

Article



# **Progress Assessment and Spatial Heterogeneity Analysis of** Water Conservancy Modernization Construction in China

Nan Lu<sup>1,2</sup>, Jiwei Zhu<sup>1,2,\*</sup>, Hui Chi<sup>3</sup>, Bing Wang<sup>1,2</sup> and Lu Chen<sup>1,2</sup>

- <sup>1</sup> State Key Laboratory of Eco-Hydraulics in Northwest Arid Region, Xi'an University of Technology, Xi'an 710048, China; 1190711013@stu.xaut.edu.cn (N.L.); 1200411016@stu.xaut.edu.cn (B.W.); 2180720064@stu.xaut.edu.cn (L.C.)
- <sup>2</sup> Research Center of Eco-Hydraulics and Sustainable Development, The New Style Think Tank of Shaanxi Universities, Xi'an 710048, China
- <sup>3</sup> College of Ocean Engineering, Guangdong Ocean University, Zhanjiang 524088, China; chihui@gdou.edu.cn
- Correspondence: zhujiwei@xaut.edu.cn; Tel.: +86-1591-3599669

Abstract: To achieve the sustainable development goals established by the United Nations in 2015, China has adopted a series of measures to promote the modernization of water conservancy. However, its construction in China is imbalanced across regions as the endowment of water resources and economic development are distinct. Consequently, it is important to assess the progress of and analyze the spatial heterogeneity of water conservancy modernization construction in China from the perspective of sustainable development goals (SDGs). In this study, 31 regions in China were selected, and data on water conservancy construction in these sampled regions (excluding Hong Kong, Macao, and Taiwan) were collected in 2018. The results show that there exists an imbalanced development in terms of the overall level and the index level. About 60% of the regions scored below the overall average score for China's current modernization of water conservancy. The eastern areas presented a high level of modernization, while the central, northeast, and western areas showed comparable modernization of water conservancy, all of which lag behind eastern areas of China. Furthermore, China's water conservancy modernization also presented a strong spatial autocorrelation, and there was at least one deficiency in 55% of the regions, with the rate of deficiencies emerging in the West being much higher than in other regions. In a nutshell, this study provides a novel framework that can be extended to evaluate the SDGs and the effectiveness of water governance in other countries.

**Keywords:** water conservancy modernization; sustainable development goals; water governance; spatial effects; progress assessment

# 1. Introduction

Achieving the sustainable use of finite freshwater resources is essential for the survival of human beings and for economic development [1]. In September 2015, the United Nations Sustainable Development Summit adopted 17 Sustainable Development Goals (SDGs). Goal 6 of the SDGs was "to provide water and sanitation to all people and to manage them sustainably" [2]. This can be achieved by improving water quality, substantially increasing water efficiency in all industries, integrating water resources management at all levels, and protecting and restoring water-related ecosystems, among others [3]. SDG 11 and SDG 13 also put forward specific requirements to deal with water-related disasters, climate-related hazards, and natural disasters [4]. These goals contribute to the sustainable utilization and management of water resources. After these goals were established, many governments took numerous measures in order to meet the SDGs by 2030. However, these targets are a challenge for any government as they require complex policy formulations.

As a developing country with the largest population in the world [5], China has been formulating several sustainable development strategies to realize the modernization of its water conservancy since the 1990s [6]. Water conservancy modernization (WCM) is a



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**Copyright:** © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). product of China's development towards modernization [7,8]. It represents China's pursuit of sustainable use of water resources and its efforts to achieve a sustainable and coordinated development of water, the economy, society, the environment, and other resources, which is consistent with the SDGs.

Since 2015, in response to the SDGs, the Chinese government has repeatedly mentioned the reform of the "ecological civilization" and put forward the goals of building the "beautiful China" [9,10]. In 2018, the government reiterated its objective "to accelerate the modernization of water conservancy in the new era", such that water resources, water ecology, water environment, and water disasters were considered in order to create an overarching policy for water governance to continuously promote the modernization of both the water governance system and governance capabilities [11,12].

On the other hand, many other developed countries began the process of WCM in the 1970s. They mainly focused on three aspects: modernization of concepts, modernization of production technology and equipment, and modernization of water management [13]. Bolognesi [14] identified and explained the effects of modernization of European urban water systems with respect to their organization and sustainability. Many scholars have conducted extensive research on the modernization of irrigation in Spain, Iran, Australia, and other countries [15–19]. Furthermore, they have established an index system to evaluate the modernization process and identify the main factors affecting it. In order for China's WCM process to be faster than the other economically developing countries, there needs to be improvement in national policies and an increase in social awareness [20]. Wang et al. [21] divided the 100 year process (1949–2050) of China's water conservancy development into seven stages and revealed that China is projected to achieve comprehensive and coordinated development by 2030 and sustain a balance between human needs and conservation of water resources by 2050.

Obviously, there is still a long way before WCM and SDGs are realized for many countries. Because of the imbalance of natural endowment and socioeconomic development among regions, new problems have emerged in different regions; therefore, several scholars have focused on the heterogeneity of regional sustainable development [22]. Xu, et al. [23] assessed China's progress towards sustainable development from 2000 to 2015 and observed large spatiotemporal variations across regions. Wang, et al. [24] evaluated sustainable development indicators at the provincial scale and revealed that eastern provinces had a higher score than western provinces. Furthermore, Cole, et al. [25] established an evaluation framework for SDGs in South Africa at a provincial level to explore spatial heterogeneity. Yang and Yang [26] focused on the unbalanced development of regional and industrial water-use efficiency. Ahmed and Araral [27] utilized the institutional decomposition and analysis framework to assess the effectiveness of water governance in eight Indian states; their results demonstrated the persistence of imbalance. Jia, et al. [28] established an index system to quantify the water environmental carrying capacity and determine the sustainable trends and regional differences in China's water resources.

Most of available studies have either evaluated the degree of sustainable development as a whole or have only focused on the sustainable use of water resources; thus, more studies are needed to evaluate the progress of achieving sustainability and the differences between different regions. Therefore, in this study, a WCM evaluation framework was constructed from the perspective of water-related SDGs, and the level of WCM on the provincial scale in China in 2018 was calculated to explore the heterogeneity among the different regions by assessing them in addition to those in the existing research.

The rest of the paper is as follows. Section 2 introduces the research methods and data sources. Section 3 analyzes the relevance and heterogeneity of China's WCM at the national and provincial levels and focuses on identifying the deficiency of water modernization in different regions. Section 4 draws conclusions and proposes policy recommendations.

## 2. Materials and Methods

#### 2.1. Construction of the Evaluation Index System

WCM is a multi-element, dynamic development process that includes flood control, water supply, water ecology, water governance, culture, and water landscape [29–31]. Conceptually, it is very similar to some of the descriptions of SDGs, as shown in Table 1.

**Table 1.** Descriptive Comparison of water conservancy modernization (WCM) goals and the United Nations Sustainable

 Development Goals (SDGs).

The Goals of WCM	Sustainable Development Goals and Targets	Indicators
Prevent losses from disasters such as floods, as well as protect cities and residents around the watershed.	<ul> <li>SDG 11.5: By 2030, significantly reduce the number of deaths and the number of people affected by disasters, and substantially decrease the direct economic losses relative to the global gross domestic product caused by disasters, including water-related disasters</li> <li>SDG 13.1: Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries.</li> </ul>	<ul> <li>11.5.1 Number of deaths, missing persons, and directly affected persons attributed to disasters per 100,000 population</li> <li>13.1.1 Number of deaths, missing persons, and directlyaffected persons attributed to disasters per 100,000 population</li> </ul>
Improve the water conservation capacity of the whole society and further increase the water efficiency in various industries [32].	SDG 6.4: By 2030, substantially increase water-use efficiency across all sectors, ensure sustainable withdrawals, and ensure a supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity.	6.4.1 Change in water-use efficiency over time
Supply water to more people and reduce regional water stress to ensure sustainable water supply.	SDG 6.1: By 2030, achieve universal and equitable access to safe and affordable drinking water for all. SDG 6.4: By 2030, substantially increase water-use efficiency across all sectors, ensure sustainable withdrawals, and ensure a supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity.	<ul> <li>6.1.1 Proportion of population using safely managed drinking water services</li> <li>6.4.2 Level of water stress: freshwater withdrawal as a proportion of available fresh-water resources</li> </ul>
Achieve better water quality with sewage treatment to provide a healthy water environment for people's daily consumption.	SDG 6.3: By 2030, improve water quality by reducing pollution, eliminating dumping, and minimizing the release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.	6.3.1 Proportion of domestic and industrial wastewater flows that are safely treated6.3.2 Proportion of bodies of water with good ambient water quality
Increase the area ratio of wetlands, such as rivers and lakes in the region, and ensure the good functioning of water ecosystems.	SDG 6.6: By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers, and lakes.	6.6.1 Change in the extent of water-related ecosystems over time
Promote the modernization and informatization of water management, institutionalize and standardize water management, and establish a management team that meets the requirements of management modernization [33].	SDG 6.5: By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate.	6.5.1 Degree of integrated water resources management

By analyzing the goals of WCM construction and the water-related requirements of SDGs, a six-dimensional indicators system was established, including the prevention of flood disasters (PFD), water-use efficiency (WUE), sustainable supply of water (SSW), water ecological restoration (WER), water environment treatment (WET), and level of water governance (LWG) [6,7,21,34]. These six dimensions contain 22 specific indicators (shown in Table 2), some of which are already covered by the SDGs, such as the indicators X11, X12 (SDG 11.5.1), X31, X32 (SDG 6.1.1), X33 (SDG 6.4.2), X34 (SDG 13.1.1), X41 (SDG 6.3.1), and X42 (SDG 6.3.2) [35–37].

Apart from this, there are some additional indicators which are important for the WCM and SDGs, some indicators may be specific to China, and are explained in Table 2 as a footnote. These indicators were chosen on the basis of research conducted by scholars in recent years. Specifically, as the SDG 11.5 presented, water-related disasters have a huge impact on sustainable development. Floods, droughts, and extreme storms have become the three primary water-related disasters in China [38]. As drought is essentially a problem of water scarcity, we classify its influence on the SSW (X34). For flood defenses, besides X11 and X12, we chose the flood control capacity index (X13) to reflect and evaluate the flood protection capacity, which was calculated as the proportion of the area of high-standard flood protection areas (flood protection areas with a standard greater than or equal to 50 years) to the total area of flood protection areas [21,39].

WUE was mainly used to evaluate the regional water-saving capacity and water-use efficiency, which falls under the scope of SDG 6.4.1, and the selection of indicators X22, X23, and X25 was mainly based on the study by Zhang, et al. [40] and Long and Pijanowski [41]. The elasticity index of water consumption (X21) refers the ratio of the water consumption growth rate to the gross domestic product (GDP) growth rate in the same period, reflecting the relationship between the economic growth rate and the water consumption change rate of a country or region [42]. The reuse coefficient of industrial water (X24) is one of the national water-saving city assessment standards [43], and was chosen as a measure of water supply and water pressure in the region. The goal of water conservancy modernization in China is to achieve a sustainable water supply under different water pressures. The basis of the index selection can be found in the description above.

It is essential that the evaluation of WET should involve the quantity or treatment ratio of sewage (X41) and the water quality (X42), as well as determine the amount of sewage discharged and the quality of harmful substances discharged after sewage treatment [44]. In this study, COD emissions were selected as representative, and at the same time, to make these data comparable, the amount of sewage discharged per capita (X43) and the COD emissions per capita (X44) were determined as the indicators for evaluation.

WER is also an important task in water modernization. Referring to SDG6.6.1, the changes in a water area in a short span of time are quite insignificant in the collected statistics, so the rate of change of a water area per capita was used as an evaluation indicator in this study; thus, X52 and X53 were selected to evaluate the efforts made to restore water ecology in different regions [33,39,45].

The modernization of water management requires a sophisticated and reasonable system, informatization management tools, and a high level of management teams [46]; it is difficult, however, to quantify the reasonableness of the management system in different regions. This study, therefore, mainly selected indicator X61 to determine the degree of water informatization and X62 to determine the level of knowledge of the water management team [21,47]. As the modernization of water management requires a large amount of financial investment [48,49], the indicator X63 was also chosen.

In addition to the 22 indicators listed in Table 1, there are certain indicators that can reflect the construction of WCM. However, limited by basic work and statistical data, some of these indicators lack authoritative definitions. To ensure the smooth development of the evaluation work, this paper does not list them as an evaluation index. However, they can still be used in the future.

The data for this paper were obtained for the year 2018 from the "China Statistical Yearbook" [50], "China Water Conservancy Statistical Yearbook" [51], "China Soil and Water Conservation Bulletin" [52], "China Rural Statistical Yearbook", "Urban and Rural Construction Statistical Yearbook", relevant bulletins of the Ministry of Water Resources [53], and water resource bulletins of various provinces, cities, and autonomous regions.

Primary Indicator	Secondary Indicator	Indicator Meaning	Max Value	Min Value	Mean Value	STD <sup>1</sup> Deviation	Weight
	X11 Flood loss rate	Direct losses caused by floods/GDP (%)	1.57	0.003	0.27	0.004	0.375
Prevention of Flood Disasters (X1)	X12 Population affected by floods (per 100,000)	Flood-affected population × 100,000/total population	12,376.56	151.92	3523.98	2574.413	0.375
	X13 Flood control capacity index	The proportion of the area of high standard <sup>2</sup> flood protection areas (%)	99.50	31.29	73.90	0.189	0.250
	X21 Elasticity coefficient of water use	Water consumption growth rate/GDP growth rate	2.33	-6.53	-0.17	1.280	0.262
Water-Use Efficiency	X22 Agricultural water-use efficiency index	Agricultural value/agricultural water consumption(yuan/m <sup>3</sup> )	54.26	3.48	20.67	11.438	0.211
(X2)	X23 Industrial water-use efficiency index	Industrial value added/industrial water consumption (yuan/m <sup>3</sup> )	1711.41	152.11	461.19	363.630	0.211
	X24 Industrial water reuse factor	Water reuse/total industrial water production (%)	95.82	36.32	80.21	0.183	0.158
	X25 Water-saving irrigation rate <sup>3</sup>	Water-saving irrigation area/total irrigation area (%)	93.90	11.50	52.03	0.241	0.158
	X31 Proportion of safe drinking water by population	The number of people receiving municipal water supply/total population (%)	100	38.54	58.80	0.140	0.300
	X32 Urban water supply penetration rate	People covered by the urban water supply/total population (%)	100	85.90	97.85	0.003	0.300
Sustainable Supply of Water (X3)	X33 Level of water stress	Freshwater withdraw/available freshwater resources	4.50	0.01	0.64	0.919	0.300
	X34 Proportion of people with drinking difficulties due to drought	The number of people with drinking difficulties due to drought/total population (%)	1.20	0	0.21	0.003	0.100
	X41 Treatment rate of domestic sewage	Total urban sewage treatment/total sewage discharge (%)	98.60	87.70	94.88	0.026	0.273
Water Environment Treatment (X4)	X42 Quality compliance rate of water function zones	Number of water function zones up to standard <sup>4</sup> /total number (%)	95.00	61.00	81.36	0.079	0.363
	X43 Per capita sewage discharge	Sewage discharge(m <sup>3</sup> )/total population	0.02	0.004	0.007	0.002	0.182
	X44 Per capita COD emissions	COD emissions(Ton)/total population	94.82	15.69	37.63	19.671	0.182
	X51 Per capita wetland area <sup>5</sup> change rate	Per capita wetland area change/Per capita wetland area in previous year	0.01	-0.02	-0.01	0.006	0.385
- Water Ecological Restoration (X5)	X52 Soil erosion treatment rate	Soil erosion treatment area/total soil erosion area (%)	15.6	0	5.01	0.031	0.385
	X53 Proportion of ecological water consumption	Ecological water consumption/total water consumption (%)	34.10	0.4	4.86	0.068	0.230

# Table 2. WCM Evaluation Index System.

Primary Indicator	Secondary Indicator	Indicator Meaning	Max Value	Min Value	Mean Value	STD <sup>1</sup> Deviation	Weight
	X61 Proportion of water conservancy professionals above junior college	Number of water conservancy professionals above junior college/total water conservancy professionals (%)	33.09	12.75	21.89	0.054	0.357
Level of Water Governance (X6)	X62 Automatic detection proportion of hydrological station network	Number of automatic detection hydrological stations/total stations (%)	100	0.37	54.56	0.328	0.357
	X63 Per capita water conservancy investment	Annual completed total investment in water conservancy/total population (yuan per person)	1655.44	138.62	580.46	373.247	0.286

#### Table 2. Cont.

Note: 1. The standard deviation was calculated without considering the percentage sign. 2. High-standard flood protection areas means flood protection areas with a standard greater than or equal to 50 years. 3. Water-saving irrigation includes sprinkling irrigation, micro-irrigation, and low-pressure pipeline irrigation. 4. Water function area refers to the area designated by the government in order to ensure the use function of the water. The water quality in the region must meet the corresponding classification standards [54]. 5. Wetland areas including natural wetlands, such as offshore, coastal, rivers, lakes, and marshes, as well as constructed wetlands.

#### 2.2. Evaluation of Modernization Construction Level of Water Conservancy

After the establishment of the evaluation index system of WCM, standardization was necessary to eliminate the discrepancies between the raw data and the orders of magnitude for each indicator unit. Indicators related to different properties can generally be classified as positive or negative; the value of each metric is converted to a range from 0 to 1, where 0 indicates the worst and 1 indicates optimal performance, and all indicators are standardized using following formulas.

positive indexes : 
$$f_{ij} = \frac{x_{ij} - \min\{x_{1j}, \cdots, x_{nj}\}}{\max\{x_{1j}, \cdots, x_{nj}\} - \min\{x_{1j}, \cdots, x_{nj}\}}$$
 (1)

negative indexes : 
$$f_{ij} = \frac{\max\{x_{1j}, \dots, x_{nj}\} - x_{ij}}{\max\{x_{1j}, \dots, x_{nj}\} - \min\{x_{1j}, \dots, x_{nj}\}}$$
 (2)

where  $x_{ij}$  is the original value of the  $j^{\text{th}}$  index of the  $i^{\text{th}}$  evaluation object, and  $f_{ij}$  is the value after dimensionless processing. The means and variances of each indicator after standardization can be found in Appendix A Table A1.

As each indicator has a different impact on the final evaluation results, it is important to quantify their relative importance. The weights of each indicator were subsequently determined by using the analytical hierarchy process (AHP). Firstly, we constructed a comparison judgment matrix based on the principle of pairwise comparison and the relationship of all the elements in sequence of importance. Based on the hierarchical model, six judgement comparison matrices were established (refer to Appendix B). Based on the solutions of these matrices, the judgement matrix was then used to reflect the relative importance of each factor and determine the single-level weights of each evaluation index. The consistency ratio (CR) values were then used to evaluate the sensitivity and consistency of the judgement matrices [55]. The weights of the WCM evaluation indexes were obtained and are listed in Table 2. At the same time, each dimension was given equal weight in the first layer of indicators, in accordance with the spirit of China's need to achieve all WCM goals through an overall strategy [21,23].

The comprehensive evaluation value of WCM in each region was calculated by Equation (3).

$$P_i = \sum_{j=1}^n w_j \mathbf{f}_{ij} \tag{3}$$

#### 2.3. Unbalanced Development Calculation

The Gini coefficient is commonly used in the field of economics to comprehensively examine the differences in income distribution among residents [56]. It is generally believed that the Gini coefficient is a key evaluation indicator for income imbalance, and scholars have promoted this concept as an important tool to judge the imbalance in the distribution of different types of data [57,58]. Therefore, this paper uses the Gini coefficient to judge the imbalance of China's water modernization, where the Gini coefficient adopts the calculation method proposed by Zhang [59].

$$G = 1 - \frac{1}{n} \left(2\sum_{i=1}^{n-1} Y_i + 1\right)$$
(4)

where  $Y_i$  is an index that represents the percentage of water modernization accumulated from the first region to the *i*<sup>th</sup> region in the total index of all 31 regions.

# 2.4. Analysis of Spatial Heterogeneity

There is a certain degree of interaction between the economic and geographic activities in different regions, and this interaction attenuates as the distance increases. This behavior is called the spatial dependence between variables. To explore the characteristics of China's WCM, the first step was to determine whether a spatial correlation exists between variables, which was measured by using the global Moran index I [60,61].

$$I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{i=1}^{n}w_{ij}(x_{i}-\overline{x})}{\sum_{i=1}^{n}\sum_{j=1}^{n}w_{ij}(x_{i}-\overline{x})^{2}} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}w_{ij}(x_{i}-\overline{x})(x_{i}-\overline{x})}{S^{2}\sum_{i=1}^{n}\sum_{j=1}^{n}w_{ij}}$$
(5)

$$S^{2} = \frac{\sum_{i=1}^{n} (x_{i} - \overline{x})^{2}}{n}$$
(6)

$$w_{ij} = \frac{1}{d_{ij}} \tag{7}$$

where *n* refers to the number of individuals (31 provinces and municipalities in China, which represent the neighboring relationship between region *i* and region *j*),  $d_{ij}$  is the spatial distance between the centers of two places, and  $S^2$  is the variance of variable *x*. The range of I is (-1, 1), where I > 0 indicates a positive correlation between variables, and I < 0 indicates a negative spatial autocorrelation.

To test the local spatial correlation, the local Moran index was used in this study, which can be calculated by the following equation.

$$I_i = \frac{(x_i - \overline{x})}{S^2} \sum_{j=1}^n w_{ij}(x_j - \overline{x})$$
(8)

When the local Moran index is positive, it means that the neighboring areas of this region have similar attributes; that is, if their development level is high, the development level of neighboring regions is also high; thus, the high-high (H-H) cluster denotes a high value surrounded by high values (similarly there are low-low (L-L) clusters). When  $I_i < 0$ , it indicates agglomeration in the adjacent areas; in other words, the self-development level is high, but the development of neighboring areas is low; thus, a high-low (H-L) cluster denotes a high value surrounded by low values (similarly, there are also low-high (L-H) clusters).

# 3. Results

## 3.1. Measurement and Analysis of the Water Modernization Level

According to the indicator system presented in Section 2.1, the water conservancy construction data of 31 provinces, municipalities, and autonomous regions in China in 2018 ("regions" is used throughout the paper to represent provinces, cities, and autonomous regions) were collected to assess the level of WCM. The results are presented in Table 3.

In 2018, the average score of China's WCM was 0.548, and approximately 60% of the regions were below it, thereby indicating a huge potential for construction from the regional perspective. In this study, China was divided into four parts called eastern, central, western, and northeastern, according to the division method of the National Bureau of Statistics of China [62], and the average score of each part was 0.595, 0.532, 0.520, and 0.531, respectively, as shown in Figure 1. Overall, 7 of the top 10 regions were from the eastern part, including Beijing, Fujian, Zhejiang, Shandong, Shanghai, Hebei, and Jiangsu, and the two western provinces of Guizhou and Yunnan, as well as the Shanxi Province from the central part, took up the other three top regions. The bottom 10 regions included Heilongjiang Province in the northeast and Hunan Province in the central part; six provinces and cities in the western part: Guangxi, Inner Mongolia, Ningxia, Gansu, Chongqing, and Tibet; and two provinces in the eastern part: Hainan and Guangdong. This demonstrated that the overall level of China's WCM was the highest in the eastern part, followed by the central, northeast, and western parts of China.



Figure 1. WCM scores for 31 regions in China.

Table 3. WCM	scores in	each	region.
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Region	Abbreviation	WCM Score	PFD Score	WUE Score	SSW Score	WET Score	WER Score	LWG Score	Region	Abbreviation	WCM Score	PFD Score	WUE Score	SSW Score	WET Score	WER Score	LWG Score
BeiJing	BJ	0.786	0.955	0.699	0.884	0.638	1.000	0.538	AnHui	AH	0.529	0.713	0.305	0.738	0.723	0.241	0.453
FuJian	FJ	0.651	0.421	0.740	0.635	0.511	0.760	0.421	HeNan	HA	0.524	0.772	0.442	0.623	0.730	0.409	0.170
ZheJiang	ZJ	0.626	0.916	0.480	0.830	0.595	0.241	0.694	QingHai	QH	0.524	0.766	0.273	0.743	0.522	0.217	0.620
GuiZhou	GZ	0.595	0.922	0.348	0.593	0.782	0.340	0.588	JiangXi	JX	0.514	0.729	0.192	0.683	0.748	0.337	0.394
ShanDong	SD	0.589	0.700	0.558	0.758	0.724	0.394	0.397	GuangXi	GX	0.513	0.804	0.374	0.666	0.737	0.287	0.211
ShanXi	SX	0.585	0.908	0.405	0.717	0.623	0.394	0.462	Inner Mongolia	NM	0.512	0.701	0.420	0.675	0.654	0.363	0.260
ShangHai	SH	0.584	0.952	0.366	0.822	0.516	0.247	0.599	HaiNan	HI	0.510	0.803	0.284	0.706	0.646	0.279	0.339
HeBei	HE	0.580	0.772	0.530	0.650	0.714	0.395	0.417	NingXia	NX	0.508	0.938	0.360	0.489	0.513	0.323	0.423
YunNan	YN	0.579	0.782	0.376	0.583	0.789	0.334	0.612	Guang Dong	GD	0.507	0.680	0.332	0.729	0.599	0.238	0.461
JiangSu	JS	0.571	0.875	0.358	0.728	0.606	0.365	0.494	GanSu	GS	0.506	0.438	0.404	0.661	0.784	0.343	0.407
ShaanXi	SN	0.554	0.921	0.450	0.663	0.670	0.316	0.303	HeiLong Jiang	HL	0.505	0.714	0.261	0.707	0.462	0.479	0.407
TianJin	TJ	0.552	0.802	0.508	0.846	0.363	0.476	0.316	HuNan	HN	0.505	0.715	0.156	0.659	0.782	0.329	0.387
SiChuan	SC	0.552	0.947	0.436	0.591	0.648	0.337	0.351	ChongQing	CQ	0.492	0.231	0.342	0.785	0.678	0.346	0.572
LiaoNing	LN	0.547	0.852	0.458	0.759	0.593	0.455	0.167	Tibet	XZ	0.368	0.546	0.012	0.412	0.707	0.032	0.500
JiLin	JL	0.540	0.784	0.513	0.645	0.488	0.488	0.321	Mean Value		0.548	0.776	0.375	0.693	0.649	0.354	0.439
HuBei	HB	0.536	0.683	0.299	0.752	0.672	0.374	0.436	Standard Deviation	_	0.067	0.157	0.130	0.099	0.107	0.160	0.145
XinJiang	XJ	0.533	0.885	0.260	0.655	0.775	0.091	0.534									

A K-value cluster analysis was performed on the comprehensive index of each region. The development level of China's WCM was divided into six echelons, and the results are shown in Figure 2. The first three echelons included 10 provinces and cities. The remaining 21 regions were located in the other three echelons. The first three echelons contained seven provinces and cities that were all located in the eastern part. Among the remaining eastern cities, Tianjing was in the fourth echelon, and Guangdong Province and Hainan Province were in the fifth echelons. As compared to the other regions, the overall level of construction of WCM in the eastern part was relatively high. There were six provinces in the central part of China, and among these, one was in the third echelon, three were in the fourth echelon, and two were in the fifth echelon. All provinces and municipalities in the western and northeast parts besides Guizhou and Yunnan were in the last three echelons, and their degree of WCM was relatively low.



Figure 2. Cluster analysis results of WCM in 2018.

The spatial distribution of the construction level of China's six first-level indicators of water modernization is illustrated in Figure 3. The average value of PFD capabilities was 0.776, the average SSW value was 0.693, and the average WET value was 0.649. These three dimensions all had relatively high scores. The results represented a strong capability for flood prevention and control in China as a whole, owing to a combination of engineering and non-engineering flood control strategies that have been implemented for many years [63]. At the same time, most cities have a strong capacity to supply clean drinking water and can better treat wastewater to ensure that the drinking water quality is up to standard, which is an important step forward in compliance with the SDGs. The average scores of the three dimensions of WUE, WER, and LWM were 0.375, 0.354, and 0.439, respectively, which were the relatively weaker aspects of the WCM construction.



Figure 3. Spatial distribution of WCM first-grade index scores.

# 3.2. Analysis on the Imbalance of WCM

## 3.2.1. Distribution Characteristics of Imbalance

The Gini coefficient was used to analyze the imbalanced development of China's WCM process (Figure 4). According to the calculations results, the Gini coefficient of China's WCM in 2018 was 0.121, which shows that the imbalance in the general construction level of WCM was not significant. Among all the first-level indicators, two categories were classified according to their characteristics: the first category contains three dimensions, PFD, SSW, and WET, which showed higher levels of modernization and lower imbalances. It is worth noting that the average modernization indexes of the second category, which contains WUE, WER, and LWM, were comparatively low, with the exception of Beijing, which had the highest score of 1 in WER. The remaining regions had the highest scores of 0.699, 0.511, and 0.760 in the three dimensions, and their Gini coefficients were significantly higher than the other three dimensions. This is also reflected in the mean and standard deviation of the indicators (see Appendix A), and in essence, the regional imbalance in the WCM is due to the variation in the scores of the indicators across regions.

Therefore, according to the above analysis, different measures should be taken for these two characteristics to further enhance their modernization level. The first type of indicator should be prioritized to improve the construction level of the backward regions, while maintaining the status quo level in most regions; the second type needs to proceed to develop a nationwide strategy to improve the overall construction level, while accelerating the construction process of the lagging regions to reduce the inter-regional differences.



Figure 4. WCM scores and the Gini coefficients of the different indicators.

3.2.2. Global Spatial Autocorrelation Analysis

The Moran's I index significance test and the spatial autocorrelation test were performed on the level of water modernization in 31 regions of China in 2018. The results are presented in Table 4.

Table 4. Spatial autocorrelation results.

Index	Level of WCM	PFD	WUE	SSW	WET	WER	LWM
Moran's I	0.869	0.178	0.233	0.113	-0.093	0.408	0.239
Z-Value	6.946	1.576	1.910	1.049	-0.422	3.587	1.907
<i>P</i> -Value	0.001	0.057	0.028	0.147	0.336	0.001	0.028

The Moran's I value for China's WCM was 0.869, and the Z-value and the *P*-value were 6.946 and 0.001, respectively, which showed strong spatial clustering characteristics. Among the six indicator layers, the four indicators PFD, WUE, WER, and LWM showed a certain degree of clustering in space, which was caused by a positive spatial correlation, and exhibited global spatial dependence.

#### 3.2.3. Local Spatial Autocorrelation Analysis

A local spatial autocorrelation analysis of WCM construction data in China in 2018 revealed that China's WCM level showed a strong spatial autocorrelation effect, as is shown in Figure 5. Five regions showed high-high (H-H) clusters, which were mainly concentrated in the regions located in the Bohai Bay region and Yangtze River Delta region. The integration of the Beijing-Tianjin-Hebei region is a policy that China has been trying to pursue in recent years [64], Shandong and Shanghai are also the provinces with more developed economies in China. In these areas, they tend to devote more money to obtain the sustainable use of water resources, and thus, better achieve the goals of WCM. It is worth referencing the "trickle drop effect" [51], as there were more interconnections between these regions, the implementation of an effective water governance strategy in one region might provide inspiration to neighboring regions, and this would result in a high level of water modernization in both these areas and the surrounding areas, which consequently has a H-H clustering effect. There were two regions with low-low (L-L) clusters, Xinjiang and Qinghai, both of which were located in the northwestern part of China. Due to their relatively low economic development, the government has not had sufficient funds to enhance the sustainable use of water resources, and it has been difficult for them to emerge from the L-L cluster. Moreover, two low-high (L-H) clusters were located around the Beijing-Tianjin-Hebei region. These had relatively low WCM levels, whereas their neighboring regions had relatively high WCM levels. Henan Province is in

the central plain of China, and Inner Mongolia is located in the north of China, so the high modernization of water conservancy in the surrounding areas can significantly contribute to the modernization of these two regions.



Figure 5. Spatial effect diagram of China's WCM in 2018.

## 3.3. Identification of Deficiencies in WCM

In order to determine the deficiencies of WCM in each region, we considered taking a value as the control value of insufficient capacity for modernization. According to the findings of Deng [65], the difference between the mean and standard deviation of each set of data can be used as a method of consideration. By discussing and analyzing the scores of each region, we believed that the last 15% of the regions are relatively backward, that is, the last 5 of the 31 regions [21,65,66]. Assuming that the values of each indicator are standard normal distribution,  $P(|\xi| < 1.04) \approx 0.7$ , the mean minus the standard deviation is, therefore, considered as the limit value of the deficiency. Subsequently, after further analysis, we determined the deficiencies of different regions under each dimension; the results are shown in Figure 6. Overall, there were 19 deficiencies in the country, including 2 in the eastern part, 3 in the central part, 1 in the northeastern part, and 13 in the western part, accounting for 10.5%, 15.8%, 5.3%, and 68.4% of the total number of deficiencies, respectively.

From the perspective of each region, there are 10 provinces and cities in the eastern part of China, and in consideration of the six dimensions of evaluation indicators in each region, the emergence of its two deficiencies was only 1/30, i.e., 3.33%. The rates of other regions were 3.33% in the central part, 5.56% in the northeastern part, and 18.06% in the western part; thus, it can be concluded that although the overall level of modernization in the western part is not significantly different from that in the northeastern and central parts of China, either the number or the proportion of deficiencies in the western part are much higher than the other regions, which is an important issue that requires to be addressed in order to accelerate the progress of WCM in China and to achieve sustainable development goals.



Figure 6. Distribution of deficiencies of WCM in China.

From the perspective of the six evaluation dimensions, Gansu, Chongqing, and Tibet showed deficiency with PFD. Among them, Gansu is located in the upper reaches of the Yellow River Basin, and Tibet and Chongqing are located in the upper reaches of the Yangtze River Basin. It is remarkable that although there are three regions with deficiencies in PFD, Tibet scored 0.546; thus, it is only because of the excellent flood control capabilities of other areas that led to the relatively backward position of Tibet. As for the Gansu Province (0.433), because of its geographical location, although the average annual rainfall is low, its precipitation distribution is extremely spatially and temporally imbalanced, which is the reason why flood disasters occur every year [67]. Chongqing (0.231) has a huge average annual rainfall and abundant water resources, together with a mountainous location, which makes it highly susceptible to flash floods causing damage [68].

Both the SSW and WET indicators demonstrated four regions with deficiencies; nevertheless, due to the high overall level, the sustainability problems faced by these cities are not serious, but they are in need of further modernization by learning from the construction experience of other regions. There were two provinces with deficiencies in WUE, and two provinces with deficiencies in WER. Tibet had the lowest scores in both WUE and WER, and was far below the average of each dimension, which means that Tibet is still a long way from modernizing its water conservancy, and because of its backward economic development level, it needs more help from the government of China to achieve this goal. In addition to this, Hunan and Jiangxi, both located in central China, suffered from deficiencies in water-use efficiency. Hunan Province's water-use elasticity coefficient in 2018 was the worst of the 31 study areas in this study. The ineffectiveness of industrial water reuse and water-saving irrigation in both provinces was the main source of the WUE deficiency in both regions. Xinjiang was deficient in WER; Xinjiang is located in the interior of northwestern China, with a vast area, arid climate, lower average annual rainfall, high evaporation, and a very fragile ecological environment, as well as serious soil erosion problems [69]. To solve this problem, the Chinese government plans to transfer water from Tibet to Xinjiang through the North-South Water Diversion Project in order to build a good water ecology in Xinjiang [70]. Henan, Guangxi, and Inner Mongolia were deficient in LWM. This is an issue that needs further attention, as Henan Province ranked 2nd in the country for the number of water conservancy employees in 2018, but the average education of members needs to be improved. The informatization management of Guangxi and Inner Mongolia is also relatively weak, which is an essential requirement that needs to be addressed.

# 4. Conclusions

A WCM evaluation index system was established by combining the functional characteristics of China's WCM and the SDGs. On the basis of the water conservancy construction data of 31 regions across China in 2018, the current level and spatial characteristics of WCM in China were analyzed and the deficiencies of the region were identified, which provided a basis for the evaluation of SDGs. As a result of our analysis, the following conclusions were obtained.

- (1) China's WCM scored 0.548 as a whole, and the distribution of the level of modernization across regions was somewhat comparable to the level of economic development. From a geographical point of view, the average level in the eastern part was the highest, followed by that in the central and northeastern parts, and the western region was ranked at the bottom. However, the gap between the evaluation results of WCM of the last three regions was not actually significant.
- (2) According to the evaluation results of the six dimensions, China had a relatively high level of PFD, a good level of SSW and WET, and a relatively poor level of WUE, WER, and LWG. All of them had more imbalance than the level of imbalance of WCM. The other three modernized dimensions, PFD, SSW, and WET, had a lower imbalance, while the other three had approximately the same level of imbalance and were relatively high.
- (3) China's WCM showed strong spatial clustering, with H-H clustering in the Bohai Bay region and Shanghai. The L-L clusters were mainly found in Xinjiang and Qinghai in the northwestern part of China. Provinces with L-H characteristics included Henan and Inner Mongolia.
- (4) There is still a heterogeneous distribution of deficiencies in different regions of China across different dimensions. The western region had significantly more deficiencies and higher generation rates than the other three regions. The number of regions with deficiencies in each dimension was in the range of 2–4 deficiencies. Except for Tibet, which had four deficiencies, the other provinces had a maximum of one deficiency.

The results of this study show that there is scope for improvement in the overall level of China's WCM. The level of economic development in the eastern part of China was relatively prominent, and investments in the water conservancy industry in this region were high. Furthermore, the level of construction in these regions was comparatively high and showed strong spatial correlations. However, future research should focus on strengthening the communication between other regions, promoting advanced ideas and construction experiences, and developing the surrounding areas. Western regions were mainly classified into two types. The northwestern part of China is relatively arid and has insufficient water resources. The southwestern part has abundant water, but they are not well equipped for a sustainable water supply since they are mostly mountainous areas. At present, the Chinese government is working to provide significant support to the western region from an economic and policy perspective. Urban water affair managers should carefully analyze the deficiencies in construction, carry out targeted construction, improve management capabilities, improve the imbalance of China's water modernization, and work towards the overall progress of China's water modernization. As this study analyzed the data of just one year, it cannot verify the reliability of the index system or summarize the relationship between the modernization of water conservancy development and its influencing factors. Future research should focus on long-term data, further optimize the index system, and determine the trend of China's water modernization and the degree of realization of sustainable development goals.

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#### Appendix A

 Table A1. Means and variances of each indicator after standardization.

Indicators	X11	X12	X13	X21	X22	X23	X24	X25	X31	X32	X33	X34
Means variances	0.828 0.071	$0.724 \\ 0.044$	0.624 0.077	0.283 0.021	0.339 0.051	$0.198 \\ 0.054$	0.694 0.150	0.492 0.086	0.330 0.052	$0.848 \\ 0.038$	0.859 0.042	0.823 0.071
Indicators	X41	X42	X43	X44	X51	X52	X53	X61	X62	X63		
Means variances	0.659 0.055	0.599 0.054	0.660 0.042	0.723 0.062	0.520 0.046	0.321 0.040	0.133 0.041	0.449 0.063	0.544 0.108	0.293 0.060		

# Appendix B

The comparison judgment matrix.

Table A2. Judgment matrix for X1.

	X11	X12	X13
X11	1	1	3/2
X12	1	1	3/2
X13	2/3	2/3	1

Table A3. Judgment matrix for X2.

	X21	X22	X23	X24	X25
X21	1	5/4	5/4	5/3	5/3
X22	4/5	1	1	4/3	4/3
X23	4/5	1	1	4/3	4/3
X24	3/5	3/4	3/4	1	1
X25	3/5	3/4	3/4	1	1

#### Table A4. Judgment matrix for X3.

	X31	X32	X33	X34
X31	1	1	1	3
X32	1	1	1	3
X33	1	1	1	3
X34	1/3	1/3	1/3	1

	X41	X42	X43	X44
X41	1	3/4	3/2	3/2
X42	4/3	1	2	2
X43	2/3	1/2	1	1
X44	2/3	1/2	1	1

Table A5. Judgment matrix for X4.

#### Table A6. Judgment matrix for X5.

	X11	X12	X13
X11	1	1	5/3
X12	1	1	5/3
X13	3/5	3/5	1

#### Table A7. Judgment matrix for X6.

	X11	X12	X13
X11	1	1	5/4
X12	1	1	5/4
X13	4/5	4/5	1

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