sustainability

MDPI

Article

Receiving Robust Analysis of Spatial and Temporary Variation of Agricultural Water Use Efficiency While Considering Environmental Factors: On the Evaluation of Data Envelopment Analysis Technique

Hongguang Dong, Jie Geng * and Yue Xu

School of Economics and Management, Anhui University of Science and Technology, Huainan 232001, China
* Correspondence: gejie046@163.com

Abstract: With accelerated urbanisation, continued growth in water demand and the external pressure of water demand from the South–North Water Transfer Project, agricultural water use in Jiangsu is facing a critical situation. Therefore, it is important to explore the spatial and temporal variation in agricultural water use efficiency in order to clarify the pathway for improving agricultural water use efficiency. Firstly, the Super-Slacks-Based Measure (SBM) model was utilized to measure agricultural water use efficiency in Jiangsu Province, China, from 2011 to 2020, and secondly, a fixed-effects model was used to investigate agricultural water use efficiency and the factors influencing it in 13 prefectures in Jiangsu Province in both time and space. The results show that (1) the overall value of agricultural water use efficiency in Jiangsu Province is below 1, which means that agricultural water use efficiency in Jiangsu Province is low and far from the effective boundary, and there is more room for improvement in agricultural water use efficiency; (2) a total of 92% of prefectures in Jiangsu Province have input redundancy, which seriously inhibits the progress of agricultural water use efficiency in Jiangsu Province, among which the redundancy of total agricultural machinery power and agricultural water use is the highest; (3) Regarding total factor productivity and its decomposition index for agricultural use in Jiangsu Province, in the time dimension, the number of professional and technical personnel inputs has a positive impact on agricultural water use efficiency. In the spatial dimension, the number of professional and technical personnel inputs, industrial structure and arable land area have a positive impact on improving regional agricultural water use efficiency, among which the industrial structure has a smaller contribution to agricultural water use efficiency.

Keywords: Jiangsu Province; prefecture-level cities; agricultural water use; efficiency evaluation; Super-Slacks-Based Measure model; Malmquist index; computational modelling; influence factor analysis

Citation: Dong, H.; Geng, J.; Xu, Y. Receiving Robust Analysis of Spatial and Temporary Variation of Agricultural Water Use Efficiency While Considering Environmental Factors: On the Evaluation of Data Envelopment Analysis Technique. *Sustainability* **2023**, *15*, 3926. https://doi.org/10.3390/su15053926

Academic Editors: Francesco Granata and Mohammad Najafzadeh

Received: 12 November 2022
Revised: 30 December 2022
Accepted: 31 January 2023
Published: 21 February 2023

1. Introduction

The total volume of water resources in Jiangsu in 2019 was only 23.17 billion m^3, and the province's water supply amounted to 49.34 billion m^3, with water supply far exceeding the total water resources. Among them, agricultural water consumption accounted for 61.4% of the total water consumption, and the average water consumption of farmland irrigation mu reached 474.7 m^3, exceeding the national water consumption of farmland irrigation mu by 106 m^3. In addition, Jiangsu, as the source of the South–North Water Diversion Project, has transferred a total of over 4.5 billion cubic metres of water outside the province. It has been used to moisten Suzhou and Lu and to help North China, effectively alleviating the water shortage in Shandong and other places, especially the Jiaodong Peninsula. As can be seen from the above, Jiangsu Province has to face the serious problem of water shortage and waste in the province while mobilising a large amount of water resources for the north. In this context, Jiangsu Province should take water resources as the biggest rigid constraint and improve agricultural water efficiency across the board.

There is a wealth of academic research on agricultural water use efficiency and the existing literature on agricultural water use efficiency focuses on three main areas: efficiency measurement, identification of influencing factors and spatial variation. There are three main approaches to measuring agricultural water use efficiency: single factor efficiency assessment and full factor efficiency assessment, which is more realistic in that full factor efficiency considers not only water-resource-related variables but also inputs from other factors. The most common method used to evaluate full factor efficiency is Data Envelopment Analysis (DEA). Shang et al. used the Super-Slacks-Based Measure (SBM) model and the Malmquist index decomposition method to analyse panel data from 2009 to 2018 for major grain producing regions in China to analyse the impact of technological progress on agricultural water use efficiency [1]; Azad et al. [2] proposed measuring agricultural water use efficiency from an environmental perspective with the help of the Luenberger model for 17 of the Murray–Darling Basin in Australia Azad et al. [2]. The model is a guide to developing regional policies and strategies to achieve sustainable water use in the agricultural sector based on efficiency values. Lu Weinan et al. [3] measured and analysed agricultural water use efficiency in the Yellow River Basin and found a gradual upward trend in agricultural efficiency over the period examined. With the development of efficiency assessment models, models such as SBM Unsighed [4] and Super SBM Unsighed [5] have been developed. To deepen the study of water resource use efficiency, exploratory spatial data analysis [6–8], the Gini coefficient [9,10] and Thiel's index [11–14] were used, such as Wang Chun et al. [15], who combined spatial autocorrelation analysis with the Super SBM model to analyse the agricultural water resource use rate of provinces, cities and autonomous regions in China. Ying Han et al. [16] and others used the ESDA method to explore the agricultural water use efficiency of 218 prefecture-level cities in China from 2003 to 2018. Yu Liu et al. [17] analysed the spatial differences in agricultural water use efficiency of 52 cities in northwest China from 2000 to 2018 and explored the factors affecting agricultural water use efficiency with the help of a spatial econometric model. This paper examines the changing trends of agricultural water use efficiency in Jiangsu Province from the spatial and temporal dimensions. Based on the complexity of the factors influencing agricultural water use efficiency and regional location differences, we selected suitable regression models to find the influencing factors of water use efficiency and to determine the correlation and degree of influence between the influencing factors and agricultural water use efficiency. Common regression models include the Tobit model [18–20], the spatial Durbin model [21–23] and the spatial autocorrelation regression model [24,25].

Jiangsu has more than 1000 km of coastline, and the ocean has a significant impact on the climate of Jiangsu. See Figure 1 for the details of the administrative region map of Jiangsu.Under the comprehensive influence of solar radiation, atmospheric circulation and specific geographical location and geomorphic characteristics of Jiangsu, the basic climatic characteristics of Jiangsu are mild climate, four distinct seasons, significant monsoon, cold winter and hot summer, variable spring temperature, and bright and hot autumn. The annual average temperature in Jiangsu is between 13.6 °C and 16.1 °C, and the distribution is decreasing from south to north. The highest annual average temperature appears at Dongshan Mountain in the south, and the lowest annual average temperature appears in Ganyu in the north. The average temperature in winter is 3.0 °C. The extreme minimum temperature in various regions usually occurs in January or February in winter, the average temperature in summer is 25.9 °C, the extreme maximum temperature in various regions usually occurs in July or August in midsummer, and the average temperature in spring is 14.9 °C. The average temperature in autumn is 16.4 °C, and the climate in spring and autumn is relatively mild. The unique natural conditions make Jiangsu suitable for the development of aquaculture and rice planting, so it is called a land of fish and rice.

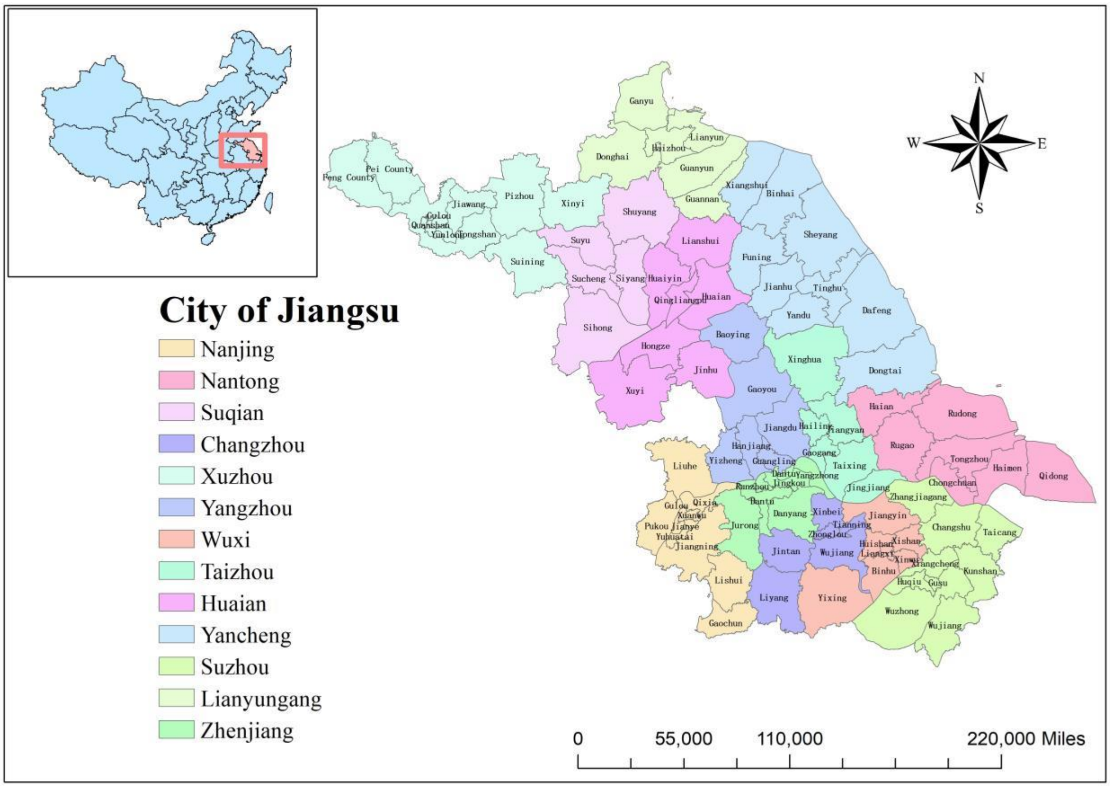

Figure 1. Division of County and City Administrative Regions in Jiangsu Province.

Due to the deep-rooted perception of Jiangsu as the "land of fish and rice", a large amount of existing literature focuses on agricultural water use efficiency in water-scarce regions such as the arid regions of central China and northwest China, while less research has been conducted on agricultural water use efficiency in Jiangsu Province, and even less on agricultural water use efficiency in Jiangsu cities. It is also clear from the above analysis that agricultural water use is the largest indicator of water use expenditure in Jiangsu Province, given the huge external pressures of the South–North Water Transfer and the huge water demand in the province. There is a need to quantify the efficiency of agricultural water use in Jiangsu Province, to analyse the spatial differences in agricultural water use efficiency between municipalities in Jiangsu Province, and to answer questions such as these. Based on this, this paper first uses the super-efficient SBM model to measure the agricultural water use efficiency in Jiangsu Province from 2011 to 2020. The fixed-effects model is then used to empirically analyse the factors influencing agricultural water use efficiency in Jiangsu, with the aim of contributing to the research on agricultural water use efficiency in Jiangsu. Through the use of mathematical modelling, the agricultural water use efficiency of Jiangsu Province is presented in a digital way, so that the general public can more intuitively understand the current water shortage problem facing Jiangsu Province. According to the results of mathematical modelling, targeted research on important statistics encountered in future water conservancy work can further save water resources, and the mathematical model can be combined with actual work. In the future, the problems encountered in the actual work can be considered in future mathematical modelling, and it is expected to make a more practical mathematical model.

2. Research Methodology and Data Sources

2.1. Agricultural Water Efficiency

2.1.1. Super-SBM Model

Data envelopment analysis (DEA) is an efficiency evaluation method proposed by Charnes [26], a leading American operations researcher, and others. It does not require prior determination of indicators to construct functional relationships, avoids the influence of subjective factors on model construction, and can distinguish the efficiency of effective and ineffective decision units. However, the classical DEA model cannot solve how to continue to make an evaluation when the efficiency values of multiple decision units are simultaneous. Therefore, Charnes and Andersen et al. [27,28] proposed super-efficiency DEA to overcome this shortcoming. In 2001, the Super-SBM model was developed by combining the Super-Efficiency DEA model with the SBM model in order to solve the problem of input-output variable looseness in the traditional DEA model and to compare multiple relatively efficient DMUs horizontally. The modified model solves the problem of invalid efficiency ranking while correcting for invalid DMU slackness variables.

Previous studies have focused on a particular economic system, such as enterprises and banks, and have mainly been used for efficiency analysis of banks and service industries. This paper creatively uses this model to measure agricultural water use efficiency, applying research methods from the financial and service sectors of the economy to agriculture. It enriches the scale and content of the evaluation methodology. Based on existing research results, agricultural water use, agricultural employment, agricultural fertilizer use and total agricultural machinery power are selected as input indicators and agricultural value added as an output indicator. The efficiency values were measured according to MAX DEA 6.0 and visualised with the help of Arc GIS 10.2. The Super SBM model is shown below.

$$\min \rho_{SE} = \frac{1 + \frac{1}{m}\sum_{i=1}^{m} S_i^- / x_{ik}}{1 - \frac{1}{S}\sum_{r=1}^{s} S_r^+ / y_{rk}}$$

$s.t.$

$$\sum_{j=1, j \neq k}^{n} x_{ij}\gamma_i - S_i^- \leq x_{ik}$$

$$\sum_{j=1, j \neq k}^{n} x_{rj}\gamma_j + S_r^+ \geq y_{rk}$$

$$\gamma, S^-, S^+ \geq 0$$

$$i = 1, 2, \ldots, q;\ j = 1, 2, \ldots, n (j \neq k) \tag{1}$$

In Equation (1), ρ_{SE} is agricultural water use efficiency; x and y are input and output factors, respectively; m and s denote the number of input and output indicators; k denotes the production period; i and r represent the DMU of input and output decision units, respectively; S^+ and S^- represent the slack variables of input and output, respectively; ν is the weight vector. When $\rho_{SE} \geq 1$, it indicates that the decision-making unit is relatively effective and in the state of effective production frontier; when $\rho_{SE} < 1$, it indicates that the decision unit is relatively inefficient and efficiency loss occurs.

2.1.2. Malmquist Index

In 1953, Swedish mathematician Sten Malmquist proposed the M-index analysis for consumption analysis. The year 1978 saw Chanmes' first combination of a DEA model with the Malmquist index, which is suitable for analysis of samples applicable to multiple regions across time. It is widely used in efficiency measurement and evaluation. Therefore, Equation (2) expresses the index of change in agricultural water use efficiency in this this study:

$$TIEC_t^{t+1} = M_t^{t+1} = \left[\frac{D^t(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)} \times \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^{t+1}(x^t, y^t)} \right]^{\frac{1}{2}} \tag{2}$$

The agricultural water efficiency change index can be further decomposed into an index of technical efficiency change (EFFCH) and an index of technological progress (TECHCH), from which the relationship between efficiency changes can be seen as follows:

$$TIEC_t^{t+1} = M_t^{t+1} = \underbrace{\frac{D^t\left(x^{t+1}, y^{t+1}\right)}{D^t\left(x^t, y^t\right)}}_{EFFCH} \times \underbrace{\left[\frac{D^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D^t\left(x^t, y^t\right)} \times \frac{D^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D^{t+1}\left(x^t, y^t\right)}\right]^{\frac{1}{2}}}_{TECH} \quad (3)$$

In Equation (3), M is total factor productivity, expressed as TFPCH; x and y are input-output indicator vectors; D is the input-output distance function; TECHCH is technological progress change; EFFCH is technical efficiency change; PECH is pure technical efficiency change; and SECH is scale efficiency change.

When $M > 1$, agricultural water use efficiency tends to increase with time; when $M = 1$, agricultural water use efficiency does not change with time; and when $M < 1$, agricultural water use efficiency decreases.

2.2. Technical Roadmap

According to the above research methods, the research idea of this paper is shown in Figure 2.

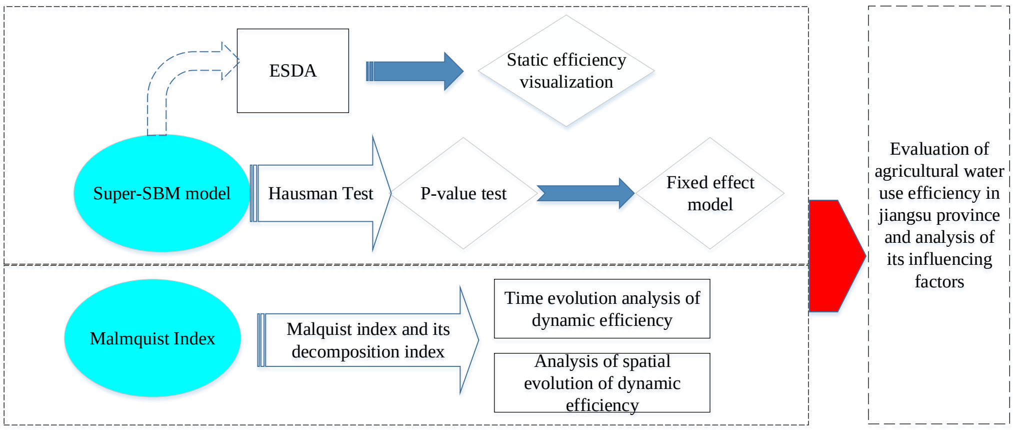

Figure 2. Technical roadmap.

2.3. Selection of Indicators and Data Sources

2.3.1. Data Sources

In order to study the level of agricultural water use efficiency in Jiangsu Province and to collect relevant research data, the relevant data in this paper were mainly obtained from the Water Resources Bulletin of Jiangsu municipalities from 2011 to 2020, the Jiangsu Provincial Statistical Yearbook and the China Urban Statistical Yearbook. Descriptive statistics for each statistical indicator are shown in Table 1.

According to the terms in the statistical yearbook and the specific meanings of each indicator in this paper, the specific meanings of the input-output variables in Table 1 are as follows:

Agricultural water consumption: agricultural water consumption is mainly used for agricultural irrigation, forestry, animal husbandry, fishery and related auxiliary activities, among which agricultural irrigation water consumption accounts for a large proportion, accounting for more than 90% of agricultural water consumption.

Number of employees in agricultural industry: people over the age of 16 who actually participate in production and business activities and receive income in kind or in currency from the rural population.

Agricultural fertilizer consumption: Refers to the amount of chemical fertilizer actually used for agricultural production in this year, including nitrogen fertilizer, phosphorus fertilizer, potassium fertilizer and compound fertilizer. The application amount shall be calculated based on the converted amount, that is, the actual application amount of various chemical fertilizers shall be based on their nitrogen content. The proportion containing phosphorus pentoxide and potassium oxide shall be converted into 100%.

Table 1. Description statistics of agricultural water input and output in Jiangsu Province.

Target Level	Level 1 Indicators	Unit	Min	Max	Average	Standard Deviation
Input indica-tors	Water use in agriculture (Input 1)	Billion cubic meters	6.84	45.4060	15.179570	10.69
	Number of people working in agriculture (Input 2)	10,000 persons	99.1	358.55	200.61	77.01
	Fertiliser usage in agriculture (Input 3)	Refined tonne	45,047	777,308	245,399.38	188,647.31
	Gross power of agricultural machinery (Input 4)	Kilowatts	952,381	7,651,900	364,4802.1	2,116,285
Output indicators	Value added in agriculture (Output 1)	billion	100.770	718.6800	281.0248	137.44
	Nitrogen and phosphorus losses (Output 2)	ton	29,280.55	505,250.2	159,509.59	122,620.75

Total power of agricultural machinery: Refers to the total power mainly used for agriculture, forestry, animal husbandry and fishery, including farming machinery, agricultural irrigation and drainage machinery, harvesting machinery, plant protection machinery, forestry machinery, animal husbandry machinery, fishery machinery, agricultural product processing machinery, agricultural transport machinery, etc. The mechanical power of village and household industries engaged in primary processing of agricultural and sideline products should also be included.

Agricultural added value: Agricultural added value equals to the output of the agricultural sector minus the input of intermediate products. Agriculture includes added value from forestry, hunting, fishery, crop cultivation and livestock production. That is, the balance of the current gross output value of agriculture, forestry, animal husbandry and fishery after deducting the current intermediate input of agriculture, forestry, animal husbandry and fishery.

Loss of nitrogen and phosphorus: The use of agricultural fertilizer will lead to non-point source pollution. The loss of nitrogen and phosphorus used in this paper is calculated through the use of agricultural fertilizer and conversion coefficient.

2.3.2. Evaluation Indicator System Construction

In order to make Jiangsu's agricultural water efficiency evaluation index system more reasonable, the principles considered to develop the DEA technique are expressed as (*i*) systematic, each indicator has a certain degree of relevance to each other and can reflect the characteristics of the research subject from different perspectives; (*ii*) clarity, the indicators should be chosen with clear concepts and definitions, so that data can be collected easily and the indicators should not be overly detailed or redundant; (*iii*) quantifiable, the indicators should be selected in such a way that they can be calculated and measured in a consistent way for the purpose of evaluation and countermeasure provision; (*iv*) scientific, the selection of indicators for each dimension should reflect the scientific nature, be representative and reflect the characteristics of the research area, and the quantification of indicators must be based on scientific criteria.

In reference to relevant scholars' research [1–7], it is found that the study of water resource efficiency issues are mostly from two perspectives: input and output to build an evaluation index system. From the input perspective, indicators are mostly constructed from equipment, labour and resources, while from the output perspective, indicators are selected from the economic and social dimensions to represent desired outputs, and in addition to economic and social outputs, there are also negative outputs that are not required by people, called non-desired outputs. The final construction of the Jiangsu agricultural water use efficiency indicator system. The specific Jiangsu agricultural water use efficiency indicator system is shown in Figure 3.

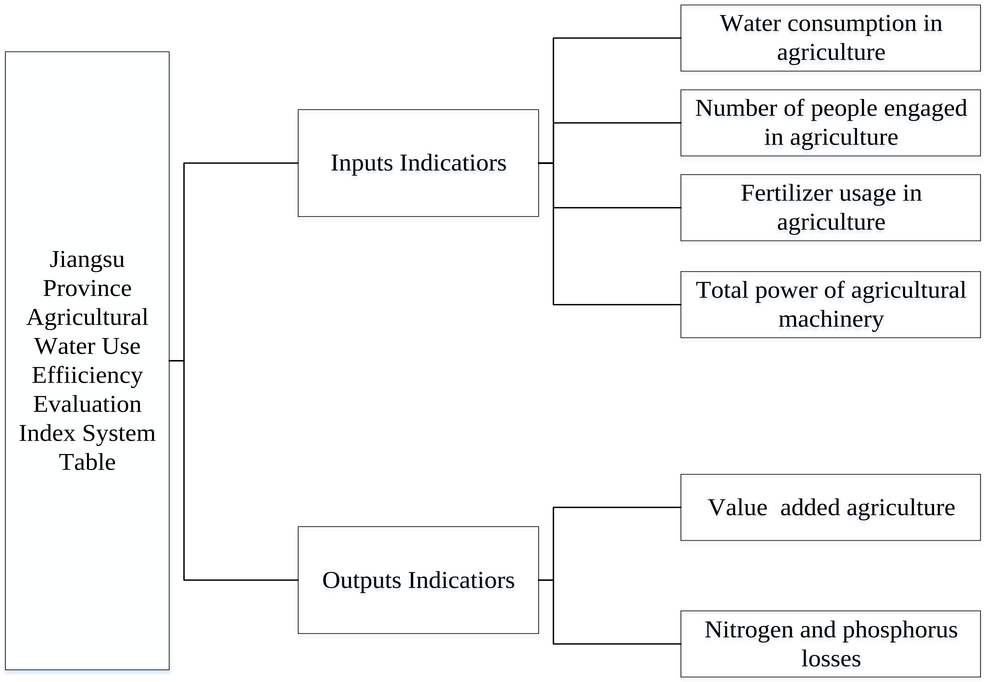

Figure 3. Jiangsu Province agricultural water use efficiency evaluation index system.

The specific indicators from the input perspective are as follows: (*i*) Due to the variety and complexity of agricultural equipment, the total power of agricultural machinery is used to characterise the equipment inputs, which allows for a greater degree of statistical uniformity in the number of agricultural machines. (*ii*) Labour inputs are characterised by the number of people employed in agriculture in each municipality in Jiangsu Province. (*iii*) Resource inputs are characterised by the amount of water used in agriculture and the amount of fertilizer used. Agricultural water consumption refers to the amount of water used in the agricultural production process. Fertiliser, as one of the important resources in the agricultural production process, is therefore used as one of the important input indicators in this paper.

As agriculture causes less environmental pressure, water use efficiency evaluation indicators are generally selected from the economic dimension only. In this paper, however, the evaluation of agricultural water use efficiency adds the environmental dimension, which together with the economic and environmental dimensions constitute the desired output layer and the non-desired output layer. The desired output indicators and non-desired output indicators are agricultural value added and nitrogen and phosphorus losses, respectively. Value added in agriculture is used to characterise the economic benefits generated by the water use of crops, while nitrogen and phosphorus losses are used to characterise the environmental pollution caused by the loss of nitrogen and phosphorus from fertilizers after the crops have been irrigated with water, so they are called undesired outputs.

2.4. Factors Influencing Agricultural Water Efficiency

This paper explores the factors affecting agricultural water use efficiency in Jiangsu Province from the following six aspects: (*i*) Natural resources: annual precipitation (N) indicates that appropriate and sufficient rainfall plays an important role in irrigating agricultural land, and that low costs and easy access affect water use efficiency. (*ii*) Economic development: expressed in terms of GDP per capita (G). However, the accumulation of capital will, to a certain extent, enhance the protection of resources and the environment, thus improving agricultural water use efficiency. (*iii*) Industrial structure: expressed by the proportion of output value of the secondary and tertiary industries (P), which is relatively low, optimising the industrial structure will reduce the amount of water wasted in agriculture. (*iv*) Technical personnel: expressed by the number of agricultural professionals and technicians (T). Excellent technical personnel can optimise agricultural production processes and promote the secondary recycling of water resources, thereby improving agricultural water use efficiency. (*v*) Water use status: crop cultivation area (S) and crop sowing area can reflect the degree of water consumption, more consumption indicates a high demand for water resources, affecting agricultural water efficiency. (*vi*) Resource endowment: The amount of water per capita (W) indicates the adequacy of the amount of water available per capita in the local area. To a certain extent, the final regression results can be used to analyse whether local residents need to be more aware of water conservation.

There were no significant time-lagged effects between the explanatory variables and no definite correlation between the municipalities. Hence, for T = 10 and N = 13, a short panel model was used for regression with the explanatory variables taken as natural logarithms to remove the effect of magnitude to model agricultural water use efficiency and its influences.

$$ln\eta_{ij} = a_0 + a_1 lnN_{ij} + a_2 lnG_{ij} + a_3 lnP_{ij} + a_4 lnT_{ij} + a_5 lnS_{ij} + a_6 lnW_{ij} + \xi_{ij} \quad (4)$$

In Equation (4) [8], η_{ij} is agricultural water use efficiency; I = 2011, 2012, ... , 2020; j = 1, 2, ... , 13; a_0 is the intercept term; a_1, ... , a_6 are the regression coefficients of the variables; and ξ_{ij} is the random disturbance term.

3. Analysis of Agricultural Water Use Efficiency in Jiangsu Province

3.1. Static Analysis of Agricultural Water Use Efficiency

This study uses MAX DEA 6.0 software as the measurement tool and the Super-SBM model to measure the agricultural water use efficiency of each municipality in Jiangsu Province from 2011 to 2020, with the specific efficiency values shown in Figure 4 and Table 2.

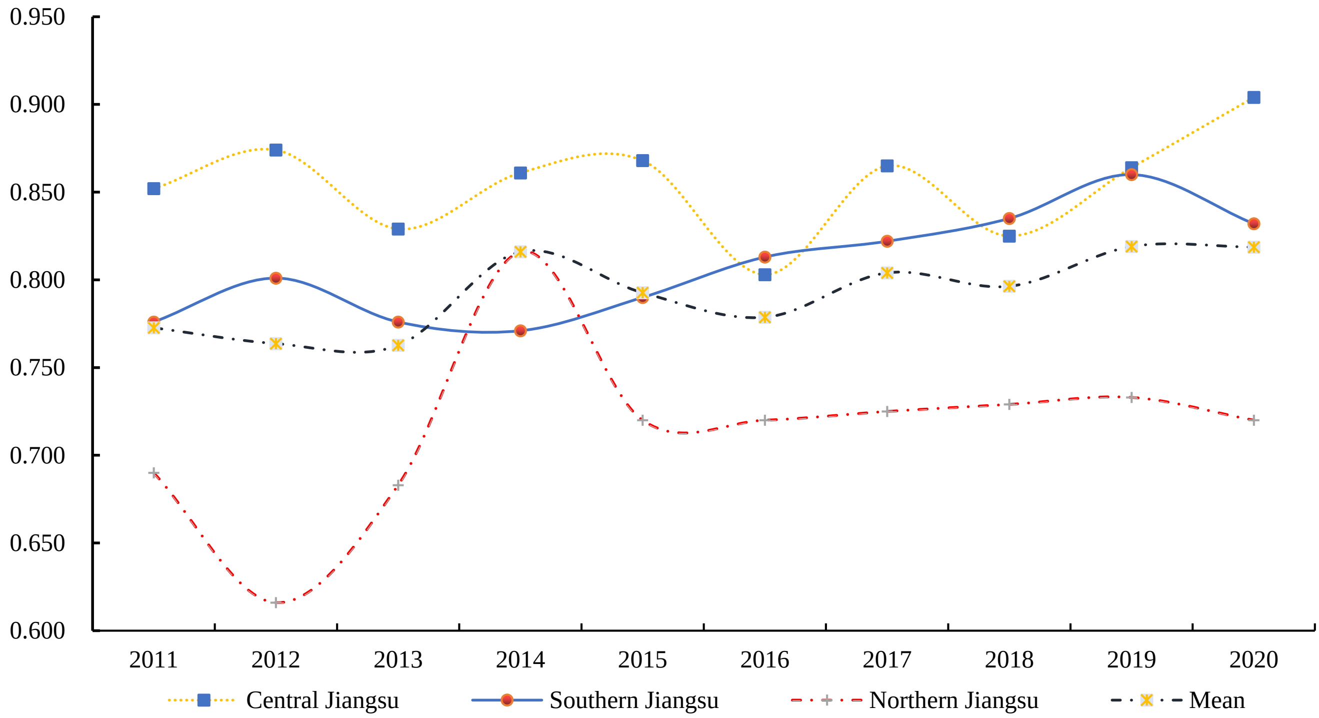

Figure 4. Trends in agricultural water use efficiency in three major regions of Jiangsu Province.

Table 2. Agricultural water use efficiency by city in Jiangsu Province, 2011–2020.

	2011	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**Mean**
Nanjing	0.794	0.797	0.798	0.783	0.916	0.968	1.012	1.086	1.234	1.241	0.963
Wuxi	0.830	0.824	0.901	0.875	0.827	0.836	0.833	0.862	0.912	0.925	0.863
Xuzhou	0.392	0.701	0.515	0.747	0.782	0.844	0.882	0.943	0.913	0.880	0.760
Changzhou	0.557	0.700	0.607	0.702	0.707	0.770	0.791	0.767	0.703	0.544	0.685
Suzhou	0.855	0.820	0.829	0.753	0.760	0.746	0.736	0.727	0.720	0.716	0.766
Nantong	1.114	0.880	1.153	1.248	1.107	1.063	1.074	1.020	0.997	1.042	1.070
Lianyungang	0.713	0.407	0.726	0.737	0.721	0.720	0.719	0.724	0.736	0.747	0.695
Huai'an	0.709	0.372	0.713	0.713	0.742	0.739	0.743	0.756	0.745	0.724	0.696
Yancheng	1.031	0.989	0.935	1.333	0.827	0.788	0.745	0.717	0.716	0.719	0.880
Yangzhou	0.766	0.872	0.603	0.572	0.712	0.599	0.710	0.604	0.711	0.726	0.688
Zhenjiang	0.845	0.862	0.743	0.743	0.739	0.747	0.738	0.735	0.730	0.733	0.762
Taizhou	0.677	0.870	0.730	0.762	0.784	0.747	0.811	0.852	0.885	0.943	0.806
Suqian	0.603	0.609	0.528	0.550	0.529	0.509	0.534	0.505	0.500	0.528	0.540
Mean	0.760	0.746	0.752	0.886	0.781	0.775	0.795	0.792	0.808	0.805	0.782

Overall, the efficiency of agricultural water use in Jiangsu Province from 2011 to 2020 is less than 1, indicating that agricultural water use in Jiangsu Province is inefficient and there is still more room for improvement from the effective frontier. The efficiency level of each city is gradually improving, but, by 2020, the efficiency of agricultural water use in Jiangsu Province will be effective in only two cities, Nanjing and Nantong, indicating that the efficiency of agricultural water use in other cities in Jiangsu Province is low. By region, agricultural water use efficiency in central and southern Jiangsu is generally higher than the provincial average, except for 2014, when it was lower than the provincial average; in northern Jiangsu, there is still more room for improvement than the provincial average. Except for Yancheng, which was in relatively good shape during the study period, Suqian's overall efficiency was below 0.6; Huai'an and Lianyungang's overall efficiency was below 0.7; and Xuzhou's agricultural water use efficiency was slightly above 0.7. In southern Jiangsu, the overall efficiency of agricultural water use in the region is slowly increasing year by year, with Changzhou and Suzhou experiencing large fluctuations in agricultural water use efficiency, resulting in a decline in the region's agricultural water use efficiency in 2020. This is mainly due to the increased use of agricultural fertilizers in Nantong in 2012 and the decrease in agricultural value added in the same year. The agricultural water use efficiency in central Jiangsu started at a high level of 0.852 during the study period and has since shown a "W"-shaped trend, fluctuating more frequently, with agricultural water use fluctuating from high to low and a certain amount of wasteful agricultural water use, but it has always been at the highest level of agricultural water use efficiency in the province. As other cities in Jiangsu Province are unable to improve their agricultural water use efficiency with the help of the radiation of Nanjing and Nantong, the agricultural water use efficiency in Jiangsu Province is only 0.782.

3.2. Analysis of Spatial Variation in Agricultural Water Use

Visual representation of agricultural water use efficiency in Anhui Province for the years 2011, 2014, 2017 and 2020 was carried out using ArcGIS 10.2 software (Figure 5). The efficiency measured based on the Super-SBM model is greater than or equal to 1, and this category of efficiency is divided into one category, called the super-efficient state; the efficiency between 0 and 1 is divided into four categories by the equal division method, from high to low, called the high-efficiency, medium-efficiency, medium-efficiency and low-efficiency states, respectively, see Figure 2 for details. In 2011 and 2014, Yancheng and Nantong were the most efficient cities in terms of agricultural water use efficiency, and, in 2017 and 2020, Nantong and Nanjing were the most efficient cities. Nanjing maintained its high-efficiency status for agricultural water use during the period under review, while Nantong maintained an over-efficient status. In terms of sub-regions, the agricultural water use efficiency in southern Jiangsu continued to rise, with the phenomenon of water use efficiency regressing. The water use efficiency in the central Su region fluctuates most frequently, showing a "rising-declining-rising" trend, eventually showing an increasing trend in 2020. The agricultural water use efficiency in Jiangsu Province from 2011 to 2020 is only 0.782, and the number of cities with high and medium efficiency levels of agricultural water use has not changed significantly. It is clear from the above that there has been no significant improvement in agricultural water use efficiency in Jiangsu Province in recent years, and the results have been minimal. Therefore, the People's Government of Jiangsu Province issued the *14th Five-Year Plan for the Construction of a Water-Saving Society* to strengthen the management and development of water resources, which emphasises that Jiangsu Province should focus on water conservation activities, improve water use efficiency, protect and improve the ecological environment, build a water-saving society and promote sustainable economic and social development in the province. The plan emphasises the importance of water conservation activities, improving water efficiency, protecting and improving the ecological environment, building a water-saving society and promoting sustainable economic and social development. Water resources for agriculture in economically underdeveloped areas are managed, and economically developed cities provide technical support for economic and water use in economically underdeveloped cities.

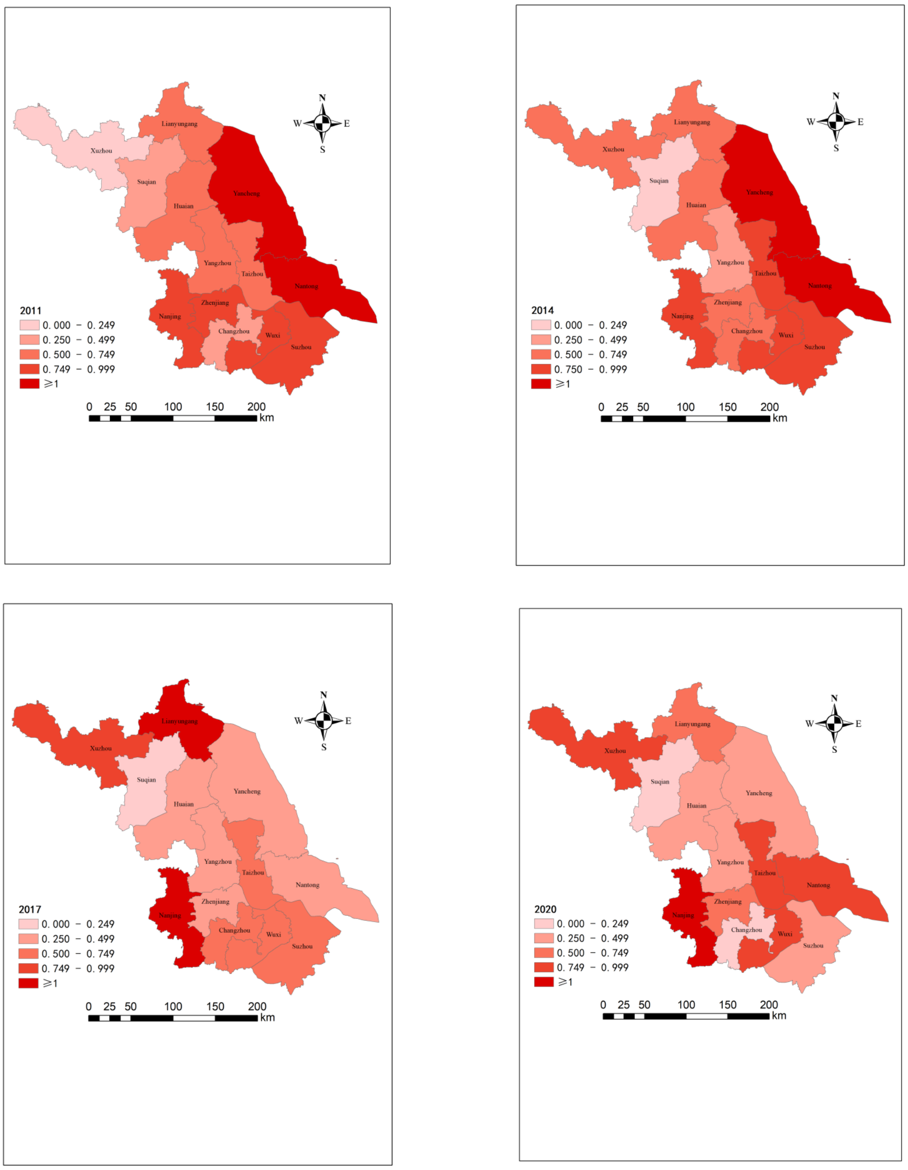

Figure 5. Spatial distribution pattern of agricultural water use efficiency in Jiangsu Province in 2011, 2014, 2017 and 2020.

The non-edge areas of Jiangsu Province from north to south are Suqian, Huai'an, Yangzhou, Taizhou, Zhenjiang, Changzhou and Wuxi, which are in the inland areas of Jiangsu Province. Without taking into account the current efficiency of agricultural water use, the seven cities mentioned above can mobilise their water resources to help each other in the cities on the edge of Jiangsu Province. Considering the current agricultural water consumption and efficiency, southern and central Jiangsu should support the agricultural water needs of northern Jiangsu and technical support for agricultural irrigation. Improving the overall level of agricultural water use efficiency in Jiangsu Province and reducing regional differences in agricultural water use efficiency are issues that need to be addressed in Jiangsu Province. Firstly, agricultural water use efficiency loss analysis was used to identify the factors affecting agricultural water use efficiency from the agricultural water use efficiency evaluation indicators in Jiangsu, and then multiple regression analysis was used to explore the factors affecting agricultural water use efficiency outside of the evaluation system of agricultural water use efficiency indicators. The above research ideas are the current issues and those needing to be addressed in Jiangsu and are the focus of the next part of this paper.

3.3. Analysis of Agricultural Water Input Redundancy Rates

As can be seen from Table 3, there are cities in each year that are inefficient in agricultural water use (Super-SBM model efficiency values less than 1, indicating that there are varying degrees of slack in the input and output elements of agricultural water use efficiency in each city in Jiangsu Province, leading to a loss of agricultural water use efficiency and resulting in inefficient agricultural water use. In order to explore the causes of inefficient agricultural water use in each municipality, the input redundancy rate and output deficiency rate were measured, and the input and output factors were then adjusted to improve agricultural water use efficiency. Figure 6 shows the annual average values of input redundancy and output deficiency rates for agricultural water use in Jiangsu, where the input redundancy rates for total agricultural machinery power and agricultural water use are higher than other input and output indicators, which is an important cause of inefficient agricultural water use in Jiangsu. From the above analysis, it is clear that attention should be focused on the actual demand for total agricultural machinery power in agricultural production in each municipality in Jiangsu Province, and agricultural owners are advised to arrange the amount of agricultural machinery used according to actual conditions. A quantitative analysis of water demand in agricultural production should be carried out to strengthen agricultural producers' awareness of water conservation. The use of fertilizers in agriculture has fallen to a low level at the end of the study, but the future trend of change is unknown, as fertilizer use is the main material source of pollution of agricultural water resources and land resources. Therefore, in the context of today's ecological and environmental protection, it is particularly important that fertilizer use is managed in the course of future agricultural production activities in Jiangsu and that technical guidance on agricultural production is provided to conserve water and use agricultural fertilizers scientifically while ensuring yields.

Regionally, the factors affecting urban water use efficiency in southern Jiangsu are the total power of agricultural machinery and agricultural water use, while the factors affecting urban agricultural water use efficiency in central Jiangsu and northern Jiangsu focus on the total power of agricultural machinery, the number of agricultural employees and agricultural water use. In terms of cities, only Nantong performs better in terms of inputs and outputs, while the rest of the cities have a large input redundancy. Of the 13 municipalities in Jiangsu, only 1, Nantong, performs well in terms of agricultural water use, with the rest performing poorly. This shows that there is a serious misallocation of resources in the agricultural water use process in Jiangsu Province, so the agricultural sector should allocate resources appropriately to improve the utilisation of water resources in agriculture.

Table 3. Agricultural water use input redundancy rate and output deficiency rate by city in Jiangsu Province.

	Input1	Input2	Input3	Input4	Output1	Output2
Nanjing	0%	11%	2%	43%	12%	3%
Wuxi	14%	12%	8%	32%	11%	13%
Xuzhou	19%	12%	25%	35%	4%	23%
Changzhou	23%	14%	22%	37%	2%	12%
Suzhou	13%	4%	25%	15%	0%	1%
Nantong	0%	2%	1%	2%	0%	0%
Lianyungang	23%	15%	15%	22%	0%	15%
Huai'an	10%	17%	14%	33%	0%	14%
Yancheng	17%	14%	11%	23%	12%	17%
Yangzhou	35%	26%	25%	32%	0%	10%
Zhenjiang	38%	18%	12%	16%	0%	9%
Taizhou	25%	16%	29%	28%	5%	13%
Suqian	33%	17%	34%	21%	0%	21%
Southern Jiangsu	18%	12%	14%	29%	5%	8%
Central Jiangsu	20%	15%	18%	21%	2%	8%
Northern Jiangsu	20%	15%	20%	27%	3%	18%
Mean	19%	14%	17%	26%	4%	12%

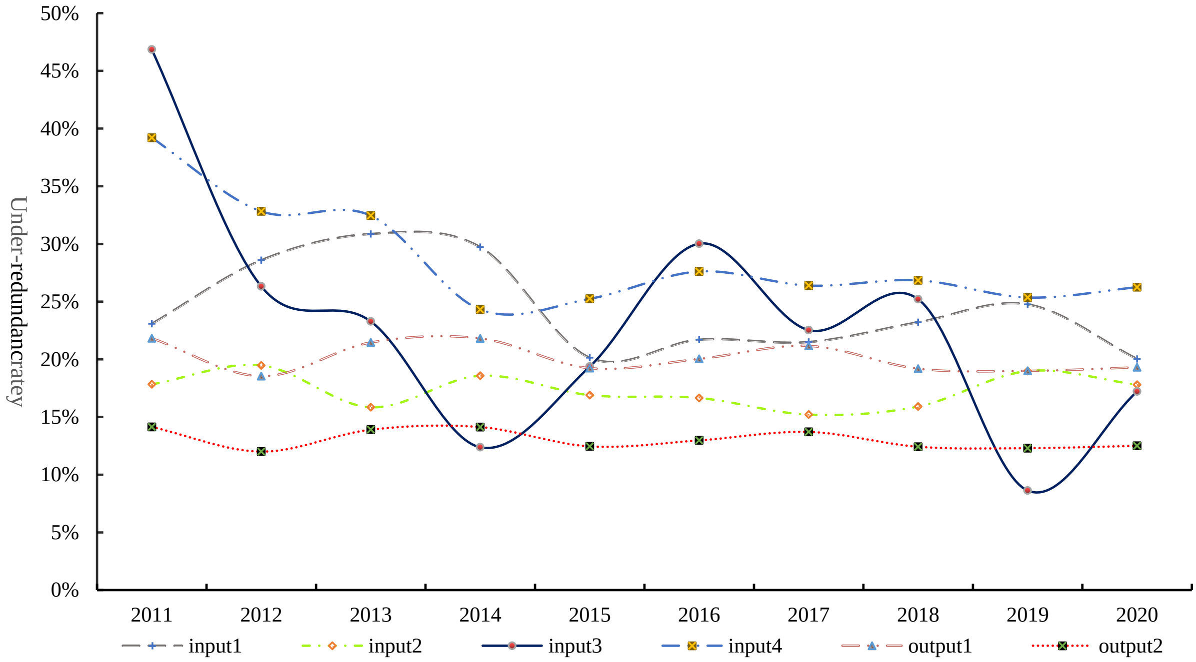

Figure 6. The annual average value of agricultural water input redundancy rate and output deficiency rate in Jiangsu Province.

3.4. Dynamic Analysis of Agricultural Water Use Efficiency

The Malmquist index method was used to explore the dynamic evolution of total factor productivity of agricultural water use in Jiangsu Province from 2011 to 2020. As can be seen from Table 4 and Figure 7, the total factor productivity of agricultural water use (TFPCH) in Jiangsu Province during the study period was above 1 in only four study intervals, 2011–2012, 2013–2014, 2018–2019 and 2019–2020, indicating poor performance in agricultural water use efficiency in Jiangsu Province and internal regions during the study period. In the technical efficiency change (EFFCH), the mean values of its decomposition of pure technical efficiency (PECH) and scale efficiency (SECH) are both close to 1, indicating a more combined effect of both on technical efficiency. In the TFPCH decomposition, the EFFCH values for 2011–2012, 2013–2014, 2015–2016, 2017–2018 and 2019–2020 are all less than 1, showing an "∧" trend, which shows that the output decreases with constant inputs and has a negative effect on improving agricultural water use efficiency. TECHCH only has a positive impact on agricultural water efficiency in 2011–2012, 2013–2014 and 2019–2020, and the trend is almost the same as that of TFPCH during the study period, so it is clear that TECHCH is the main factor affecting agricultural water efficiency. The active use of advanced technologies is therefore conducive to the rational allocation of agricultural input and output resources.

Table 4. Malmquist index decomposition of agricultural water use efficiency in Jiangsu Province.

	EFFCH	TECHCH	PECH	SECH	TFPCH
2011–2012	0.919	1.471	1.039	0.884	1.351
2012–2013	1.199	0.600	1.021	1.175	0.719
2013–2014	0.969	1.077	0.994	0.975	1.043
2014–2015	1.011	0.884	0.983	1.029	0.894
2015–2016	0.972	0.984	0.987	0.984	0.957
2016–2017	1.006	0.981	0.996	1.010	0.987
2017–2018	0.966	0.999	0.962	1.004	0.965
2018–2019	1.046	0.979	1.051	0.995	1.023
2019–2020	0.941	1.076	0.966	0.974	1.012
Mean	1.003	1.009	1.000	1.003	0.995

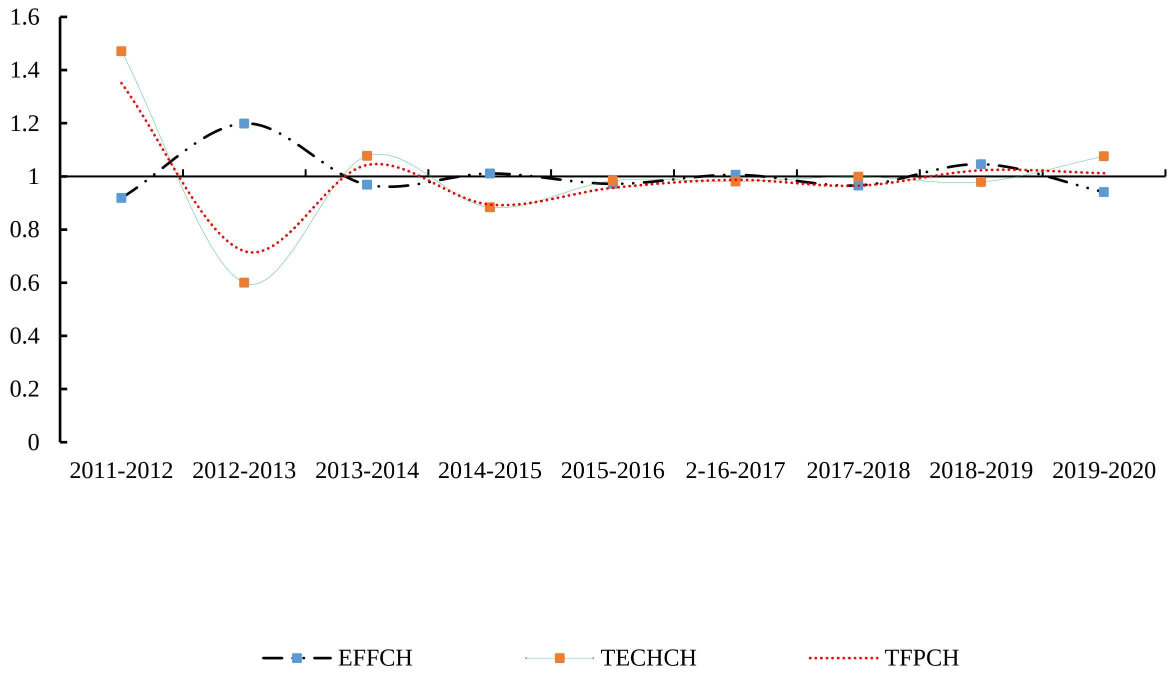

Figure 7. Trend of Malmquist index decomposition of agricultural water use efficiency in Jiangsu Province.

Table 5 shows the annual averages of the Malmquist Index and its decomposition for each city in Jiangsu Province. The average values of TFPCH and TECHCH for the 13 cities in Jiangsu Province are both very close to 1. It is clear that agricultural water use efficiency in Jiangsu is improving and that technological progress has been playing a positive role, with the southern Jiangsu region having the highest TFPCH of the three regions in Jiangsu at 1.018 and exceeding the average for Anhui Province at 0.952, respectively, indicating that geographical factors can affect agricultural water use efficiency to some extent. By city, the EFFCH for Nanjing, Wuxi and Yancheng are all 1, and the TECHCH is less than 1, suggesting that the decline in agricultural water use efficiency is mainly due to ineffective technological progress. SECH is the deeper reason for the increase in agricultural water use efficiency. Suzhou has the highest TFPCH of all cities, with agricultural water use efficiency increasing by 5.2%, driven by both TECHCH and EFFCH. Compared to other cities, Nanjing, Wuxi, Yangzhou, Changzhou, Zhenjiang and Suqian have a higher TFPCH, exceeding the provincial average. In summary, it can be seen that all cities have suitable methods to improve local agricultural water use efficiency, and individual cities should optimise their resource allocation to promote local scale efficiency to further achieve the aim of improving water use efficiency. In addition, technological progress is a key positive factor in improving agricultural water use efficiency. Jiangsu Province is actively pursuing the implementation of the Agricultural Technology Promotion Law of the People's Republic of China approach, which points out the importance of technological progress at a governmental level and helps to create a friendly situation for resource conservation, environmental friendliness and synergistic economic development.

Table 5. Malmquist index decomposition of agricultural water use efficiency by cities in Jiangsu Province.

	EFFCH	TECHCH	PECH	SECH	TFPCH
Nanjing	1	0.996	1	1	0.996
Wuxi	1	0.999	1	1	0.999
Xuzhou	0.964	0.96	0.966	0.998	0.925
Changzhou	1.019	0.994	1	1.019	1.013
Suzhou	1.051	1.001	1.039	1.011	1.052
Nantong	0.983	0.993	0.997	0.986	0.976
Lianyungang	0.968	0.961	1.002	0.965	0.93
Huai'an	0.964	0.959	0.997	0.967	0.924
Yancheng	1	0.976	1	1	0.976
Yangzhou	1.017	0.984	0.997	1.02	1.001
Zhenjiang	1.03	0.999	1	1.03	1.03
Taizhou	0.977	0.984	0.969	1.008	0.961
Suqian	1.037	0.968	1.026	1.011	1.004
Southern Jiangsu	1.02	0.998	1.008	1.012	1.018
Central Jiangsu	0.992	0.987	0.988	1.005	0.979
Northern Jiangsu	0.987	0.965	0.998	0.988	0.952
Mean	1.001	0.983	0.999	1.001	0.984

4. Empirical Analysis of Factors Influencing Agricultural Water Use Efficiency in Jiangsu Province

4.1. Unit Root Test

In order to check whether the panel series is stable or not, a unit root test is required, and the LLC test and the IPS test are used, respectively. The unit root test shows that there is no unit root for all six variables, that is, the panel series is stable.

4.2. Selection of Regression Models

The traditional regression model selection method is to do the Hausman test on the static panel data and select the fixed-effects model or the random-effects model according to the value of the test statistic P. In the panel data of this paper, n = 13 is relatively small, and the assumptions of the random-effects model are too demanding, so the fixed-effects model is chosen more securely.

4.3. Empirical Analysis of Regression Results

Fixed effects, i.e., control variables with fixed invariant characteristics, are designed to control for fixed invariant characteristics that are unique within each subgroup. Fixed-effects models can therefore be classified as individual effects models, time effects models, and two-factor effects models. The regression results are presented in Table 6.

Table 6. Regression results of factors influencing agricultural water use efficiency in Jiangsu Province (***, ** and * respectively represent that each variable has passed the significance test of 1%, 5% and 10%).

Variables	Time Fixed-Effects Model	Individual Fixed-Effects Models	Two-Way Fixed-Effects Model
lnN	−0.345 ***	−0.330 **	−0.567 ***
lnG	−2.362	−2.421 *	−2.357 **
lnP	−0.537 **	0.472	0.564 ***
lnT	3.471 ***	2.352 ***	2.543 ***
lnS	0.377	0.467 *	0.484
lnW	−3.024***	−2.896 **	−3.095 *
a_0	−3.151***	−3.836 **	−3.927 **
R-sq within	0.736	0.770	0.748
Prob > F	000 ***	000 ***	000 ***

As seen in Table 6, the regression coefficients for annual precipitation are all negative, meaning that precipitation and agricultural water use efficiency are negatively correlated, with the increase in annual precipitation inhibiting the improvement of agricultural water use efficiency. The main reason for this is the low cost of water in China and the lack of water shortages in the daily lives of residents in Jiangsu Province, which has led to a weak awareness of water conservation among all sectors of society, resulting in a large amount of wasted water resources and reduced agricultural water use efficiency. Additionally, the regression coefficient of the spatial fixed-effects model for GDP per capita is negative and significant at the 5% level, indicating that the level of economic development between cities within Jiangsu Province affects the water use efficiency of neighbouring cities and that there is a correlation between the level of agricultural water use efficiency between cities. The main reason for the negative correlation between agricultural water use efficiency and GDP per capita is that Jiangsu Province's GDP growth is mainly based on the industrial economy, with 32,600 industrial enterprises, the largest in China. Industry has a huge demand for water, and on top of the already poor agricultural water resources, the huge demand for water from industry has made it impossible to improve agricultural water efficiency in Jiangsu Province. So, the allocation of resources is an unavoidable reality in the development of any region, and a boom in any one of these industries—agriculture, industry, services—will lead to a reduction in the allocation of resources to another industry.

Moreover, the regression coefficient of the two-way fixed-effect model for the proportion of output value of the secondary and tertiary industries is positive and significant at the 1% level; the regression coefficient of the time-fixed-effect model is −0.537, significant at the 5% level, indicating that the development of the secondary and tertiary industries has a certain degree of influence on the amount of water resources, and that the optimisation of industrial structure has failed to solve problems such as water allocation. Considering the spatial effect, industrial structure has a non-significant positive impact on agricultural water use efficiency; the positive effect of industrial structure optimisation is specifically reflected at the spatial level, but the effect is not significant. In this regard, the municipalities of Jiangsu Province should make long-term plans to optimise their industrial structures in terms of improving agricultural water use efficiency.

Furthermore, the regression coefficients for professional and technical personnel were all positive and significant at the 1% level, indicating that the effect of agricultural-related technical personnel on improving agricultural water use efficiency is significant. The greater the number of technical professionals, the more effective the implementation of specialist techniques and equipment in the use of agricultural water resources. Jiangsu Province has indeed put this work into practice, with municipalities in Jiangsu constantly seizing the high ground in agricultural technology, promulgating the "Jiangsu Professional and Technical Qualification Conditions for Agricultural Technicians" and actively developing and training relevant technical personnel. Table 6 indicates that the regression coefficients for sown acreage were 0.377, −0.467 and −0.484, respectively, passing the 1% significance test for individual fixed effects only, indicating that sown acreage has a small negative impact on industrial water use efficiency. The larger the sown arable area, the greater the total water use, but the inhibitory effect on agricultural water use efficiency is minimal. Therefore, the crop sown area had no substantial effect on agricultural water use efficiency and did not result in a large change in water use efficiency.

Ultimately, the regression coefficients of the time, individual and two-factor fixed-effects models of water endowment are all negative, with a significant effect on agricultural water use efficiency. These data characterise the wastefulness of agricultural water resources in Jiangsu Province in either the time dimension, spatial dimension or the space-time dimension. Although Jiangsu Province has an important responsibility for the transfer of water from the south to the north, sending large amounts of water to northern China each year, it has the sixth highest water endowment in the country. In this regard, the relevant authorities in Jiangsu should strengthen awareness of water conservation in the province and water resource management in all production and water-demanding sectors. It is recommended to imitate the environmental management perspective and propose penalties for relevant departments that experience serious wastage of water resources.

5. Results and Policy Recommendations

5.1. Results

As an economic and agricultural province rich in water resources and an important support for the South–North Water Diversion Project, Jiangsu Province's agricultural water use efficiency directly affects its surroundings and its corresponding cities that are supplied with water, but little research has been done on its agricultural water resources. Therefore, this paper measures the agricultural water use efficiency of 13 prefecture-level cities in Jiangsu from 2011 to 2020 based on the Super-SBM model and the Malmquist index method, and also does a time and space fixed-effects analysis through agricultural water use efficiency. The specific conclusions are as follows:

(*i*) The development of agricultural water use efficiency in 13 prefecture-level cities of Jiangsu Province is generally poor.

The agricultural water use efficiency of 13 cities in Jiangsu Province is generally poor, but Yancheng, Nantong, Nanjing and other cities have developed well. In the spatial dimension, the agricultural water use efficiency of Jiangsu Province from 2011 to 2020 was only 0.782, and the number of cities with high and medium efficiency levels of agricultural water use did not change significantly. To sum up, there has been no significant progress in agricultural water use efficiency in Jiangsu Province in recent years. Considering the input redundancy rate of agricultural water efficiency, it is found that the total power of agricultural machinery and industrial water consumption are seriously wasted.

(*ii*) The total factor productivity and its decomposition index of agricultural water use in Jiangsu Province showed an upward trend during the inspection period.

According to the calculation results of the Malmquist index, in terms of time span, the total factor productivity of agricultural water use (TFPAWS) in Jiangsu Province during the study period was only above 1 in the four research ranges of 2011–2012, 2013–2014, 2018–2019 and 2019–2020, indicating that the agricultural water use efficiency of Jiangsu Province and its internal regions was poor during the study period, and the improvement of agricultural water use efficiency must be combined with technological progress, the active use of advanced technology is conducive to the rational allocation of agricultural input and output resources. In terms of geographical span, the Malmquist index and its decomposition average annual value of all cities in Jiangsu Province are greater than 1. The average values of TFPCH and TECHCH in 13 cities in Jiangsu Province are close to 1. The efficiency of agricultural water use in Jiangsu is improving, and technological progress has been playing a positive role.

(*iii*) Science and technology are the primary productive forces.

According to the regression results, whether in time or space, annual precipitation, economic development level and water resource endowment all have a negative effect on agricultural water use efficiency, and the sowing area and the investment of professional and technical personnel have a positive effect on agricultural water use efficiency. Therefore, scientific and technological progress is conducive to improving agricultural water use efficiency in Jiangsu Province.

5.2. Policy Recommendations

In the process of urbanisation and agricultural modernisation, agricultural water use is an essential element of agricultural production, and improving the efficiency of agricultural water use is very important for promoting high-quality agricultural development:

(*i*) Actively implement the Ministry of Agriculture's zero-growth action on fertilizer and pesticide use to reduce the amount of agricultural chemical inputs in Hubei Province. First, increase publicity on the dangers of excessive chemical fertilizer and pesticide inputs to enhance farmers' awareness of environmental protection. Second, scientific research institutions should strengthen research and development on organic fertilizers and ecological pesticides, and vigorously promote organic fertilizers and ecological pesticides. Again, continue to promote soil testing and fertilizer application and straw return technology to reduce the pollution and waste of water and soil resources caused by blind fertilizer application, and increase organic matter in the soil.

(*ii*) To introduce policies to improve the efficiency of water resource use according to the differences in water resources in Jiangsu Province. To address the problem of excess agricultural labour in northern Jiangsu, it is necessary to reasonably transfer surplus agricultural labour and improve the efficiency of agricultural water use, so as to prevent the "internalisation" of agricultural production. To address the problem of excessive agricultural water input in southern and central Jiangsu, it is necessary to introduce corresponding policies, reasonably adjust the crop cultivation structure and grain replanting index, and vigorously promote dry farming techniques, with a focus on crops such as maize, potatoes and cotton, and coordinate the planning of agricultural water input. Vigorously promote dry farming techniques, with a focus on crops such as maize, potatoes and cotton, and coordinate the planning of agricultural water use inputs.

(*iii*) Vigorously promote agricultural water conservation technology, improve the agricultural water infrastructure in Jiangsu Province, and promote the efficient use of water resources in Jiangsu Province. The local government should play a leading role in giving sufficient financial support to research institutions and researchers, and actively carry out innovative technology exchange activities. It is necessary to improve basic water conservancy construction projects from the actual situation in rural areas, strengthen the function of water conservancy projects for drought prevention, water drainage and water diversion and irrigation, and alleviate the contradiction between the supply and demand of water resources between regions.

Author Contributions: J.G., methodology; H.D. writing—original draft preparation; Y.X., supervision. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

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

References

1. Shang, J.; Wei, D.; Qiang, J.X. Technological progress, agricultural water use efficiency and rebound effect-An empirical study based on panel data from major grain-producing regions in China. *Ecol. Econ. Econ.* **2020**, *36*, 94–100.
2. Azad, M.A.S.; Ancev, T. Measuring environmental efficiency of agricultural water use: A Luenberger environmental indicator. *J. Environ. Manag.* **2014**, *145*, 314–320. [CrossRef]
3. Lu, W.; Liu, W.; Zhao, M. Dynamic evolution and convergence of agricultural water use efficiency in the Yellow River Basin. *Northwest Agric. For. Univ. Sci. Technol. Soc. Sci. Ed.* **2022**, *22*, 123134.

4. Zhi, Y.; Zhang, F.; Wang, H.; Qin TTong, J.; Wang, T.; Wang, Z.; Kang, J.; Fang, Z. Agricultural Water Use Efficiency: Is There Any Spatial Correlation between Different Regions? *Land* **2022**, *11*, 77. [CrossRef]
5. Liu, K.; Xue, Y.; Lan, Y.; Fu, Y. Agricultural Water Utilization Efficiency in China: Evaluation, Spatial Differences, and Related Factors. *Water* **2022**, *14*, 684. [CrossRef]
6. Cao, X.; Liu, Y.; Li, T.; Liao, W. Analysis of Spatial Pattern Evolution and Influencing Factors of Regional Land Use Efficiency in China Based on ESDAGWR. *Sci. Rep.* **2019**, *9*, 520. [CrossRef]
7. Qin, S.; Chen, H.; Wang, H. Spatial-temporal heterogeneity and driving factors of rural residents' food consumption carbon emissions in China-based on an ESDA-GWR model. *Sustainability* **2021**, *13*, 12419. [CrossRef]
8. Wu, W.; Feng, Y. Digital Economy, Consumption Upgrading and Urban Land Use Efficiency—An Empirical Study Based on Wuhan Urban Circle. *Stat. Decis. Mak.* **2022**, *38*, 107–110. [CrossRef]
9. Dong, Y.M.; Bi, J.H.; He, Q.E.; Song, K. ESDA: An improved approach to accurately identify human snoRNAs for precision cancer therapy. *Curr. Bioinform.* **2020**, *15*, 34–40. [CrossRef]
10. Druckman, A.; Jackson, T. Measuring resource inequalities: The concepts and methodology for an area-based Gini coefficient. *Ecol. Econ.* **2008**, *65*, 242–252. [CrossRef]
11. Dai, C.; Qin, X.S.; Chen, Y.; Guo, H.C. Dealing with equality and benefit for water allocation in a lake watershed: A Gini-coefficient based stochastic optimization approach. *J. Hydrol.* **2018**, *561*, 322–334. [CrossRef]
12. Malakar, K.; Mishra, T.; Patwardhan, A. Inequality in water supply in India: An assessment using the Gini and Theil indices. *Environ. Dev. Sustain.* **2018**, *20*, 841–864. [CrossRef]
13. Malakar, K.; Mishra, T. Application of Gini, Theil and concentration indices for assessing water use inequality. *Int. J. Soc. Econ.* **2017**, *44*, 1335–1347. [CrossRef]
14. Wang, R.; Wang, Q.; Yao, S. Evaluation and difference analysis of regional energy efficiency in China under the carbon neutrality targets: Insights from DEA and Theil models. *J. Environ. Manag.* **2021**, *293*, 112958. [CrossRef] [PubMed]
15. Wang, C.; Yu, J. The Measurement of the Equalization Level of Basic Public Services in the Yangtze River Delta Region and Spatial Difference Analysis-An Empirical Analysis based on Theil Index. *Front. Econ. Manag.* **2022**, *3*, 75–83.
16. Ying, H.; Shan, Z. Analysis of influencing factors of inter provincial agricultural water use efficiency in China-Based on static and dynamic spatial panel models. *Ecol. Econ.* **2020**, *36*, 124–131.
17. Yu, L.; Zhaofeng, W.; Junbiao, Z. Analysis of influencing factors of agricultural water resource utilization efficiency. *Econ. Issues* **2007**, *6*, 75–77.
18. Lu, W.; Liu, W.; Hou, M.; Deng, Y.; Deng, Y.; Zhou, B.; Zhao, K. Spatial-temporal evolution characteristics and influencing factors of agricultural water use efficiency in Northwest China-Based on a super-DEAmodel and a spatial panel econometric model. *Water* **2021**, *13*, 632. [CrossRef]
19. Wang, S.; Zhou, L.; Wang, H.; Li, X. Water use efficiency and its influencing factors in China: Based on the data envelopment analysis (DEA)-Tobit model. *Water* **2018**, *10*, 832. [CrossRef]
20. Yang, Y. Evaluation of China's water-resource utilization efficiency based on a DEA-Tobit two-stage model. *Water Supply* **2021**, *21*, 1764–1777. [CrossRef]
21. Hong, N.B.; Yabe, M. Improvement in irrigation water use efficiency: A strategy for climate change adaptation and sustainable development of Vietnamese tea production. *Environ. Dev. Sustain.* **2017**, *19*, 1247–1263. [CrossRef]
22. 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]
23. Ramadani, I.R.; Rahmawati, R.; Hoyyi, A. Analisis Faktor-Faktor yang Mempengaruhi Gizi Buruk Balita di Jawa Tengah dengan Metode Spatial Durbin Model. *J. Gaussian* **2013**, *2*, 333–342.
24. Li, M.; Long, K. Direct or spillover effect: The impact of pure technical and scale efficiencies of water use on water scarcity in China. *Int. J. Environ. Res. Public Health* **2019**, *16*, 3401. [CrossRef]
25. Chakir, R.; Le Gallo, J. Spatial Autocorrelation in Econometric Land Use Models: An Overview. In *Advances in Contemporary Statistics and Econometrics*; Springer: Berlin, Germany, 2021; pp. 339–362.
26. Li, X.; Jiang, W.; Duan, D. Spatio-temporal analysis of irrigation water use coefficients in China. *J. Environ. Manag.* **2020**, *262*, 110242. [CrossRef] [PubMed]
27. Charnes, A.; Copper, W.W.; Rhodes, E. Measuring the efficiency of decision making units. *Eur. J. Oper. Res.* **1978**, *6*, 429–444. [CrossRef]
28. Andersen, P.; Pertersen, N.C. A procedure for ranking efficient units in data envelopment analysis. *Manag. Sci.* **1993**, *39*, 1261–1264. [CrossRef]