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Study on utilization efficiency of water resources in Shijiazhuang City

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ABSTRACT

From the perspective of input and output, using agricultural water, production water, domestic water, COD emissions, labor input, and investment in fixed assets as input indicators and GDP as an output indicator, a DEA model was established to evaluate the utilization efficiency of water resources in Shijiazhuang City for 2010–2016. The results showed that the efficient yearsfor DEA account for 28.6% in the seven years, and the input and output reach a relatively optimal status. Besides, the inefficient years for DEA account for 71.4%, and there exist the situation of redundancy, waste of resources and the insufficient factor utilization efficiency. On the whole, the utilization efficiency of water resources in Shijiazhuang City has been at a low level with a fluctuation, which can be improved through the redundancy analysis results of DEA, so that the optimal allocation of resource inputs can be achieved. As a result, the utilization efficiency of water resources will be improved.

Keywords: DEA; City; Water resources; Efficiency

1. Introduction

Water, the source of life for all things in the earth, is the basic condition for human survival and development and the irreplaceable basic natural resource and strategic resource for sustaining the functions of the earth's ecosystem and supporting the development of social and economic systems. Per capita water resource of China, who is one of the poorest countries in terms of per capita water resources, is only 2,300 m^3, which is only one-fourth of the world average level. Meanwhile, with the development of economy and the increase of population, the contradiction between the supply and demand of water resources in China has become increasingly prominent. Especially, the shortage of urban water resources in North China is even more serious. Therefore, the research on the utilization efficiency of urban water resources presents its significance.

Shijiazhuang City, who is a water resource-deficient area is one of the 35 severely water-starved cities in the country. Total water resources in Shijiazhuang City are 23.500 million m^3. Compared with the required water 3.281 billion m^3, nearly 1 billion m^3 of difference have to be maintained by the over-exploitation of groundwater. Furthermore, the per capita water resource 258 m^3, is 1/8 of the national per capita water resources, which is less than Israel known for lack of water. According to the internationally recognized quantitative standard for lean water, Shijiazhuang City is an absolute water-poor area. Shijiazhuang City,on the one hand, has a serious shortage of water resources and an outstanding contradiction between supply and demand. On the other hand, the water use efficiency is relatively low and the water pollution is serious, which greatly restrict economic development. Therefore, accelerating the effective and full use of water resources is one of the most important issues faced by Shijiazhuang City in the future.

With the attention paid to the protection, development and utilization of water resources, the issue of the utilization efficiency of water resources has received increasing attention. From the perspective of research progress abroad, some scholars have evaluated the use efficiency of agricultural water [1–4] and industrial water [5,6]. More scholars have studied the utilization efficiency of water resources

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from a regional perspective [7–9]. The above studies have either analyzed the utilization efficiency of partial water or evaluated the utilization efficiency of the total regional water consumption. Compared with previous studies, this study has gathered the agricultural water, industrial water, domestic water, and COD emissions into the water resources input index system simultaneously, and adopted the more widely used data envelopment analysis (DEA) method to evaluate the utilization efficiency of water resources in Shijiazhuang City. And the results have been further projected, adjusted and improved.

2. Methodology

2.1. Brief description of DEA method

Data envelopment analysis (DEA), founded in 1978 by Charnes, Cooper, and Rhodes [10], is a field of cross-disciplinary research in operations research, management, and mathematical economics, which is a system analysis method developed on the basis of "Relative Efficiency Evaluation". Based on the concept of relative efficiency, DEA mainly adopts mathematical programming methods and employs the observed data sample data to regard each evaluated unit as a decision making unit (DMU). And then a number of DMUs form the evaluated group. Using a comprehensive analysis of input and output ratios, the weights of the various input and output indicators in the DMU are used as variables to determine whether each DMU is DEA efficiency. It is also possible to use projection methods to find out the reasons for non-DEA efficiency and the direction and degree of the improvement. Since the DEA method does not require pre-estimation of parameters, it has the advantage that it can't be underestimated in terms of avoiding subjective factors, simplifying calculations and reducing errors.

2.2. DEA model

Common models for DEA include C2R, C2 GS 2, C2WH, C2W, BCCD, and so on. The C2R model in DEA was adopted to analyze the utilization efficiency of water resources. And the mathematical expression of the model is as follows:

$$\begin{cases} \min\theta-\varepsilon\left[\sum_{r=1}^{t}S_r^{+}+\sum_{i=1}^{m}S_i^{-}\right], \\ \sum_{j=1}^{n}\lambda_j x_{ij}+S_r^{+}+-\theta x_{ij0}=0, \\ \sum_{j=1}^{n}\lambda_j y_{rj}-S_r^{+}=y_{rj0}, \\ \lambda_j\geq 0, j=1,2,\cdots,n; \\ S_i^{-}\geq 0, S_r^{+}\geq 0, \end{cases} \tag{1}$$

where n is the number of DMUs in the decision making unit. The evaluation index system consists of m and t, which represent input indicators (resources consumed) and output indicators (effectiveness of work), respectively. And x_{ij} is the input amount of the jth decision making unit for the ith type of input. While y_{rj} is the output amount of the jth decision making unit for the rth type of output. S_r^{+} called input redundancy and S_i^{-} called insufficient output are the slack variables. The symbol ε is the non-Archimedes infinitesimal quantity, which is taken as 10^{-6} when calculating. The symbol λj is the combined proportion of the jth decision making unit DMU in an effective DMU combination reconstructed with respect to DMU i. And the symbol θ is the effective value of the decision making unit, that is, the relative efficiency of input and output.

2.3 Meaning of DEA model

1) When $0^{*}=1$ and $S_r^{+}=S_i^{-}=0$, the DMN in the DEA is efficient, the effective frontier formed by DMN is considered as constant returns to scale, and DUM is regarded as scale and technical efficiency;
2) If $\theta^{*}<1$ or $S_i^{-}\neq 0$ and $S_r^{+}\neq 0$, it is considered that the DMU in the DEA is inefficient or the technology is inefficient, or that the scale is inefficient. If $S_r^{+}=S_i^{-}=0$, it is considered that the technology is efficient. Let $K=\frac{1}{\theta}\sum_{j=1}^{n}\lambda_j^{*}$, when $K=1$, it is defined as the efficiency of the DMU scale. Otherwise, when $K<1$, returns to scale increase. Contrarily, returns to scale decrease.
3) If DMU is inefficient, the non-DEA efficient decision making unit can be modified by the projection of the DMU on a relatively effective plane, so that the original input can be reduced ($x_0\geq 0$) without reducing the output, or the output can be increased without increasing the input. ($y_0\geq 0$), that is:

$$\begin{cases} X_0=\left(1-\theta^{*}\right)x_0=S^{*-}\geq 0 \\ y_0^{*}=S^{*+}\geq 0 \end{cases} \tag{2}$$

3. Selection of indicators and calculation results

3.1 Selection of indicators

When the DEA model is employed to evaluate the utilization efficiency of water resources in Shijiazhuang City from 2010 to 2016, the population, water use type, capital and energy are the factors must be taken into account in the study of the utilization efficiency of water resources. Based on the characteristics of water resources utilization in Shijiazhuang City, seven indicators such as agricultural water, industrial water, domestic water, the number of laborers, investment in fixed assets, and COD emissions were used as model input variables, and GDP was used as an output variable. The data mainly were obtained from the "Shijiazhuang Statistical Yearbook" from 2011 to 2017.

3.2. Calculation results

The relevant data of input and output indicators of Shijiazhuang City from 2010 to 2016 substituted into the C2R model and the deap2.1 software were used for calculation. The results are shown in Tables 1 and 2.

Table 1
DEA evaluation results of use efficiency of water resources in Shijiazhuang City

Year	θ	$K=\frac{1}{\theta}\sum_{j=1}^{n}\lambda_j^*$	Relative effectiveness	Scale effectiveness	Technical effectiveness
2010	0.8996	$K>1$	DEA inefficiency	decreasing	inefficiency
2011	0.8184	$K>1$	DEA inefficiency	decreasing	inefficiency
2012	1	$K=1$	DEA efficiency	appropriate	efficiency
2013	0.7952	$K>1$	DEA inefficiency	decreasing	inefficiency
2014	1	$K=1$	DEA efficiency	appropriate	efficiency
2015	0.8539	$K<1$	DEA inefficiency	increasing	inefficiency
2016	0.8205	$K>1$	DEA inefficiency	decreasing	inefficiency

Table 2
Redundancy analysis of years for non-DEA efficiency

Year	Saving agricultural water (100 million tons)	Saving industrial water (100 million tons)	Saving domestic water (100 million tons)	Saving water by laborers (10 thousand people)	Saving investment of fixed asset (100 million Yuan)	Reducing COD (10 thousand tons)
2010	4.7528	2.1467	0.5634	26.5861	14.5264	2.5649
2011	6.8761	2.7589	0.8142	34.5216	37.7467	8.3461
2013	9.3741	3.6003	1.2892	64.2267	74.3528	12.6584
2015	5.7564	2.4469	0.6199	28.9045	32.9152	3.3297
2016	6.2143	2.4961	0.7548	30.7855	34.0426	5.1285
Average saving rate (%)	6.34	10.67	4.98	4.62	6.61	12.63

4. Results and discussion

From Table 1, it can be seen that the utilization efficiency of water resources in Shijiazhuang City had reached the relative efficiency in 2012 and 2014 during the period from 2010 to 2016, which means that the input and output reached an optimal state, and both technology and scale reached their efficiency. Besides, the DEA had been inefficient in all other years. Among them, years for efficiency had accounted for 28.6%, and years for inefficiency had accounted for 71.4%. And among the years for DEA inefficiency, the utilization efficiency of water resources had been less than 0.9.

In the view of the technical effectiveness, all non-DEA effective years had been technically inefficient, indicating that too much resources had been used in the production process, the input can be reduced by the same proportion as θ* , and the factor input structure needs to be further improved.

From the point of scale effectiveness, it had been in the right stage in the years for DEA effectiveness, which had reached the best point of scale profit. Besides, in the years for non-DEA effectiveness, the increasing scale in 2015 indicates that the expansile investment can improve water use efficiency. And the scale had declined in the remaining four years, indicating that the increase in input had not bring about an increase in output. The excessive scale of investment will cause unnecessary waste of resources and the efficiency should be improved through science and technology and economic means.

The non-DEA efficient years in Table 1 were projected on the effective plane, and the results are shown in Table 2. Among these years, there exist redundancy in agricultural water, industrial water, domestic water, labor input, fixed asset investment, and COD emissions in Shijiazhuang City, where they can be respectively saved or reduced 650.47 million tons, 2.6898 million tons, 80.83 million tons, 370,490 people, 3.8777 billion yuan and 640.55 million tons. From the perspective of average saving (cutting) rate, COD can be cut to the most extent, reaching 12.63%, followed by industrial water consumption, which is 10.67%. Therefore, saving industrial water consumption and reducing wastewater COD emissions are future focus on water resource utilization in Shijiazhuang City.

5. Conclusions

On the whole, the utilization efficiency of water resources in Shijiazhuang City from 2010 to 2016 had been relatively low. In these seven years, the years for DEA efficiency had accounted for 28.6%, and the years for DEA inefficiency had accounted for 71.4%. The reasons for the DEA inefficiency for water resources use in Shijiazhuang City are the technological inefficiency and scale inefficiency.

The sustainable use of water resources has an important foundational and supportive role for sustainable economic and social development. Therefore, Shijiazhuang City should focus on improving the efficiency of water resources. The specific recommendations are as follows:

Firstly, the proportion of agricultural water needs to be vigorously reduced and the efficiency of agricultural water has to be vigorously increased. Meanwhile, the water-saving efforts in agricultural production must be strengthened and the capital investment in basic water conservancy facilities should also be increased. As well as, the water-saving technological transformation ought to be speed up and the reasonable layout of the agricultural industry is actively supposed to be adjusted.

Secondly, in order to increase the use efficiency of the water resources, the industrial layout in Shijiazhuang City should be adjusted by developing low-water-consumption industries and limiting high-water-consuming industries. The industrial water model with "reducing water consumption" and "recycling wastewater" should be established to improve the use efficiency of industrial water by absorbing advanced technologies at home and abroad.

Thirdly, according to the evaluation results of scale effectiveness, the input of production factors in Shijiazhuang City should be rationally planned, COD emissions are supposed to be reduced, and the proportion of investment in production such as capital, labor and so on should be decrease. Adhere to the development of technology as the main line, continuously improve the scale effect and technology effectiveness, and optimize various resources, so that the efficiency of input and output can achieve the optimal state.

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