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Utilization efficiency and influencing factors of agricultural water resources in Hubei province

Yewang Zhou

School of Business, Huanggang Normal University, Huanggang 438000, China, email: whuw@sina.com

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ABSTRACT

This paper comprehensively and objectively studies the efficiency of agricultural water resources utilization in Hubei Province from 2006 to 2017, provides scientific theoretical basis for the sustainable utilization of water resources in Hubei Province and the improvement of water use efficiency. The paper chooses the relevant index data of Hubei Province from 2006 to 2017, based on the DEA method, the efficiency of agricultural water resources utilization in Hubei Province was calculated. Then the gray relational analysis model is used to explore the factors which affect the utilization efficiency of agricultural water resources in Hubei Province.

Keywords: Agriculture; Water resources; Efficiency; Influencing factors

1. Introduction

Hubei Province is located in the middle reaches of the Yangtze River, Dongting Lake north, west, north, east surrounded by mountains, the surface area of the province's total area of about 10%. Hubei is known as "thousands of Lake Province". The territory of the lake is mainly distributed in the Jianghan Plain. More than 800 lakes are over 100 acres, the total lake area is 2,983.5 km^2. Areas more than 100 km^2 of lakes are Honghu, Changhu, Liangzi Lake, Ax Lake. Hubei water resources characteristics of specific performance: the total rich, but less per capita resources. The existing lake area of 2,984 km^2, the total area ranks first in the country. The province's total surface water resources nearly to the average 102.786 billion m^3 for many years, but the per capita effective possession of only 1,731 m^3 per year, the advantage is not obvious across the country. The distribution of time and space is uneven. In the space, the regional distribution of precipitation is decreasing from south to north. However, with the development of society, the quantity and area of surface water resources are reduced and the water quality is deteriorating. The main reason is that the city interception system is imperfect, a large number of untreated sewage is released directly into the water, while the use of pesticides within the province also increased year by year, becoming another important reason for the deterioration of water. Water resources ensure the quality of people's living standards and social development, as an important natural resource to support the sustainable development of national economy in Hubei Province. With the industrialization of Hubei Province, the speed of urbanization is gradually accelerating, and the contradiction between the high demand of water resources and the irrational distribution of local water resources is becoming more and more serious. How to effectively improve the efficiency of water use is becoming an urgent problem to solve.

In the domestic research, most scholars have made a lot of research on the utilization efficiency of agricultural water resources according to China's existing national conditions. Many scholars have put the focus on the water use efficiency at the provincial or national level; Gao et al. [1] evaluated the water use efficiency of 31 provincial administrative regions in China by genetic projection pursuit method. Sultana et al. [2] used DEA and Malmquist index to study the water use efficiency of 12 provinces in western China; Sun et al. [29]

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used data envelopment analysis to study the water use efficiency of Liaoning Province. Issaka and Ashraf [3] used the DEA model under the framework of total factor production to calculate the water use efficiency of China from 1998 to 2008 and the Tobit regression model to analyze the influencing factors of water resources utilization. Domestic researchers adopted different research methods to study water use efficiency from different levels and scales. The research methods include genetic projection pursuit method, GIS, ratio analysis method, envelope analysis method, production function method and analytic hierarchy process law and so on [4–6]. Scale to county, provincial or national as the object of study.

For Hubei Province, rare scholars use DEA to evaluate the efficiency of agricultural water resources currently [7–12]. Because there is no need for dimensionless processing of data before the model is established by DEA method. In this paper, two common models of C2R and BC2 in DEA method are used to evaluate the efficiency of agricultural water use in Hubei province from 2006 to 2017 [13–18]. The DEA is used to identify the ineffective and effective years, to measure the severity of invalidity, and through the comparison of invalid and effective years, find to reduce the ineffective methods to improve the utilization of agricultural water resources in Hubei Province [19–26].

2. Research methods and indicators of choice

2.1. DEA model

Data envelopment analysis (DEA) is a combination of theory and method of mathematics, economics and management, formed with their own characteristics of the model, methods and theory.

Assuming n years of data, each year can be seen as a decision unit DMU, so there are n decision-making unit, each decision-making unit has m kinds of "input" and s "output"; "input" indicates the consumption of the resource by the DMU, and the "output" indicates the number of "results" that the DMU consumes "resources".

When the efficiency evaluation of j_0 ($1 \le j_0 \le n$) DMUs is taken as the target, the efficiency indices of the j_0th DMU are targeted with the weight coefficients v and u as constraints, and the efficiency indices of all DMUs (also including the j_0th) are constrained, that is, $h_j \le 1$, $j = 1,2,...,n$. The relative efficiency of agricultural water resources in year K can be derived from the following optimization model.

$$(I)\begin{cases} \max \quad h_{j0} = \dfrac{\left(\sum_{i=1}^{s} U_r \times Y_{r0}\right)}{\left(\sum_{i=1}^{m} V_r \times X_{i0}\right)} \\ \text{s.t.} \dfrac{\left(\sum_{r=1}^{s} U_r \times Y_{rj}\right)}{\left(\sum_{i=1}^{m} V_r \times X_{ij}\right)} \le 1, j = 1,2,\cdots,n \\ v = (v_1, v_2, \cdots, v_m)^T \ge 0 \\ u = (u_1, u_2, \cdots, u_m)^T \ge 0 \end{cases} \tag{1}$$

DEA has multiple models, of which two important models are C^2R and BC^2.

2.2. Gray relational analysis model

Gray relational refers to the uncertainty association between things, or the uncertainty of the relationship between the system factor and the principal behavior [27–36]. The gray relational analysis is an analysis method based on the geometric proximity of the behavioral factor sequence, the analysis and the determination of the degree of influence between the factors or the contribution of the factors to the main behavior.

2.2.1. A gray correlation coefficient

The time series of the main factors and the time series of comparative factors are, respectively, as follows:

$$X_0(t) = \{x_0(1), x_0(2), \cdots, x_0(n)\} \tag{2}$$

$$X_i(t) = \{x_i(1), x_i(2), \cdots, x_{i.}(n)\} \tag{3}$$

Among them, t can be a time series, also it can be a sequence of indicators or a spatial distribution sequence. Remember

$$\Delta_i(t) = \left|x_0(t) - x_i(t)\right| \tag{4}$$

$$\Delta_{\min}^{(i)} = \min_{i,t}\left|x_0(t) - x_i(t)\right| \tag{5}$$

$$\Delta_{\max}^{(i)} = \max_{i,t}\left|x_0(t) - x_i(t)\right| \tag{6}$$

The gray correlation coefficients for definition 1 are as follows:

$$\xi_i(t) = \frac{\Delta_{\max}^{(i)} + \rho\Delta_{\max}^{(i)}}{\Delta_i(t) + \rho\Delta_{\max}^{(i)}} \tag{7}$$

In the formula, $\xi_i(t)$ is called $x_i(0)$ for $x_i(t)$ at time t's gray correlation coefficient, $\rho \in [0,1]$, called the resolution coefficient.

Note: The gray correlation coefficient is satisfied

$$\frac{\rho}{1+\rho} \le \xi_i(t) \le 1 \tag{8}$$

Therefore, when $\Delta_i(t) = \Delta_{\min}^{(i)}$, the upper bound of the gray correlation coefficient $\xi_i(t)$ is 1. When $\Delta_i(t) = \Delta_{\max}^{(i)}$, the gray correlation coefficient $\xi_i(t)$ reaches the minimum lower bound as follows:

$$\xi_i(t) = \frac{\Delta_{\min}^{(i)} + \rho\Delta_{\max}^{(i)}}{\Delta_i(t) + \rho\Delta_{\max}^{(i)}} = \frac{\Delta_{\min}^{(i)} + \rho\Delta_{\max}^{(i)}}{\Delta_{\max}^{(i)} + \rho\Delta_{\max}^{(i)}} = \frac{\Delta_{\min}^{(i)} / \Delta_{\max}^{(i)}}{1+\rho} + \frac{\rho}{1+\rho} \tag{9}$$

$$= \frac{\Delta_{\min}^{(i)}}{\Delta_{\max}^{(i)}}\left[\frac{\rho}{1+\rho}\right] + \left[\frac{\rho}{1+\rho}\right] \tag{10}$$

$$= \frac{\rho}{1+\rho}\left[1+\frac{\Delta_{\min}^{(i)}}{\Delta_{\max}^{(i)}}\right] \quad (11)$$

In practice, after gray-related data processing, usually will be a case where $\Delta_{\min}^{(i)} = 0$ situation. It can be seen that $\rho/1 + \rho$ is the lower bound of the gray correlation coefficient $\xi_i(t)$.

2.2.2. B gray correlation degree

Since gray correlation coefficient represents only the degree of gray correlation between the time data, in order to further compare the whole data sequence, that is the comparison of $X_0(t)$ and $X_i(t)$, the mean value of the gray correlation coefficient is taken as the overall correlation between $X_0(t)$ and $X_i(t)$, thus, as defined below.

Definition 2 Set the gray correlation degree between degrees $X_0(t)$ and $X_i(t)$ to $\gamma_i = \frac{1}{n}\sum_{t=1}^{n}\xi_i(t)$.

2.2.3. C selection of indicators and data sources

Agriculture is the largest water user in Hubei Province. With the development of industrial and urbanization process, the competition of industrial and agricultural water is intensified, and the shortage of water resources is an important factor restricting the sustainable development of agriculture. So finding a solution to solve the limited water resources to support regional agriculture and economic and social sustainable development has become an urgent task for all levels of government.

According to the "China Statistical Yearbook" and "Hubei Statistical Yearbook" [37,38], the crop acreage, farmland irrigation water consumption and the number of workers in agriculture are selected as input indicators. These three indicators comprehensively reflect the supply capacity of agricultural water resources in Hubei Province, GDP and crop yield as output indicators, and then use the DEA model to evaluate the province's agricultural water use efficiency (Table 1).

3. Empirical analysis

3.1. Efficiency evaluation

Using the DEAP software, the original data of each year of the table is substituted into the C^2R model, and the agricultural water resource utilization efficiency (θ) and the value of the relaxation unit of the decision unit are obtained from 2006 to 2017. The calculation results are shown in Table 2. Similarly, using the DEAP software to replace the original data into the BC^2 model, we can get the pure technical efficiency value (σ) of agricultural water resources utilization in Hubei Province from 2006 to 2017. Through the analysis, technical efficiency, pure technical efficiency, scale efficiency and so on are shown in Table 3 for each year.

According to the results in Table 2, it can be seen that the utilization of agricultural water resources in Hubei Province is only valid for DEA in 2017, and the remaining water use efficiency values are less than 1, DEA is invalid. In the invalid year of 2006, 2007, 2008, 2010 and 2011, the water use efficiency values were less than 0.95, indicating that the utilization efficiency of agricultural water resources in Hubei Province was at a low level. Relaxation variable is not 0, indicating that there is an inefficiency and lack of output in the ineffective year. Indicating that farmland water consumption, agricultural sown area, the number of agricultural workers in the field put too much. According to the results in Table 3, it can be seen that only the technical efficiency of water use efficiency in 2017 is 1, to achieve the optimal state.

Performing an effective planar projection adjustment for invalid year of DEA, get cases where an individual input, output indicators to be adjusted. "–" represents redundant, and "+" represents insufficient output. From Table 4 it can be drawn that crop acreage has not been fully utilized in Hubei Province, agricultural water consumption, the number of workers in agriculture put too much, resulting in waste of water resources and human resources in addition to 2017. The level of water using efficiency in the region is largely determined by the local production technology, the advanced level of equipment and the implementation level

Table 1
Input and output indicators of Hubei Province from 2006 to 2017

Time	Agricultural water amount	Crop acreage	Number of people in agriculture	Agricultural gross domestic product	Crop yield
2006	131.71	7,155.88	1,877.03	564.00	2,100.12
2007	142.12	7,279.42	1,932.76	572.00	2,177.38
2008	142.96	6,900.59	1,967.12	611.00	2,099.10
2009	132.65	7,060.01	2,030.61	720.00	2,185.44
2010	142.80	7,298.31	2,078.77	878.00	2,227.23
2011	149.43	7,527.50	2,123.29	938.00	2,309.10
2012	138.29	7,997.57	2,154.44	1,244.00	2,315.80
2013	142.26	8,009.57	2,203.02	1,495.00	2,388.53
2014	146.44	8,078.89	2,259.91	1,594.00	2,441.81
2015	159.61	8,106.19	2,263.21	1,710.00	2,501.30
2016	156.89	8,112.26	2,271.65	1,773.00	2,584.17
2017	158.10	7,952.36	2,280.03	1,795.00	2,703.28

Table 2
C^2R model solution results

DMU	θ	S_1^-	S_2^-	S_3^-	S_1^+	S_2^+
2006	0.944	1.466943	574.8075	0	830.4968	0
2007	0.95	7.696567	511.462	0	873.7981	0
2008	0.9	5.901924	35.64733	0	782.8195	0
2009	0.964	0	373.6378	113.3185	731.15	0
2010	0.912	0	105.3864	17.68529	600.8989	0
2011	0.917	2.016587	111.7406	0	595.2613	0
2012	0.979	0	1,020.165	156.7975	293.7101	0
2013	0.982	0	838.5399	148.6922	91.00343	0
2014	0.975	0	695.3387	144.3625	27.38178	0
2015	0.96	2.568533	203.9373	0	0	73.96953
2016	0.995	0	219.7385	9.027875	0	85.97788
2017	1	0	0	0	0	0

Table 3
Technical efficiency (θ), pure technical efficiency (σ) and scale efficiency (*s*) of agricultural water resources and utilization in Jiangsu Province

Year	Technical efficiency	Pure technical efficiency	Scale efficiency	Σ^λ	Return to scale
2006	0.944	1	0.944	0.777	Increasing
2007	0.95	0.998	0.952	0.805	Increasing
2008	0.9	1	0.9	0.777	Increasing
2009	0.964	1	0.964	0.808	Increasing
2010	0.912	0.985	0.926	0.824	Increasing
2011	0.917	0.971	0.944	0.854	Increasing
2012	0.979	1	0.979	0.857	Increasing
2013	0.982	1	0.982	0.884	Increasing
2014	0.975	1	0.975	0.903	Increasing
2015	0.96	0.995	0.965	0.953	Increasing
2016	0.995	1	0.995	0.988	Increasing
2017	1	1	1	1	Constant

Table 4
DEA projection result in the invalid year

Year	Agricultural water consumption	Crop acreage	Number of agricultural workers	Gross agricultural production	Crop yield
2006	–8.886	–977.863	–105.724	830.497	0
2007	–14.777	–874.124	–96.29	873.798	0
2008	–20.195	–725.573	–196.674	782.82	0
2009	–4.836	–631.003	–187.342	731.15	0
2010	–12.542	–746.368	–200.255	600.899	0
2011	–14.383	–734.717	–175.724	595.261	0
2012	–2.852	–1,185.077	–201.223	293.71	0
2013	–2.568	–983.124	–188.46	91.003	0
2014	–3.632	–895.708	–200.412	27.382	0
2015	–8.997	–530.404	–91.148	0	73.97
2016	–0.728	–257.366	–19.565	0	85.978

of agricultural water saving measures. The technical redundancy rate reflects on the input redundancy that is caused by external causes such as the technical level and management system of the region in different time periods, while the output of agricultural and crop yield is insufficient, need to increase the crop yield and agricultural income.

3.2. Analysis of influencing factors

Due to the relative efficiency of agricultural water resources utilization and natural conditions, agricultural equipment, science and technology, population quality and other factors are closely linked, select the following indicators for gray correlation analysis: independent variable group indicators include agricultural fixed assets investment x_1, agricultural machinery total power x_2, rural households have the number of pumps x_3, per capita expenditure on education costs x_4; dependent variable for the comprehensive value Y of agricultural water resources in Hubei Province. According to the above index system, the original data values of each index can be obtained on the website of the China Statistics Bureau.

First, the original data will be standardized to calculate the main factors and comparative factors in the absolute value of time, take $\rho = 0.5$, calculate the correlation coefficient of the relevant data in Tables 5 and 6.

According to the results of Tables 5 and 6, the gray correlation values between the independent variables and the dependent variables are calculated. The results are shown in Table 7 and 8.

Table 5
Correlation coefficient of the relevant data calculated value of the one

i	1	2	3	4
Δ_{min}	0	0	0	0
Δ_{max}	7.31	7.09	7.21	7.16
$\phi = \rho\Delta_{max}$	3.66	3.55	3.61	3.58

Table 6
Correlation coefficient of the relevant data calculated value of the two

2006	3.66	3.55	3.61	3.62
2007	3.80	3.71	3.75	3.68
2008	4.01	3.84	4.06	4.00
2009	4.15	3.87	4.31	4.25
2010	4.38	4.06	4.44	4.37
2011	4.51	4.28	4.46	4.39
2012	4.87	4.69	4.85	4.79
2013	5.26	4.98	5.39	5.34
2014	5.47	5.16	5.58	5.53
2015	5.29	5.03	5.24	5.17
2016	5.75	5.27	5.75	5.69
2017	5.95	5.53	5.99	5.93
t	$\Delta_i(t) + \phi_1$	$\Delta_i(t) + \phi_2$	$\Delta_i(t) + \phi_3$	$\Delta_i(t) + \phi_4$

Table 7
Calculation results of correlation coefficient

T	ξ_1	ξ_2	ξ_3	ξ_4
2006	1.00	1.00	1.00	1.00
2007	0.96	0.96	0.96	0.98
2008	0.91	0.92	0.89	0.91
2009	0.88	0.92	0.84	0.85
2010	0.84	0.87	0.81	0.83
2011	0.81	0.83	0.81	0.83
2012	0.75	0.76	0.74	0.76
2013	0.70	0.71	0.67	0.68
2014	0.67	0.69	0.65	0.65
2015	0.69	0.71	0.69	0.70
2016	0.64	0.67	0.63	0.64
2017	0.62	0.64	0.60	0.61
Σ	8.47	8.68	8.29	8.44

Table 8
Correlation calculation and sorting results table

	γ_1	γ_2	γ_3	γ_4
Calculated value order	0.7058	0.7233	0.6908	0.7033
	2	1	4	3

From the calculation results, it can be seen that among the four influencing factors, the total power of agricultural machinery has the greatest influence on the utilization efficiency of agricultural water resources in Hubei Province, followed by agricultural fixed assets investment.

4. Conclusion

Through the C^2R model analysis, the utilization efficiency of agricultural water resources in Hubei Province was only valid in 2017, and the efficiency value was at a low level in the ineffective year.

There are both technical and scale reasons for the invalidity of DEA in the utilization of agricultural water resources in Hubei Province. In the input indicators, there is a redundant phenomenon that the total amount of agricultural water, crop acreage, and the number of workers in agriculture. In the output indicator value, there is a lack of output that agricultural production and crop yield, need to further adjust the combination of resources to achieve the best output.

With the development of the times, the progress of technology, agricultural water resources using input redundancy and output deficiency as a whole showed a decreasing trend in Hubei Province from the time level analysis. These account for that the use of agricultural water resources in Hubei Province has been gradually improved.

The utilization efficiency of agricultural water resources is at a low level in Hubei Province. In order to further improve the utilization efficiency, it is necessary to reduce the water resources utilization efficiency and labor force, the technological innovation should be encouraged to improve the contribution of technological progress in the utilization of agricultural water resources. The government should focus on solving the problems of low utilization of water resources, begin to improve the level of science and technology, management system reformation, quality of the growth of workers. Closing to a healthy, high-tech development direction, no longer rely solely on the consumption of large amounts of resources to obtain rapid economic development, thus contributing to the effective use of water resources efficiency.

The total power of agricultural machinery has the greatest influence on the utilization efficiency of agricultural water resources in Hubei Province, should rely on water saving technology and the introduction of advanced irrigation equipment to improve the efficiency of agricultural water use.

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