

Article

Urban Water Inclusive Sustainability: Evidence from 38 Cities in the Yangtze River Economic Belt in China

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Abstract: The ecological environment of urban water resources in the Yangtze River Economic Belt (YREB) is in a huge challenge; yet, while myriad studies have investigated the carrying capacity or sustainable utilization of Chinese water resources, few to none have looked at the inclusive sustainable development of water resources. In this article, a new concept of urban water inclusive sustainability (UWIS) is firstly proposed, and the conceptual framework of ASFII and a five-dimensional indicator system are developed, integrating availability, sustainability, friendliness, inclusiveness and innovation. The panel data of 38 cities in the YREB are adopted from 2008 to 2018 to measure UWIS and five development indexes by the TOPSIS (technique for order preference by similarity to ideal solution) and entropy method. Moreover, the characteristics of the temporal-spatial evolution of the overall system and subsystems coupling coordination are described using the coupling coordination degree model. Key factors that hinder UWIS are identified through the obstacle degree model. The results indicate that the overall UWIS showed a gradual upward trend at a lower to medium level from 2008 to 2018 and a friendliness > sustainability > inclusiveness > innovation > availability index. The UWIS from high to low is YRDUA (Yangtze River Delta urban agglomeration), MRYRUA (middle reaches of the Yangtze River urban agglomeration) and CCUA (Chengdu–Chongqing urban agglomeration). The 38 cities are in low-level coordination, and their temporal characteristics show a trend of economy > science and technology > water resources > environment > societal system, YRDUA > MRYRUA > CCUA. The spatial differentiation is manifested as high in the east and low in the west. The main obstacles come from 12 factors, such as the water resources utilization rate, etc. The findings of our study will be a scientific reference for the Chinese government to track UWIS and ensure urban water resources security in the YREB.



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Keywords: urban water inclusive sustainability (UWIS); ASFII conceptual framework; Yangtze River Economic Belt (YREB); coupling coordination degree; technique for order preference by similarity to ideal solution (TOPSIS)

1. Introduction

The Yangtze River Economic Belt (YREB) is the river basin economic belt with the largest population and industrial scale in the world. The urban development and 500 million people's lives in the YREB are closely related to water resources. According to the China Water Resources Bulletin of 2019, the total water resources of the nine provinces and two municipalities in the YREB accounted for 42.95% of the nation. The water consumption of industry, agriculture, residents and ecological environment accounted for 59.4%, 36.85%, 44.7% and 19.57%, respectively, and wastewater discharge accounted for more than 40%. Moreover, heavy energy consumption, water consumption and polluting industries such as coal, chemicals, steel, non-ferrous metals and papermaking are gathered along the Yangtze River, which poses a major threat to the drinking water of urban residents in the YREB. The imbalance of regional development has further aggravated the contradiction

between supply and demand of urban water resources and the difficulty of water resources management. The water resources utilization rate in the Yangtze River basin is 17.8%, the reuse rate of industrial water is about 62%, the leakage rate of urban water supply pipe network is generally about 20% and the utilization coefficient of irrigation water is about 0.45 [1]. As a result, the Yangtze River Economic Belt is in a huge challenge for ecological environment and support capacity of urban water resources, and it is urgent to solve the problems of sustainability of water resources and coordinated development between cities in the YREB.

Myriad studies have investigated the carrying capacity or sustainable utilization of Chinese water resources [2–4], yet few to none have looked at the inclusive sustainable development of water resources. The holistic approach for sustainability is centered on the three pillars of sustainable development: the economy, society and environment, not fully considering the contribution of scientific and technological progress, and even less for social equity. The concept of inclusive growth was firstly proposed by the Asian Development Bank in 2007, which refers to the process of ensuring that everyone can participate in the growth process fairly and benefit from it [5]. Subsequently, the World Bank and the United Nations have adopted inclusive growth as an important strategy to guide the development of countries. In 2016, Chinese President Jinping Xi stated at the G20 summit in Hangzhou that China should boost inclusive growth.

The Yangtze River Economic Belt is an important national strategic development area in China. In September 2016, the “Outline of the Yangtze River Economic Belt Development Plan” established a new development pattern of “one-axis, two-wing, three-pole and multi-point” in the YREB. The cities along the Yangtze River, as key carriers, are playing an extremely important role in promoting the coordinated and high-quality development of the upper, middle and lower reaches of the Yangtze River, under the background of ecological priority and green development. To propel the development of these cities, special attention should be paid to inclusive growth, not only economic development: that is, extensive participation, efficiency improvement, outcomes sharing and environmental sustainability. In addition, since science and technology play a key role in the development and utilization of water resources and water pollution control, the innovative applications of scientific and technological achievements are especially required in such areas as industrial wastewater and urban sewage treatment and recycling, agricultural water pollution control, river basin water pollution governance and comprehensive management, water saving and unconventional water resources integration, drinking water safety, etc. In order to achieve effectiveness and fairness in water resources sustainable development, we must adhere to the guidelines of people-oriented, high-quality development, environmental friendliness, science and technology development and incorporate the three pillars of sustainable development: economy, society and environment, and technological innovation. Therefore, it is necessary to integrate the concept of inclusive growth and sustainable development into the research of urban water resources. To this end, a new concept of urban water inclusive sustainability (UWIS) is developed in this article.

Regarding the water resources of Yangtze River Economic Belt, scholars have conducted fruitful research. Most of the existing research focused on water resource efficiency [6] and carrying capacity [2–4], but less on the sustainability and coupling coordination of urban water resources in the YREB. The water sustainability of cities is affected by the interaction of economic, social, environmental and technological subsystems. However, there are few ways to measure the degree of interaction between subsystems in the water sustainability system, thus a suitable evaluation method is badly needed in this respect.

In addition, most predecessors conducted empirical research along a river basin or at the provincial level. The research focusing on water resources in the YREB is mostly undertaken in nine provinces and two municipalities, while the theoretical and empirical research from the city level is quite rare in this regard. Since the prefecture-level cities along the Yangtze River are major carriers for the development of a new pattern of “one-

axis, two-wing, three-pole and multi-point”, it is valuable to conduct research at the level of cities.

Since the inclusive and sustainable development of water resources of cities in the Yangtze River Economic Belt is crucial, the following questions have arisen and are also puzzling water resources researchers and policymakers:

(1) How can inclusive sustainability of water resources be characterized at the prefecture-level city?

(2) How to measure inclusive sustainability of water resources of cities along the Yangtze River on the basis of the panel data of 38 cities from 2008 to 2018?

(3) How to reveal the coupling coordination effect between the five major subsystems and their temporal–spatial evolution trend?

(4) How to identify the key factors in the water resources, economic, social, environmental and scientific and technological subsystems that promote or hinder the inclusive sustainability of water resources of cities in the Yangtze River Economic Belt?

The layout of this article is as follows. In Section 2, we review the existing research literature. In Section 3, we develop a new concept of urban water inclusive sustainability (UWIS) and present a conceptual framework and indicator system. In Section 4, we discuss data and methodology for assessing UWIS. An intensive empirical study of 38 cities in the YREB is conducted in Section 5. The context includes measurement of UWIS using the TOPSIS (technique for order preference by similarity to ideal solution) and entropy method, temporal–spatial evolution analysis of the coupling coordination and identification of obstacle factors. Some discussions and conclusions are provided in the last section. We hope our findings will be a scientific reference for public decision makers to determine that, in the integral water management cycle, water resource management should be carried out under the paradigm of water inclusive sustainability.

2. Literature Review

Since the Asian Development Bank first proposed the concept of inclusive growth in 2007 [5], scholars at home and abroad have carried out a series of studies concerning it. Domestic and foreign literature is centered upon the connotation and measurement of inclusive growth [7,8], focusing on the relationships between different objects or factors, such as financial inclusiveness [9], land use inclusiveness [10], green inclusiveness [11], inclusive innovation performance [12], the relationship between agriculture, poverty, food and energy security and inclusive growth [13–16], growth path [17,18] and inclusive growth strategic plan [19], etc. They have constructed national or provincial evaluation systems of economic inclusive growth from three or four levels of economic growth sustainability, coordination, fairness and effectiveness [20]. Some of them have established an inclusive development triangle [21], the triangle of land use inclusiveness [10], and other analytical frameworks. For example, McKinley proposed four dimensions of inclusive growth: namely, economic infrastructure, capacity development, income equity and social security [8]. In particular, there are also the five pillars proposed by Garrido-Lecca and his colleagues, who began to take innovation and knowledge into consideration but somewhat missed out the contribution of scientific and technological progress and intergenerational equity [22].

Scholars have recently begun to dabble in inclusive economy, inclusive wealth, etc., regarding the research of inclusiveness and sustainability. For instance, Asongu and Odhiambo examined the relevance of inclusive development in modulating the role of governance on environmental degradation [23]; Kalkanci and his colleagues put forward an “inclusive innovation” approach to discuss sustainability [24]; Ikeda and Managi developed a framework for evaluating the sustainability of regions, predicting the inclusive wealth index (IWI) under different future scenarios from 2015 to 2100 [25]; Kurniawan and Managi explored that shared socioeconomic pathways with high investments in broad societal development are associated with the highest growth in inclusive wealth [26]; Siddiqi and Collins discussed how the emerging concept of inclusive innovation bridges dimensions

of environment and social inclusivity [27]. Some scholars have designed indicators of circular economy as evaluating instruments for sustainability and efficiency in wastewater treatment [28,29].

Consequently, inclusive growth emphasizes people-oriented, fair and reasonable sharing of economic growth, while sustainable development focuses on the coordinated development of economy, society and environment. Thus, our study must be based on social inclusiveness, economic sustainability, environmental friendliness and technological innovation, which requires us to consider all the above aspects and incorporate them into the unified framework for research. For this purpose, in this article, we propose a new concept of inclusive sustainability to fully describe the inclusive sustainable development capacity of urban water resources.

Regarding the water resources of Yangtze River Economic Belt, scholars have conducted fruitful research, mainly exploring the water ecological footprint [30,31], utilization efficiency [32], green efficiency [33,34] and carrying capacity [35] of water resources. Lots of the research has focused on water resource efficiency [6] and carrying capacity [2–4], but little on sustainable use of water resources. Most of the indicators are based on the pressure–state–response (PSR) framework [36], less on indicators for scientific and technological innovation. Measurement is mainly performed using principal component analysis [37], improved analytic hierarchy process [38], fuzzy comprehensive evaluation [39,40], grey relational analysis [41], data envelopment analysis (DEA) [42], system dynamics [6,43], technique for order preference by similarity to ideal solution (TOPSIS) [35,44] and back propagation (BP) neural network [45]. However, there are few ways to measure the degree of interaction between subsystems in the water resources sustainability system, and most scholars have undertaken their research on water resources in the Yangtze River Economic Belt from nine provinces and two municipalities, while the research from the urban level is quite rare in this regard. Since the cities along the Yangtze River are major carriers for the development of a new pattern of “one-axis, two-wing, three-pole and multi-point”, it is valuable to conduct research at the level of cities. Due to the fact that the water inclusive sustainability system is characterized by complexity and ambiguity, and the interaction between various subsystems needs to be considered, it is necessary to find out a suitable method for evaluation.

As for the research on the coupling coordination of urban water resources, scholars have mostly conducted empirical research on two subsystems between water resources and economy [46], social economy [47,48], ecological environment [49], energy [50], land resources [51,52], population [53], urbanization [54,55], etc. Only a few studies have focused on three subsystems [56,57]. Few scholars have discussed the interaction and multiple coupling relationships between water resources and economy, society, environment, and science and technology systems [58,59]. In this article, we will take this as the starting point to carry out the research.

In this context, we attempt to develop the theoretical framework and indicator system to characterize UWIS at the prefecture-level city in the Yangtze River Economic Belt. The TOPSIS integrated entropy method is employed to measure UWIS on the basis of the panel data of 38 cities in the YREB from 2008 to 2018. The coupling coordination degree model is used to describe the trend of temporal–spatial evolution of the coupling coordination of the overall UWIS system and the five major subsystems. Key factors that promote or hinder UWIS in the YREB are identified through the obstacle degree model and solutions to the constraints are given. The results will offer suggestions for the Chinese government to enhance the level of UWIS in the YREB.

3. Conceptual Framework and Indicator System

From the perspectives of inclusiveness and sustainable development, integrating the three pillars of sustainable development: economy, society and environment, and technological innovation, a new concept of urban water inclusive sustainability (UWIS) is proposed by authors in this article. UWIS is defined as: under a certain scientific and

technological and natural condition, urban residents, whether present or future generations, can obtain the water resources needed for their development in a timely, appropriate, fair and economic manner through rivers, lakes and reservoirs, while ensuring that water quality and ecological environment are not destroyed, thus achieving economic, social and environmental coordination and high quality development.

The inclusive sustainability of urban water resources is a complex system involving such subsystems as water resources, society, economy, environment, science and technology, etc. The new concept of “urban water inclusive sustainability” proposed in this article combines the ideas of water availability, economic sustainability, environmental friendliness, social inclusiveness and technological innovation. Based on the five pillars proposed by Garrido-Lecca and his colleagues, in this article we establish the conceptual framework of ASFII of urban water inclusive sustainability, including five dimensions of availability, sustainability, friendliness, inclusiveness and innovation (as shown in Figure 1).

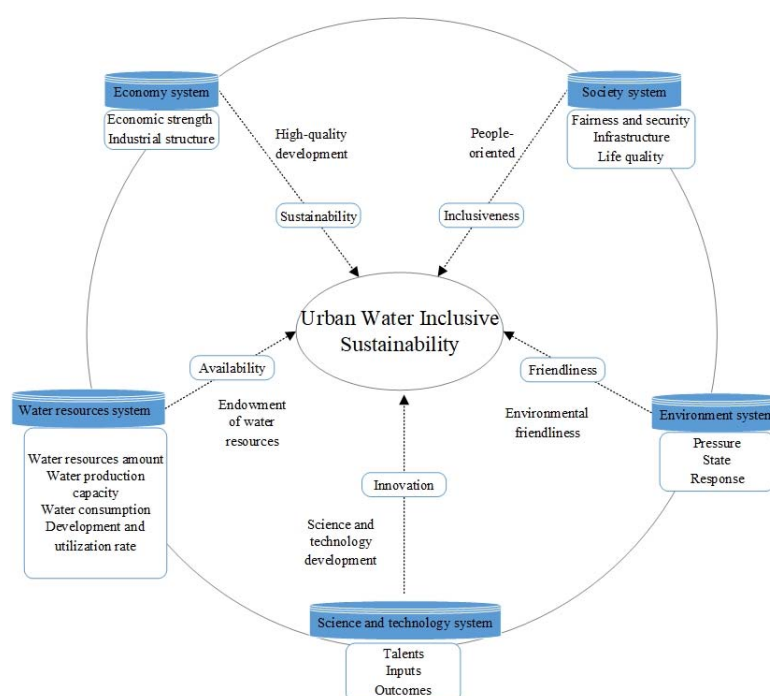


Figure 1. The ASFII conceptual framework of urban water inclusive sustainability (UWIS).

In the conceptual framework of ASFII, “A” refers to availability, which indicates the endowment of water resources, characterized by water resources amount, water production capacity, water consumption, water development and utilization rate; “S” is sustainability, which reflects the high-quality development of the economy, involving economic strength and industrial structure; “F” symbolizes to friendliness, which indicates the friendly state of environment, characterized by pressure, state, and response; two “I” represent inclusiveness and innovation, respectively. Inclusiveness means that the social subsystem is people-oriented, focusing on fairness and security, infrastructure and life quality; and innovation describes the development of science and technology, characterized by talents, inputs and outcomes.

As explained above, UWIS is a new concept integrating the ideas of availability, sustainability, friendliness, inclusiveness and innovation of water resources, and stressing five perspectives of water resources endowment, high-quality development, environmental friendliness, people-oriented and science and technology development.

Based on the availability, sustainability, friendliness, inclusiveness and innovation (ASFII) conceptual framework, the key factors affecting UWIS are identified, and the corresponding evaluation indicators are selected accordingly (see Table 1), fully considering the drivers and constraints of UWIS, as well as the interaction between subsystems.

Table 1. The indicator system of urban water inclusive sustainability (UWIS).

Objective Level	Criterion Level	Element Level	Indicator Level	Formula	Indicator Attributes
UWIS	Availability index	Water resources amount, Water production capacity	W ₁ Total water resources per capita	Total water resources/Annual average population	Positive
			W ₂ Surface water resources per square kilometer	Surface water resources/Total land area of administrative region	Positive
			W ₃ Ground water resources per square kilometer	Ground water resources/Total land area of administrative region	Positive
			W ₄ Water production modulus	Total water resources/Total land area of administrative region	Positive
		Water consumption	W ₅ Rainfall depth	Total rainfall/Total land area of administrative region	Positive
			W ₆ Total water consumption per capita	Total water consumption/Annual average population	Negative
		Water development and utilization rate	W ₇ Water consumption per ten thousand yuan of GDP	Total water consumption/Ten thousand yuan of GDP	Negative
			W ₈ Water resources utilization rate	(Total water supply/Total water resources) × 100%	Positive
	Sustainability index	Economic strength	Ec ₁ GDP per capita	Regional GDP/Annual average population	Positive
			Ec ₂ GDP annual growth rate	[(The <i>n</i> -th GDP-the (<i>n</i> −1)-th GDP)/ the (<i>n</i> −1)-th GDP] × 100%	Positive
		Industrial structure	Ec ₃ Secondary industry output value as a share of GDP	(Secondary industry output value/GDP) × 100%	Moderate
			Ec ₄ Tertiary industry output value as a share of GDP	(Tertiary industry output value/GDP) × 100%	Positive
	Inclusiveness index	Fairness and security	S ₁ Population density	Annual average population/Total land area of administrative region	Moderate
			S ₂ Urban registered unemployment rate	(Urban registered unemployed population/Annual average population) × 100%	Negative
			S ₃ Number of beds in hospitals per 10,000 persons	Number of beds in hospitals/Annual average population	Positive
		Infrastructure	S ₄ Rate of urban employees covered by basic endowment insurance	Number of urban employees covered by basic endowment insurance/Annual average population	Positive
			S ₅ Drainage pipe length per 10,000 persons	Drainage pipe length/Annual average population	Positive
			S ₆ Number of public vehicles owned by 10,000 persons	Number of public operating vehicles/Annual average population	Positive

Table 1. Cont.

Objective Level	Criterion Level	Element Level	Indicator Level	Formula	Indicator Attributes
UWIS	Inclusiveness index	Life quality	S_7 Penetration rate of water usage	$(\text{Water users} / \text{Average annual population}) \times 100\%$	Positive
			S_8 Consumption expenditure of urban residents per capita	$\text{Consumption expenditure of urban residents} / \text{Annual average population}$	Positive
			S_9 Ratio of disposable income of urban and rural residents per capita	$\text{Disposable income of urban residents per capita} / \text{Disposable income of rural residents per capita}$	Negative
			S_{10} Rate of Internet user	$\text{Number of Internet users} / \text{Annual average population}$	Positive
	Friendliness index	Pressure	En_1 Volume of industrial wastewater discharged per 10,000 yuan of GDP	$\text{Volume of industrial wastewater discharged} / 10,000 \text{ yuan GDP}$	Negative
			En_2 Volume of industrial sulfur dioxide emissions per 10,000 yuan of GDP	$\text{Volume of industrial sulfur dioxide emissions} / 10,000 \text{ yuan GDP}$	Negative
			En_3 Volume of industrial smoke (dust) emissions per 10,000 yuan of GDP	$\text{Volume of industrial smoke (dust) emissions} / 10,000 \text{ yuan GDP}$	Negative
		State	En_4 Proportion of river water superior to Class III water in quality throughout the year	$(\text{Class I, II, III water river length} / \text{Annual monitoring water river length}) \times 100\%$	Positive
			En_5 Proportion of water in lakes and reservoirs superior to Class III water in quality	$(\text{Number of Class I, II, III water lakes and reservoirs} / \text{Total number of monitoring lakes and reservoirs}) \times 100\%$	Positive
			En_6 Rate of key water functional zones up to standard	$(\text{Number of water functional zones up to standards} / \text{Total number of water functional zones}) \times 100\%$	Positive
		Response	En_7 Area of green land per capita	$\text{Area of green land} / \text{Average annual population}$	Positive
			En_8 Rate of sewage under centralized treatment	$(\text{Amount of treated sewage} / \text{Total amount of sewage discharged}) \times 100\%$	Positive
			En_9 Rate of household waste under harmless treatment	$(\text{Amount of household waste under harmless treatment} / \text{Amount of household waste}) \times 100\%$	Positive
			En_{10} Green coverage rate in built-up area	$(\text{Green coverage in built-up area} / \text{built-up area}) \times 100\%$	Positive
	Innovation index	Talents	T_1 College students per 10,000 persons	$\text{Number of college students} / \text{Average annual population}$	Positive
		Inputs	T_2 Education expenditure as a share of GDP	$(\text{Education expenditure} / \text{GDP}) \times 100\%$	Positive
			T_3 Science and technology expenditure as a share of GDP	$(\text{Science and Technology Expenditure} / \text{GDP}) \times 100\%$	Positive
		Outcomes	T_4 Number of patents granted per 10,000 persons	$\text{Number of patents granted} / \text{Average annual population}$	Positive

4. Data and Methodology

4.1. Sample and Data

The Yangtze River Economic Belt is an important national strategic development area in China. Covering nine provinces and two municipalities, the Yangtze River Economic Belt contains 41 cities. Considering the fact that the data of a few county-level cities such as Chaohu in Anhui Province, Shishou in Hubei Province and Shuifu in Yunnan Province are not available, the remaining 38 prefecture-level cities and above along the Yangtze River (see Figure 2) are selected as a sample for this research, covering the Yangtze River Delta urban agglomeration (YRDUA) (21 cities), the middle reaches of the Yangtze River urban agglomeration (MRYRUA) (12 cities) and the Chengdu–Chongqing urban agglomeration (CCUA) (5 cities). According to comprehensive competitiveness, the research sample is divided into four categories, which include 1 primary central city, 11 secondary central cities, 15 regional central cities and 11 general cities.

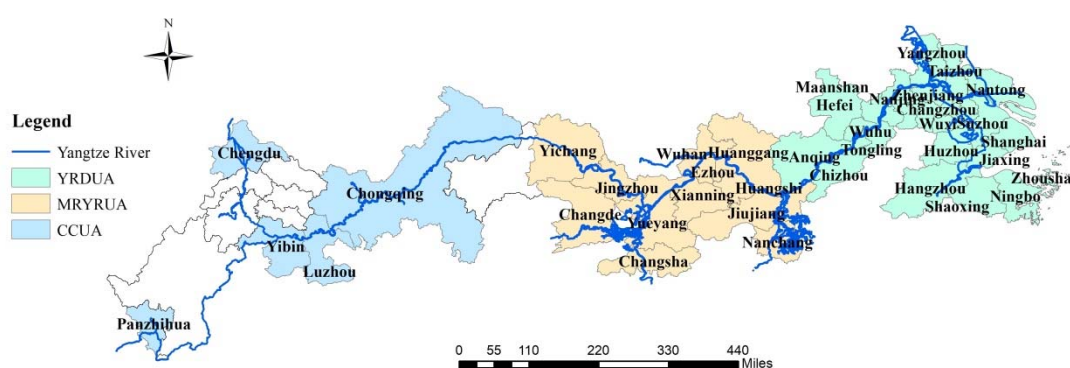


Figure 2. The distribution map of sample cities in the Yangtze River Economic Belt.

Data are gathered from 38 cities in the Yangtze River Economic Belt from 2008 to 2018. The data were taken from “China City Statistical Yearbook (2009–2019)”, “China Environment Statistical Yearbook (2009–2019)”, “China City Construction Statistical Yearbook (2009–2019)”, statistical yearbooks of nine provinces and two municipalities in the Yangtze River Economic Belt (2009–2019), Water Resources Bulletin (2008–2018), City Statistical Yearbook (2009–2019), National Economic and Social Development Bulletin (2008–2018), etc. The indicator data were obtained by calculating some of the original data, and the default data were estimated by fitting.

4.2. Methodology

The UWIS measurement is a multi-criteria decision problem. From the literature review and existing research, it can be seen that the TOPSIS mainly judges the pros and cons of the alternative by calculating the Euclidean distance between each evaluation alternative and the positive and negative ideal alternative. It is suitable for multi-criteria decision problems. Different from the subjective weight determination method, the entropy method is often used to analyze the usefulness of information in decision-making problems through actual data. Therefore, the entropy method is a scientific and objective method for determining indicator weights, which is superior to the subjective weighting method. In this article, the TOPSIS and entropy method are employed to measure UWIS. We will use the entropy method to determine the weights of indicator and element levels. Since there are fewer dimensions at criterion level, the weight of criterion level is determined by the expert scoring method.

4.2.1. Entropy Method

The main steps of the entropy method [60] are as follows:

(1) Normalize the original data for positive, negative, moderate indicators, and use Formulas (1)–(4) for normalization, respectively.

For a positive indicator,

$$x'_{ij} = (x_{ij} - \min\{x_{ij}\}) / (\max\{x_{ij}\} - \min\{x_{ij}\}) \quad (1)$$

For a negative indicator,

$$x'_{ij} = (\max\{x_{ij}\} - x_{ij}) / (\max\{x_{ij}\} - \min\{x_{ij}\}) \quad (2)$$

For a moderate indicator,

$$x''_{ij} = (x_{ij} - \text{median}\{x_{ij}\}) / (\max\{x_{ij}\} - \min\{x_{ij}\}) \quad (3)$$

$$x'_{ij} = (x''_{ij} - \min\{x''_{ij}\}) / (\max\{x''_{ij}\} - \min\{x''_{ij}\}) \quad (4)$$

$$(i = 1, \dots, m, j = 1, \dots, n)$$

where m is the number of evaluated cities, and n is the number of indicators.

In the Formulas (1)–(4), x_{ij} , x'_{ij} and x''_{ij} refer to the actual value, the normalized value and the median value of the j – th indicator of the i – th city, respectively, and $\max\{x_{ij}\}$ and $\min\{x_{ij}\}$ represent the maximum and minimum value of the j – th indicator of all evaluated cities in a certain year.

(2) Calculate the characteristic proportion of each attribute value p_{ij} by using Formula (5).

$$p_{ij} = x'_{ij} / \sum_{i=1}^m x'_{ij} \quad (5)$$

(3) Calculate the entropy value e_j of the j – th indicator based on Formula (6).

$$e_j = - \sum_{i=1}^m p_{ij} \ln p_{ij} / \ln m \quad (6)$$

If $p_{ij} = 0$, then define

$$\lim_{p_{ij} \rightarrow 0} p_{ij} \ln p_{ij} = 0$$

(4) Calculate the coefficient g_j of variance of the j – th indicator according to Formula (7).

$$g_j = 1 - e_j \quad (7)$$

(5) Use the entropy value to calculate the weight w_j of the j – th indicator and obtain the weight set using the following Formulas (8) and (9):

$$w_j = g_j / \sum_{j=1}^n g_j \quad (8)$$

$$w = [w_1, w_2, \dots, w_n] \quad (9)$$

4.2.2. TOPSIS

The main steps of TOPSIS [35] are as follows:

(1) Calculate the weighted normalized decision matrix Z by using Formula (10).

$$Z = (z_{ij})_{m \times n}, z_{ij} = w_j \times x'_{ij} \quad (10)$$

$$(i = 1, \dots, m, j = 1, \dots, n)$$

(2) Determine the positive ideal alternative Z^+ and the negative ideal alternative Z^- on the basis of Formulas (11) and (12):

$$Z^+ = (z_1^+, z_2^+, \dots, z_j^+, \dots, z_n^+) \quad (11)$$

$$Z^- = (z_1^-, z_2^-, \dots, z_j^-, \dots, z_n^-) \quad (12)$$

where

$$z_j^+ = \max_i (x'_{ij})$$

$$z_j^- = \min_i (x'_{ij})$$

(3) Calculate the Euclidean distance d_i^+ and d_i^- between each evaluation alternative and the positive and negative ideal alternative according to Formulas (13) and (14).

$$d_i^+ = \sqrt{\sum_{j=1}^n (z_{ij} - z_j^+)^2} \quad (13)$$

$$d_i^- = \sqrt{\sum_{j=1}^n (z_{ij} - z_j^-)^2} \quad (14)$$

(4) Calculate relative closeness C by using Formula (15).

$$C = d_i^- / (d_i^+ + d_i^-) \quad (15)$$

4.2.3. Coupling Coordination Degree Model

The coupling degree is a measure of interaction between systems. The coupling degree model [61] is:

$$C = \left\{ U_1 \times U_2 \times \dots \times U_k / \left(\frac{U_1 + U_2 + \dots + U_k}{k} \right)^k \right\}^{\frac{1}{k}} \quad (16)$$

In Formula (16), C is the coupling degree ($0 \leq C \leq 1$), U_k is the development level (i.e., index) of the k -th subsystem and k is the number of subsystems. This study includes five subsystems: namely, water resources (W), economy (Ec), society (S), environment (En), and science and technology (T) systems; that is, $k = 5$. In our study, $W(w)$, $Ec(ec)$, $S(s)$, $En(en)$, and $T(t)$ indicate availability, sustainability, friendliness, inclusiveness and innovation index, respectively. The Formula (17) is:

$$C = \left\{ \frac{W(w) \times Ec(ec) \times S(s) \times En(en) \times T(t)}{\left(\frac{W(w) + Ec(ec) + S(s) + En(en) + T(t)}{5} \right)^5} \right\}^{\frac{1}{5}} \quad (17)$$

To further characterize the development level of the UWIS system and the level of interaction and coordination between the subsystems, the coupling coordination degree model is introduced on the basis of the coupling degree as follows [61]:

$$\begin{cases} T = v_1 W(w) + v_2 Ec(ec) + v_3 S(s) + v_4 En(en) + v_5 T(t) \\ D = \sqrt{C \times T} \end{cases} \quad (18)$$

In Formula (18), T is the comprehensive evaluation value reflecting the development level of the UWIS system; D is the coupling coordination degree; v_1 , v_2 , v_3 , v_4 , v_5 are the weights of the criterion level, and $v_1 + v_2 + v_3 + v_4 + v_5 = 1$. By inviting experts, scholars

and managers from water resources planning and management departments in the field of water resources, we use the expert scoring method to obtain $v1 = 0.275$, $v2 = 0.182$, $v3 = 0.192$, $v4 = 0.193$, $v5 = 0.158$, respectively.

4.2.4. Obstacle Degree Model

In order to identify the key factors that promote or restrict the inclusive sustainability of urban water resources, the obstacle degree model [61] is adopted in this study:

$$F_{ij} = w_{ij} * w_i \quad (19)$$

$$I_{ij} = 1 - x'_{ij} \quad (20)$$

$$p_{ij} = F_{ij} \times I_{ij} / \sum_{i=1}^m (F_{ij} \times I_{ij})$$

$$P_{ij} = \sum_{i=1}^m p_{ij} \quad (21)$$

In Formulas (19)–(21), w_{ij} is the weight of the j – th indicator of the i – th criterion level, w_i is the weight of the criterion level where the j – th indicator is located, x'_{ij} refers to the normalized value of the j – th indicator of the i – th city, F_{ij} is the element contribution degree, I_{ij} is the indicator deviation degree and P_{ij} is the obstacle degree.

5. An Intensive Empirical Study

Based on the panel data of 38 cities in the Yangtze River Economic Belt from 2008 to 2018, the entropy method and expert scoring method are used to determine the weights. In light of the conceptual framework of ASFII and a five-dimensional indicator system for UWIS proposed in this article, TOPSIS is employed to measure UWIS and the five major development indexes of 38 cities in the YREB from 2008 to 2018. The characteristics of the temporal–spatial evolution of the coupling coordination of the overall UWIS system and the five major subsystems are described by the coupling coordination degree model. Key factors that promote or hinder UWIS in the YREB are identified through the obstacle degree model, so as to explore the changing trends and constraints of UWIS of the YREB, three major urban agglomerations and the cities involved.

5.1. Measurement of UWIS Based on the TOPSIS and Entropy Method

5.1.1. Measurement of UWIS

Firstly, based on the data of 38 cities in the Yangtze River Economic Belt from 2008 to 2018, the entropy method is used to calculate the weight w_j of each indicator using Formulas (1)–(9) (see Appendix A).

Secondly, the weighted normalized decision matrix Z is given by Formula (10) so as to determine the positive and negative ideal solution Z_j^+ and Z_j^- of the matrix Z by Formulas (11) and (12), as shown in Appendix A.

Finally, according to Formulas (13)–(15), the evaluation results of UWIS of 38 cities from 2008 to 2018 are obtained by calculating the Euclidean distance d_i^+ and d_i^- between each city and the positive and negative ideal alternative, and by computing the relative closeness C , as shown in Table 2, Figure 3.

Table 2. The UWIS of 38 cities in the YREB based on the TOPSIS and entropy method (2008–2018).

	Shanghai	Nanjing	Wuxi	Changzhou	Suzhou	Nantong	Yangzhou	Zhenjiang
2008	0.5679	0.5126	0.4687	0.3793	0.5284	0.3520	0.3589	0.4012
2009	0.5440	0.4723	0.4585	0.3763	0.5171	0.3386	0.3436	0.3701
2010	0.5562	0.4916	0.5041	0.3996	0.5170	0.3586	0.3523	0.3952
2011	0.5440	0.4890	0.4859	0.4040	0.5085	0.3619	0.3582	0.3766
2012	0.4884	0.4599	0.4673	0.3687	0.4723	0.3206	0.3239	0.3481

Table 2. Cont.

	Shanghai	Nanjing	Wuxi	Changzhou	Suzhou	Nantong	Yangzhou	Zhenjiang
2013	0.5366	0.4951	0.5124	0.4453	0.5188	0.3614	0.3840	0.3830
2014	0.5365	0.5455	0.4814	0.4392	0.4986	0.3464	0.3694	0.4188
2015	0.4962	0.5187	0.4757	0.4228	0.4857	0.3615	0.3691	0.3985
2016	0.5377	0.5378	0.4955	0.4560	0.5101	0.3777	0.3892	0.4308
2017	0.5493	0.5564	0.4963	0.4479	0.5289	0.3642	0.3869	0.4277
2018	0.5630	0.5721	0.4932	0.4496	0.5398	0.3863	0.4078	0.4359
	Taizhou	Hangzhou	Ningbo	Jiaxing	Huzhou	Shaoxing	Zhoushan	Hefei
2008	0.3269	0.4452	0.5004	0.3934	0.3675	0.4294	0.3928	0.4420
2009	0.3163	0.4802	0.4953	0.4172	0.3762	0.4214	0.4263	0.4320
2010	0.3282	0.4813	0.4913	0.3969	0.3742	0.3658	0.4081	0.4419
2011	0.3250	0.4535	0.4437	0.3875	0.3582	0.3566	0.4064	0.4105
2012	0.3059	0.4434	0.4204	0.3313	0.3251	0.3080	0.4046	0.3887
2013	0.3498	0.4772	0.4974	0.4369	0.3865	0.3905	0.4245	0.4598
2014	0.3540	0.4853	0.4730	0.4009	0.3911	0.3733	0.4521	0.4198
2015	0.3505	0.4827	0.4380	0.3919	0.4050	0.4049	0.4571	0.4078
2016	0.3715	0.5229	0.4704	0.4447	0.4371	0.4322	0.4407	0.4350
2017	0.3629	0.5172	0.4664	0.4121	0.4282	0.4275	0.4107	0.4280
2018	0.3683	0.5524	0.5017	0.4347	0.4539	0.4601	0.4607	0.4576
	Wuhu	Maanshan	Tongling	Anqing	Chizhou	Nanchang	Jiujiang	Wuhan
2008	0.3976	0.3969	0.3449	0.3146	0.3364	0.4371	0.3372	0.4862
2009	0.3851	0.3110	0.3048	0.2714	0.3059	0.4013	0.3169	0.4629
2010	0.4199	0.3478	0.3516	0.2764	0.3028	0.4070	0.3230	0.4519
2011	0.3865	0.3162	0.3784	0.2907	0.3247	0.4167	0.3273	0.4678
2012	0.3699	0.2821	0.3866	0.2736	0.3182	0.3877	0.3014	0.4476
2013	0.4134	0.3056	0.4357	0.2766	0.3182	0.3430	0.3941	0.4265
2014	0.3852	0.2736	0.4058	0.2844	0.3301	0.4270	0.3215	0.5022
2015	0.3522	0.2965	0.3710	0.2875	0.3191	0.4143	0.3197	0.4787
2016	0.4052	0.3332	0.3651	0.3250	0.3534	0.4499	0.3153	0.4917
2017	0.4246	0.3231	0.3621	0.3030	0.3087	0.4482	0.3243	0.5339
2018	0.4690	0.4292	0.3760	0.3102	0.3288	0.5049	0.3363	0.5747
	Huangshi	Yichang	Ezhou	Jingzhou	Huanggang	Xianning	Changsha	Yueyang
2008	0.2951	0.3378	0.3165	0.2861	0.3265	0.2927	0.4382	0.2911
2009	0.2632	0.3290	0.3093	0.2620	0.3032	0.2584	0.4298	0.2793
2010	0.2579	0.3261	0.3064	0.2549	0.2724	0.2740	0.4316	0.2911
2011	0.2785	0.3291	0.3323	0.2699	0.2783	0.2976	0.4607	0.3229
2012	0.2525	0.2831	0.3104	0.2451	0.2697	0.3064	0.4071	0.2589
2013	0.2877	0.3351	0.3439	0.2599	0.2563	0.3197	0.3828	0.2785
2014	0.2756	0.3279	0.3237	0.2662	0.3051	0.3246	0.4502	0.3025
2015	0.2637	0.3252	0.3007	0.2735	0.2930	0.3068	0.4337	0.2978
2016	0.3200	0.3434	0.3557	0.3308	0.2747	0.3347	0.4573	0.3103
2017	0.3025	0.3389	0.3358	0.2891	0.2859	0.3219	0.3192	0.2865
2018	0.3263	0.3504	0.4244	0.2946	0.2685	0.3080	0.3140	0.2994
	Chengde	Chongqing	Chengdu	Panzihua	Luzhou	Yibin		
2008	0.2855	0.3355	0.4175	0.3710	0.2626	0.2806		
2009	0.2996	0.3313	0.4021	0.3206	0.2637	0.2737		
2010	0.3063	0.3466	0.4185	0.3129	0.2701	0.2721		
2011	0.3385	0.3762	0.4157	0.3281	0.2891	0.3177		
2012	0.2813	0.3392	0.3853	0.3434	0.3233	0.2927		
2013	0.3053	0.3835	0.4217	0.3587	0.3126	0.3210		
2014	0.3272	0.3678	0.4361	0.3020	0.3126	0.3014		
2015	0.3296	0.3470	0.4308	0.2502	0.3504	0.3016		
2016	0.3369	0.3863	0.4347	0.2648	0.3569	0.3171		
2017	0.3392	0.3644	0.4372	0.3387	0.3192	0.2865		
2018	0.3560	0.3560	0.4682	0.3281	0.3140	0.2994		

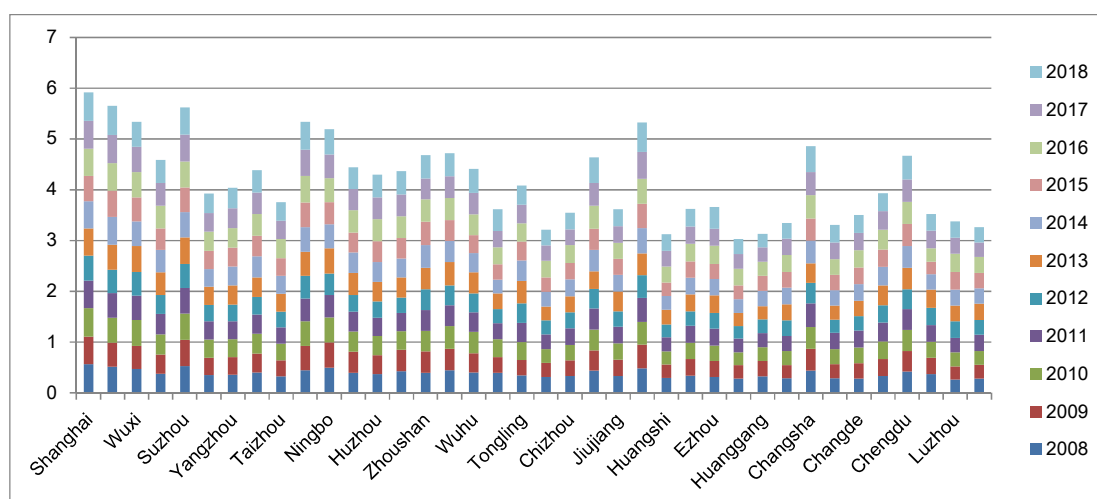


Figure 3. The UWIS based on the TOPSIS and entropy method.

Considering the actual situation of this study, the classification of the levels of UWIS is determined as shown in Table 3.

Table 3. Classification of urban water inclusive sustainability.

Rank	Lowest	Lower	Medium	Higher	Highest
UWIS	0~0.2	0.2~0.4	0.4~0.6	0.6~0.8	0.8~1.0

The results in Figure 3 showed that UWIS in the Yangtze River Economic Belt, though generally low and fluctuating, witnessed an upward trend from 2008 to 2018. In 2008, among 38 cities in the YREB, UWIS was at a medium level in 13 cities (accounting for 34.2%) and a lower level in 25 cities (accounting for 65.8%). In 2011, affected by severe drought and local floods in the Yangtze River basin, UWIS dropped to its lowest level in 2012, and the number of cities at a lower level increased to 29 (accounting for 76.3%). Compared with 2008, in 2018, 8 cities were elevated from a lower level to a medium level, and 20 cities were at a medium level (accounting for 52.6%), but there were still 18 cities at a lower level (accounting for 47.6%). It can be observed that the cities in the YREB are facing a rigorous situation in inclusive and sustainable development.

Within the three major urban agglomerations in the Yangtze River Economic Belt, the top 10 cities in UWIS are Shanghai, Nanjing, Wuxi, Suzhou, Hangzhou, Ningbo, Wuhan, Changsha, Nanchang and Hefei. Among them, six cities belong to the Yangtze River Delta urban agglomeration, and four belong to the middle reaches of Yangtze River urban agglomeration. The bottom 10 cities in UWIS are Anqing, Chizhou, Huangshi, Jingzhou, Huanggang, Xianning, Yueyang, Panzhihua, Luzhou and Yibin. Of them, two cities belong to the YRDUA, accounting for 9.5% in this area, five belong to the MRYRUA, accounting for 41.7% in this area and three belong to the CCUA, accounting for 60% in this area. Therefore, we ranked the three major urban agglomerations in terms of UWIS as follows: YRDUA, MRYRUA and CCUA. The UWIS of the primary and secondary central cities is significantly better than that of the regional central cities and general cities. This is mainly due to the fact that the primary and secondary central cities are located in the lower coastal areas of the YREB. In those areas, the vigorous governance of water resources and environment and a high level of economic development and urbanization all provide a driving force for UWIS in the YREB.

5.1.2. Measurement of the Five Major Development Indexes

From the perspective of each subsystem (as shown in Figure 4), among the five major development indexes, the average comprehensive development level from 2008 to 2018 in descending order is as follows: friendliness index (0.5855) > sustainability index (0.4470) > inclusiveness index (0.3366) > innovation index (0.2462) > availability index (0.1599).

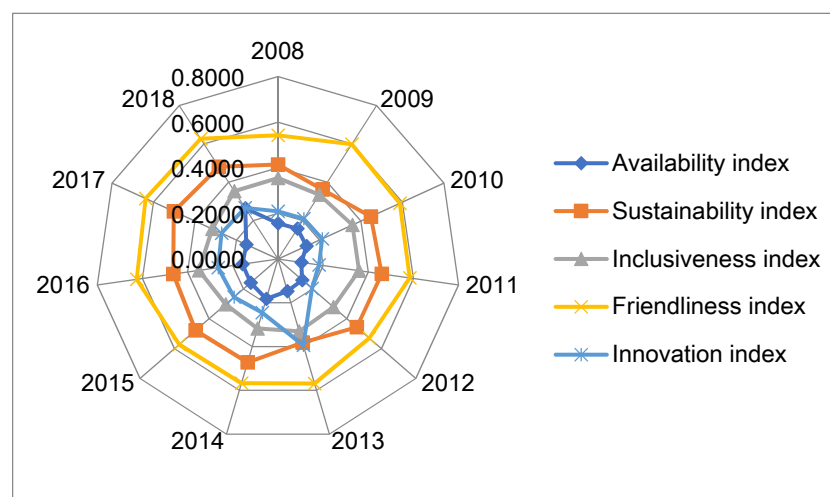


Figure 4. Changes of the five major development indexes of cities in the YREB from 2008 to 2018.

As shown in Figure 5a, the availability index shows a fluctuating upward trend. From 2008 to 2011, it gradually declined at first, reaching its lowest point in 2011 and then began to rise. After a slight decrease in 2014, a significant surge was observed in 2018. The availability index ranks last among the five major development indexes and stays at the lowest level, indicating that the water resources endowment situation in the Yangtze River Economic Belt is severe. The availability index of cities in the YRDUA is generally higher than the average level of the YREB, while the MRYRUA's and CCUA's availability index are generally lower than the average level of the YREB. The availability index of the MRYRUA only surpassed the YREB in 2018, and even exceeded that of the YRDUA in that year.

As seen in Figure 5b, the sustainability index shows a clear upward trend of volatility, staying at a medium level on the whole and ranking second among the five major development indexes. The sustainability index of the cities in the YRDUA is significantly higher than the average level of the YREB, while the sustainability index of the MRYRUA and the CCUA are relatively close and generally lower than the average level of the YREB.

From Figure 5c, the inclusiveness index shows decline at first and then rise, both in fluctuations. Among the five major development indexes, it ranks third and stays at a lower level. The inclusiveness index of the cities in the YRDUA is significantly higher than the average level of the YREB, while the inclusiveness index of the MRYRUA and the CCUA are relatively close and generally lower than the average level of the YREB.

As shown in Figure 5d, the trend of the friendliness index of the YREB and the three major urban agglomerations is basically the same, showing a slight upward tendency in fluctuations. Among the five major development indexes, it ranks first and stays at a medium level, indicating the government has made great efforts in water resources environmental governance and achieved initial success in implementing the “four waters and co-governance” model. However, it declined only in 2012. The friendliness index of the MRYRUA is higher than the average level of the YREB, while the CCUA's and YRDUA's friendliness indexes are slightly lower than the average level of the YREB.

The innovation index witnessed a fluctuating upward trend, reaching its peak in 2013 (see Figure 5e). It ranks fourth among the five major development indexes, staying at a lower level. The innovation index of the cities in the YRDUA is significantly higher than the average level of the YREB, while the MRYRUA's and CCUA's innovation indexes are

relatively close, generally lower than the average level of the YREB. Only in 2013 was the innovation index of the CCUA above the average level and close to that of the YRDUA.

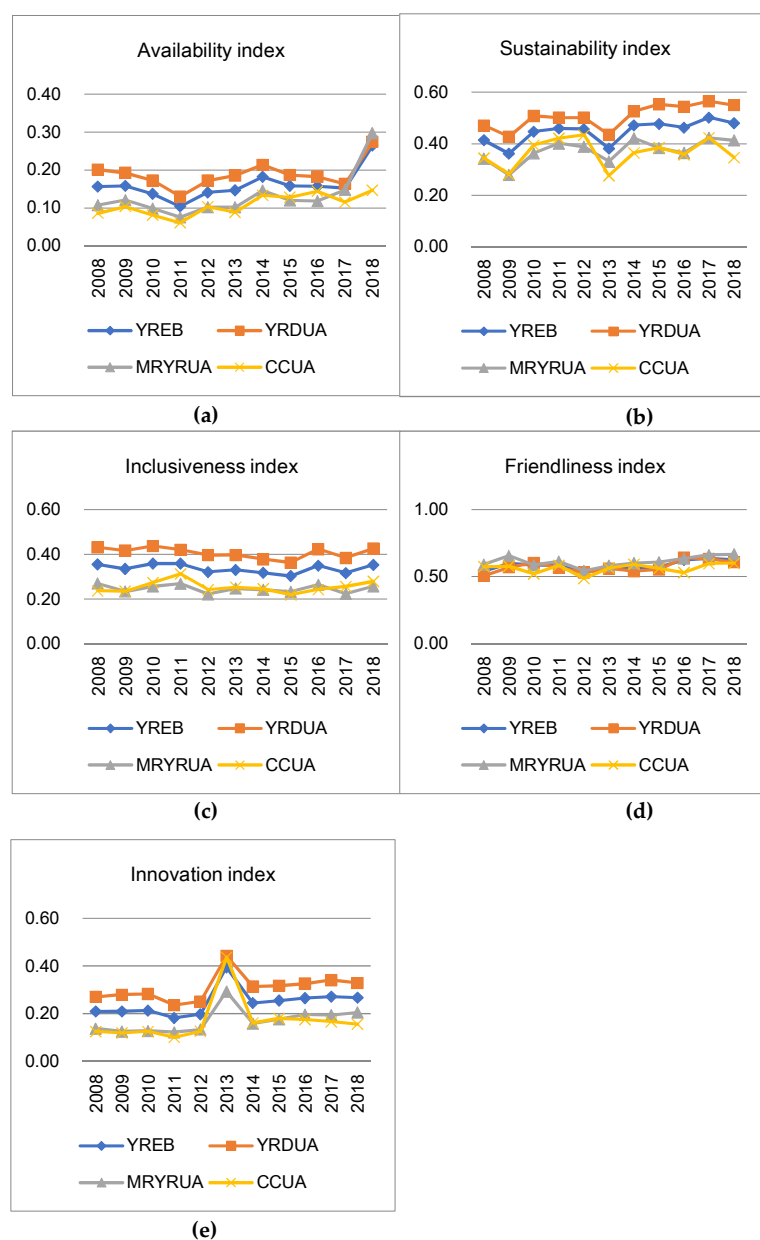


Figure 5. Changes of the five major development indexes of the three major urban agglomerations from 2008 to 2018: (a) availability index; (b) sustainability index; (c) inclusiveness index; (d) friendliness index; (e) innovation index.

5.2. Analysis of Temporal–Spatial Evolution of Coupling Coordination

5.2.1. Analysis of Coupling Coordination Sequence

In order to further describe the temporal–spatial characteristics of the coupling coordination of the UWIS system in the Yangtze River Economic Belt, the coupling degree, coordination degree, and the coupling coordination degree of 38 cities from 2008 to 2018 are calculated according to Formulas (16)–(18), as shown in the Table 4.

Table 4. The coupling degree (C), coordination degree (T) and coupling coordination degree (D) of the YREB and the three major urban agglomerations (2008–2018).

UA	Var.	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
YREB	C	0.8062	0.8225	0.8068	0.7511	0.8171	0.8546	0.8470	0.8421	0.8352	0.8118	0.8585
	T	0.3244	0.3224	0.3352	0.3225	0.3171	0.3455	0.3452	0.3394	0.3574	0.3602	0.3911
	D	0.5083	0.5112	0.5159	0.4898	0.5056	0.5391	0.5372	0.5310	0.5420	0.5380	0.5764
YRDU	C	0.8529	0.8746	0.8537	0.8069	0.8588	0.8777	0.8939	0.8826	0.8634	0.8450	0.8994
	T	0.3647	0.3651	0.3851	0.3546	0.3571	0.3850	0.3815	0.3790	0.4060	0.3978	0.4268
	D	0.5544	0.5613	0.5702	0.5321	0.5509	0.5772	0.5808	0.5755	0.5895	0.5777	0.6177
MRYRUA	C	0.7478	0.7428	0.7398	0.6811	0.7542	0.8300	0.7776	0.7785	0.7801	0.7637	0.8055
	T	0.2796	0.2755	0.2760	0.2832	0.2675	0.2947	0.3046	0.2929	0.3038	0.3193	0.3677
	D	0.4552	0.4502	0.4484	0.4369	0.4456	0.4913	0.4831	0.4733	0.4824	0.4906	0.5404
CCUA	C	0.7505	0.7951	0.7703	0.6850	0.7931	0.8169	0.8163	0.8245	0.8487	0.7878	0.8135
	T	0.2628	0.2556	0.2675	0.2823	0.2681	0.3012	0.2902	0.2847	0.2818	0.3001	0.2977
	D	0.4420	0.4475	0.4496	0.4388	0.4594	0.4936	0.4838	0.4821	0.4853	0.4847	0.4893

According to the current research, this study determines the classification of the coupling coordination degree as shown in Table 5.

Table 5. Classification of coupling coordination degree (D).

Classification	Null Coordination	Mild Coordination	Low Coordination	Moderate Coordination	High Coordination	Quality Coordination
D	0~0.4	0.4~0.5	0.5~0.6	0.6~0.7	0.7~0.8	0.8~1.0

From the perspective of the Yangtze River Economic Belt and the three major urban agglomerations (Tables 4 and 5, Figure 6a–c), the UWIS system’s coupling coordination degree of 38 cities in the YREB from 2008 to 2018, to some extent, showed an upward trend on the whole. The overall coupling degree is high (>0.8) (except 0.7511 in 2011), the coordination degree is low (<0.4) and the coupling coordination degree is in a low coordination state (a mild coordination state only in 2011 (0.4898)). Among the three major urban agglomerations, the coupling coordination degree of the YRDU is better than that of the MRYRUA and the CCUA, and the YRDU is in a low-level coordination state, reaching a moderate coordination state in 2018 (0.6177). The MRYRUA is in a state of mild coordination, and it has improved obviously in 2018, reaching a state of low coordination; the CCUA has always been in a state of mild coordination.

Due to the large number of cities evaluated, the Spearman coefficient of rank correlation is introduced in this study in order to describe the changing trend of the coupling coordination degree of the UWIS’s system and each subsystem more explicitly. The calculation formula [61] is:

$$\begin{cases} R_n = 1 - \left[6 \times \sum_{i=1}^N d_i^2 / (N^3 - N) \right] \\ d_i = X_i - Y_i \end{cases} \quad (22)$$

In Formula (22), R_n is the coefficient of rank correlation, N is the number of years (in this study, $N = 11$), X_i represents the serial number of the coupling coordination degree from low to high in 2008–2018, Y_i stands for the serial number in chronological order and d_i is the difference between the two. From the related tables of statistics, when $N = 11$, at the confidence level of $\alpha=0.01$, the critical value of the rank correlation coefficient test is $W_p = 0.755$, which means when $|R_n| \geq W_p = 0.755$, the changing trend is significant; when $|R_n| < W_p = 0.755$, the changing trend is not significant, and it can be initially judged whether it is an upward or downward trend based on the positive and negative of R_n . Thus, the overall coupling coordination degree of 38 cities in the YREB and the coupling coordination degree of each subsystem were finally obtained, as shown in Figure 7.

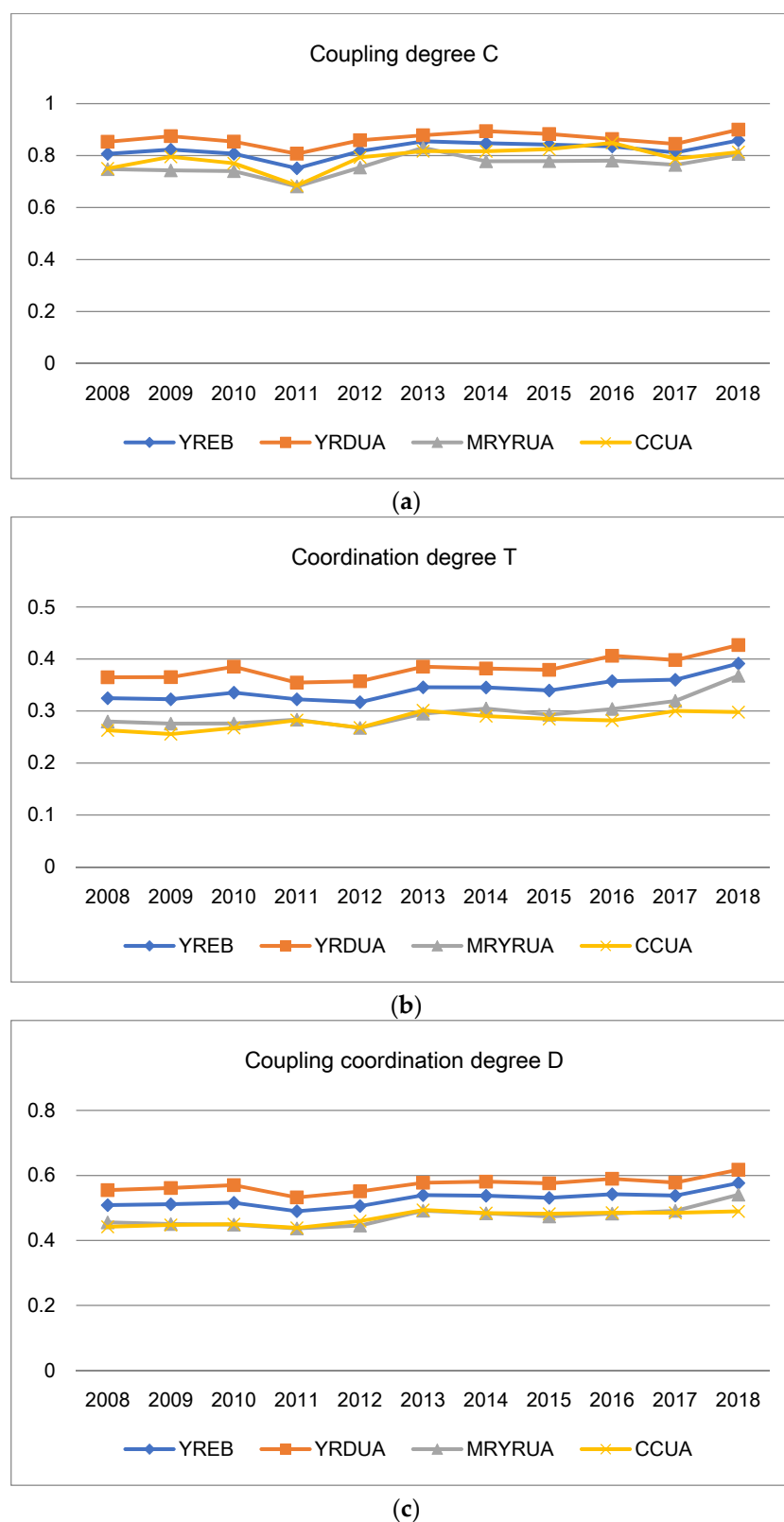


Figure 6. The coupling degree (C), coordination degree (T) and coupling coordination degree (D) of the YREB and the three major urban agglomerations from 2008 to 2018: (a) coupling degree (C); (b) coordination degree (T); (c) coupling coordination degree (D).

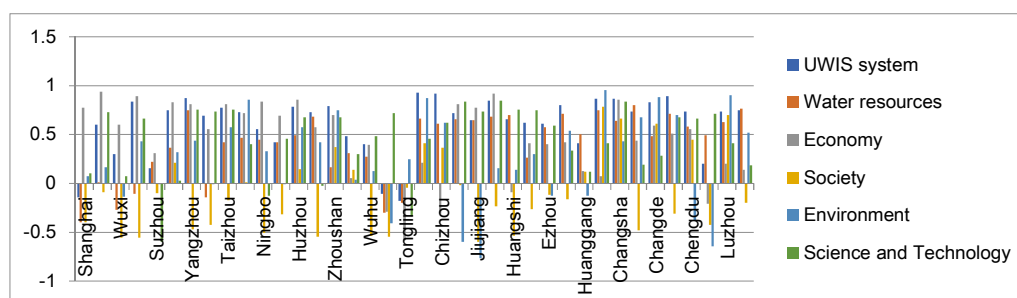


Figure 7. The coefficient of rank correlation of coupling coordination degree of the UWIS system and each subsystem of 38 cities in the YREB.

From 38 cities in the Yangtze River Economic Belt, only three cities (Tongling, Shanghai and Maanshan) showed a downward trend in the coupling coordination degree of the overall UWIS system, while the remaining 35 cities witnessed an upward trend. The 13 cities with a significant upward tendency ($R_n \geq 0.755$) are Anqing, Chizhou, Chongqing, Yangzhou, Xianning, Changsha, Wuhan, Changzhou, Changde, Jingzhou, Zhoushan, Huzhou and Taizhou, most of which are regional central cities in the YRDUA, secondary central cities and general cities in the MRYRUA and secondary central cities in the CCUA.

Among the five major subsystems of the UWIS system, the economy system has the highest coupling coordination degree, followed by the science and technology system, water resources system and environment system; the society system performed worst in this regard.

Among the 38 cities, 32 cities (more than 5/6) presented an upward or significant upward trend in the coupling coordination degree of the water resources system. The six cities with the highest coupling coordination degree are Yueyang ($R_n = 0.8$), Yibin ($R_n = 0.7636$), Yangzhou ($R_n = 0.7455$), Xianning ($R_n = 0.7455$), Chongqing ($R_n = 0.7091$) and Jingzhou ($R_n = 0.7091$), which are mainly located in the MRYRUA and the CCUA. Only six cities showed a downward trend in the coupling coordination degree of the water resource system, which are Shanghai ($R_n = -0.4$), Maanshan ($R_n = -0.3$), Wuxi ($R_n = -0.2727$), Tongling ($R_n = -0.2$), Zhenjiang ($R_n = -0.1455$) and Changzhou ($R_n = -0.1091$); all of them are located in the YRDUA. The average coupling coordination degree of the YRDUA is much lower than that of the CCUA and the MRYRUA. This is also the main reason for the low availability index in UWIS. In general, the three major urban agglomerations can be ranked as follows in terms of water resources coupling coordination degree: CCUA > MRYRUA > YRDUA. Therefore, the water resources coupling coordination capacity of the YRDUA should be strengthened.

Within the five major subsystems, the economy system has the highest degree of coupling coordination. The five cities of Tongling ($R_n = -0.5818$), Chizhou ($R_n = -0.3091$), Maanshan ($R_n = -0.2909$), Panzhihua ($R_n = -0.2091$) and Huangshi ($R_n = -0.0909$) showed a downward trend in their coupling coordination degree, and among them Tongling showed a significant decline. The remaining 33 cities presented a climb. Of them, 12 cities including Nanjing, Wuhan, Changzhou, Huzhou, Changsha, Ningbo, Nantong, Yangzhou, Taizhou, Nanchang, Shanghai and Jiujiang were in a substantial upward tendency. The rise in the sustainability index of cities in the YREB is due to its strong economic coupling coordination capabilities, making it rank second among the five major development indexes, at a moderate level. Generally, the three major urban agglomerations can be ranked as follows in terms of economic coupling coordination degree: YRDUA > MRYRUA > CCUA. Therefore, the economic coupling coordination capacity of the CCUA should be enhanced.

Among the five major subsystems, the society system performed worst in coupling coordination degree. About two-thirds of the cities' social coupling coordination degree showed a downward trend, covering all types of cities, such as primary and secondary central cities, regional central cities and general cities. Among them, the five cities with the low-

est degree of social coupling coordination are Jiujiang ($R_n = -0.6$), Wuxi ($R_n = -0.5545$), Changzhou ($R_n = -0.5545$), Shaoxing ($R_n = -0.5455$) and Maanshan ($R_n = -0.5455$), demonstrating an obvious descending trend. Only 13 cities (Xianning, Luzhou, Changsha, Changde, Chengdu, Nantong, Hangzhou, Huzhou, Zhoushan, Hefei, Anqing, Chizhou and Huanggang) presented a rising trend, of which Xianning showed an a substantial climb, and Luzhou, Changsha, Changde and Chengdu showed a marked climb. This also keeps the urban inclusiveness index of the YREB at a lower level. In general, the overall degree of social coupling coordination is in a downward trend: $CCUA > MRYRUA > YRDUA$. Therefore, the social coupling coordination capacity of the three major urban agglomerations in the YREB should be strengthened to improve the level of inclusiveness.

From the coupling coordination degree of the environment system, nearly one-third of the cities (11 cities) showed a downward trend. The five cities with the lowest degree of environmental coupling coordination are Jiujiang ($R_n = -0.7636$), Panzhihua ($R_n = -0.6455$), Nanchang ($R_n = -0.6$), Maanshan ($R_n = -0.4091$) and Chengdu ($R_n = -0.3818$). All these five cities presented an obvious downward trend, and Jiujiang's decline was the most significant, followed by Panzhihua, Nanchang and Maanshan. These cities are mainly located in the MRYRUA and the CCUA. More than two-thirds of the cities' environmental coupling coordination degree is on a rise. Of them, the cities that performed highest in environmental coupling coordination degree are Xianning, Luzhou, Changde, Anqing and Hangzhou, which demonstrated a substantial climb. Overall, as regards the environmental coupling coordination degree, the three major urban agglomerations can be ranked as follows: $YRDUA > CCUA > MRYRUA$. Thus, special importance needs to be attached to improving the environmental coupling coordination capacity of the MRYRUA and the CCUA.

From the coupling coordination degree of the science and technology system, only four cities—Suzhou ($R_n = -0.6$), Tongling ($R_n = -0.3364$), Ningbo ($R_n = -0.1273$), and Shaoxing ($R_n = -0.0273$)—showed a descending trend. Among them, Suzhou was in a sharp decline, and these cities are all located in the YRDUA; the remaining 34 cities showed an upward trend in the scientific and technological coupling coordination degree. Among these cities, Wuhan, Changsha, Nanchang, Huangshi, Yangzhou and Taizhou presented a substantial upward trend. Generally, the three major urban agglomerations can be ranked as follows in terms of scientific and technological coupling coordination degree: $MRYRUA > CCUA > YRDUA$. Therefore, the scientific and technological coupling coordination capacity of the YRDUA should be enhanced.

In summary, among the three major urban agglomerations, the YRDUA is relatively high in economic and environmental coupling coordination degree, while in social, water resources, and scientific and technological coupling coordination degree, it is relatively low; the MRYRUA is high in scientific and technological coupling coordination degree, but low in environmental and social coupling coordination degree, and its water resources and economic coupling coordination degree is at a moderate level. In comparison, the CCUA's water resources and social coupling coordination degree is relatively high, its economic coupling coordination degree is low, and its environmental and scientific and technological coupling coordination degree is at a moderate level.

5.2.2. Analysis of Spatial Evolution Characteristics

To describe the spatial evolution characteristics of the coupling coordination of the various subsystems of 38 cities in the Yangtze River Economic Belt, three sample years of 2008, 2013 and 2018 were selected during the evaluation period, and the corresponding spatial distribution of coupling coordination degrees were drawn in Figure 8.

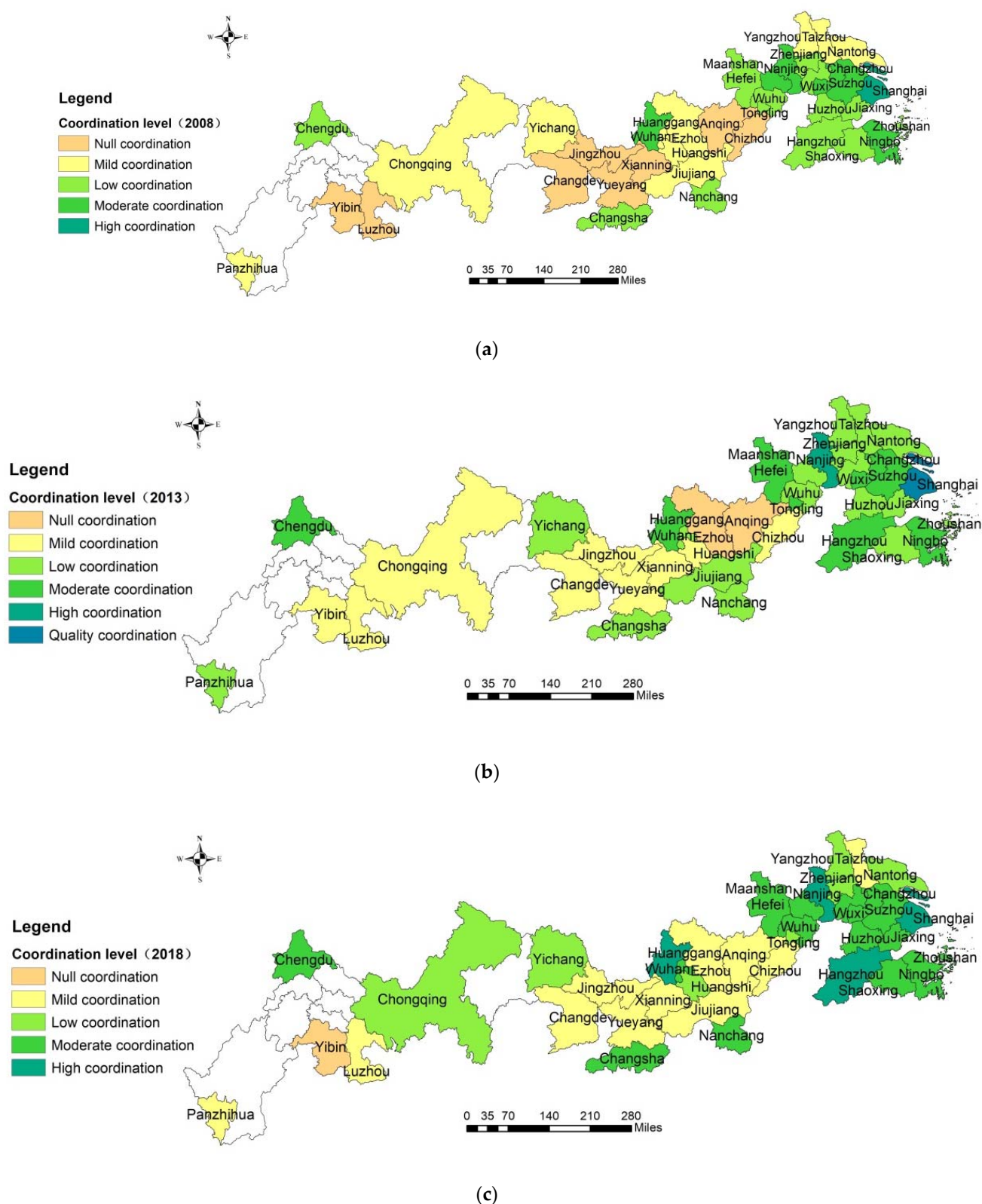


Figure 8. The spatial distribution map of coupling coordination degree of 38 cities in the YREB in 2008, 2013 and 2018: (a) 2008; (b) 2013; (c) 2018. (Note: The blank areas in the figure are the unstudied regions).

From Figure 8a–c, it can be seen that, on the whole, the cities in the YREB presented the characteristic of evolving from mild and low coordination to moderate and high coordination. Their spatial evolution is characterized by being high in the east and low in

the west, and the coupling coordination degree in the primary and secondary central cities is generally higher than that in the regional central cities and general cities.

In 2008, the urban coupling coordination degree of the CCUA in the western region of the YREB was basically in null and mild coordination; most of the cities in the central region of the MRYRUA were also in null and mild coordination, and only a few cities in this area were in the low and moderate coordination. Most cities in the eastern region of the YRDUA were in low to moderate coordination, while a few cities in this area were in null and mild coordination. By 2013, the three major urban agglomerations all witnessed an increase in the degree of coupling coordination. The cities in the YRDUA were generally at a low to moderate coordination level. The cities of Shanghai and Nanjing reached the level of quality coordination and high coordination. The cities located in the MRYRUA and the CCUA were mainly upgraded by one level.

By 2018, among the 21 cities in the YRDUA, the coupling coordination degree of Shanghai, Nanjing and Hangzhou climbed to a high level of coordination, and 11 cities including Suzhou stayed at a moderate level of coordination. The reasons for the YRDUA being at a higher level of coordination is that it contains megacities such as the municipality of Shanghai, the provincial capitals of Nanjing and Hangzhou, which are the core cities of the urban agglomeration with developed economies, complete social security and infrastructure, and vigorous environmental governance. The YRDUA is a pioneering area of national policies and a centralized area of high-quality resources, which leads to a high level of economic and environmental coupling coordination in this part. However, due to the low level of social coupling coordination of some cities such as Yangzhou and Taizhou, the degree of coupling coordination of water resources and science and technology are at a moderate level, making Yangzhou and the other four cities, and Taizhou and the other three cities still stay at a low level and mild coordination level, respectively.

Among the 12 cities in the MRYRUA, only Wuhan reached a high level of coordination in 2018. Wuhan, together with Shanghai and Chongqing, is one of the three core cities along the Yangtze River Golden Waterway. Its economic strength, social security, and scientific and technological development are comparatively advanced. Moreover, with a superior location, abundant water resources and a gathering of universities and talents, Wuhan has a more obvious radiative effect on improving the coordination level of other surrounding cities. The three cities of Nanchang, Changsha and Ezhou reached a moderate level of coordination. The remaining cities were at a low or mild level of coordination, owing to their insufficient environmental governance, incomplete infrastructure and inadequate social security, etc.

Compared with the YRDUA and the MRYRUA, the CCUA, although with two core megacities such as Chengdu and Chongqing, is relatively backward in development due to geographical restrictions. Among five cities in the CCUA, only Chengdu reached a moderate level of coordination in 2018, and the remaining four cities were in a state of low, mild coordination and even null coordination concerning the underdeveloped economy in the western region, the backward scientific and technological development, and the poor environmental governance. Although the CCUA reached a high level of water resources coupling coordination, its social coupling coordination was at a moderate level due to comparatively low economic development and slow development speed.

From the above spatial evolution analysis, the coupling coordination degree of the YRDUA surpasses that of the MRYRUA, while the CCUA is relatively weak in this regard.

5.3. Identification of Obstacle Factors

The Formulas (19)–(21) are used to calculate the obstacle degree of each indicator in 38 cities from 2008 to 2018, and then the mean values of the obstacle degree of each subsystem were obtained. The five subsystems can be ranked as follows in terms of obstacle degree: water resources > society > science and technology > economy > environment. The corresponding average obstacles degrees are 0.3048, 0.207, 0.1975, 0.1679 and 0.1228, respectively, as shown in Figures 9 and 10. It can be observed that the main obstacle factors

affecting UWIS in the Yangtze River Economic Belt are mainly from the subsystems of water resources, society, and science and technology. This is inseparable from the relatively high level of economic development and ecological priority initiatives.

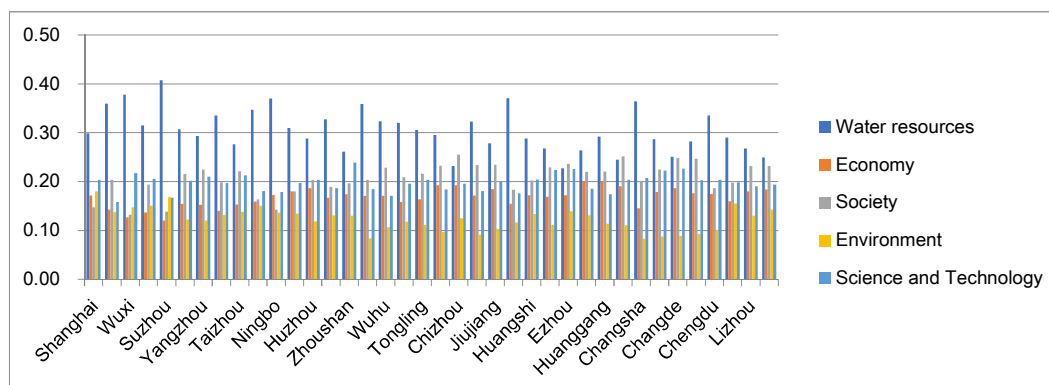


Figure 9. The mean value of obstacle degree for each city in the YREB from 2008 to 2018.

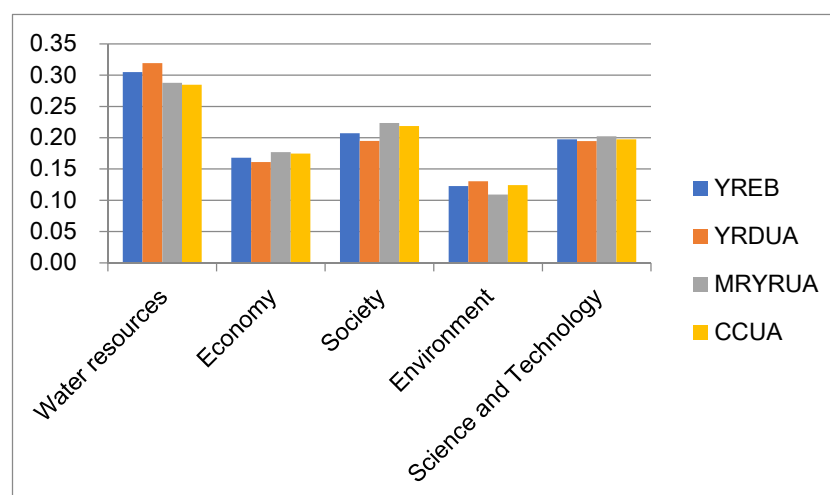


Figure 10. The mean value of obstacle degree in the YREB and the three major urban agglomerations from 2008 to 2018.

5.3.1. Analysis of Obstacle Degree of the Indicators

The top one-third of the obstacle degree indicators is selected. The main obstacle factors of each subsystem are water resources utilization rate, rainfall depth and total water consumption per capita in the water resources system, drainage pipe length per 10,000 persons, rate of internet users in the society system, number of patents granted per 10,000 persons, college students per 10,000 persons, science and technology expenditure as a share of GDP in the science and technology system, GDP per capita, tertiary industry output value as a share of GDP, secondary industry output value as a share of GDP in the economy system and area of green land per capita in the environment system.

5.3.2. Analysis of Obstacle Degree in the Subsystems

From the distribution of the mean values of the obstacle degree in the city subsystem (see Figure 9), the top 10 obstacle factors in the water resources system mainly come from seven cities of the YRDUA, including Suzhou, Wuxi, Ningbo, Nanjing, Hefei, Hangzhou and Zhenjiang, the provincial capital cities of Wuhan and Changsha in the MRURYA, and the provincial capital city of Chengdu in the CCUA. Obviously, the obstacle factors of the water resources system are primarily from provincial capital cities and secondary central cities, which, characterized by high living standards, are large in scale, population and

water consumption per capita, and thus water resources development and utilization rate in those areas needs to be improved. Based on the obstacle degree of the water resources system, the three major urban agglomerations can be ranked in descending order as follows: YRDUA > MRYRUA > CCUA.

The top 10 obstacle factors in the society system generally come from Chizhou and Anqing in the YRDUA, Xianning, Changde, Ezhou, Jiujiang and Nanchang in the MRYRUA, and Chongqing, Yibin and Luzhou in the CCUA. It is obvious that obstacle factors in the society system are primarily from regional central cities and general cities (except Chongqing), and their social security and infrastructure are incomplete. In terms of the obstacle degree of the society system, the three major urban agglomerations can be ranked as follows: MRYRUA > CCUA > YRDUA.

The top 10 obstacle factors in the science and technology system mainly come from Zhoushan, Wuxi, Taizhou, Yangzhou and Changzhou in the YRDUA, and Changde, Ezhou, Yichang, Yueyang and Changsha in the MRYRUA. It is evident that the obstacle factors of science and technology system are primarily from regional central cities, followed by secondary central cities and general cities, whose talents and investment in science and technology are relatively insufficient. Based on the obstacle degree of the science and technology system, the three major urban agglomerations from high to low are MRYRUA > CCUA > YRDUA.

The top 10 obstacle factors in the economy system mainly come from Anqing, Chizhou and Huzhou in the YRDUA, Jingzhou, Huanggang, Xianning, Changde and Jiujiang in the MRYRUA, and Yibin and Luzhou in the CCUA. The obstacle factors of the economy system are generally from regional central cities and general cities, whose economic strength is not strong enough, and the industrial structure layout needs to be improved. Based on the obstacle degree of the economy system, the three major urban agglomerations in descending order are as follows: MRYRUA > CCUA > YRDUA.

The top 10 obstacle factors of environment system primarily come from seven cities, including Shanghai, Suzhou, Hangzhou, Changzhou, Wuxi, Taizhou and Nanjing in the YRDUA, Ezhou in the MRYRUA, and Panzhihua and Yibin in the CCUA. The obstacle factors of environment system are generally from primary and secondary central cities, and a few from central and general cities in the central and western regions. Due to the rapid economic development of the primary and secondary central cities, the heavy chemical industry has basically formed a pattern surrounding the river, involving five steel bases, seven oil refineries and a number of petrochemical bases. More than 400,000 chemical enterprises have gathered along the Yangtze River. The high energy consumption, high water consumption and pollution intensiveness have placed heavy pressure on the water environment and become a major obstacle factor. The regional central cities and general cities in the central and western regions are limited by their economic strength and poor water environment governance. Based on the obstacle degree of environment system, the three major urban agglomerations can be ranked as follows: YRDUA > CCUA > MRYRUA.

6. Discussions and Conclusions

6.1. Discussions

Based on the panel data of 38 cities in the Yangtze River Economic Belt from 2008 to 2018, the conceptual framework and a five-dimensional indicator system for UWIS proposed in this article are employed to measure UWIS using TOPSIS and the entropy method. It is found that UWIS in the YREB, though generally low and fluctuating, witnessed an upward trend from 2008 to 2018, staying at a lower to medium level. Among the three major urban agglomerations, UWIS from high to low is the YRDUA, MRYRUA, and CCUA. The UWIS of the primary and secondary central cities is obviously superior to that of regional central cities and general cities. The five major development indexes from 2008 to 2018 in descending order are friendliness index > sustainability index > inclusiveness index > innovation index > availability index.

From the analysis of temporal characteristics, the coupling coordination degree of the UWIS system for the 38 cities from 2008 to 2018 in the YREB, to some extent, has presented an upward trend on the whole, staying at a low level of coordination. Among the three major urban agglomerations, the coupling coordination degree of the YRDUA preceded that of the MRYRUA and CCUA, remaining at a low level of coordination and reaching a moderate coordination level in 2018; the MRYRUA was at a mild coordination level and went up the level of low coordination in 2018, while the CCUA has always been at the level of mild coordination.

The degree of coupling coordination of the five subsystems from high to low is as follows: economy system, science and technology system, water resource system, environment system and society system. From the perspective of the three major urban agglomerations, their coupling coordination in descending order is YRDUA > MRYRUA > CCUA. Among them, the YRDUA has relatively strong degrees of economic and environmental coupling coordination, while the YRDUA is relatively weak in the degrees of social, water resources, and scientific and technological coupling coordination; the MRYRUA has a strong degree of scientific and technological coupling coordination, weak degrees of environmental and social coupling coordination, and moderate degrees of water resource and economic coupling coordination; the CCUA is relatively strong in the degrees of water resources and social coupling coordination, weak in the degree of economic coupling coordination, and moderate in the degrees of scientific and technological and environmental coupling coordination.

From the spatial differentiation analysis, the cities in the YREB on the whole showed the characteristics of evolving from mild and low coordination to moderate and high coordination, and their spatial evolution is characterized by being high in the east and low in the west. Among them, the degree of coupling coordination of primary and secondary central cities is generally higher than that of regional central cities and general cities. The degree of coupling coordination of the YRDUA is superior to that of the MRYRUA, while the CCUA performs relatively weak in this regard.

The analysis of obstacle factors proved that the obstacle degree of each subsystem in descending order is as follows: water resources > society > science and technology > economy > environment system. The main obstacle factors come from 12 factors, such as the water resources utilization rate, drainage pipe length per 10,000 persons, etc. The three major urban agglomerations can be ranked as follows in terms of the obstacle degree of water resources system: YRDUA > MRYRUA > CCUA; MRYRUA > CCUA > YRDUA in terms of the obstacle degree of society, science and technology and economy system; and YRDUA > CCUA > MRYRUA in terms of the obstacle degree of environment system.

In response to the above evaluation results of UWIS, coupling coordination degree and obstacle degree, this study proposes the following suggestions to improve the urban water inclusive sustainability in the Yangtze River Economic Belt and the coupling coordination level of various subsystems.

The firstly is to improve urban water availability and scientific and technological innovation in the YREB.

The government should increase investment in the research and development of technologies for the efficient development and utilization of water resources, focusing on comprehensive water saving, the development and utilization of unconventional water resources, and the governance of rivers and lakes, and the technology and equipment patents of water resources in order to promote the transformation and application of scientific and technological achievements and tap into the potential of water resources. The total water consumption per capita is reduced by popularizing water-saving technologies and the recycling use of water resources. Through technological innovation, enterprises should improve the sewage treatment rate and the comprehensive development and utilization efficiency of water resources. Scientific research institutions are supposed to rely on scientific and technological progress to seek new and succeed resources of water.

To summarize, the availability of water resources will be further improved by means of systematic planning, efficient development and reasonable utilization.

The second is to enhance the inclusiveness of urban water resources in the YREB and the level of coupling coordination of society system.

The government ought to further strengthen the construction of water resources infrastructure, such as urban water pipe networks, sewage treatment systems, etc., so as to extend the length of drainage pipes owned by 10,000 persons, which will enable urban residents to obtain the water resources they need in a timely, appropriate, fair and economical manner. Internet companies need to accelerate the construction of broadband networks across cities, mobile communication networks and broadband wireless access networks in order to further expand the ratio of Internet users, reinforce the information linkage between cities in the YREB and share information resources, thus realizing the high quality economic development and the coordinated development of society.

The third is to facilitate the coupling coordination of urban water environment in the YREB.

The government should improve the water environment, optimize the industrial structure, strictly control the discharge of industrial wastewater from cities along the Yangtze River and raise the rate of sewage under centralized treatment. On the basis of further maintaining and increasing the proportion of water, in rivers, lakes and reservoirs, superior to Class III water in quality throughout the year, and raising the rate of key water functional zones up to standard, the government is supposed to carry out a solid promotion of the construction of forest cities, expand urban greening renovation projects, restore urban natural ecology and increase the green coverage rate in built-up area and the area of green land per capita. Urban housing and urban–rural construction departments should add investment into highway greening to build a greenway system. Water conservancy departments should build multi-level and various green ecological channels.

From the perspective of the three major urban agglomerations, the Yangtze River Delta urban agglomeration is one of the most vigorous and open regions in China, energized in science and technology, education and innovation. As a guiding development zone for the YREB and an important intersection of the “One Belt and One Road” and the Yangtze River Economic Belt, it has a pivotal strategic position in promoting the high-quality development of other cities. The UWIS of the YRDUA is at a lower to medium level, with low degree of coordination. The obstacle factors are mainly from water resources and environment systems. Due to the developed economy and a huge population, the pressure on water resources and the environment has increased. Therefore, efforts should be made to remove the barriers in water resources and environment systems, and special attention needs to be paid to enhance the coupling coordination of society, water resources, and science and technology.

Shanghai needs to be taken as the leader to drive the coordinated development of surrounding cities in inclusive sustainable development of the YRDUA. In accordance with the requirement of “water saving priority”, we will exert the YRDUA’s advantages in science and technology, education and innovation, and actively propel the construction of water saving and conservation projects such as irrigation area reconstruction, rainwater and flood resource utilization, and seawater desalination, so as to solve the problem of water shortage and ensure the safety of drinking water. The government ought to strengthen the protection of drinking water sources and establish a mutual water supply system from rivers, reservoirs and seawater desalination. Meanwhile, the total amount and efficiency of water consumption and the pollution red lines of water functional zones must be scientifically decided. Moreover, an inclusive and sharing system needs to be established to facilitate the water resources of the YRDUA toward inclusive and sustainable development.

Owing to the golden waterway of the Yangtze River, the urban agglomeration in the middle reaches of the Yangtze River is superior in transportation. As a pioneering area for new urbanization in the central and western regions and a demonstration zone for inland opening and cooperation, the MRYRUA has been an important new economic growth pole

in China, playing a leading and radiative role in the development of the western region. The UWIS in the MRYRUA is at a lower to medium level, staying at a mild coordination level. The obstacle factors mainly come from the society, science and technology, and economy systems. Therefore, efforts should be made to remove the obstacles in the society, science and technology, and economy systems, and the focus should be mainly placed on the improvement of the environmental and social coupling coordination.

Specifically, it is important to make full use of Wuhan's advantages in science, education and industry to promote the transformation of technological achievement in water pollution governance; to further improve the coordination mechanism for joint prevention and governance of water pollution in the MRYRUA; to strictly control the development of heavy water consumption and polluting industries at the sources of rivers and drinking water protection zones; to optimize the industrial structure and implement the clean transformation of such heavy water consumption and polluting industries such as petrochemicals, non-ferrous metals, papermaking and printing; and to strengthen the comprehensive treatment and ecological restoration of the water environment.

Simultaneously, it is important to establish a compensation mechanism for water environment and ecological protection between cities, enhance the cooperation and linkage with the regions of the Yangtze River Delta and Chengdu–Chongqing to promote the coordinated development of the upper, middle and lower reaches of the Yangtze River. Moreover, the government should strengthen the interconnection of infrastructure, jointly construct a water conservancy infrastructure system and build an inclusive and sustainable water resources guarantee system focusing on river governance, water source engineering, irrigation engineering and recycled water utilization. Efforts will be made to increase the urban sewage treatment rate, step up the use of recycled water and start projects of high-quality water resources development and utilization. Furthermore, it is important to establish the monitoring and early warning mechanisms for water resources and water environment and to promote the coordination between the inclusive and sustainable economic and social development and carrying capacity of water resources and environment.

As an important platform for the development of the western region, the Chengdu–Chongqing urban agglomeration has obvious geographical advantages. The CCUA is not only a major demonstration area in the nation to accelerate new urbanization, but also a strategic hub to jointly develop the Yangtze River Economic Belt and the Silk Road Economic Belt. It has been China's new economic growth pole. The UWIS of the CCUA is at a lower to medium level, staying at a mild coordination level. The obstacle factors are mainly from the society, science and technology, economy and environment systems. Although Chengdu and Chongqing, the two core cities, are playing a leading role in the regional development, they are not strong enough in radiation to drive the entire region. This is specifically reflected in the underdevelopment of regional central cities and general cities, the low level of infrastructure interconnection and the incomplete coordinated development mechanism. Therefore, the government should make more efforts to remove the obstacles in the society, science and technology, economy and environment systems, emphasizing the improvement of the economic coupling coordination.

Since the problem of inclusive and sustainable development of water resources in the Chengdu–Chongqing urban agglomeration is prominent, it is urgent to integrate the five perspectives of resource endowment, high-quality development, environmental friendliness, people-oriented and science and technology development into the sustainable development of water resources in the CCUA in order to ensure the coordinated development of economic development, environmental protection, technological innovation, infrastructure construction and social security.

The first is to facilitate the construction of major water storage, water lifting and water transfer projects across regions and establish a mutual supply system for waters in rivers and reservoirs.

The second is to set up a strict water resources management system, to make sure the regulations on the amount and efficiency of water consumption and pollution red lines of

water function zones are followed, to strengthen ecological protection and restoration along the river, to promote the joint efforts in water ecology protection and water environment governance and to introduce multiple governance models to improve the coordination mechanism between the upper and lower reaches of the Yangtze River.

The third is to propel the construction of water resources scheduling, water quality and quantity supervision, water resources and water environment monitoring and early warning information platforms, actively promote the network coverage of urban agglomerations and increase the ratio of Internet users.

The fourth is to make full use of the advantages of the innovative resources of Chongqing and Chengdu as national innovative cities to drive the construction of regional central cities (Luzhou, Yibin) and general cities (Panzhihua), to improve the population and economic agglomeration capacity, to create a green ecological corridor along the river, so as to realize the inclusive and sustainable development of water resources in Chengdu-Chongqing urban agglomeration, to take advantage of the abundant water resources in the upper reaches of the Yangtze River, to optimize the layout of industries along the river and accelerate the industrial transformation and upgrading with a focus being placed on strengthening innovation drive protecting the water resources environment and consolidating the industry foundation, to enhance the population and economic agglomeration capacity and to create a green ecological corridor along the river so as to realize the inclusive and sustainable development of water resources in the CCUA.

6.2. Conclusions

In this article, we firstly proposed a new concept of urban water inclusive sustainability (UWIS), which expands the connotation of water resource efficiency and carrying capacity. We also developed the ASFII conceptual framework and a five-dimensional indicator system of UWIS, integrating availability, sustainability, friendliness, inclusiveness and innovation, which can be applied to comprehensively and scientifically measure UWIS at the level of cities and river basins as well as provinces.

Unlike the predecessors who only focused on a specific river basin or provinces, the uniqueness of this article lies in applying the data covering the length of 11 years and expanding the scope of research to all prefecture-level cities along the Yangtze River of YREB in China's national strategic basin. Moreover, empirical studies were carried out to measure UWIS and five development indexes by using the panel data of 38 cities in the YREB. The characteristics of temporal-spatial evolution of the coupling coordination are described, and key factors that hinder UWIS are identified. The results indicate that, from 2008 to 2018, the overall UWIS of the YREB shows a gradual upward trend, at a relatively weak to medium level, and the indexes are ranked as follows: friendliness > sustainability > inclusiveness > innovation > availability. The 38 cities are in a low-level coordination, and their temporal characteristics show the following trend: economy > science and technology > water resources > environment > society system. The spatial differentiation is manifested as high in the east and low in the west. Twelve factors, such as the water resources utilization rate, are observed as main obstacles. The findings in this article will be helpful for future academic research, for they not only offer suggestions to the cities along the Yangtze River in promoting coordinated and high-quality development of the upper, middle and lower reaches of the Yangtze River under the background of ecological priority and green development, but are also a valuable reference and empirical case for the sustainable use and coordinated development of urban water resources in other river basins.

Therefore, this research provides a new concept, framework and indicator system for UWIS measurement. The concept integrates quite successfully the three pillars of traditional sustainability: economy, society and environment, while also incorporating the idea of inclusive growth and highlighting the important role of scientific and technological progress. It concludes that the inclusive and sustainable development of water resources must adhere to the guidelines of people-oriented, high-quality development, environmental

Table A1. *Cont.*[illegible]

Table A1. Cont.

		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	En1	En2
2017	w_j	0.2754	0.0488	0.3641	0.3117	0.5776	0.4224	0.053	0.371	0.077	0.4989	0.3745	0.2148
	Z_j^+	0.2754	0.0488	0.3641	0.3117	0.5776	0.4224	0.053	0.371	0.077	0.4989	0.3745	0.2148
	Z_j^-	0	0	0	0	0	0	0	0	0	0	0	0
2018	w_j	0.2358	0.0831	0.3197	0.3614	0.4775	0.5225	0.0474	0.3528	0.2251	0.3747	0.5137	0.1651
	Z_j^+	0.2358	0.0831	0.3197	0.3614	0.4775	0.5225	0.0474	0.3528	0.2251	0.3747	0.5137	0.1651
	Z_j^-	0	0	0	0	0	0	0	0	0	0	0	0
		En3	En4	En5	En6	En7	En8	En9	En10	T1	T2	T3	T4
2008	w_j	0.1345	0.2326	0.1817	0.2535	0.3323	0.3956	0.2418	0.3626	1	0.5219	0.4781	1
	Z_j^+	0.1345	0.2326	0.1817	0.2535	0.3323	0.3956	0.2418	0.3626	1	0.5219	0.4781	1
	Z_j^-	0	0	0	0	0	0	0	0	0	0	0	0
2009	w_j	0.1368	0.3729	0.103	0.2206	0.3035	0.4232	0.3738	0.203	1	0.5794	0.4206	1
	Z_j^+	0.1368	0.3729	0.103	0.2206	0.3035	0.4232	0.3738	0.203	1	0.5794	0.4206	1
	Z_j^-	0	0	0	0	0	0	0	0	0	0	0	0
2010	w_j	0.3102	0.2491	0.1091	0.1693	0.4725	0.3525	0.3816	0.2659	1	0.4691	0.5309	1
	Z_j^+	0.3102	0.2491	0.1091	0.1693	0.4725	0.3525	0.3816	0.2659	1	0.4691	0.5309	1
	Z_j^-	0	0	0	0	0	0	0	0	0	0	0	0
2011	w_j	0.2397	0.3026	0.0705	0.241	0.3859	0.3869	0.4144	0.1986	1	0.3988	0.6012	1
	Z_j^+	0.2397	0.3026	0.0705	0.241	0.3859	0.3869	0.4144	0.1986	1	0.3988	0.6012	1
	Z_j^-	0	0	0	0	0	0	0	0	0	0	0	0
2012	w_j	0.1529	0.2548	0.0799	0.178	0.4873	0.2723	0.2081	0.5197	1	0.5343	0.4657	1
	Z_j^+	0.1529	0.2548	0.0799	0.178	0.4873	0.2723	0.2081	0.5197	1	0.5343	0.4657	1
	Z_j^-	0	0	0	0	0	0	0	0	0	0	0	0
2013	w_j	0.2809	0.3041	0.0918	0.1614	0.4427	0.3877	0.2269	0.3853	1	0.3916	0.6084	1
	Z_j^+	0.2809	0.3041	0.0918	0.1614	0.4427	0.3877	0.2269	0.3853	1	0.3916	0.6084	1
	Z_j^-	0	0	0	0	0	0	0	0	0	0	0	0
2014	w_j	0.3492	0.3387	0.1219	0.1967	0.3427	0.2856	0.3034	0.411	1	0.5439	0.4561	1
	Z_j^+	0.3492	0.3387	0.1219	0.1967	0.3427	0.2856	0.3034	0.411	1	0.5439	0.4561	1
	Z_j^-	0	0	0	0	0	0	0	0	0	0	0	0
2015	w_j	0.3149	0.345	0.0852	0.1739	0.3959	0.3485	0.2293	0.4221	1	0.6569	0.3431	1
	Z_j^+	0.3149	0.345	0.0852	0.1739	0.3959	0.3485	0.2293	0.4221	1	0.6569	0.3431	1
	Z_j^-	0	0	0	0	0	0	0	0	0	0	0	0
2016	w_j	0.4686	0.3191	0.2463	0.1489	0.2856	0.4073	0.2146	0.3781	1	0.5049	0.4951	1
	Z_j^+	0.4686	0.3191	0.2463	0.1489	0.2856	0.4073	0.2146	0.3781	1	0.5049	0.4951	1
	Z_j^-	0	0	0	0	0	0	0	0	0	0	0	0
2017	w_j	0.4107	0.4177	0.2456	0.0816	0.2551	0.2172	0.2663	0.5165	1	0.3143	0.6857	1
	Z_j^+	0.4107	0.4177	0.2456	0.0816	0.2551	0.2172	0.2663	0.5165	1	0.3143	0.6857	1
	Z_j^-	0	0	0	0	0	0	0	0	0	0	0	0
2018	w_j	0.3211	0.3343	0.1976	0.1268	0.3412	0.2323	0.1912	0.5765	1	0.2431	0.7569	1
	Z_j^+	0.3211	0.3343	0.1976	0.1268	0.3412	0.2323	0.1912	0.5765	1	0.2431	0.7569	1
	Z_j^-	0	0	0	0	0	0	0	0	0	0	0	0

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