sustainability

Article

Are China's Water Resources for Agriculture Sustainable? Evidence from Hubei Province

Hao Jin and Shuai Huang *

School of Public Economics and Administration, Shanghai University of Finance and Economics, Shanghai 200433, China; 2017310003@live.sufe.edu.cn
* Correspondence: hswb2006@163.sufe.edu.cn; Tel.: +86-21-65903686

Abstract: We assessed the sustainability of agricultural water resources in Hubei Province, a typical agricultural province in central China, for a decade (2008–2018). Since traditional evaluation models often consider only the distance between the evaluation point and the positive or negative ideal solution, we introduce gray correlation analysis and construct a new sustainability evaluation model. Our research results show that only one city had excellent sustainable development capacity of agricultural water resources, and the evaluation value of eight cities fluctuated by around 0.5 (the median of the evaluation result), while the sustainable development capacity of agricultural water resources in other cities was relatively poor. Our findings not only reflect the differences in the natural conditions of water resources among various cities in Hubei, but also the impact of the cities' policies to ensure efficient agricultural water use for sustainable development. The indicators and methods in this research are not difficult to obtain in most countries and regions of the world. Therefore, the indicator system we have established by this research could be used to study the sustainability of agricultural water resources in other countries, regions, or cities.

Keywords: water resources; agricultural water resources; sustainability; gray correlation analysis; evaluation model

check for updates

Citation: Jin, H.; Huang, S. Are China's Water Resources for Agriculture Sustainable? Evidence from Hubei Province. *Sustainability* **2021**, *13*, 3510. https://doi.org/10.3390/su13063510

Academic Editors: Daniela Malcangio, Alan Cuthbertson, Juan Tomás García-Bermejo, Alessandra Saponieri and Janek Laanearu

Received: 8 February 2021
Accepted: 19 March 2021
Published: 22 March 2021

1. Introduction

All kinds of human production and living activities rely on water resources, especially the sustainable development of agriculture [1–3]. On the one hand, agricultural water resources are crucial for the production of food and other crops, and directly impact the food security of a country or region [4–6]. On the other hand, whether there can be a sustainable supply of agricultural water resources to meet the growing agricultural needs of the people also impacts the sustainable development level of a country or region [7–10]. As pointed out in a research report by the United Nations, the main cause of the global water resource crisis is a lack of scientific methods to effectively manage water resources and ultimately achieve sustainable utilization of them [11–14]. To achieve sustainable development of a human society, it is necessary to carefully manage water resources, especially agricultural water resources which take up the largest proportion of the supply, and to balance the relationship between population growth, socio-economic development and environmental protection [15]. Therefore, an important method used to reduce the pressure on agricultural water resources is to scientifically manage the water resources, and promote the concerted development of the economy and ecology through effective scientific methods to achieve the goal of sustainable utilization [16–20].

In 2018, China's total population had reached 1.395 billion, and the total planted area of crops was 1.659 million km^2, accounting for 16.7% of the total land area of 9.364 million km^2. The land area sown with food crops was 1.17 million km^2, accounting for 12.15% of the total planted area of crops. China's total water supply in 2018 was 601.55 billion m^3, and the total agricultural water consumption reached 369.31 billion m^3, accounting for

61.39% of the total water supply [21]. The imbalance between the supply and demand of agricultural water resources has become increasingly prominent.

In addition, the uneven geographical distribution of water resources in China, as well as the inefficient utilization and allocation of water resources, have led to an annual decrease in available agricultural water resources, such that a stable supply of water resources cannot be guaranteed [22–24]. The predatory development of agricultural water resources in pursuit of economic benefits in many regions has severely affected the hydrological cycle and caused catastrophic damage to the environment and agricultural production, which will ultimately constrain the sustainable development of society [25–27]. Therefore, scientific evaluation of the utilization of agricultural water resources in China and designing reasonable and effective policies and measures to ensure that agricultural water resources can support the sustainable development of society and the economy have become topics of common concern to the academic community [28–32], and are the research focus of this paper.

As far as research on agricultural water resources is concerned, Hubei province has typical research value in China and the world. It is located in central China and covers 17 cities including Wuhan, Huangshi, Shiyan, Yichang, Xiangyang, E'zhou, Jingmen, Xiaogan, Jingzhou, Huanggang, Xianning, Suizhou, Enshi, Xiantao, Qianjiang, Tianmen, and Shennongjia [33]. Although Hubei appears to have an abundant water supply based on the statistical data, there is a high consumption of agricultural water, which has been an ongoing problem. Except for some regions with a mountain climate, most of the cities have a subtropical monsoon humid climate, with abundant rainfall and favorable natural conditions in terms of water resources typical in the middle level of the country [34]. In 2018, the water resource per capita in Hubei Province was 1448 m^3, with water resources per mu (Mu is the Chinese land area unit. One mu equals 0.067 hectare) of 1300 m^3 (see Figure 1) [35]. In 2018, the total agricultural water consumption of Hubei was 15.07 billion m^3, accounting for 50.80% of the total water supply [35]. With the development of Hubei's society and economy, its industrial and domestic water consumption has been increasing. As the economic benefits of agriculture are relatively low compared to those of industrial production, the water supply needed for agricultural production is often taken by other sectors, especially the industrial sector [36–38]. The conflict between the industrial economy and the agricultural sector has become increasingly tense [39,40]. If this continues, the sustainable development of Hubei Province may be impacted.

The academic circle has conducted in-depth studies on the water resources of Hubei province. Yang and Zhu [41] studied the water planning process in Wuhan, Hubei province, and found that the water supply and drainage system in Wuhan have been regulated by a water utility planning framework, with financial support from the Asian Development Bank. Their results showed that water utility planning is essential to increase the climate resilience of the city. Moreover, the framework for ranking and identifying impacts and vulnerabilities related to water resources is suitable for the situation in Hubei. However, policy makers still need to choose an appropriate methodology with which to judge the water resource circumstances to meet the specific needs of people. Zhou et al. [40] focused on the spatial dependence and local patterns of water usage in Hubei province from 2003 to 2012. Using exploratory spatial data analysis and a gravity center model, they analyzed the spatial variation of Hubei's water usage. They found that the spatial dependence of the domestic and agricultural water usage pattern in Hubei is significant. Due to rapid industrial development, the approximate random distribution in the industrial water usage pattern was confirmed, which was also influenced by the government's policies and natural environment. Liu [42] used a multiple regression model to study the relationship between water pollution and economic development in Hubei province, arguing that the overall situation of Hubei's water pollution and economic development was not promising during 2008–2017. Their results showed that an inverted U-shape relationship exists between the industrial wastewater discharge and per capita gross domestic product, and between urban domestic sewage and per capita gross domestic product. Initially, when per capita gross domestic product increases, the industrial wastewater discharge and urban domestic sewage also increase. When the inverted U-shape curve reaches its peak, the opposite will happen. Zhu et al. [43] used reservoir water storage as a new indicator to calculate the carrying capacity of water resources in Hubei. Using a cloud model and the Dematel method, they calculated the carrying capacity of water resources and the importance of reservoir water storage in Hubei. They argued that although the carrying capacity of water resources in Hubei was increasing, it was mainly influenced by the amount of water resources per unit area. Wei et al. [44] evaluated the carrying capacity of the water environment in Wuhan, constructing an optimized projection pursuit model with a quantum genetic algorithm. They found that the carrying capacity of the water environment in Wuhan improved from 2006 to 2015. However, it was still significantly affected by the per capita water resource required, the proportion of irrigated area, water consumption per 10,000 Yuan industrial value-added, percentage of collective disposal of sewage, and population density. They showed that the daily sewage treatment capacity was the main factor affecting the performance of the carrying capacity of the water services in Wuhan.

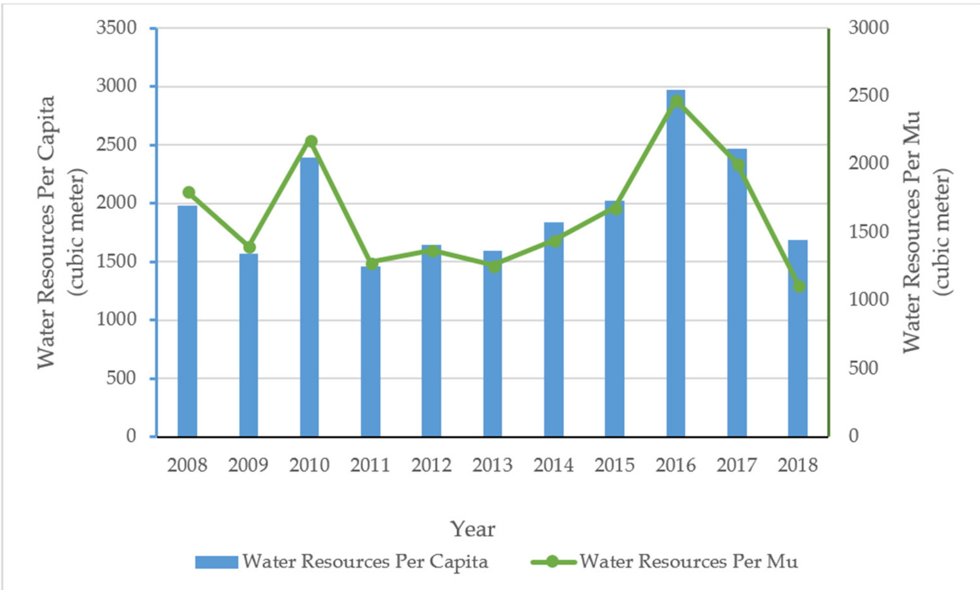

Figure 1. Water resources per capita and water resources per Mu in Hubei, China (2008–2018) [35]. (Mu is the Chinese land area unit; one mu equals 0.067 hectare).

To date, few studies have comprehensively evaluated the sustainability of agricultural water resource use in the cities of Hubei. Therefore, this paper first constructs an evaluation indicator system for the sustainable development level of agricultural water resources in Hubei. By utilizing a combined model with improved gray correlation (GC) and the technique for order preference by similarity to an ideal solution (TOPSIS), we calculated agricultural water resource sustainability evaluation scores for Hubei's cities based on official statistics from 2008 to 2018. Through an analysis of the evaluation scores, we discuss the agricultural water resource sustainability of different cities in Hubei province during the research period, and we provide policy recommendations for Hubei to maintain and improve its sustainable development of agricultural water resources in the future.

In this study we have attempted to expand upon existing research methods. The indicators and methods in this research are not difficult to obtain in most countries and regions of the world. Therefore, the indicator system we have established by this research could be used to study the sustainability of agricultural water resources in other countries, regions, or cities.

The contributions of this paper include: (1) the construction of an evaluation system for the sustainable development of agricultural water resources, and conducting an in-depth evaluation and analysis of different cities' strengths in terms of the sustainable development of agricultural water resources; and (2) improving the existing GC and TOPSIS combination model, determining the combination coefficients by adopting the weighting method based on game theory to eliminate subjectivity in the determination of combination coefficients [45–48]. Compared with traditional TOPSIS models [49–51], multiple weighting issues are considered in this research, making the calculation results more objective.

2. Materials and Methods

2.1. Evaluation Indicator System for the Sustainable Development Level of Agricultural Water Resources

We constructed a new sustainable development evaluation indicator system for agricultural water resources based on the existing sustainable development evaluation indicator system [52–55] used by the academic community. The indicator system we developed includes distinguishable and comparable evaluation indicators related to agriculture, agricultural water resources, and the overall economic sustainability of a society [56–58] to describe the sustainable development level of agricultural water resources from the perspective of aggregate value [59–62]. We aimed to build an evaluation system for which the raw indicator data should be easy to obtain, the calculation of the indicators should be simple, and the data should be complete and quantifiable during the research period [63].

Based on the above principles, we constructed an evaluation indicator system to measure the sustainable development level of agricultural water resources in the cities of Hubei province as shown in Table 1. For the following calculations, the raw data of the indicators were extracted from the "China Statistical Yearbook" officially published by the National Bureau of Statistics of China [21], and the "Hubei Province Statistical Yearbook" officially released by the Hubei Provincial Bureau of Statistics and the Hubei Investigation Team under the National Bureau of Statistics of China [33].

Table 1. Evaluation indicator system for the sustainable development level of agricultural water resources in Hubei Province.

Category	Indicator	Description	Mean	Variance
Overall Indicator	Agriculture as a percentage of gross domestic product (GDP, %)	Reflecting the proportion of agriculture in the industrial structure	10.99	0.0016
	Proportion of cultivated land to total urban area (%)	Reflecting the conservation of cultivated land in each city	76	0.0581
	Population density (population/km^2)	Reflecting the population pressure of each city	1845.40	243,182.20
	GDP per capita (ten thousand yuan)	Reflecting the level of economic development of each city	5.67	61.65
Efficiency Indicator of Sustainable Development	Cultivated area per capita (ha/person)	Reflecting the per capita cultivated land of each city	1.23	0.0024
	Food production per capita (kg)	Reflecting the security of food in each city	416.20	2204.33
	Agricultural water resources per capita (m^3)	Reflecting the security of agricultural water resources in each city	19,231.63	14,356.24
	Agricultural water resources per unit of cultivated area (m^3/ha)	Reflecting the matching degree of cultivated land and agricultural water resources	2127.99	214,365.24
	Effective irrigation rate on cultivated land (%)	Reflecting the actual utilization efficiency of agricultural water resources	23	0.0024

Table 1. *Cont.*

Category	Indicator	Description	Mean	Variance
	Agricultural water consumption per capita (m^3)	Reflecting the per capita agricultural water usage in each city	172.57	1537.25
	Water consumption per unit of agricultural output (m^3/ten thousand yuan)	Reflecting the productivity of agricultural water resources	56.20	88.57
	Agricultural output per unit of cultivated land (ten thousand yuan/ha)	Reflecting the productivity of cultivated land	1.04	2.13
Indicator Related to Resource and Energy	Degree of agricultural mechanization (%)	Reflecting the level of agricultural modernization of each city	13	0.0042
	Fertilizer usage per unit of cultivated land (t/ha)	Reflecting other key resource input in agricultural production	0.42	0.04
	Electricity consumption per unit of cultivated land (Kwh/ha)	Reflecting other key energy input in agricultural production	11.25	21.38

2.2. Improved Gray Correlation (GC) and Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) Combination Model

The combination model of GC and TOPSIS has been adopted by researchers who have used the combination coefficient to effectively integrate the two methods [64–66]. However, the existing combination model of GC and TOPSIS tends to determine the combination coefficient based on the researchers' views on the position and shape, and therefore has strong subjectivity [67]. To overcome this, studies have introduced methods, such as game theory, to determine combination weighting [68]. Here, we introduced game theory into the combination model of GC and TOPSIS by setting Nash equilibrium as the coordination goal to objectively determine the combination coefficients and eliminate subjectivity in the determination of combination coefficients and calculation results [69]. The calculation steps of the improved model are as follows:

(1) Construct an evaluation matrix X consisting of raw data:

$$X = \left[x_{ij}\right]_{n\times m} \tag{1}$$

Let x_{ij} be the value of the j^{th} evaluation indicator of the i^{th} city in the evaluation of agricultural water resources; the indicator weight set is $\omega = \{\omega_1, \omega_2, \ldots, \omega_m\}$.

(2) Standardize the above evaluation matrix X (all values are divided by the maximum value in the attribute column) to obtain a standardized evaluation matrix Y:

$$Y = \left(y_{ij}\right)_{n\times m} \tag{2}$$

in which,

$$y_{ij} = \begin{cases} \frac{x_{ij}-min_i\{x_{ij}\}}{max_i\{x_{ij}\}-min_i\{x_{ij}\}} (\text{in which } j \text{ is } a \text{ positive indicator; the larger the better}) \\ \frac{max_i\{x_{ij}\}-x_{ij}}{max_i\{x_{ij}\}-min_i\{x_{ij}\}} (\text{in which } j \text{ is } a \text{ negative indicator; the smaller the better}) \end{cases} \tag{3}$$

(3) Obtain the positive ideal solution T_0^+ and the negative ideal solution T_0^-:

$$T_0^+ = \left[max_{1\le i\le n}\left(\{y_{ij}\}\right)_{i=1}^n\right] = \{T_1^+, T_2^+, \ldots, T_m^+\}(j = 1,2,\ldots,m) \tag{4}$$

$$T_0^- = \left[min_{1\le i\le n}\left(\{y_{ij}\}\right)_{i=1}^n\right] = \{T_1^-, T_2^-, \ldots, T_m^-\}(j = 1,2,\ldots,m) \tag{5}$$

(4) Calculate the Euclidean distance of each evaluation indicator to the positive ideal solution and the negative ideal solution, D_i^+ and D_i^-, respectively:

$$D_i^+ = \sqrt{\sum_{j=1}^{m}\left(T_{ij} - T_j^+\right)^2} \qquad (i = 1, 2, \ldots, n) \tag{6}$$

$$D_i^- = \sqrt{\sum_{j=1}^{m}\left(T_{ij} - T_j^-\right)^2} \qquad (i = 1, 2, \ldots, n) \tag{7}$$

(5) Calculate the gray correlations of the i^{th} city with the positive ideal solution and the negative ideal solution, R_i^+ and R_i^-, respectively:

$$r_{ij}^+ = \frac{min_i min_j\left|T_{ij} - T_j^+\right| + \rho^+ max_i max_j\left|T_{ij} - T_j^+\right|}{\left|T_{ij} - T_j^+\right| + \rho^+ max_i max_j\left|T_{ij} - T_j^+\right|} \tag{8}$$

$$r_{ij}^- = \frac{min_i min_j\left|T_{ij} - T_j^-\right| + \rho^- max_i max_j\left|T_{ij} - T_j^-\right|}{\left|T_{ij} - T_j^-\right| + \rho^- max_i max_j\left|T_{ij} - T_j^-\right|} \tag{9}$$

$$R_i^+ = \frac{1}{m}\sum_{j=1}^{m} r_{ij}^+ \tag{10}$$

$$R_i^- = \frac{1}{m}\sum_{j=1}^{m} r_{ij}^- \tag{11}$$

where $\rho^+ = \rho^-$ is the distinguishing coefficient whose range is $[0, 1]$. In this paper, we assigned the median value of 0.5.

(6) Determine the degree of approximation in terms of distance (e_i) and in terms of the gray correlation (f_i) of the i^{th} city, both in the range of $[0, 1]$:

$$e_i = \frac{d_i^-}{d_i^+ + d_i^-} \qquad (i = 1, 2, \ldots, n) \tag{12}$$

$$f_i = \frac{r_i^-}{r_i^+ + r_i^-} \qquad (i = 1, 2, \ldots, n) \tag{13}$$

(7) Construct the matrixes consisting of the degree of approximation in terms of distance (W_1) and in terms of the gray correlation (W_2):

$$W_1 = \{e_1, e_2, \ldots, e_m\}^T \tag{14}$$

$$W_2 = \{f_1, f_2, \ldots, f_m\}^T \tag{15}$$

(8) Couple the matrixes consisting of the degree of approximation in terms of distance (W_1) and in terms of the gray correlation (W_2), i.e., construct the combination model of GC and TOPSIS:

$$CS = \sum_{j=1}^{2} \beta_j W_j \ (j = 1, 2) \tag{16}$$

where β_1 is the weight of the degree of approximation in terms of distance (W_1), and β_2 is the weight of the degree of approximation in terms of the gray correlation (W_2). $\beta_1 + \beta_2 = 1$.

(9) Optimize β_j based on game theory:

$$minQ_k = \| \sum_{j=1}^{2} \beta_j W_j - W_k^T \|_2, k = 1, 2 \tag{17}$$

(10) Solve β_j based on the differential property of the matrixes and obtain the normalized value:

$$\beta_1^* = \frac{|\beta_1|}{|\beta_1| + |\beta_2|} \tag{18}$$

$$\beta_2^* = \frac{|\beta_2|}{|\beta_1| + |\beta_2|} \quad (19)$$

(11) Finally, obtain the comprehensive degree of approximation, CS^*, which is the evaluation score of the sustainable development level of agricultural water resources in each city:

$$CS^* = \beta_1^* W_1 + \beta_2^* W_2 \quad (20)$$

The larger CS^* is, the higher the sustainability level of that city's agricultural water resources; on the contrary.

The Matlab (version R2017b; the software of MathWorks, Natick, MA, USA) algorithm for this model is provided in Appendix B.

3. Results and Discussion

By using the indicator system, data sources, and model methods discussed in Part 2, we calculated the evaluation results of the sustainable development level of agricultural water resources in the cities of Hubei from 2008 to 2018. For the calculation, X was used to represent the set of indicators: x_{11} represents the original data of the proportion of agriculture in GDP in 2008, x_{12} represents the original data of the proportion of cultivated land in the total urban area, and so on; ${x^G}_{11}$ represents the standardized value of the proportion of agriculture in GDP in 2008, ${x^G}_{12}$ represents the standardized value of the proportion of cultivated land to the total urban area, and so on [70,71].

Based on the model method in Section 2, we calculated values of 0.52 and 0.48 for β_1^* and β_2^*, respectively. The results of the degree of approximation in terms of distance (W_1) and the degree of approximation in terms of the gray correlation (W_2) are listed in Tables 2 and 3, respectively.

Table 2. The results of the degree of approximation in terms of distance (W_1) from 2008 to 2018.

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Enshi	0.6732	0.6140	0.6173	0.6368	0.5710	0.5817	0.5783	0.5217	0.5080	0.5334	0.5304
Ezhou	0.3341	0.3084	0.3182	0.3255	0.3152	0.3238	0.3309	0.3146	0.3269	0.3243	0.3306
Huanggang	0.3404	0.3479	0.3320	0.3480	0.3744	0.3649	0.3949	0.4365	0.4066	0.4014	0.3728
Huangshi	0.2832	0.2764	0.2553	0.2611	0.2772	0.2842	0.2741	0.3102	0.3058	0.2811	0.2883
Jingmen	0.5792	0.4830	0.4585	0.4865	0.5319	0.5614	0.5754	0.5798	0.5988	0.5443	0.5930
Jingzhou	0.4410	0.4848	0.4675	0.5001	0.4992	0.5138	0.5028	0.5468	0.5305	0.5141	0.5025
Qianjiang	0.5136	0.4930	0.5041	0.4990	0.4901	0.5011	0.4784	0.4922	0.4770	0.5040	0.5206
Shennongjia	0.7352	0.7666	0.7189	0.7702	0.7162	0.7858	0.7754	0.7275	0.7667	0.7392	0.7404
Shiyan	0.2434	0.2756	0.2886	0.2695	0.2784	0.2599	0.2598	0.2736	0.2682	0.2537	0.2511
Suizhou	0.3944	0.4359	0.4534	0.4436	0.4433	0.4210	0.4284	0.3972	0.4108	0.4247	0.4156
Tianmen	0.5196	0.5023	0.4983	0.5215	0.4822	0.4910	0.5153	0.5045	0.4868	0.4956	0.5133
Wuhan	0.5325	0.4114	0.4298	0.4311	0.4627	0.4826	0.4565	0.4461	0.4578	0.4719	0.4652
Xiangyang	0.4070	0.4399	0.4748	0.4732	0.4673	0.4188	0.4355	0.4239	0.4526	0.4582	0.4386
Xianning	0.3227	0.3385	0.3183	0.3445	0.3324	0.3118	0.3343	0.3416	0.3384	0.3260	0.3152
Xiantao	0.5036	0.5062	0.5018	0.5175	0.4875	0.5105	0.4761	0.4743	0.5068	0.5058	0.4771
Xiaogan	0.4747	0.4242	0.4179	0.4209	0.4166	0.4357	0.4231	0.4077	0.3805	0.4199	0.4182
Yichang	0.3448	0.3569	0.3849	0.3630	0.3790	0.3772	0.3984	0.4012	0.3941	0.3857	0.3998

Table 3. The results of the degree of approximation in terms of the gray correlation (W_2) from 2008 to 2018.

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Enshi	0.6924	0.7043	0.6822	0.6530	0.6465	0.6544	0.5916	0.5369	0.5823	0.6227	0.6525
Ezhou	0.3514	0.3623	0.3488	0.3429	0.3655	0.3596	0.3547	0.3809	0.3647	0.3653	0.3585
Huanggang	0.3962	0.3775	0.3971	0.3872	0.4139	0.4224	0.4237	0.4447	0.4585	0.4308	0.4505
Huangshi	0.2928	0.2912	0.3143	0.3116	0.3162	0.3130	0.3315	0.3124	0.3110	0.3306	0.3215
Jingmen	0.6100	0.5474	0.5443	0.5316	0.5786	0.5766	0.5841	0.6494	0.6052	0.6468	0.5949
Jingzhou	0.5244	0.5176	0.5493	0.5179	0.5626	0.5317	0.5857	0.6087	0.6081	0.5827	0.5778
Qianjiang	0.5828	0.6048	0.5901	0.5920	0.5750	0.5634	0.5725	0.5261	0.5515	0.5376	0.5248
Shennongjia	0.8911	0.8110	0.8537	0.8018	0.8757	0.8112	0.8192	0.8739	0.8293	0.8639	0.8666
Shiyan	0.2979	0.2966	0.2890	0.3070	0.2845	0.2974	0.2981	0.2782	0.2863	0.3004	0.3011
Suizhou	0.4657	0.5184	0.5191	0.5227	0.4848	0.4968	0.4792	0.4862	0.4806	0.4723	0.4819
Tianmen	0.6059	0.5664	0.5572	0.5334	0.5688	0.5758	0.5268	0.5079	0.5338	0.5488	0.5413
Wuhan	0.5494	0.4937	0.4359	0.4476	0.4686	0.4861	0.5032	0.5247	0.5044	0.5060	0.5274
Xiangyang	0.4834	0.5059	0.4800	0.4777	0.4690	0.5083	0.4962	0.5094	0.4798	0.4659	0.4816

Table 3. *Cont.*

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Xianning	0.3405	0.3544	0.3833	0.3538	0.3630	0.3807	0.3591	0.3534	0.3569	0.3667	0.3763
Xiantao	0.5432	0.5507	0.5568	0.5378	0.5586	0.5320	0.5644	0.5551	0.5233	0.5289	0.5610
Xiaogan	0.5008	0.4735	0.4600	0.4571	0.4483	0.4432	0.4324	0.4119	0.4499	0.4340	0.4480
Yichang	0.3723	0.4045	0.3866	0.4119	0.4165	0.4081	0.4089	0.4456	0.4434	0.4272	0.4014

It can be seen from Tables 2 and 3 that the changing trends of the degree of approximation in terms of distance (W_1) and the degree of approximation in terms of the gray correlation (W_2) of the same city in different years are relatively close, and they are also consistent with the abundance of agricultural water resources [35]. Taking Shennongjia, which has the richest agricultural water resources in Hubei Province [35,72], as an example, the calculation results of the two distances are both at the best level of 17 cities.

According to Equation (20) and the calculation results in Tables 2 and 3, the evaluation results of the sustainable development level of agricultural water resources in cities of Hubei from 2008 to 2018 are shown in Figure 2 (for detailed results, please refer to Table A1 in Appendix A).

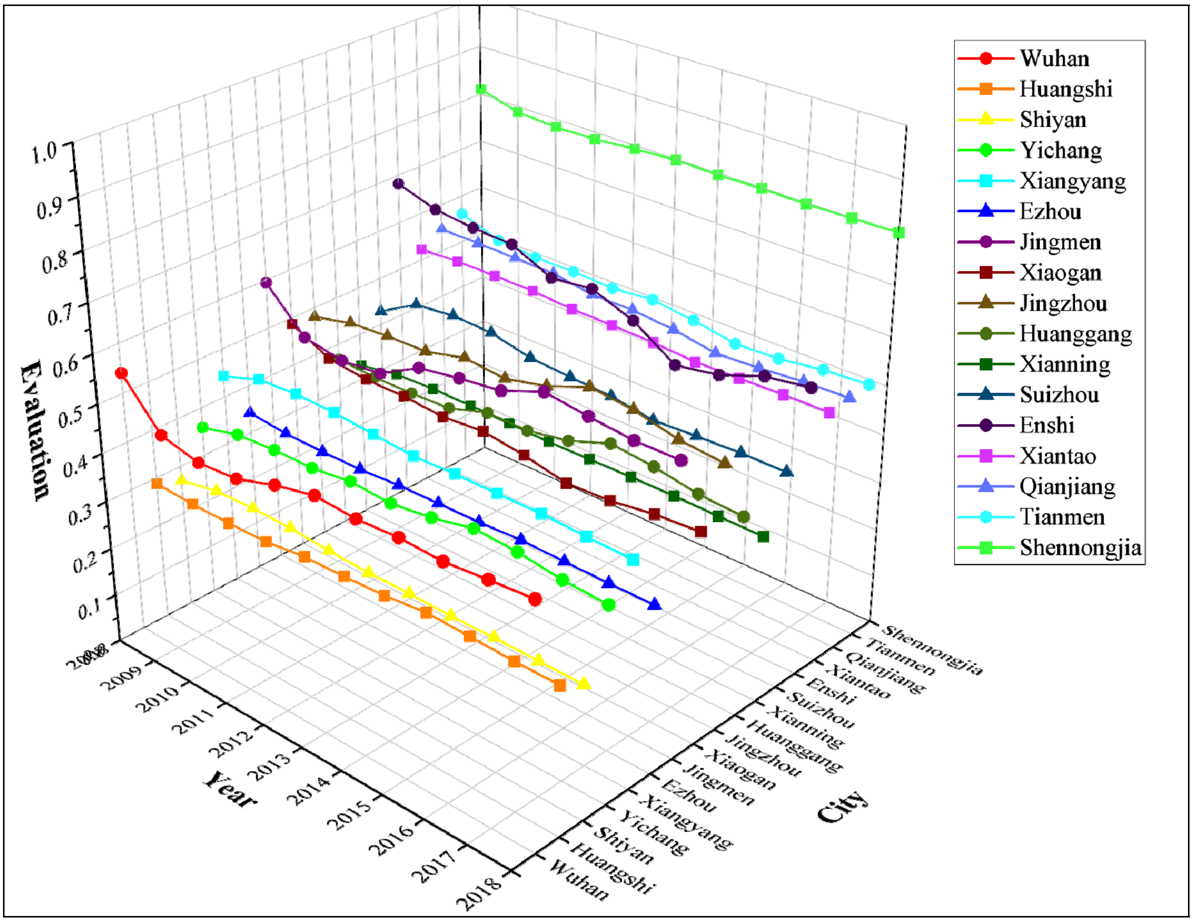

Figure 2. Evaluation results of the sustainable development level of agricultural water resources in cities of Hubei from 2008 to 2018.

There were large differences in the sustainable development level of agricultural water resources among the 17 cities. According to the quantile interval of the evaluation score obtained, cities could be divided into three categories (see Table 4) [73–75]. Since this classification was calculated based on the evaluation indicators in Table 1, it reflects the contribution of the overall indicator, the efficiency indicator of sustainable development, and the indicator related to resources and energy.

Table 4. Categories of evaluation results.

Category	Evaluation Score	Cities
I	0.7500–1.0000	Shennongjia
II	0.5000–0.7499	Enshi, Jingmen (0.4997 in 2010), Jingzhou (0.4810 in 2008), Qianjiang, Tianmen, Xiantao
III	0.2500–0.4999	Ezhou, Huanggang, Huangshi, Shiyan, Suizhou, Wuhan (0.5406 in 2008), Xiangyang, Xianning, Xiaogan, Yichang

Category I. Evaluation score higher than 0.7500. This category only included Shennongjia. This city has favorable natural conditions in terms of water resources, which has laid a solid foundation for the sustainable development of its agricultural water resources.

Shennongjia is rich in surface water resources. The four river systems that originate from this area—Xiangxi River, Yandu River, Nanhe River, and Duhe River—have an annual surface runoff of around 2.2 billion m^3, making Shennongjia the city with the highest per capita water resources in Hubei province [33].

During the research period, various governmental departments of Shennongjia worked together on the conservation of agricultural water resources, taking active measures to protect agricultural water sources and installing protective nets and electronic monitoring equipment in place.

At the same time, the local government made efforts to advance environmental protection and restoration work, developing traditional fuel replacement projects by hydropower, shutting down some of the small hydropower plants, and promoting environmental water discharge. The local government has carried out strict supervision and inspection on the management of agricultural water resources, actively promoted the transformation of agricultural water pipeline networks, and effectively improved the efficiency in agricultural water resource utilization [76].

In addition, Shennongjia has been vigorously developing eco-agriculture, and comprehensively considers the ecological capacity and protection measures when formulating various agricultural policies [72]. Consequently, its sustainable development level of agricultural water resources consistently ranked first in Hubei province during the research period. Despite the small drop in its evaluation score in 2018, its evaluation score has remained above 0.8000.

Category II. Evaluation score between 0.5000 and 0.7499. This category included the six cities of Enshi, Jingmen (0.4997 in 2010), Jingzhou (0.4810 in 2008), Qianjiang, Tianmen, and Xiantao. These cities have generally paid attention to the utilization and protection of agricultural water resources during the research period and implemented a number of related policies and measures.

Jingmen is a typical example among the cities of Category II. During the research period, Jingmen strictly monitored one of the key sources of agricultural water resources, underground water, and achieved satisfactory results. In 2008, Jingmen formulated the "Measures for the Management of Underground Water Resources of Jingmen City" [77] in accordance with the "Water Law of the People's Republic of China" [78], "Regulations on Water Permits and the Collection of Water Resources Fees" [79], and "Hubei Province's Measures for Implementing the Water Law of the People's Republic of China" [80] to supervise the usage and conservation of underground water resources. In 2010, Jingmen further enhanced its supervision and management of underground water resources, making it a strategic measure in the transformation of economic development patterns. Jingmen government enforced the most stringent water management policies in the history of the city by adhering to the principles of conservation first, green development, and strict water management, thus further enhancing the effectiveness and rigid constraints of the agricultural water resource management system.

By 2015, the evaluation score of Jingmen had seen significant improvements after a brief decline, and four of its indicators, including the effective irrigation rate of cultivated land and the compliance rate of agricultural water quality, were among the highest in the province. Since 2017, Jingmen has driven the construction of a water-saving society, and refined the system and measures in areas such as underground water recycling and efficient utilization of agricultural water resources to increase the supply of high-quality underground water and enhance the local government's competency in agricultural water resource management [81]. The sustainable development level of agricultural water resources in Jingmen has steadily improved since 2010. As of the end of the research period in 2018, Jingmen has managed to maintain a high level of sustainable development of agricultural water resources while achieving economic development, which is worth learning from by other cities of Hubei Province.

Category III. Evaluation score between 0.2500 and 0.4999. This category included the 10 cities of Ezhou, Huanggang, Huangshi, Shiyan, Suizhou, Wuhan (0.5406 in 2008), Xiangyang, Xianning, Xiaogan, Yichang. Due to the constraints in their geographical location and natural water resources, these cities have poor natural endowments in terms of the sustainability of agricultural water resources. However, these cities have adopted proactive policies and measures to improve the sustainable development level of their agricultural water resources during the research period.

Taking Wuhan, the provincial capital, as an example, since 2008 there has been a significant decline in its sustainable development level of agricultural water resources. However, a turning point occurred in 2010, after which the declining trend turned into a trend of volatile rise. During this period, the upward trend between 2010 and 2015 was most obvious, with its evaluation score rising from 0.4327 in 2010 to 0.4838 in 2015. The Wuhan government issued the "Water Resources Protection Regulations" in 2011 [82], striving to improve the water quality of 4–5 lakes of Inferior V Class, and made great efforts improving the structure of its crop cultivation and water consumption.

In addition to food crops, such as rice and wheat, the Wuhan government has encouraged planting of cash crops such as cotton, oilseed rape, sugarcane, citrus, tea, chestnut and tobacco. These measures improve water quality and increase the proportion of cash crops while ensuring the production of food crops significantly improved the effective irrigation rate of cultivated land and productivity of agricultural water resources.

According to the "Hubei Statistical Yearbook", in 2017, Wuhan's planted area of sugarcane ranked first in Hubei, and its planted area of other cash crops also took a large proportion of its total cultivated land area [33]. In its annual water resource bulletin released by Wuhan in 2017, among the 80 key lakes in Wuhan, there were only 12 lakes classified as Inferior V Class [83], which greatly enhanced the sustainable development level of its agricultural water resources.

Huanggang is another typical example among these cities. During the research period, this city utilized advanced agricultural irrigation equipment and irrigation technologies to improve the effective irrigation rate and facilitate water-saving irrigation to ensure the sustainable development of its agricultural water resources. Since 2015, while upgrading its agricultural irrigation equipment and irrigation technologies, Huanggang has also established a strict assessment system for water resource management, and has formulated strict performance assessment indicators for all counties under its jurisdiction to help them focus on the sustainable development of agricultural water resources [84].

Huanggang has also actively promoted water-saving agriculture across the city. Taking one county in Huanggang as an example, during the research period Wuxue renovated and reconstructed more than 200 km of water supply pipeline networks, and expanded, restored and improved an area of irrigated farmland of 18,000 mu [85].

Four cities (Huangshi, Shiyan, Ezhou and Xianning) had evaluation scores lower than 0.3500. These cities had relatively poor natural conditions in terms of water resources compared with the other cities evaluated [33], which negatively affected the sustainable development level of their agricultural water resources. However, in the process of economic development, the decline in water quality has also restricted the sustainable development of these cities' agricultural water resources.

Taking Huangshi as an example, this city is located to the north of the Mufu Mountains with poor natural water resources. In addition, during its economic development, Huangshi has suffered serious water pollution. Due to the development of its society and economy, as well as its rapid population expansion, the development of Huangshi has outgrown the natural capacity of its water resources to a certain extent, and the self-purification capacity of surrounding lakes has declined. In particular, a large number of industrial enterprises have set up factories near lakes, and the large amount of industrial wastewater discharged has caused a high level of heavy metal pollutants to enter the lakes and a deteriorating water quality year by year. In addition, the emissions of urban sewage have grown while the renewal rate of lake water is slow and the renewal cycle is long. Thus, the sustainable development of agricultural water resources is under threat [86].

Faced with such a disadvantageous situation, Huangshi has also taken relevant measures to improve the sustainability of its agricultural water resources. Through active application, the "Huangshi Water Pollution Comprehensive Treatment Project" was successfully included in the "Candidate Project Financing Plan of the Asian Development Bank for 2010–2012" [87]. With financing support from the Asian Development Bank, Huangshi has carried out comprehensive environmental improvement projects on the three lakes of Cihu Lake, Qingshan Lake, and Qinggang Lake. The main elements of these projects included 6 sub-projects of pipeline network and pollution source investigation project, sewage interception project, lake dredging project, ecological remediation project, sludge treatment project, and institutional capacity building project. Through this project, Huangshi has been working hard to restore a healthy water cycle in the natural water system of the city, remove existing lake pollutants, and strengthen its capacity in agricultural water supply [88].

It can be seen that this project along with other measures taken by Huangshi government have achieved encouraging results—the city's evaluation score of sustainable development level of agricultural water resources has improved since 2012 and reached 0.3042 at the end of the research period, which has improved by 5.70% compared with that of the beginning of the research period in 2018 (0.2878). However, the sustainable development level of agricultural water resources in Huangshi and the other three cities of this category is still quite low, which calls for further improvement in the future.

Compared with previous studies on sustainability indicators, the indicator system we constructed in this paper focuses more on evaluating the sustainability of a city/region in terms of agricultural water resources and is, therefore, more targeted. For example, compared with the indicator system of the United Nations [89,90], this paper has emphasized the evaluation of the sustainable development efficiency of agricultural water resources; compared with other previous studies [91–93], the improvement in the method of determining indicator weights also makes this paper has its own value.

4. Conclusions

By constructing an evaluation indicator system for the sustainable development level of agricultural water resources in Hubei, and with the help of the combination model with improved gray correlation (GC) and technology for order preference by similarity to an ideal solution (TOPSIS), we calculated and analyzed the evaluation score of the sustainable development level of agricultural water resources in cities of Hubei from 2008 to 2018. The results showed that during the period of 2008–2018, the 17 cities of Hubei Province differed greatly in terms of their agricultural water resource sustainability level, with fluctuating levels for individual cities as well. Among the cities, only Shennongjia achieved an excellent evaluation result, receiving an evaluation score of 0.8010 in 2018; eight cities were given an evaluation score between 0.45000 and 0.60000, and these cities implemented numerous policies and measures, including improving the effective irrigation rate of cultivated land and productivity of agricultural water resources, to strengthen the utilization and conservation of agricultural water resources. The remaining eight cities obtained an evaluation score of less than 0.45000, with four of these having scores below 0.35000. Apart from their poor natural conditions related to water resources (in terms of both total amount of water resources and the quality of water resources), the development of these cities has outgrown the natural capacity of their water resources to some extent. In addition, the low self-renewal rate of natural water resources is also an important factor affecting the sustainable development level of agricultural water resources.

Based on our findings, we propose the following policy recommendations for Hubei to maintain and improve its sustainable development level of agricultural water resources in the future.

I. Reform the existing agricultural water resource management system to improve the degree of agricultural mechanization and the agricultural output per unit of cultivated land. Considering the current situation of agricultural water resource utilization in Hubei province, it is suggested that the provincial government establish an integrated agricultural water resource management system for the entire province through unified coordination [94]. At the same time, Hubei province should strengthen the management of agricultural water resources by basin, and centralize the management of major rivers in the province, such as the Yangtze River and Hanjiang River, so that cities belonging to different river basins can make use of agricultural water resources to maximize agricultural water resources per unit of cultivated area and minimize water consumption per unit of agricultural output.
II. Improve the effective irrigation rate on cultivated land. The sustainability level of agricultural water resources not only depends on the total amount of water resources and the quality of water resources of a certain city, but on the utilization efficiency of water resources. Therefore, other cities could learn from the experience of cities like Wuhan and Jingmen to combine the characteristics of agricultural land, field irrigation adaptability and technical requirements in the 17 cities, and actively adopt water-saving surface irrigation technologies such as plastic film mulching technology [95], small border irrigation technology [96], and furrow irrigation technology [97] to improve the effective irrigation rate on cultivated land.
III. Protect cultivated land and improve agricultural energy efficiency. The government should protect the quantity and quality of cultivated land through the use of legal, economic, technical and other measures. Through the improvement of Hubei's basic farmland protection system, cultivated land occupation compensation system, and high-standard basic farmland construction system, etc., the government can develop, consolidate and reclaim cultivated land. At the same time, the utilization efficiency of agricultural electricity should be continuously improved [98] to minimize electricity consumption per unit of cultivated land.

Author Contributions: Conceptualization, H.J. and S.H.; methodology, H.J.; software, S.H.; validation, S.H.; formal analysis, S.H.; resources, H.J.; data curation, S.H.; writing—original draft preparation, H.J.; writing—review and editing, H.J.; visualization, H.J.; project administration, S.H. Both authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by General Project in Humanities and Social Sciences of Ministry of Education of the People's Republic of China, grant number 16YJC790041.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are all from the statistical data officially released by China and have been explained in the text and references.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Evaluation Results of the Sustainable Development Level of Agricultural Water Resources in Cities of Hubei from 2008 to 2018

Table A1. Evaluation results of the sustainable development level of agricultural water resources in cities of Hubei from 2008 to 2018.

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Enshi	0.6824	0.6574	0.6485	0.6446	0.6073	0.6166	0.5847	0.5290	0.5437	0.5763	0.5890
Ezhou	0.3424	0.3343	0.3329	0.3339	0.3394	0.3410	0.3423	0.3464	0.3451	0.3440	0.3440
Huanggang	0.3672	0.3621	0.3633	0.3668	0.3933	0.3925	0.4087	0.4404	0.4315	0.4155	0.4101
Huangshi	0.2878	0.2835	0.2836	0.2854	0.2959	0.2980	0.3016	0.3112	0.3083	0.3049	0.3042
Jingmen	0.5940	0.5139	0.4997	0.5081	0.5543	0.5687	0.5796	0.6132	0.6019	0.5935	0.5939
Jingzhou	0.4810	0.5006	0.5067	0.5087	0.5296	0.5224	0.5426	0.5765	0.5678	0.5470	0.5386
Qianjiang	0.5468	0.5466	0.5454	0.5436	0.5309	0.5310	0.5236	0.5085	0.5128	0.5202	0.5226
Shennongjia	0.8100	0.7879	0.7836	0.7854	0.7927	0.7980	0.7964	0.7978	0.7968	0.7991	0.8010
Shiyan	0.2696	0.2857	0.2888	0.2875	0.2813	0.2779	0.2782	0.2758	0.2769	0.2761	0.2751
Suizhou	0.4286	0.4755	0.4849	0.4816	0.4632	0.4574	0.4528	0.4399	0.4443	0.4476	0.4474
Tianmen	0.5610	0.5331	0.5266	0.5272	0.5238	0.5317	0.5208	0.5061	0.5094	0.5211	0.5267
Wuhan	0.5406	0.4509	0.4327	0.4390	0.4655	0.4843	0.4789	0.4838	0.4801	0.4883	0.4951
Xiangyang	0.4437	0.4716	0.4773	0.4754	0.4681	0.4618	0.4647	0.4650	0.4657	0.4619	0.4592
Xianning	0.3312	0.3461	0.3495	0.3489	0.3471	0.3449	0.3462	0.3473	0.3473	0.3456	0.3445
Xiantao	0.5226	0.5276	0.5282	0.5273	0.5216	0.5208	0.5185	0.5131	0.5147	0.5169	0.5174
Xiaogan	0.4872	0.4479	0.4381	0.4383	0.4318	0.4393	0.4276	0.4097	0.4138	0.4267	0.4325
Yichang	0.3580	0.3797	0.3857	0.3865	0.3970	0.3920	0.4035	0.4225	0.4178	0.4057	0.4006

Appendix B. The Matlab Algorithm for the Model

Algorithm A1. Matlab algorithm for the Model.

```
function [ output_args ] = TOPSIS(A,W)
A = [];
W = []
[ma,na] = size(A);
for I = 1:na
    B(:,i) = A(:,i)*W(i);
end
V1 = zeros(1,na);
V2 = zeros(1,na);
BMAX = max(B);
BMIN = min(B);
for i = 1:na
    V1(i) = BMAX(i);
    V2(i) = BMIN(i);
end
for i = 1:ma
    C1 = B(i,:) − V1;
    S1(i) = norm(C1);
    C2 = B(i,:) − V2;
    S2(i) = norm(C2);
    T(i) = S2(i)/(S1(i) + S2(i));
end
output_args = T
```

References

1. Darzi Naftchali, A.; Ritzema, H. Integrating Irrigation and Drainage Management to Sustain Agriculture in Northern Iran. *Sustainability* **2018**, *10*, 1775. [CrossRef]
2. Yang, W.X.; Li, L.G. Analysis of Total Factor Efficiency of Water Resource and Energy in China: A Study Based on DEA-SBM Model. *Sustainability* **2017**, *9*, 1316. [CrossRef]
3. Expósito, A. Irrigated Agriculture and the Cost Recovery Principle of Water Services: Assessment and Discussion of the Case of the Guadalquivir River Basin (Spain). *Water* **2018**, *10*, 1338. [CrossRef]
4. Kang, S.; Hao, X.; Du, T.; Tong, L.; Su, X.; Lu, H.; Li, X.; Huo, Z.; Li, S.; Ding, R. Improving agricultural water productivity to ensure food security in China under changing environment: From research to practice. *Agric. Water Manag.* **2017**, *179*, 5–17. [CrossRef]

5. Wang, S.; Hu, Y.; Yuan, R.; Feng, W.; Pan, Y.; Yang, Y. Ensuring water security, food security, and clean water in the North China Plain—Conflicting strategies. *Curr. Opin. Environ. Sustain.* **2019**, *40*, 63–71. [CrossRef]
6. Huai, H.; Chen, X.; Huang, J.; Chen, F. Water-Scarcity Footprint Associated with Crop Expansion in Northeast China: A Case Study Based on AquaCrop Modeling. *Water* **2019**, *12*, 125. [CrossRef]
7. Kotir, J.H.; Brown, G.; Marshall, N.; Johnstone, R. Systemic feedback modelling for sustainable water resources management and agricultural development: An application of participatory modelling approach in the Volta River Basin. *Environ. Model. Softw.* **2017**, *88*, 106–118. [CrossRef]
8. Ozturk, I. The dynamic relationship between agricultural sustainability and food-energy-water poverty in a panel of selected Sub-Saharan African Countries. *Energy Policy* **2017**, *107*, 289–299. [CrossRef]
9. Yang, W.; Li, L. Efficiency Evaluation and Policy Analysis of Industrial Wastewater Control in China. *Energies* **2017**, *10*, 1201. [CrossRef]
10. Entezari, A.; Wang, R.Z.; Zhao, S.; Mahdinia, E.; Wang, J.Y.; Tu, Y.D.; Huang, D.F. Sustainable agriculture for water-stressed regions by air-water-energy management. *Energy* **2019**, *181*, 1121–1128. [CrossRef]
11. United Nations Educational Scientific and Cultural Organization. *Water, a Shared Responsibility*; UNESCO Publishing: New York, NY, USA, 2006.
12. Carrard, N.; Foster, T.; Willetts, J. Groundwater as a Source of Drinking Water in Southeast Asia and the Pacific: A Multi-Country Review of Current Reliance and Resource Concerns. *Water* **2019**, *11*, 1605. [CrossRef]
13. Li, Y.; Yang, W.; Shen, X.; Yuan, G.; Wang, J. Water Environment Management and Performance Evaluation in Central China: A Research Based on Comprehensive Evaluation System. *Water* **2019**, *11*, 2472. [CrossRef]
14. Awume, O.; Patrick, R.; Baijius, W. Indigenous Perspectives on Water Security in Saskatchewan, Canada. *Water* **2020**, *12*, 810. [CrossRef]
15. United Nations Educational Scientific and Cultural Organization. *Nature-Based Solutions for Water*; UNESCO Publishing: New York, NY, USA, 2018.
16. Singh, A. Assessment of different strategies for managing the water resources problems of irrigated agriculture. *Agric. Water Manag.* **2018**, *208*, 187–192. [CrossRef]
17. Li, L.; Yang, W. Total Factor Efficiency Study on China's Industrial Coal Input and Wastewater Control with Dual Target Variables. *Sustainability* **2018**, *10*, 2121. [CrossRef]
18. Yerushalmi, E. Using Water Allocation in Israel as a Proxy for Imputing the Value of Agricultural Amenities. *Ecol. Econ.* **2018**, *149*, 12–20. [CrossRef]
19. Li, M.; Fu, Q.; Singh, V.P.; Liu, D.; Li, T.; Zhou, Y. Managing agricultural water and land resources with tradeoff between economic, environmental, and social considerations: A multi-objective non-linear optimization model under uncertainty. *Agric. Syst.* **2020**, *178*, 102685. [CrossRef]
20. Gao, H.; Yang, W.; Wang, J.; Zheng, X. Analysis of the Effectiveness of Air Pollution Control Policies based on Historical Evaluation and Deep Learning Forecast: A Case Study of Chengdu-Chongqing Region in China. *Sustainability* **2021**, *13*, 206. [CrossRef]
21. National Bureau of Statistics of China. *China Statistical Yearbook, 2004–2018*; China Statistic Press: Beijing, China, 2019.
22. Zhang, C.; Liu, Y.; Qiao, H. An empirical study on the spatial distribution of the population, economy and water resources in Northeast China. *Phys. Chem. Earth Parts A/B/C* **2015**, *79–82*, 93–99. [CrossRef]
23. He, Y.; Wang, Y.; Chen, X. Spatial patterns and regional differences of inequality in water resources exploitation in China. *J. Clean. Prod.* **2019**, *227*, 835–848. [CrossRef]
24. Wang, Y.; Wang, Y.; Su, X.; Qi, L.; Liu, M. Evaluation of the comprehensive carrying capacity of interprovincial water resources in China and the spatial effect. *J. Hydrol.* **2019**, *575*, 794–809. [CrossRef]
25. Zou, Y.; Duan, X.; Xue, Z.; Mingju, E.; Sun, M.; Lu, X.; Jiang, M.; Yu, X. Water use conflict between wetland and agriculture. *J. Environ. Manag.* **2018**, *224*, 140–146. [CrossRef] [PubMed]
26. Wang, F.; Yu, C.; Xiong, L.; Chang, Y. How can agricultural water use efficiency be promoted in China? A spatial-temporal analysis. *Resour. Conserv. Recycl.* **2019**, *145*, 411–418. [CrossRef]
27. Giménez, L.; Paredes, P.; Pereira, L.S. Water Use and Yield of Soybean under Various Irrigation Regimes and Severe Water Stress. Application of AquaCrop and SIMDualKc Models. *Water* **2017**, *9*, 393. [CrossRef]
28. Chekli, L.; Kim, Y.; Phuntsho, S.; Li, S.; Ghaffour, N.; Leiknes, T.; Shon, H.K. Evaluation of fertilizer-drawn forward osmosis for sustainable agriculture and water reuse in arid regions. *J. Environ. Manag.* **2017**, *187*, 137–145. [CrossRef]
29. D'Ambrosio, E.; Girolamo, A.M.D.; Rulli, M.C. Assessing sustainability of agriculture through water footprint analysis and in-stream monitoring activities. *J. Clean. Prod.* **2018**, *200*, 454–470. [CrossRef]
30. Lake, J.A.; Kisielewski, P.; Hammond, P.; Marques, F. Sustainable soil improvement and water use in agriculture: CCU enabling technologies afford an innovative approach. *J. CO_2 Util.* **2019**, *32*, 21–30. [CrossRef]
31. Zhong, H.; Sun, L.; Fischer, G.; Tian, Z.; Liang, Z. Optimizing regional cropping systems with a dynamic adaptation strategy for water sustainable agriculture in the Hebei Plain. *Agric. Syst.* **2019**, *173*, 94–106. [CrossRef]
32. Kropp, I.; Nejadhashemi, A.P.; Deb, K.; Abouali, M.; Roy, P.C.; Adhikari, U.; Hoogenboom, G. A multi-objective approach to water and nutrient efficiency for sustainable agricultural intensification. *Agric. Syst.* **2019**, *173*, 289–302. [CrossRef]

33. Hubei Provincial Bureau of Statistics and Hubei Investigation Team of National Bureau of Statistics of China. *Hubei Statistical Yearbook, 2004–2018*; China Statistic Press: Beijing, China, 2019.
34. Hubei Provincial People's Government. Overview of Hubei Province. Available online: http://www.hubei.gov.cn/jmct/hbgk/201810/t20181001_1594266.shtml (accessed on 30 January 2020).
35. Hubei Provincial Department of Water Resources. *Hubei Province Water Resources Bulletin, 2008–2018*; Hubei Science & Technology Press: Wuhan, China, 2019.
36. Wang, J.; Huang, Q.; Huang, J.; Rozelle, S. Chapter 3—China's Agricultural Water Policy Reforms: Increasing Investment, Resolving Conflicts, and Revising Incentives. In *Managing Water on China's Farms*; Wang, J., Huang, Q., Huang, J., Rozelle, S., Eds.; Academic Press: Cambridge, MA, USA, 2016; pp. 53–76, ISBN 978-0-12-805164-1.
37. Yang, W.; Li, L. Energy Efficiency, Ownership Structure, and Sustainable Development: Evidence from China. *Sustainability* **2017**, *9*, 912. [CrossRef]
38. Huang, C.; Huang, X.; Peng, C.; Zhou, Z.; Teng, M.; Wang, P. Land use/cover change in the Three Gorges Reservoir area, China: Reconciling the land use conflicts between development and protection. *CATENA* **2019**, *175*, 388–399. [CrossRef]
39. Xing, L.; Xue, M.; Hu, M. Dynamic simulation and assessment of the coupling coordination degree of the economy–resource–environment system: Case of Wuhan City in China. *J. Environ. Manag.* **2019**, *230*, 474–487. [CrossRef]
40. Zhou, H.; Huang, J.; Yuan, Y. Analysis of the Spatial Characteristics of the Water Usage Patterns Based on ESDA-GIS: An Example of Hubei Province, China. *Water Resour. Manag.* **2017**, *31*, 1503–1516. [CrossRef]
41. Yang, J.J.; Zhu, X. Adapting Urban Water Utilities to Climate Uncertainties: A Case Study of Wuhan, PRC. *Procedia Eng.* **2017**, *198*, 496–510. [CrossRef]
42. Liu, J. Relationship Between Water Pollution and Regional Economic Development: Empirical Evidence from Hubei, China. *Nat. Environ. Pollut. Technol.* **2019**, *18*, 599–603.
43. Zhu, L.; Li, X.; Bai, Y.; Yi, T.; Yao, L. Evaluation of Water Resources Carrying Capacity and Its Obstruction Factor Analysis: A Case Study of Hubei Province, China. *Water* **2019**, *11*, 2573. [CrossRef]
44. Wei, X.; Wang, J.; Wu, S.; Xin, X.; Wang, Z.; Liu, W. Comprehensive evaluation model for water environment carrying capacity based on VPOSRM framework: A case study in Wuhan, China. *Sustain. Cities Soc.* **2019**, *50*, 101640. [CrossRef]
45. Yang, Z.; Chu, T.; Han, L.; Liu, X.; Xiao, W.; Huang, G. Application of GC-TOPSIS on optimizing choice of utilization programs of crop straw. *Trans. Chin. Soc. Agric. Eng.* **2013**, *29*, 179–191.
46. Changwu, H. Application of the TOPSIS method and gray correlation model in the competitiveness evaluation of basketball teams. *Comput. Model. New Technol.* **2014**, *18*, 833–837.
47. Krohling, R.A.; Pacheco, A.G.C. A-TOPSIS—An Approach Based on TOPSIS for Ranking Evolutionary Algorithms. *Procedia Comput. Sci.* **2015**, *55*, 308–317. [CrossRef]
48. Zhou, S.; Liu, B.; Meng, J. Quality evaluation of raw moutan cortex using the AHP and gray correlation-TOPSIS method. *Pharmacogn. Mag.* **2017**, *13*, 528–533.
49. Yue, Z. Extension of TOPSIS to determine weight of decision maker for group decision making problems with uncertain information. *Expert Syst. Appl.* **2012**, *39*, 6343–6350. [CrossRef]
50. Song, W.; Ming, X.; Wu, Z.; Zhu, B. Failure modes and effects analysis using integrated weight-based fuzzy TOPSIS. *Int. J. Comput. Integr. Manuf.* **2013**, *26*, 1172–1186. [CrossRef]
51. Biswas, A.; Sarkar, B. Pythagorean fuzzy TOPSIS for multicriteria group decision-making with unknown weight information through entropy measure. *Int. J. Intell. Syst.* **2019**, *34*, 1108–1128. [CrossRef]
52. Yuan, G.; Yang, W. Evaluating China's Air Pollution Control Policy with Extended AQI Indicator System: Example of the Beijing-Tianjin-Hebei Region. *Sustainability* **2019**, *11*, 939. [CrossRef]
53. Kumar, P.; Masago, Y.; Mishra, B.K.; Jalilov, S.; Rafiei Emam, A.; Kefi, M.; Fukushi, K. Current Assessment and Future Outlook for Water Resources Considering Climate Change and a Population Burst: A Case Study of Ciliwung River, Jakarta City, Indonesia. *Water* **2017**, *9*, 410. [CrossRef]
54. Eustachio, J.H.P.P.; Caldana, A.C.F.; Liboni, L.B.; Martinelli, D.P. Systemic indicator of sustainable development: Proposal and application of a framework. *J. Clean. Prod.* **2019**, *241*, 118383. [CrossRef]
55. Yang, W.; Yuan, G.; Han, J. Is China's air pollution control policy effective? Evidence from Yangtze River Delta cities. *J. Clean. Prod.* **2019**, *220*, 110–133. [CrossRef]
56. Ghosh, B.; Chakma, N. Composite indicator of land, water and energy for measuring agricultural sustainability at micro level, Barddhaman District, West Bengal, India. *Ecol. Indic.* **2019**, *102*, 21–32. [CrossRef]
57. Van Oel, P.; Chukalla, A.; Vos, J.; Hellegers, P. Using indicators to inform the sustainable governance of water-for-food systems. *Curr. Opin. Environ. Sustain.* **2019**, *40*, 55–62. [CrossRef]
58. Yang, W.; Li, L. Efficiency evaluation of industrial waste gas control in China: A study based on data envelopment analysis (DEA) model. *J. Clean. Prod.* **2018**, *179*, 1–11. [CrossRef]
59. Chandrakumar, C.; McLaren, S.J. Towards a comprehensive absolute sustainability assessment method for effective Earth system governance: Defining key environmental indicators using an enhanced-DPSIR framework. *Ecol. Indic.* **2018**, *90*, 577–583. [CrossRef]
60. Yuan, G.; Yang, W. Study on optimization of economic dispatching of electric power system based on Hybrid Intelligent Algorithms (PSO and AFSA). *Energy* **2019**, *183*, 926–935. [CrossRef]

61. Wang, Q.; Ma, Z.; Ma, Q.; Liu, M.; Yuan, X.; Mu, R.; Zuo, J.; Zhang, J.; Wang, S. Comprehensive evaluation and optimization of agricultural system: An emergy approach. *Ecol. Indic.* **2019**, *107*, 105650. [CrossRef]
62. Shen, X.; Yang, W.; Sun, S. Analysis of the Impact of China's Hierarchical Medical System and Online Appointment Diagnosis System on the Sustainable Development of Public Health: A Case Study of Shanghai. *Sustainability* **2019**, *11*, 6564. [CrossRef]
63. Liu, H.; Liu, J.; Yang, W.; Chen, J.; Zhu, M. Analysis and Prediction of Land Use in Beijing-Tianjin-Hebei Region: A Study Based on the Improved Convolutional Neural Network Model. *Sustainability* **2020**, *12*, 3002. [CrossRef]
64. Tian, G.; Zhang, H.; Zhou, M.; Li, Z. AHP, Gray Correlation, and TOPSIS Combined Approach to Green Performance Evaluation of Design Alternatives. *IEEE Trans. Syst. Man, Cybern. Syst.* **2018**, *48*, 1093–1105. [CrossRef]
65. Liu, D.; Qi, X.; Fu, Q.; Li, M.; Zhu, W.; Zhang, L.; Faiz, M.A.; Khan, M.I.; Li, T.; Cui, S. A resilience evaluation method for a combined regional agricultural water and soil resource system based on Weighted Mahalanobis distance and a Gray-TOPSIS model. *J. Clean. Prod.* **2019**, *229*, 667–679. [CrossRef]
66. Gao, H.; Yang, W.; Yang, Y.; Yuan, G. Analysis of the Air Quality and the Effect of Governance Policies in China's Pearl River Delta, 2015–2018. *Atmosphere* **2019**, *10*, 412. [CrossRef]
67. Lu, L.; Yuan, Y. A novel TOPSIS evaluation scheme for cloud service trustworthiness combining objective and subjective aspects. *J. Syst. Softw.* **2018**, *143*, 71–86. [CrossRef]
68. Yang, Y.; Yang, W. Does Whistleblowing Work for Air Pollution Control in China? A Study Based on Three-party Evolutionary Game Model under Incomplete Information. *Sustainability* **2019**, *11*, 324. [CrossRef]
69. Yang, W.; Yang, Y. Research on Air Pollution Control in China: From the Perspective of Quadrilateral Evolutionary Games. *Sustainability* **2020**, *12*, 1756. [CrossRef]
70. Dong, H.; Feng, Z.; Yang, Y.; Li, P.; You, Z. Sustainability assessment of critical natural capital: A case study of water resources in Qinghai Province, China. *J. Clean. Prod.* **2021**, *286*, 125532. [CrossRef]
71. Pan, W.T.; Zhuang, M.E.; Zhou, Y.Y.; Yang, J.J. Research on sustainable development and efficiency of China's E-Agriculture based on a data envelopment analysis-Malmquist model. *Technol. Forecast. Soc. Chang.* **2021**, *162*, 120298. [CrossRef]
72. Hubei Provincial People's Government. Shennongjia Has Completed the Balance Sheet of Natural Resources. Available online: http://www.hubei.gov.cn/hbfb/szsm/201609/t20160925_1545161.shtml (accessed on 30 January 2020).
73. Barkallah, M.; Dammak, M.; Louati, I.; Hentati, F.; Hadrich, B.; Mechichi, T.; Ayadi, M.A.; Fendri, I.; Attia, H.; Abdelkafi, S. Effect of Spirulina platensis fortification on physicochemical, textural, antioxidant and sensory properties of yogurt during fermentation and storage. *LWT* **2017**, *84*, 323–330. [CrossRef]
74. Saeidi, P.; Nourbakhsh, Z. The investigation of topological phase of Gd1−xYxAuPb (x = 0, 0.25, 0.5, 0.75, 1) alloys under hydrostatic pressure. *J. Magn. Magn. Mater.* **2018**, *451*, 681–687. [CrossRef]
75. Gran, S.S.; Ajol, T.A.; Ali, A.N.A. Utilization of Fuzzy Logic approach for evaluating student's performance: A case study at secondary school. In Proceedings of the 14th International Conference on Language, Education, Humanities and Innovation, Kuala Lumpur, Malaysia, 18–19 January 2020; Volume 2, pp. 34–44.
76. Hubei Provincial People's Government. Shennongjia Inspects and Rectifies Small Hydropower Construction Projects. Available online: http://www.hubei.gov.cn/hbfb/szsm/201108/t20110818_1534841.shtml (accessed on 30 January 2020).
77. Jingmen Municipal People's Government. Measures for the Management of Underground Water Resources of Jingmen City. Available online: http://www.jingmen.gov.cn/art/2008/12/20/art_6606_3806.html (accessed on 30 January 2020).
78. Standing Committee of the National People's Congress of the People's Republic of China. *Water Law of the People's Republic of China*; China Legal Publishing House: Beijing, China, 2002.
79. State Council of People's Republic of China. Regulations on Water Permits and the Collection of Water Resources Fees. Available online: http://www.gov.cn/gongbao/content/2017/content_5219162.htm (accessed on 30 January 2020).
80. Standing Committee of the People's Congress of Hubei Province. Hubei Province's Measures for Implementing the Water Law of the People's Republic of China. Available online: http://www.hubeiwater.gov.cn/policy/dfxfg/200801/t20080117_642.shtml (accessed on 30 January 2020).
81. Jingmen Municipal People's Government. 2017 Government Work Report of Jingmen City. Available online: http://www.jingmen.gov.cn/art/2017/1/26/art_469_135035.html (accessed on 30 January 2020).
82. Wuhan Municipal People's Congress. Water Resources Protection Regulations in Wuhan. Available online: http://www.whrd.gov.cn/html/lfgz/dfxfg/2019/0814/16296.shtml (accessed on 30 January 2020).
83. Hubei Provincial People's Government. Wuhan Released its Annual Water Resource Bulletin of 2017. Available online: http://www.hubei.gov.cn/hbfb/szsm/201803/t20180328_1547564.shtml (accessed on 30 January 2020).
84. Huanggang Municipal People's Government. Notice of the Office of the Municipal Government on Printing and Distributing the Work Plan for Examining the Most Strict Water Resources Management System in Huanggang City. Available online: http://www.hg.gov.cn/xxgk/jcms_files/jcms1/web1/site/view/art/2015/11/16/art_5783_35850.html (accessed on 30 January 2020).
85. Statistics Bureau of Huanggang City. Huanggang Statistical Yearbook. 2015. Available online: http://tjj.hubei.gov.cn/tjsj/sjkscx/tjnj/gsztj/hgs/201911/P020191104696257428846.pdf (accessed on 30 January 2020).
86. People's Government of Huangshi City. 2018 Water Pollution Prevention Action Plan of Huangshi City. Available online: http://www.huangshi.gov.cn/xxxgk/ghjh/201807/t20180723_324829.html (accessed on 30 January 2020).

87. Ministry of Finance of the People's Republic of China. Asian Development Bank Approves Comprehensive Water Pollution Treatment Project in Huangshi, Hubei Province. Available online: http://www.mof.gov.cn/mofhome/guojisi/pindaoliebiao/xmdt/xmdt/201211/t20121121_700867.html (accessed on 30 January 2020).
88. Huangshi Environmental Protection Bureau. Special Report on Prevention and Control of Water Pollution in Cihu Lake, Huangshi City. Available online: http://sthjt.hubei.gov.cn/hjsj/ztzl/wrfzgjz/szxd/201809/t20180921_591950.shtml (accessed on 30 January 2020).
89. The Department of Economic and Social Affairs of the United Nations. Indicators of Sustainable Development: Guidelines and Methodologies. Available online: https://www.un.org/esa/sustdev/natlinfo/indicators/guidelines.pdf (accessed on 1 March 2021).
90. The Development Data and Outreach Branch of United Nations Statistics Division. Final List of Proposed Sustainable Development Goal Indicators. Available online: https://sustainabledevelopment.un.org/content/documents/11803Official-List-of-Proposed-SDG-Indicators.pdf (accessed on 1 March 2021).
91. Stanitsas, M.; Kirytopoulos, K.; Leopoulos, V. Integrating sustainability indicators into project management: The case of construction industry. *J. Clean. Prod.* **2021**, *279*, 123774. [CrossRef]
92. Liao, Y.; Ma, Y.; Chen, J.; Liu, R. Evaluation of the Level of Sustainable Development of Provinces in China from 2012 to 2018: A Study Based on the Improved Entropy Coefficient-TOPSIS Method. *Sustainability* **2020**, *12*, 2712. [CrossRef]
93. Lizana, J.; Manteigas, V.; Chacartegui, R.; Lage, J.; Becerra, J.A.; Blondeau, P.; Rato, R.; Silva, F.; Gamarra, A.R.; Herrera, I.; et al. A methodology to empower citizens towards a low-carbon economy. The potential of schools and sustainability indicators. *J. Environ. Manag.* **2021**, *284*, 112043. [CrossRef] [PubMed]
94. Liu, Y.; Wang, R.; Guo, T.; Engel, B.A.; Flanagan, D.C.; Lee, J.G.; Li, S.; Pijanowski, B.C.; Collingsworth, P.D.; Wallace, C.W. Evaluating efficiencies and cost-effectiveness of best management practices in improving agricultural water quality using integrated SWAT and cost evaluation tool. *J. Hydrol.* **2019**, *577*, 123965. [CrossRef]
95. Fu, W.; Fan, J.; Hao, M.; Hu, J.; Wang, H. Evaluating the effects of plastic film mulching patterns on cultivation of winter wheat in a dryland cropping system on the Loess Plateau, China. *Agric. Water Manag.* **2021**, *244*, 106550. [CrossRef]
96. Xu, J.; Cai, H.; Saddique, Q.; Wang, X.; Li, L.; Ma, C.; Lu, Y. Evaluation and optimization of border irrigation in different irrigation seasons based on temporal variation of infiltration and roughness. *Agric. Water Manag.* **2019**, *214*, 64–77. [CrossRef]
97. Wu, H.X.; Zhang, Y.; Wang, L.; Chen, D.; Ma, C. Effect of infiltration head on soil water movement of small-diameter tube outflow furrow irrigation under mulch film. *World J. Eng.* **2019**, *16*, 232–237. [CrossRef]
98. Yang, Y.; Yang, W.; Chen, H.; Li, Y. China's energy whistleblowing and energy supervision policy: An evolutionary game perspective. *Energy* **2020**, *213*, 118774. [CrossRef]