Evaluation on Sustainable Utilization of Water Resources in Shandong Province Based on Water Footprint

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Abstract. The paper adopts 17 prefecture-level cities in Shandong Province as geographical unit, selects the indicators concerning regional sustainable development capacity from the perspective of resource, environment, social economy and efficiency support, etc., introduces the concepts of water footprint and evaluates the sustainable development condition of water resource and overall sustainable development condition in these geographical units. It’s indicated that the overall sustainable development capacity of the 17 prefecture-level cities in Shandong Province is ranked in descending order as follows: Weihai, Yantai, Qingdao, Binzhou, Zibo, Dezhou, Jining, Rizhao, Jinan, Laiwu, Linyi, Zaozhuang, Weifang, Dongying, Liaocheng, Tai'an and Heze. The score of sustainable development capacity achieved by the former nine is larger than 0 and the cities are in a state of sustainable development; while the score of sustainable development capacity achieved by the latter eight is smaller than 0 and the cities are in a state of unsustainable development. On this basis, the geographical units are further divided into four types by means of optimal partition method, i.e., with strong sustainable development capacity, with comparatively strong sustainable development capacity, with comparatively weak sustainable development capacity and with weak sustainable development capacity, and the sustainable development characteristics of each type are analyzed.

Introduction

Water resources are the source of life and the foundation of ecology. In recent decades, over exploitation and pollution of water resources have been seriously threatening and hindering its own survival and development, and people have not realized the importance of water resources. The idea of sustainable development of water resources are put forward under this background, and how to evaluate the development and sustainability of water resources in the region has become a problem that scientists around the world have been exploring. In order to make a scientific evaluation of water resources, it is necessary to calculate and quantitatively express the actual state of water resources. Foreign scholars such as Tony Allan and Hoekstra have put forward the concept of "virtual water" and "water footprint", and introduced a series of indicators to evaluate the sustainable development of water resources in the country or region. The evaluation indicators of water footprint can more comprehensively and intuitively reflect the overall situation of regional sustainable development, but lightly reveal the advantages and disadvantages of the regional development and other aspects. From the perspective of environmental economics, the development of region has its respective advantages and disadvantages, which are embodied by comparison and should be reflected in the assets and liabilities of regional sustainable development. In 1999, based on the theory of sustainable development, Chinese Academy of Sciences systematically put forward the basic principles and methods of formulating the regional sustainable development capability balance sheet for the first time in Chinese Sustainable Development Strategy Report in 2000. In view of this, this article takes 17 cities of Shandong Province as an example, calculates the regional water resources sustainable utilization score, and carries on the quantitative analysis and the evaluation to the water resources sustainable development ability relative strength situation of these areas, aims to objectively understand each Regional sustainable development of water resources and its differences provide some inspiration.
Index System of Sustainable Development of Water Resources

Sustainable Development Index System of Water Conservancy

The sustainable development of water resources react the quality and quantity about the sustainable utilization of regional water resources, which is based on the system of sustainable development capacity analysis and the basic theory of comparative advantage theory in economics. The core idea of the theory is to find the comparative advantage and disadvantage of each supporting system in the three supporting system of the sustainable utilization of water resources (i.e., the ecological support system, the efficiency of support system). We quantify and standardize the comparative advantage, and then place it in the same basis to be compared, form the evaluation system of sustainable utilization of water resources. Accordingly, the index system can be divided into system level, state level and element level, see table 1.

Figure 1. Index system of sustainable development of water resources.

<table>
<thead>
<tr>
<th>System layer</th>
<th>State layer</th>
<th>Element layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Resource index</td>
<td>A1 Water resources quantity</td>
<td>A11 Per capita water footprint [m³]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A12 Water footprint per mu [m³/mu]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A13 Available water resources growth index [%]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A14 Self-sufficiency rate of water resources [%]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A15 Water scarcity degree [%]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A16 Development and utilization of surface water [%]</td>
</tr>
<tr>
<td></td>
<td>A2 Water consumption</td>
<td>A22 Groundwater exploitation and utilization [%]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A23 Water footprint growth index [%]</td>
</tr>
<tr>
<td>B Environmental indicator</td>
<td>B1 Investment of ecological environment governance</td>
<td>B11 Sewage treatment rate [%]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B12 Standard rate of water functional area [%]</td>
</tr>
<tr>
<td></td>
<td>B2 Surface water and ground water quality</td>
<td>B21 Grey water footprint [%]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B22 River water quality compliance rate [%]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B23 Wetland accounted for the proportion of administrative area [%]</td>
</tr>
<tr>
<td>C Social indicators</td>
<td>C1 Sociology</td>
<td>C11 Urban population density [per capita/km²]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C12 Proportion of water conservancy facilities [%]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C21 Per capita GDP [yuan]</td>
</tr>
<tr>
<td></td>
<td>C2 Economics</td>
<td>C22 Water resources contribution rate [%]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C23 Ten thousand yuan GDP water footprint [m³/10⁴ yuan]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C24 Water resource price exchange rate [%]</td>
</tr>
</tbody>
</table>

Asset Liability Evaluation Method

The comparative advantage theory is used to compare the comparative advantage data of water resources, water quality and water use efficiency in different regions to form a score of sustainable development of water resources in different regions of Shandong Province. For the spatial distribution of each factor in the factor level (17 prefecture-level cities in Shandong province) and their comparative advantages, the top 5 and the last 5 ranks in the province were selected to form assets and liabilities respectively. And then form the relative Quality Evaluation of Regional Water Resources in Shandong Province in Relative Sense. In the spatial distribution of each element, if the elements of sustainable development of water resources were ranked 1, 2, 3, 4, 5, the corresponding score was 1.0, 0.8, 0.6, 0.4, 0.2. Similarly, if the elements of sustainable development of water resources were ranked 17, 16, 15, 14, 13, the corresponding score was -1.0, -0.8, -0.6, -0.4, -0.2.

The total score of the sustainable development of water resources in Shandong province and sustainable development for:

\[ x_i = (1.0 \times n_1) + (0.8 \times n_2) + (0.6 \times n_3) + (0.4 \times n_4) + (0.2 \times n_5) \quad (i = 1, 2, 3, 4) \]  

\[ y_i = (-1.0 \times n_7) + (-0.8 \times n_8) + (-0.6 \times n_9) + (-0.4 \times n_{10}) + (-0.2 \times n_{11}) \quad (i = 1, 2, 3, 4) \]

Among them, \( n_1, n_2, n_3, n_4, n_5 \) respectively to ranking support system for 1, 2, 3, 4, 5 of the assets.
number \( n_{17}, n_{16}, n_{15}, n_{14}, n_{13} \) respectively to ranking support system for 17, 16, 15, 14, 13 of the number of elements of liability.

A measure of sustainable development of water resources in Shandong province for the support system:

\[
X_i = \left(\frac{x_i}{N_i}\right) \times 100\% \quad (i = 1, 2, 3, 4) \tag{3}
\]

\[
Y_i = \left(\frac{y_i}{N_i}\right) \times 100\% \quad (i = 1, 2, 3, 4) \tag{4}
\]

Among them, \( n_i \) is the total number of indicators of the support system, the corresponding value is 8, 5, 6, 7.

The coefficient \( \varepsilon_i \) of sustainable water resources in Shandong province the support system:

\[
\varepsilon_i = x_i \left(\frac{n_i + n_{i+1} + n_{i+2} + n_{i+3}}{n_i}\right) \quad (i = 1, 2, 3, 4) \tag{5}
\]

\[
\gamma_i = y_i \left(\frac{n_{i-1} + n_{i-2} + n_{i-3} + n_{i}}{n_i}\right) \quad (i = 1, 2, 3, 4) \tag{6}
\]

After obtaining the average assets and average liabilities of each geographical unit, we can evaluate the quality of the assets and liabilities by referring to the standard set by table 2.

<table>
<thead>
<tr>
<th>Sustainable development reviews</th>
<th>excellent</th>
<th>preferably</th>
<th>commonly</th>
<th>weak</th>
<th>poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>sustainable development</td>
<td>[0.8, 1)</td>
<td>[0.6, 0.8)</td>
<td>[0.4, 0.6)</td>
<td>[0.2, 0.4)</td>
<td>[0.0, 0.2)</td>
</tr>
<tr>
<td>Unsustainable development</td>
<td>[-0.2, 0]</td>
<td>[-0.4, -0.2)</td>
<td>[-0.6, -0.4)</td>
<td>[-0.8, -0.6)</td>
<td>[-1, -0.8)</td>
</tr>
</tbody>
</table>

The support system of water resources in Shandong province sustainable development (relative comparative advantage for ability):

\[
A = X_i + Y_i \quad (i = 1, 2, 3, 4) \tag{7}
\]

Shandong province water resources support system of sustainable development (relative comparative advantage for general ability):

\[
S_j = \left(\frac{\sum_{i=1}^{3} x_i / 19 + \sum_{i=1}^{3} y_j / 19}{\sum_{i=1}^{17} y_j / 19}\right) \times 100\% \quad (j = 1, 2, 3, \ldots, 16, 17) \tag{8}
\]

**Asset-liability Analysis on Sustainable Development of Water Resources in Shandong Province**

**Asset-liability Result**

The overall relative sustainable development of water resource support system in the 17 prefecture-level cities of Shandong Province are evaluated according to the foregoing formula; the development capacity of water resources support system in 17 prefecture-level cities can be proved after the overall relative sustainable development capacity is ranked in descending order. The greater (the smaller) the overall relative sustainable development capacity of water resources support system is, the stronger (the weaker) the sustainable water resources development and utilization capacity is. The result is illustrated in Figure 1.
Classification and Characteristics of Sustainable Water Resources Development Type

In the foregoing asset-liability analysis on regional sustainable water resources development capacity, the geographical units have been divided into two categories, i.e. sustainable development and unsustainable development according to whether the score of sustainable development concerning the regional overall sustainable development level is positive or not [10]. On this basis, the optimal partition method is further introduced to probe deeper into the difference of the 17 geographical units in sustainable water resources development capacity. The geographical units which fall under the category of sustainable development are divided into the unit with strong sustainable development capacity and the unit with comparatively strong sustainable development capacity.

Unit with Strong Sustainable Development Capacity

The unit with strong sustainable development capacity includes Weihai, Yantai and Qingdao. The score of sustainable development concerning the overall sustainable development level is entirely larger than 0.15, which is much higher than that of other places; it’s indicated that their overall sustainable development capacity remains the strongest in a comparative aspect. In terms of sustainable development, the type is mainly characterized by the fact that the sustainability of water resources is favorable in social and economic aspect and the capacity of sustainable development in economic perspective is especially outstanding, while the sustainability of water resources in resource and water-use efficiency is relatively weak. Therefore, it's essential that these cities should pay close attention to water resources and water environment problems and improve water-use
efficiency with a view to maintaining and enhancing the overall capacity of sustainable development of water resources.

**Unit with Comparatively Strong Sustainable Development Capacity**

The unit with comparatively strong sustainable development capacity includes Binzhou, Zibo, Dezhou, Jining, Rizhao and Jinan. These cities have performed the weakest in the sustainable development of water resources and although the score of sustainable development concerning the overall sustainable development level of water resources is larger than 0, they are facing some bottlenecks in development, which are marked by unsatisfying water resource quality and weak capacity in sustainable development of water resource in economic and environmental aspect. Therefore, it’s advisable that these cities should, when protecting the existing resources from destruction, pay more attention to improving water-use efficiency, reducing the water consumption per 10,000 GDP, improving people’s living standard and thus enhancing the overall sustainable development capacity.

**Unit with Comparatively Weak Sustainable Development Capacity**

The unit with comparatively weak sustainable development capacity includes Laiwu, Linyi, Zaozhuang, Weifang, Dongying and Taian. These cities fall under the category of unsustainable development; the score of sustainable development concerning overall sustainable development level is entirely negative and the average score of sustainable development is larger than -0.15. In terms of sustainable water resources development, the type is mainly characterized by the fact that the sustainable development capacity in the aspect of water environment, social economy and water-use efficiency is inferior to that of the unit with comparatively strong sustainable development capacity, but the sustainable development capacity in the aspect of water resource volume is close or superior to that of the unit with comparatively strong sustainable development capacity. Therefore, on the premise of protecting water resources and preventing current water environment from deterioration, these cities should devote to developing economy and improving water-use efficiency vigorously, aiming to make faster progress in enhancing the overall sustainable development capacity of water resources.

**Summary**

(1) This paper constructs an index system for sustainable development of regional water resources in Shandong Province, which is based on water footprint. We evaluate 17 cities in the province and the sustainable development ability of these geographic units. The first 9 sustainable development score is greater than 0, in a sustainable state, and then the other 8 cities’ sustainable development score are less than 0, in an unsustainable state.

(2) To describe the difference of the sustainable development ability in the 17 geographical units, we divide the 17 cities into 3 types on the basis of the optimal segmentation method: the strongest type of sustainable development (Weihai, Yantai and Qingdao), the more strong type of sustainable development (Binzhou, Zibo, Dezhou, Jining, Rizhao and Jinan), the strong type of sustainable development (Laiwu, Linyi, Zaozhuang, Weifang, Dongying, Tai'an and Heze). Besides we analyze the characteristics of different types of sustainable development.

(3) Limited by the length of the paper, this study only aims at the target level (the overall level) and the first level indicators, and only 17 prefecture level cities as samples to carry out the sustainable development of regional water resources assessment. The further development space of the study will be reflected in the extension of the index level oriented to the two level.

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References


