Water Utilization’s Green Efficiency Evaluation and Spatial Autocorrelation’s analysis in Jing-Jin-Ji region of China

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Abstract. Based on the data of 13 cities in the Jing-Jin-Ji region from 2009 to 2018, evaluating green efficiency of Water Resources by SBM Model, and analysing this region’s spatial autocorrelation by ESDA method. The results show that the green efficiency of water resources in Jing-Jin-Ji region shows a slow decline in fluctuation, with an average annual efficiency of 4.5%. Spatial autocorrelation is characterized by low agglomeration around Beijing and Tianjin, and decreases year by year.

1. Introduction

Green efficiency of water resources (GEWR) refers to the ratio of the input of water resources and the output of economic, social and ecological environment, which is used to evaluate the social benefits of water resources services[1]. Unlike the economic efficiency and environmental efficiency of water resources, green efficiency measures GDP value, social development index and grey water footprint simultaneously, which is the further development of the former in economic and environmental aspects. At present, scholars' research on water resources in Jing-Jin-Ji region focuses on the protection, development and utilization of water sources, and the evaluation of water environment security[2, 3]. In this paper, the development trend of GEWR in Jing-Jin-Ji region from 2009 to 2018 is discussed by using the SBM model and spatial autocorrelation analysis, hoping to provide reference for the future development of green ecology in Jing-Jin-Ji region.

2. Materials and methods

2.1 SBM model of unexpected output

The measurement of GEWR is a systematic evaluation method of multi-input and multi-output indicators, so the unexpected output Super-efficiency Slacks-based Measure (SBM) model, which can effectively solve the problems of relaxation variables and random error disturbance and take into account the negative environmental effects, is selected[4]. The formula is as follows:

\[ \rho = \min \left\{ \frac{1 - \frac{1}{s_1} \sum_{i=1}^{m} s_i}{\frac{1}{s_1 + s_2} \left( \frac{1}{x_0} \sum_{i=1}^{m} s_i + \sum_{i=1}^{g} s_i - \frac{1}{y_0} \sum_{i=1}^{b} s_i \right)} \right\} \]

s.t.

\[ \begin{align*}
    x_0 &= X\lambda + s^- \\
    y^g_0 &= y^g\lambda + s^g \\
    y^b_0 &= y^b\lambda + s^b \\
    s^- &\geq 0, s^g \geq 0, s^b \geq 0, \lambda \geq 0
\end{align*} \]

In the above formula, \( \rho \) is the green efficiency evaluation value of water resources, and the range of value is [0-1]; \( m, s_1, s_2 \) are the number of inputs, expected outputs and non-expected outputs, respectively; \( s^-, s^g, s^b \) are relaxation variables of input, expected output and non-expected output of
decision making unit i, respectively; \(\lambda\) is the weight vector; \(X, Y^g, Y^b\) is the input-output value of production unit. The objective function decreases strictly monotonously with respect to \(s^-, s^g, s^b\). When \(\rho = 1\) and \(s^- = s^g = s^b = 0\), the decision making unit is completely effective. When \(\rho < 1\) and \(s^-, s^g, s^b\) are not completely equal, the decision making unit is invalid.

2.2 Spatial autocorrelation analysis

Spatial autocorrelation is one of the central contents of Exploratory Spatial Data Analysis (ESDA) model. Moran's I statistic is usually used to judge the similarity degree of attribute values of adjacent units, which can be used to distinguish the aggregation or dispersion degree of observation values in the study area[5]. The formula is as follows:

\[
\text{Moran's I} = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} \omega_{ij} (Z_i - \bar{Z})(Z_j - \bar{Z})}{S^2 \sum_{i=1}^{n} \sum_{j=1}^{n} \omega_{ij}}
\]

(2)

In the above formula, \(S^2 = \frac{1}{n} \sum_{i=1}^{n} (Z_i - \bar{Z})^2\); \(\bar{Z} = \frac{1}{n} \sum_{i=1}^{n} Z_i\); \(Z_i\) denotes the observed values in area I; \(n\) is the total number of regions; \(\omega_{ij}\) is a space weight matrix. The values of Moran's I statistics are generally between \([-1, 1]\]. The closer to -1, the greater the difference between the units or the less centralized the distribution; the closer to 1, the closer the relationship between the units and the more similar the properties; and 0 represents unrelated units. According to the results of Moran's I statistics, the standardized hypothesis test is carried out. The formulas are as follows:

\[
U(d) = \frac{\text{Moran's I} - E(I)}{\sqrt{\text{VAR}(I)}}
\]

(3)

\(E(I)\) and \(\text{VAR}(I)\) represent the expectation and variance of Moran's I statistics of normal distribution.

2.3 Index Selection and Data Source

The indicators selected in this paper are shown in the table below.

| first level indexes | Secondary indicators | Index attributes |
|---------------------|----------------------|-----------------|
| Input Indicators    | Aquatic Footprint of Crop/Industrial /Domestic Products | Water demand (m³) |
|                     | Capital investment | Total investment in fixed assets (RMB 100 million) |
|                     | Labor input | Total employment at the end of the year (10,000 people) |
| Expected Output Indicators | Economic performance | Per capita GDP (RMB 100 million) |
|                      | Social results | Per capita disposable income (yuan/person) |
|                      | environmental benefit | Per capita green space area (m²) |
| Unexpected Output Indicators | Industrial, Agricultural and Domestic Ash Water Footprint | Water resource dilution pollutant demand (m³) |

The above data are from Hebei Economic Statistical Yearbook, Beijing Water Resources Bulletin, Tianjin Water Resources Bulletin and Hebei Water Resources Bulletin.

3. Results and analysis

3.1 Measurement of GEWR in Jing-Jin-Ji region

Based on the panel data of 13 cities in Jing-Jin-Ji region from 2009 to 2018, the GEWR is calculated by MaxDEA6.0 software. The results are shown in Table 2.
Table 2. GEWR’ value of Jing-Jin-Ji Region, 2009-2018

| City            | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | Average value |
|-----------------|------|------|------|------|------|------|------|------|------|------|---------------|
| Beijing         | 1    | 1    | 0.99 | 1.00 | 1.00 | 0.98 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00          |
| Tianjin         | 1    | 0.96 | 0.99 | 1.00 | 1.00 | 1.00 | 1.00 | 0.99 | 0.99 | 0.99 | 0.99          |
| Shijiazhuang    | 0.61 | 0.52 | 0.43 | 0.33 | 0.51 | 0.45 | 0.44 | 0.41 | 0.39 | 0.39 | 0.45          |
| Tangshan        | 0.53 | 0.52 | 0.49 | 0.41 | 0.41 | 0.36 | 0.46 | 0.50 | 0.50 | 0.45 | 0.46          |
| Baoding         | 0.36 | 0.38 | 0.40 | 0.36 | 0.22 | 0.28 | 0.38 | 0.25 | 0.33 | 0.38 | 0.33          |
| Langfang        | 0.38 | 0.43 | 0.38 | 0.35 | 0.33 | 0.40 | 0.36 | 0.23 | 0.19 | 0.23 | 0.33          |
| Qinhuangdao     | 0.48 | 0.46 | 0.53 | 0.44 | 0.64 | 0.61 | 0.45 | 0.56 | 0.49 | 0.47 | 0.51          |
| Cangzhou        | 0.38 | 0.29 | 0.30 | 0.31 | 0.31 | 0.35 | 0.37 | 0.28 | 0.28 | 0.20 | 0.31          |
| Zhangjiakou     | 0.46 | 0.33 | 0.31 | 0.13 | 0.16 | 0.22 | 0.27 | 0.25 | 0.21 | 0.13 | 0.25          |
| Chengde         | 0.38 | 0.27 | 0.27 | 0.21 | 0.35 | 0.31 | 0.30 | 0.25 | 0.18 | 0.12 | 0.26          |
| Xingtai         | 0.44 | 0.38 | 0.30 | 0.35 | 0.38 | 0.38 | 0.42 | 0.30 | 0.35 | 0.31 | 0.36          |
| Handan          | 0.33 | 0.32 | 0.34 | 0.29 | 0.21 | 0.31 | 0.34 | 0.28 | 0.27 | 0.30 | 0.30          |
| Hengshui        | 0.3  | 0.34 | 0.27 | 0.30 | 0.32 | 0.21 | 0.15 | 0.25 | 0.30 | 0.14 | 0.26          |
| Jing-Jin-Ji     | 0.51 | 0.48 | 0.46 | 0.42 | 0.45 | 0.45 | 0.46 | 0.43 | 0.42 | 0.39 | 0.45          |

Figure 1. Development Trend of GEWR

As shown in Figure 1, the development of GEWR in Jing-Jin-Ji region shows a slow downward trend. Taking 2009, 2012, 2015 and 2018 as examples, the spatial distribution map of GEWR in four years of each city is drawn by using ArcMap 10.2 software. The GEWR is divided into five levels: lower efficiency zone [0.000-0.200], low efficiency zone [0.200-0.300], medium efficiency zone [0.300-0.400], high efficiency zone [0.400-0.600] and higher efficiency zone [0.600-1.000].
From the analysis of Figure 2, it can be seen that Beijing and Tianjin have the highest GEWR because of their superior economic and political geographical position, strong capital adsorption capacity. In coastal areas, especially in cities near Beijing and Tianjin, the GEWR is at a higher level than that of offshore areas. The GEWR in cities far away from Beijing and Tianjin declined slowly from 2009 to 2018, and the overall efficiency was low.

3.2 Spatial Autocorrelation Analysis of GEWR in Jing-Jin-Ji Region

Using SPSS software, the values of global Moran's I statistic, Z value of normal statistic and P value of significant level of green efficiency of water resources are measured. The results are shown in Table 3 below.

| Year | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|------|------|------|------|------|------|------|------|------|------|------|
| Moran's I | 0.271 | 0.251 | 0.201 | 0.176 | 0.205 | 0.227 | 0.182 | 0.170 | 0.143 | 0.128 |
| Z-value | 2.591 | 2.438 | 1.997 | 1.990 | 2.189 | 2.341 | 1.974 | 1.701 | 1.377 | 1.115 |
| P-value | 0.005 | 0.005 | 0.049 | 0.048 | 0.049 | 0.003 | 0.042 | 0.041 | 0.038 | 0.041 |

The global Moran's I statistic of GEWR in Jing-Jin-Ji region is between [0.1286-0.2719]. The significance test of 0.05 shows that there is a positive correlation in the space of GEWR in Jing-Jin-Ji region. It's also means a phenomenon of low-value agglomeration. As shown in Table 3, the data of
2009-2012 declined year by year, rebounded in 2013-2014, declined rapidly in 2015-2018, and the global spatial autocorrelation gradually decreased.

4. Conclusion
The results show that the GEWR in Jing-Jin-Ji region declined slowly during the period of 2009-2018. Among these areas, Beijing and Tianjin had the highest efficiency, followed by coastal areas, and accompanied with low-value aggregation. The improvement of the GEWR in Jing-Jin-Ji region should be carried out from the following three aspects: a) optimizing the industrial structure and strengthening the scientific and technological innovation ability of enterprises; b) improve the ability and level of comprehensive social services and improve infrastructure construction; c) water resources utilization plans should be rationally adjusted and social synchronous development should be emphasized.

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