Spatiotemporal evolution of water use efficiency in water conservation areas in the upper reaches of the Yellow River: A case study of the Lanzhou-Xining urban agglomeration

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Abstract. The ecological protection and high quality development of the Yellow River Basin has become a major national strategy in China. Studying the water use efficiency of important water source conservation areas in the upper reaches of the Yellow River is for promoting the allocation of water resources and regional green development. This paper takes 39 county units as the research object, based on the DEA (SE-SBM) model. Introducing the Human Green Development Index (HGDI) was applied to measure its water use efficiency and analyze its spatial pattern.

1. Introduction

Coordinating the coordinated development of the upper, middle and lower reaches of the Yellow River. Promoting ecological protection and high-quality development of the Yellow River Basin is an important national strategy of China at present. With the development of urbanization in China, the contradiction between social economic development and water ecological environment is increasingly. The Lanzhou-Xining urban agglomeration is an important water source conservation and recharge area in the upper reaches of the Yellow River, the upper reaches of the Yangtze River and the inland river basin of Hexi. Under the premise of not endangering water security in the middle and lower reaches, rational development and utilization of water resources to promote economic and social development in the region has become an urgent issue in the region.

2. Study Area

The Lanzhou-Xining urban agglomeration is located in the transitional zone between the Qinghai-Tibet Plateau and the Loess Plateau. It belongs to the upper reaches of the Yellow River, the remaining mountains of the North Qilian Mountains, and the middle of the river and the valley, surrounded by national ecological barriers. According to the definition of the spatial scope of Lanzhou-Xining urban agglomeration in the Lanzhou-Xining Urban Agglomeration Development Plan issued by the state, the research area of this paper includes Lanzhou City., Baiyin District, Dingxi City, Linxia City, Xining City, Haidong City, Hainan Prefecture, Haibei Prefecture, Huangnan Prefecture, a total of 39 counties. The total area is 97,500 square kilometers. In 2017, the Lanzhou-Xining urban agglomeration has a total production value of 487.4 billion yuan and a resident population of 11.93 million. With 7.41% of the land, it carries 52.8% of the GDP and 44.36% of the population of the Gansu and Qinghai provinces. It is an important economic growth pole in the Northwest.
3. Data and Methods

3.1 Indicator selection

This article uses 2005, 2010, 2015 and 2017 as four research years. Capital stock, sub-sector water use, labor force as input indicators. Output indicators include the expected output of real GDP and the human green development index, as well as the total unexpected output. In order to implement the green development concept, it highlights the important water ecological security status of the Lanzhou-Xining urban agglomeration. This paper sets the weight of the desired output and the undesired output to 1:1. Put water pollution emissions and remediation at the same level as economic construction.

3.2 Super-efficient SBM model

Data Envelopment Analysis is a method for evaluating the relative efficiency of decision-making units in a multi-input and multi-output state using a multi-objective decision model. The SBM model solves the problem that the traditional DEA does not consider the input-output slack variables. However, when there are many indicators, there will be multiple decision-making units with an efficiency value of 1. If the effective DMU efficiency values are the same, no further distinction can be made. In order to solve this problem, Petersen proposed a "Super-efficiency" model. He model avoids the deviations that may be caused by the model setting, and can comprehensively consider the relationship between input, desired output and undesired output, and can further distinguish effective decisions.

4. Results and Analysis

4.1 Analysis of SE-SBM model results

From the time dimension, from 1995 to 2017, the water use efficiency of 39 county units in the Lanzhou-Xining urban agglomeration showed a volatility growth trend. Only 8 regions have a mean water use efficiency of 1, which is effective for DEA. Most of the rest of the region did not achieve DEA effectiveness, showing that the overall development level of water use efficiency of the
Lanzhou-Xining urban agglomeration is still relatively low. In 2005, the average utilization rate of water resources was 0.637. The areas with water use efficiency of 39 in 39 counties were Lanzhou Chengguan District, Qilihe District, Linxia City, Xining City District, Chengdong District, Haishu County and Gonghe County, Tongren County. The water use efficiency in 2010 has decreased compared with 2005. This and theoretically, with the improvement of the level of economic development, the water use efficiency will increase accordingly. The reason may be that a global financial crisis occurred in 2008, causing a short-term turmoil in resource allocation. During this period, the Lanzhou-Xining urban agglomeration region pursued economic benefits to a certain extent and ignored emissions from undesired outputs. After 2010, there will be a significant increase in water use efficiency. After 2010, the water use efficiency has increased by a large margin. The average value has increased from 0.618 in 2010 to 0.768 in 2015, which has reached 24.3%. In recent years, the state has introduced a series of water management policies to optimize water resources allocation and promote sustainable use of water resources, which has boosted water use efficiency. In 2011, the State Council promulgated the No. 1 Document of the Central Government to implement the most stringent water resources management system, further clarifying the objectives of China's water resources management. Gansu Province and Qinghai Province actively responded to a series of water resources management policies promulgated by the state, successively formulated the most stringent water resources management system assessment methods, and established the most stringent water resources management system target responsibility assessment system. These policies have prompted the aquatic ecosystem to gradually achieve a virtuous cycle. The average water use efficiency in 2017 was 0.782. Although the growth rate has slowed down compared with the previous one, the overall trend is still rising, and only a few regions have experienced a slight decline.

From the perspective of regional spatial dimension, the trends of water use efficiency in the counties and districts of the Lanzhou-Xining urban agglomeration are roughly the same. Lanzhou City Chengguan District, Qilihe District, Xining City Chengdong District, Chengxi District and other places have higher water use efficiency. This is mainly due to the better economic development level in the region, which makes the economic output per unit area of water resources higher, and the water-saving and pollution control infrastructure construction is relatively perfect. In recent years, many provinces in Qinghai Province have implemented the “clear water” governance action and continued to promote the prevention and control of water pollution in the basin. However, the water
use efficiency based on the green development concept not only focuses on its economic benefits, but also on the discharge of undesired output sewage. This has led to the high water use efficiency of agricultural and pastoral areas in Haixi County, Tongren County, and Hualong County, which are lagging behind in the Qinghai Province. In 2005 and 10 years, DEA was effective. The reason is that the region is sparsely populated and economic development is backward, but the water resources endowment is better, and the layout of high-energy-consuming industrial enterprises is very small. The low pollutant emissions have a weaker ability to destroy the aquatic ecosystem, making the region one of the regions with relatively good water use efficiency. However, it is worth noting that in 2017, the water use efficiency of Gonghe County and Yuzhong County in Qinghai Province decreased slightly, from the original DEA effective area to the ineffective area. In recent years, in order to speed up the pace of development, these regions have begun to show their economic development with high water consumption and high energy consumption industries. This approach has led to an increase in undesired output, but in these areas there is a lack of advanced waste water treatment, recycling technology, water infrastructure is not perfect, resulting in a gradual imbalance in the input and output ratio of its water use.

In Baiyin City, some counties and districts in Haidong City mainly focus on petrochemical, non-ferrous smelting, coal and other heavy-duty industries with high water consumption, high energy consumption and high pollution. Not only increased the amount of water used, but also increased the amount of sewage discharged. Advanced wastewater treatment and water recycling technologies have not been widely promoted in industrial enterprises. Large unexpected output seriously affects its efficiency and makes its water resources use not optimal. The counties and districts with low water use efficiency are mostly those with low economic development level, single industrial structure and large proportion of agricultural water use. Mainly include Jishishan County, Dongxiang County, Minhe County, Jingtai County, Yongdeng County, Dingxi City, etc. Efficient sprinkler irrigation, drip irrigation and other agricultural water-saving technologies have not yet been popularized. The water consumption per unit area of agricultural production is large, and the water resources utilization input and output redundancy are high. Driven by China’s precise poverty alleviation policy, most of the counties and districts in Huangnan and Hainan of Qinghai Province have adopted ex situ relocation measures. The peasants and herdsmen living in poverty will be relocated to urban areas with better soil and water resources, so that the population will gradually gather in the towns. Increased use of water resources in cities and towns, and the inability to build a complete water infrastructure to support a rapidly increasing population. The contradiction between supply and demand of water resources has gradually intensified, and the improvement of water use efficiency in the region has been severely challenged.

4.2 Analysis of spatiotemporal evolution characteristics

Based on ESDA exploratory spatial analysis technology, the global Moran's $I$ index of water resource utilization efficiency of the Lanzhou-Xining urban agglomeration in 2005, 2010, 2015 and 2017 was calculated by Geoda software. This indicates that the utilization efficiency of water resources in county unit of the Lanzhou-Xining urban agglomeration has a significant positive spatial correlation. Over time, this spatial dependence increased from 0.153 to 0.459, an increase of nearly three times.

| Year | 2005 | 2010 | 2015 | 2017 |
|------|------|------|------|------|
| Moran's $I$ | 0.153 | 0.273 | 0.306 | 0.459 |
| $Z(I)$ | 3.069 | 3.213 | 4.069 | 4.722 |
| $P(I)$ | 0.005 | 0.003 | 0.001 | 0.001 |

Moran's $I$ of global autocorrelation can only reveal whether the water resource utilization efficiency of the Lanzhou-Xining urban agglomeration has significant spatial agglomeration characteristics on
the whole, but it can’t judge and identify the spatial agglomeration pattern among county units within
the city group. In this paper, the LISA cluster map is drawn by calculating the local Moran's $I$ index,
which intuitively reflects the local spatial heterogeneity of LISA.

Fig. 3  2005-2017 LISA clustering distribution of water resource utilization efficiency in counties of Lanzhou-Xining urban agglomeration

According to the autocorrelation between 39 county units and their adjacent areas, the clustering
types of the 39 county units are divided into 4 types: H-H, H-L, L-H and L-L. According to the Moran
scatter chart and the local Moran's $I$ index, the LISA agglomeration chart of water resource utilization
efficiency in 39 counties and districts of Lanzhou-Xining urban agglomeration in the study year was
drawn. As can be seen from figure 3, the number of counties with H-H agglomeration and L-L
agglomeration gradually increased in the four study years. This indicates that the positive
agglomeration degree of water resources utilization efficiency in Lanzhou-Xining urban agglomeration is gradually significant, and the spatial difference between adjacent counties and districts is gradually narrowing.

1. H-H concentrated area

Within the scope of Lanzhou-Xining urban agglomeration, the stable H-H agglomeration areas of
water resource utilization efficiency are mainly distributed in Lanzhou city and Xining city. These
areas are the largest advantageous development areas in the Lanzhou-Xining urban agglomeration, and
are the growth poles that drive the development of the entire urban agglomeration. Good economic
development foundation, advanced water resources management level, water-saving technology and
strong policy support have formed a significant high-value spatial agglomeration area in the region.

2. H-L concentration area.

The spatial distribution pattern of such areas is relatively stable, and the number has decreased over
time. Most of the areas where their own water resource utilization efficiency is high and their
surrounding counties have low efficiency levels are located in Qinghai Province. In 2005, there were
mainly Haiyan County, Ledu District, and Linxia City. After more than ten years of development,
these counties have not developed into H-H cluster areas. This is due to the backward economic
development of the surrounding areas and the need to strengthen their own radiation-driven
capabilities, making such areas not become H-H clusters.

3. L-L concentration area

The L-L concentration area of water resources utilization efficiency of Lanzhou-Xining urban agglomeration includes Jishishan county, Yongdeng county, Jingta county and Weiyan county. Most
of these counties are located in the fringe areas of Lanzhou-Xining urban agglomeration. These areas
are backward in economic development, poor in natural background conditions, low accessibility to
traffic and weak in technological innovation. Moreover, due to the lack of advanced industrial and
agricultural water-saving technologies, the ability to control environmental pollution is poor. As a
result, this kind of area can generate more unexpected output while using water resources to obtain
economic benefits. Therefore, the utilization efficiency of water resources in such areas is always in the state of low efficiency agglomeration.

5. Conclusions

China highly values ecological and environmental protection. Guided by the conviction that lucid waters and lush mountains are invaluable assets, the country advocates harmonious coexistence between humans and nature, and sticks to the path of green and sustainable development. As a unique support for the protection of the “Chinese Water Tower”, the Lanzhou-Xining urban agglomeration will not only become an important economic growth pole in the northwest region, but also shoulder the heavy responsibility of maintaining the ecological security of the upper reaches of the Yellow River. In order to reflect the water resources utilization status dynamically and comprehensively, this paper estimates the utilization efficiency of green water resources in 39 counties of Lanzhou-Xining urban agglomeration in 2005, 2010, 2015 and 2017 based on the ultra-efficient DEA model considering undesired output. Draw the following conclusions:

(1) During the research year, the water use efficiency of the Lanzhou-Xining urban agglomeration showed a volatility growth trend, and most of the regions have not yet reached the optimal state of water resources utilization, and there is still a long way to go for further development.

(2) From the regional perspective, the water use efficiency of Lanzhou City and Xining City are the core growth poles of Lanzhou-Xining urban agglomeration, is relatively high. The economically backward areas such as Haiyan and Tongren county and other economically backward areas less sewage discharge. The smaller emissions also achieved the effectiveness of DEA. The areas with low water use efficiency are mainly concentrated in the fringe areas of urban agglomerations dominated by agricultural development. The backwardness of economic development and poor natural background conditions have led to a slow increase in utilization efficiency.

(3) The slow progress of technology is the main reason that restricts the water resources to the Pareto optimal state of input and output. The new water consumption of the Lanzhou-Xining urban agglomeration has been strictly controlled. Therefore, areas with high comprehensive productivity index should also pay attention to the advancement of technology.

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