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Analysis on Water Use Efficiency in Thirteen Cities of Jiangsu Province Based on DEA

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***Abstract*—Starting with the brief analysis of current utilization of water resources in 13 cities in Jiangsu province, input oriented, this thesis evaluated the changes and differences of production and living water use efficiency among the cities in Jiangsu from 2005 to 2014 based on data envelopment analysis's C2R model. In general, water utilization efficiency of the whole province as well as every city was improving in the last decade. There are obvious differences of water use efficiency among these cities, despite the similar escalating trend in the perspective of time sequence. 13 cities in Jiangsu Province are divided into four types regarding their level of water use efficiency by K-means clustering analysis. Cities in demand of improving water use efficiency can learn from cities of higher water use efficiency. Economic development has great influence on water use efficiency. Generally speaking, efficiency of water utilization is higher in the developed cities; the higher GDP per capital. This faster water use efficiency grows. The present redundant inputs of the cities showing invalid water use efficiency reveal extra resources allocation, which can be theoretically resolved to arrive at the optimal equilibrium point through the analysis of the DEA projection.**

Keywords*—*water use efficiency; data envelopment analysis (DEA); water resource

I. INTRODUCTION

Water resources are the most basic and important material resources for human beings to live on. China's water resources are relatively abundant, but the per capita water resources are far below the world average, and Jiangsu's per capita water resources are only a quarter of the country's total. In recent years, Jiangsu's economy has developed rapidly, and the annual water consumption of agriculture and industry is huge. The contradiction between supply and demand of water has become increasingly prominent, and it is extremely urgent to improve water use efficiency. At the same time, due to the differences in natural environment, population, economic structure and development level, the utilization efficiency of water resources in the 13 cities of Jiangsu Province is quite different. Therefore, through the quantitative analysis of water consumption in the 13 cities of Jiangsu Province, the spatial and temporal changes of water use efficiency in Jiangsu Province are judged, and the potential for water saving in Jiangsu Province can be effectively digested in the future, water production is determined, water is used to build cities, and water saving type is constructed. Society has important practical significance.

At present, the methods for studying water use efficiency are mainly non-parametric and parameter efficiency evaluation methods. The two most representative methods are Data Envelopment Analysis (DEA) and Random Frontier Analysis (SFA). The former belongs to the mathematical planning method, and the latter belongs to the economic measurement method. DEA method to investigate the relative efficiency of each decision-making unit (DMU) does not need to presuppose the specific production function, avoid the influence of abnormal points, and has high stability, which is more common in the study of water use efficiency.

The research on water use efficiency in foreign countries is concentrated in agriculture, industry and cities, and there is little comparative analysis between regions. Some scholars have studied the use of agricultural water resources and the improvement of efficiency [1-5], Dhehibi et al. [1] (2007) used SFA to study the agricultural water efficiency of several farms; some scholars such as Bindra et al [6] (2003) Studying the efficiency of industrial water use; some studies on urban water use efficiency, Aida et al. [7] (1998) used DEA's RAM method to evaluate the efficiency of urban water supply facilities in Japan, Alsharif et al [8] (2008) Using DEA to analyze the water efficiency of cities in

Pakistan in a time series, and to provide opinions on the management of water resources.

Domestic scholars have studied the utilization efficiency of water resources from multiple angles and aspects. Industries studied include agriculture, industry, etc. The regional scope covers national scope, provincial scope, municipal district, and watershed scope. At the same time, the changes in water use efficiency are analyzed from different angles such as time and space. Shen Xinyuan (2015) used the super-efficiency model calculation to obtain the comprehensive efficiency of each city in Jiangsu Province, and analyzed the problems existing in low-efficiency cities. Zhao Chen et al (2013) used the water footprint theory to analyze the provinces that consume the most water resources in Jiangsu Province, and analyzed the water use efficiency of Jiangsu in various years from 2000 to 2010 as the decision-making unit. Zhang Nana (2015) conducted a data envelopment analysis of agricultural water use in Jiangsu Province from 2002 to 2011, and concluded that the agricultural water use efficiency in the province is growing.

In short, in the context of building a water-saving society, the efficiency of water use has become a hot topic in academic research. This paper draws on the achievements of previous studies on water use efficiency, using the empirical analysis method of data envelope DEA, taking the regional GDP as the output indicator, taking the production water consumption, domestic water consumption, the number of employees, and fixed assets investment as input indicators. From the perspective of input-output, the production, living and total water use efficiency of cities in Jiangsu Province were compared and analyzed, and corresponding countermeasures and suggestions for improving water use efficiency in Jiangsu Province were proposed.

II. Current Status of Water Resources Utilization in Thirteen Cities of Jiangsu Province

A. *Current Situation of Water Resources in Jiangsu Province*

The surface water resources in Jiangsu Province are 29.64 billion cubic meters, and the groundwater resources are 11.89 billion cubic meters. The province's total water resources are 39.93 billion cubic meters, accounting for 1.46% of the country's total water resources. However, the population of Jiangsu Province is densely populated, and the per capita water resource is only 502.3 cubic meters, which is about the national average level. The contradiction between supply and demand of water resources is more prominent. Economic development and water resources are not coordinated. In Jiangsu's water consumption, production water is the largest proportion of total water use, accounting for 92%.

B. *Current Status of Water Resources Utilization in Jiangsu Province*

In 2014, the total water supply in Jiangsu Province was 488.62 million cubic meters, 98% of the water supply came from surface water sources, and 2% of the water supply came from groundwater. In 2014, the province's total water consumption was 488.062 million cubic meters. Among them, production water accounts for 92%, residential water consumption accounts for 7.4%, and urban environmental water accounts for 0.6%.

From a regional perspective, water use in northern Jiangsu accounted for 39.7% of the province's total water use; Suzhong area' water consumption accounted for 22.4% of total water consumption; and southern Jiangsu water consumption accounted for 38% of total water use. Compared with 2013, water use in northern Jiangsu increased by 1.76%, Suzhong area decreased by 7.2%, and southern Jiangsu decreased by 6.73%. Among them, Yancheng and Suzhou have the largest water consumption, but the main water use in salt cities is agricultural water, and the main water in Suzhou is industrial water. Cities with water consumption below 3 billion cubic meters include: Suqian, Lianyungang, Zhenjiang and Changzhou. The cities with higher agricultural water consumption are Yancheng, Xuzhou, Huai'an, Taizhou, Suqian and Lianyungang; the cities with large industrial water consumption are Suzhou, Wuxi and Changzhou; the city with the largest proportion of domestic water consumption is Nanjing.

C. *Analysis of Water Use Indicators in Various Regions of Jiangsu Province*

Since the municipalities directly under the Central Government of Jiangsu Province do not have open and complete water use data, the data is largely missing. Therefore, the analysis and research of various regions in Jiangsu Province is mainly for the urban areas of the 13 cities in Jiangsu Province. Table 1 shows some water use indicators for various regions of Jiangsu Province in 2005 and 2014.

As can be seen from the table, in 2014, the urban area with the highest per capita water consumption was Suzhou, and the lowest was Yancheng. The highest daily water consumption per capita is in Nanjing, and the lowest is Taizhou. In 2014, compared with 2005, the per capita water consumption decreased by Nanjing, Nantong, Yancheng and Taizhou. Nanjing, Nantong, Lianyungang and Taizhou have fallen in per capita daily water use. The data shows that in addition to the decline in the water use population in the urban areas of Changzhou, Yangzhou and Zhenjiang, the water use population of the other cities has increased significantly. In the past 10 years, the per capita water consumption and the per capita daily water consumption of most cities in the province have increased, which is related to the increase of urban water users, economic development and the improvement of people's living standards.

III. Empirical Analysis of Water Use Efficiency in Thirteen Cities of Jiangsu Province

A. *DEA Model Selection*

Use the model to analyze the water use efficiency of cities in Jiangsu Province. Suppose there are n decision units DMU_j, s^- and s^+ are slack variables. Each decision-making unit has input variables m and output variables s. Then the input vector of decision unit DMU_j is $x_j = (x_{1j}, x_{2j}, x_{3j}, \cdots, x_{mj})^T$ and its output vector is $y_j = (y_{1j}, y_{2j}, y_{3j}, \cdots, y_{sj})^T$. The weight vector of input and output of each city in Jiangsu Province is λ_j, which is input-oriented, and the corresponding efficiency index of each decision-making unit is θ. The C^2R model can be expressed by the dual programming of linear programming. Let DMU_{j0} input and output be (x_{j0}, y_{j0}), record as (x_0, y_0), satisfy:

$$s.t.\begin{cases} \min\theta \\ \sum_{j=1}^{n}\lambda_j x_j + s^- = \theta x_0 \\ \sum_{j=1}^{n}\lambda_j y_j - s^+ = y_0 \\ s^- \ge 0, s^+ \ge 0 \\ \lambda_j \ge 0, j = 1,2,3\cdots n \end{cases}$$

The model C^2R has the following economic implications:

- If $\theta=1$, and $s^+ = s^- = 0$, both decision unit DMU and DEA all are effective, which explains that the DMU scale and technology are effective.
- If $\theta=1$, and $s^+ \neq 0$ or $s^- \neq 0$, Then the decision unit DMU is the DEA, a weak effective. DMU is not effective or not technically effective. You can reduce the amount of redundancy while maintaining output or increase output without changing inputs.
- If $\theta<1$, and $s^+ \neq 0$ or $s^- \neq 0$ The decision unit DMU is DEA that invalid.

Both efficiency of DMU and technical efficiency are ineffective. It can be improved by projection on its relatively effective plane.

B. *Indicator Selection*

Water as a basic input factor, combined with other production factors can produce economic benefits. Referring to the literature on water efficiency related research and according to the principle of input index selection, this paper selects the following indicators as input indicators: production water consumption (10^4t), domestic water consumption (10^4t), number of employees (10^4t person), fixed assets investment (10^4t yuan). From the perspective of the output efficiency of water resources, the regional GDP (10^4t yuan) is selected as the output indicator.

C. *Data Sources*

According to the availability of data, this paper selects the relevant data of Jiangsu Province's thirteen cities in the study of water use efficiency in Jiangsu Province. The data includes 10a (2005-2014) and horizontal coverage of 13 places in Jiangsu Province. The data source for all input and output indicators in this paper are the “Jiangsu Statistical Yearbook”.

D. *Empirical Analysis*

Taking 130 samples from 13 urban areas in Jiangsu Province from 2005 to 2014 as the decision-making unit, the DEA model was used to obtain the comprehensive efficiency (θ) and the slack variables s^- of each index. According to the water efficiency value of the 13 cities in Jiangsu Province, the time series of water efficiency change analysis can be carried out, and the water use efficiency gap between cities in each year can also be analyzed by region. The water efficiency levels of 13 cities in the province can be judged intuitively by segmentation color map and cluster analysis. At the same time, the change in the water input can be measured for the projection of the current non-useful water city.

As can be seen from the figure, the average efficiency of water use in Jiangsu Province during the past 10 years is 0.723. The water use efficiency gap between cities is relatively obvious. The highest average annual water use efficiency is Suzhou, with a value of 0.892. The city with the lowest annual average water use efficiency is Lianyungang, with a value of only 0.495, which is 0.397 different from the most efficient Suzhou city. According to the annual average water use efficiency from high to low, the order of the 13 cities in Jiangsu Province is: Suzhou, Yangzhou, Xuzhou, Wuxi, Taizhou, Yancheng, Suqian, Changzhou, Nantong, Zhenjiang, Huai'an, Nanjing, Lianyungang. Among them, Suzhou, Yancheng and Taizhou have achieved the best water efficiency in the past two data years. In 2014, except for Nanjing, Wuxi, Nantong, Lianyungang, Huai'an and Suqian, the rest of the cities achieved the best water use efficiency. In 2014, Nanjing's total water use efficiency was the lowest. The urban GDP of Nanjing City was 34.42% higher than the average level of all cities and towns in Jiangsu Province. The gap was huge.

1) Spatial analysis of water use efficiency in Jiangsu province: According to the ranking of the 13 cities in terms of the total water use efficiency, production water efficiency and domestic water use efficiency of the cities in the province, it can be seen that the water efficiency indicators of Suzhou and Yangzhou are relatively high, and the water use in Nanjing and Lianyungang is high. The efficiency level is the lowest in the province. Changzhou's production water efficiency level is low, but domestic water efficiency is at the middle level. The water use efficiency levels of Yancheng and Zhenjiang are higher than their respective domestic water use efficiency levels. The levels of indicators in other cities are basically the same.

Using SPSS16.0 to cluster the total water use efficiency of each city in Jiangsu Province, K-Means clustering was used to classify the total water use efficiency of 13 cities into four categories: high water efficiency zone, higher water efficiency zone, and medium water efficiency zone. Low water efficiency zone is shown in "Table I".

TABLE I. K-MEANS CLUSTERING RESULTS

High water efficiency zone	Suzhou, Yangzhou, Xuzhou, Wuxi
A light higher water efficiency zone	Taizhou, Yancheng, Suqian
Medium water efficiency zone	Changzhou, Nantong, Zhenjiang, Huaian
low water efficiency zone	Nanjing, Lianyungang

2) Analysis of time variation of water use efficiency in Jiangsu province: According to the per capita GDP of each city in Jiangsu Province, the 13 cities in the province are divided into four categories: developed regions, more developed regions, moderately developed regions and underdeveloped regions. Developed regions include Suzhou, Wuxi, Nanjing, and Changzhou; more developed regions include Zhenjiang, Yangzhou, and Nantong; medium-developed regions include Taizhou, Xuzhou, and Yancheng; and underdeveloped regions include Huai'an, Lianyungang, and Suqian.

The change curve of water use efficiency in medium-developed areas is located above the developed areas as a whole. The water use efficiency of Nanjing and Changzhou has lowered the average water use efficiency of economically developed areas. The water efficiency curve for underdeveloped regions is below the provincial average. Water use efficiency in underdeveloped areas continued to decline in 2005-2008. In 2008, except for the water efficiency in economically developed areas, the water efficiency in the rest of the region has decreased. By 2009, the total water use efficiency in developed regions also declined slightly. Overall, the time for efficiency decline in each region coincides with the time point of the 2008 financial crisis. Since 2011, water efficiency in all regions has been on the rise. Water efficiency in underdeveloped regions has risen steadily since 2010, and the slope of the curve is also significantly higher than other types of regions.

IV. CONCLUSION AND SUGGESTION

A. Conclusion

This paper compares and analyzes the changes and differences in water use efficiency in different years and different regions of Jiangsu Province. Empirical studies show that, in addition to individual years, Jiangsu Province as various cities have experienced increasing water use efficiency over the years. Comparing the regional distribution of water use efficiency between the initial year and the current year, it is found that the areas with higher water efficiency levels in the past are located in the northwestern part of Jiangsu Province, while the areas with higher annual water use efficiency are concentrated in the central and southeastern parts of the province, reflecting the 10-year period. Factors such as the city's economy have a great impact on changes in water use efficiency. The water use efficiency varies greatly among different urban areas in the province. Through cluster analysis, it can be divided into four areas with high water efficiency: high water efficiency area {Suzhou, Yangzhou, Xuzhou, Wuxi}; higher water efficiency area {Taizhou, Yancheng, Suqian}; medium water efficiency zone {Changzhou, Nantong, Zhenjiang, Huai'an}; low water efficiency zone {Nanjing, Lianyungang}. The empirical results also projected the non-water-efficient decision-making units of the current year: Nanjing, Wuxi, Nantong, Lianyungang, Huai'an, Suqian, and calculated the radial slack and slack of production and domestic water inputs. The value of the input after projection can be used as the basis for policy recommendations.

B. Suggestion

1) The efficiency of agricultural water use should be effectively improved: The proportion of agricultural water used in total water use in the province is huge, and improving the efficiency of irrigation water is crucial. The improvement of the effective use of agricultural water depends on the extensive use of scientific agricultural irrigation measures and various water-saving projects, such as: micro-irrigation, low-pressure pipe irrigation, and film mulching. The government should also appropriately adjust the price of agricultural water and promote the water conservation to agricultural farmers, which will help raise farmers' awareness of water conservation and improve the efficiency of agricultural water use.

2) Accelerating technological innovation and increasing the repetition rate of industrial water use: The efficiency of urban industrial water use is related to its industrial structure. Each city should reduce some industries that have high water consumption and high emissions, and whose output value is not high, and develop low-water consumption industries. Enterprises with high water consumption need to eliminate old and aging equipment, apply advanced sewage treatment and re-use water equipment, and also need to improve the technical level and improve the production process.

3) Vigorously promoting the construction of a water-saving society: On the one hand, we must raise the awareness of the people's water saving. Water-saving propaganda is the most basic measure that can affect people's perceptions to a certain extent. On the other hand, the behavior of water use is greatly affected by the price of water, and the leverage mechanism of reasonable water price adjustment can greatly promote water conservation. In addition, it is necessary to reduce the leakage rate of the pipe network, regularly repair the pipe network, replace the aging water supply pipe network, and reduce the phenomenon of "running and dripping". All cities should also promote water-saving sanitary ware in residential and urban buildings throughout the city. Only in this way can we tap a considerable potential for water saving in living, and the efficiency of domestic water use will be greatly improved.

REFERENCES

[1] Dhehibi B, Lachaal L, Elloumi M, et al. Measuring irrigation water use efficiency using stochastic production frontier: an application on citrus producing farms in Tunisia [J]. African Journal of Agricultural & Resource Economics, 2007, 01 (2).

[2] Onishi A, Morisugi M, Imura H, et al. Study on the efficiency of agricultural water use in yellow River Basin [J]. Journal of Arid Land Studies, 2008, 18: 45-55.

[3] Katar Singh. Rational pricing of water as an instrument of improving water use efficiency in the agricultural sector: a case study in Gujarat, India[J]. International Journal of Water Resources Development, 2007, 23 (4): 679-690.

[4] Christian-Smith J, Cooley H, Gleick P H. Potential water savings associated with agricultural water efficiency improvements: a case study of California, USA [J]. Water Policy, 2012, 14 (2): 194-213.

[5] Mcvicar T R, Zhang G, Bradford A S, et al. Monitoring regional agricultural water use efficiency for Hebei Province on the North China Plain [J]. Crop & Pasture Science, 2002, 53 (1): 55-76.

[6] Bindra S P, Muntasser M, Khweldi M E, et al. Water use efficiency for industrial development in Libya[J]. Desalination, 2003, 158 (1-3): 167-178.

[7] Aida K, Cooper W W, Pastor J T, et al. Evaluating Water Supply Services in Japan with RAM: a Range-adjusted Measure of Inefficiency[J]. Omega, 1998, 26 (2): 207-232.

[8] Alsharif K, Feroz E H, Klemer A, et al. Governance of water supply systems in the Palestinian Territories: A data envelopment analysis approach to the management of water resources [J]. Journal of Environmental Management, 2008, 87(1): 80-94.