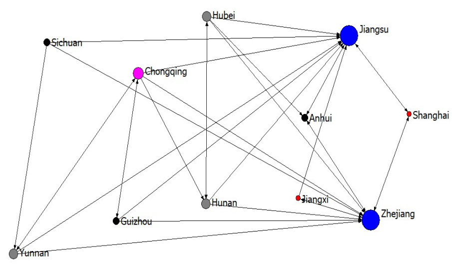
3.2. ATWCC's Spatial Correlation Network

3.2.1. Overall Characteristics

By taking the ATWCC of 11 provinces (cities) in YEB in 2012 and 2017 as the basic data, a spatial correlation binary matrix of ATWCC for the 11 provinces (cities) in YEB was constructed using a combination of gravity calculations with Equation (8). The UCINET software was then used to create a spatial network topology map of the ATWCC for the 11 provinces (cities) in YEB (Figure 3), and the spatial network structure was analyzed. The results show that the ATWCC in the 11 provinces (cities) of YEB has transcended the traditional spatial geographical proximity overflow attribute. There are no isolated points in the network, and the overall network exhibits the characteristics of a complex spatial correlation network.



(**a**)



(**b**)

Figure 3. Topologies of ATWCC in 11 provinces (cities) of YEB in (**a**) 2012 and (**b**) 2017.

Using UCINET 6.0, the overall characteristic indexes of the ATWCC spatial correlation network of 11 provinces (cities) in YEB in 2012 and 2017 are calculated (Table 3).

Table 3. Overall characteristic indexes of spatial correlation network in 11 provinces (cities) of YEB in 2012 and 2017.

Year	Network Relationship Number	Network Density	Network Correlation	Network Rank	Network Efficiency
2012	28	0.255	1	0.773	0.711
2017	32	0.291	1	0.746	0.689

Table 3 shows a slight upward trend in the number of network relationships in the ATWCC spatial correlation networks of 11 provinces (cities) in YEB, from 28 in 2012 to 32 in 2017, an increase of 14.29%. The network density also increased from 0.255 to 0.291, an increase of 25.88%. These changes indicate that the association intensity between provinces (cities) in terms of ATWCC has increased from 2012 to 2017, and the interaction between them has been strengthened. This can be attributed to the gradual improvement of the market economic system, which has facilitated the circulation of agricultural production and management factors. Additionally, the rapid development of transportation and information networks in YEB has supported agricultural water agglomeration, technology diffusion, and labor transfer, which have strengthened the correlation between agricultural production and operation among provinces (cities) and facilitated the formation of the spatial correlation of ATWCC.

In addition, during these five years, the implementation of the regional development strategy of YEB has accelerated the coordinated development within the region, and also provided impetus and support for the flow of various agricultural factors across the country. From 2012 to 2017, the number of network relationships has improved to a certain extent, but there is still a very large gap compared with the maximum possible total of 110 relationships. Therefore, there is still a lot of room for improvement.

From 2012 to 2017, the network correlation degrees were all 1, showing that all 11 provinces (cities) were included in the network, and the network structure of this spatial correlation network is stable, the ATWCCs of all provinces (cities) are interconnected, and the spatial spillover effect of ATWCC is wide, not limited to the adjacent areas. The network rank is relatively stable, falling from 0.773 in 2012 to 0.746 in 2017, reflecting that the internal rank is obvious and relatively stable. YEB spans the eastern, central, and western regions of China and there are significant regional differences in the level of agricultural development and water resources endowment in the upper, middle, and lower reaches.

Therefore, to achieve coordinated development within the YEB region, it is essential to uphold the fundamental principles of upper and lower reaches, left and right banks co-management, and systematic governance. The overall network efficiency experienced a slight decline from 0.711 in 2012 to 0.689 in 2017, representing a 3.1% decrease and indicating a strengthened network stability. This trend may be attributed to the continued implementation of the national key development strategy of YEB, which has facilitated the coordination of regional economic and social development, resulting in an increased correlation relationship among ATWCC in each province (city). The heightened spatial correlation lines between nodes have brought the network closer together, leading to stable improvement.

3.2.2. Individual Structure Characteristics

Using UCINET 6.0, the individual structure indicators of the ATWCC spatial correlation network in 11 provinces (cities) of YEB in 2017 are calculated (Table 4).

Table 4. Structural central analysis of the spatial correlation network of ATWCC in 11 provinces (cities) of YEB in 2017.

Provinces (Cities)	PCD				CCD		ICD	
	Point-Out Number	Point-In Number	Center Degree	Order	Center Degree	Order	Center Degree	Order
Shanghai	2	2	18.182	10	34.723	4	1.333	6
Jiangsu	2	9	81.818	1	52.304	2	7.333	3
Zhejiang	3	9	81.818	1	52.497	1	16.333	1
Anhui	2	3	27.273	7	36.357	3	1.333	6
Jiangxi	2	1	18.182	10	31.945	5	0.333	8
Hubei	4	1	36.364	4	16.969	11	0.333	8
Hunan	3	2	36.364	4	17.247	10	4	4
Chongqing	5	2	45.455	3	27.007	7	9	2
Sichuan	3	0	27.273	7	28.355	6	0	10
Guizhou	3	1	27.273	7	24.543	9	0	10
Yunnan	3	2	36.364	4	24.692	8	4	4
Mean	2.909	2.909	39.669		31.512		3.998	

Table 4 shows that the average PCD of the ATWCC spatial correlation network of 11 provinces (cities) in YEB in 2017 was 39.669. Among them, the PCD of Jiangsu, Zhejiang and Chongqing is higher than the average, indicating that these provinces (cities) are closer to the center of the network than other provinces (cities) in the network, and have more connections with other provinces (cities). These provinces (cities) play a key role in the formation and stable development of the overall network. Among them, Jiangsu and Zhejiang are located in developed coastal areas. These areas have advanced agricultural technology, rapid economic development, and convenient transportation network, which enable them to have an important impact on the agricultural economic output of other provinces (cities) through agricultural technology transfer, agricultural investment, absorption of agricultural labor, etc.; Chongqing, the only municipality directly under the central government in Southwest China, is the economic development area in the upper reaches of YEB, and is at the key node connecting the upper and middle reaches. The low PCD of Jiangxi and Shanghai may be mainly due to the geographical location and ultra-high ATWCC. Shanghai's economy is highly developed, however, in 2017, the proportion of the primary industry was only 0.3%. The higher ATWCC, as high as 614.1 m^3/10,000 yuan, was less than that of Jiangxi, which was 619.4 m^3/10,000-yuan. From the perspective of network structure, Shanghai has a network relationship with neighbor provinces Jiangsu and Zhejiang, and the situation of Jiangxi and Shanghai remains the same.

4. Discussion

The study uses the CONCOR algorithm to analyze the ATWCC spatial association network of 11 provinces (cities) in YEB. Here, the maximum segmentation density was set to 2 and the convergence standard was set to 0.2. Then, the overall network was respectively divided into four plates (2012) and three plates (2017), as shown in Figure 4.

Figure 4 shows that the ATWCC network structure of YEB has obvious regional characteristics, and this trend is becoming more and more obvious.

In 2017, the division of plates was almost the same as that of upper, middle, and lower reaches., as shown in Table 5.

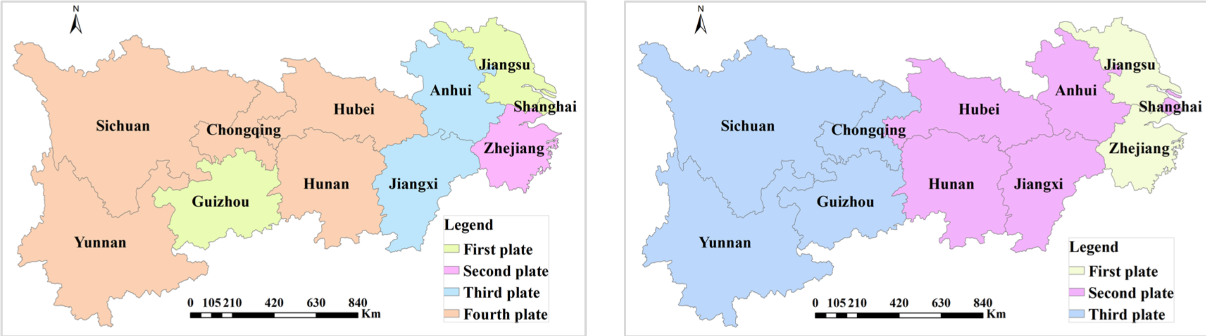


Figure 4. Division of spatial correlation plates of ATWCC of YEB in (**a**) 2012 and (**b**) 2017.

Table 5. Division of spatial correlation plates of ATWCC in 11 provinces (cities) of YEB in 2017.

Plate	Area	Number of Received Relationships		Number of Issued Relationships		Expected Internal Relationship Ratio (%)	Actual Internal Relationship Ratio (%)
		Inside	Outside	Inside	Outside		
First plate	Zhejiang, Jiangsu	0	18	0	5	10	0.000
Second plate	Shanghai, Hunan, Jiangxi, Anhui. Hubei	3	6	3	10	40	23.077
Third plate	Chongqing, Sichuan, Guizhou. Yunnan	5	0	5	9	30	35.714

It can be seen from Table 5 that there are 8 inside plate correlations and 24 outside plate correlations, accounting for 25% and 75% of the total network correlation number in 2017, showing that there are spatial agglomeration effects and spatial spillovers among the provinces (cities) in the ATWCC. Among them, the first plate includes Zhejiang and Jiangsu, with 0 internal relations, 18 received relationships outside the plate, and 5 issued relationships outside the plate. The expected internal relationship ratio is more than the actual internal relationship ratio, making it a net beneficiary region that mainly benefits from the input of factors from other regions. The second plate includes Shanghai, Hunan, Jiangxi, Anhui, and Hubei. It has 3 inside plate relations, 6 received relations outside the plate and 10 issued relationships outside the plate. The expected internal relationship ratio is more than the actual internal relationship ratio. It belongs to the broker plate. It has close spatial relations with both inside and outside plate members and acts as a link for element communication in the spatial correlation network. As an important port and trading venue, Shanghai has close connections with other cities, accompanied by the circulation of virtual water resources for agricultural products. Hunan, Hubei, Jiangxi, and Anhui are located in the central part of YEB, occupying an important geographical connection position, providing convenience for the circulation of products from the east to the west, which to some extent reflects the good regional coordination relationship of YEB as an economic demonstration belt.

The third plate includes 4 provinces (cities), that is, Chongqing, Sichuan, Guizhou and Yunnan, with 9 inside plate relationships, 0 off plate received relationships, and 9 outside plate issued relationships. The expected internal relationship ratio is less than the actual internal relationship ratio, belonging to the net overflow plate. Most of these regions are important provinces (cities) rich in water resources in China. The upper reaches of YEB are rich in natural resources, abundant in water resources, and have good agricultural production conditions. It has taken on important basic support in YEB's national strategy and coordinated development, delivering a large amount of virtual water resources to the middle and lower reaches.

On this basis, the density matrix of the ATWCC spatial correlation network was calculated by using the condensed subgroup analysis path, and the R-squared is equal to 0.607. Then, the elements in the density matrix that are greater than the density of the ATWCC spatial correlation network of 11 provinces (cities) in YEB in 2017 (0.291 measured above) were recorded as 1, and vice versa, they are 0 to obtain the image matrix (Table 6).

Table 6. Density matrix and image matrix of the spatial correlation plate of ATWCC in 11 provinces (cities) of YEB in 2017.

Plate	Density Matrix			Image Matrix		
	First Plate	**Second Plate**	**Third Plate**	**First Plate**	**Second Plate**	**Third Plate**
First plate	0.000	0.500	0.000	0	1	0
Second plate	1.000	0.150	0.000	1	0	0
Third plate	1.000	0.050	0.417	1	0	1

It can be seen that the ATWCC of the second and third plates overflows into the first plate; The ATWCC of the first plate has a certain space overflow to the second plate; The first and the second plate show asymmetric two-way spillover effect; On the whole, Zhejiang and Jiangsu are the main destinations of ATWCC spatial spillovers.

5. Conclusions

In this study, after the interregional input–output tables of 31 provinces (cities, autonomous regions) in China in 2012 and 2017, the water resource consumption row was added, and the input–output table of water resource use in YEB was constructed. Then the ATWCC of YEB was calculated. On this basis, the spatial correlation network structure of ATWCC in 11 provinces (cities) of YEB is analyzed by using a modified gravity model and social network analysis method. The main conclusions are as follows:

(1) from 2012 to 2017, the AWUE in all 11 provinces (cities) of YEB have improved to some extent, especially Guizhou (increase of 48.4%). Zhejiang, Hubei, Chongqing and Yunnan are all more than 30%. For YEB, the ATWCC decreased from 532.5 to 387.5 m^3/10,000 yuan, correspondingly, AWUE increased by 27.2%.

(2) ATWCC's spatial effect presents the characteristics of spatial correlation; the network density shows an upward trend, rising to 0.291 from 0.255, indicating that the ATWCC interaction between provinces (cities) was strengthened. The network structure of this spatial correlation network is stable, the ATWCCs of all provinces (cities) are interconnected, and the spatial spillover effect of ATWCC is wide, not limited to the adjacent areas. The network rank is relatively stable with a little fall of 3.49%, reflecting that the internal rank is obvious and relatively stable. The overall network efficiency showed a slight downward trend, indicating that network stability has been enhanced.

(3) The spatial correlation network has formed several network centers, such as Zhejiang, Chongqing and Jiangsu, which has played an important role in the formation of the spatial correlation network and has an impact and control on ATWCC in the 11 provinces (cities); In terms of cluster structure characteristics, YEB has obvious regional characteristics. Especially in 2017, the division between the upper, middle and lower reaches and the three plates has been basically continuous. Zhejiang and Jiangsu in the eastern coastal area are the main destinations of the spatial spillover of the spatial correlation network.

ATWCC accounting and its network correlation analysis are helpful to reveal the water use situation and complex status of regional agricultural sectors and can provide some decision support for the improvement of AWUE and regional coordinated development. Accurate and timely data acquisition is the premise of ATWCC accounting and the key approach to improving the reliability of results. However, China's latest interregional input-output table is the 2017 version, which inevitably leads to insufficient timeliness. In any case, this meaningful work will continue after the next version is available.

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Abbreviations

Abbreviation	Meaning
AWUE	Agricultural water use efficiency
TWCC	Total water consumption coefficient
DWCC	Direct water consumption coefficient
YEB	Yangtze River Economic Belt
ADWCC	Agricultural direct water consumption coefficient
ATWCC	Agricultural total water consumption coefficient
MRIO	Multi regional input-output
DEA	Data envelopment analysis
SNA	Social network analysis
PCD	Point center degree
CCD	Closeness center degree
ICD	Intermediation center degree

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