The Comprehensive Evaluation on Environment Sustainability of Resource Based Cities Based on Improved Scatter Degree Method

LIFENG ZHANG, QIBING CHEN and FEI XIANG

ABSTRACT

Resource based cities are the most important cities in China. With the development of resource based cities, environmental problems have become more and more serious. In order to study on sustainable development problem, we construct indexes system for sustainable development with two aspects: environment pollution and environment management. We propose improved scatter degree method to analysis environment sustainable development. The results show as follows:(I) The environment of resource based cities became more and more serious, some resource based cities sacrifice the environment in order to development economic; (II) Although the environment problem is serious, the resource based cities did not improve the ability to protect the environment; (III) Difference was found in the environment governance. Finally, according to the evaluation results, the reasonable suggestions are given.

INTRODUCTION

With the development of economic, resource based cities which the leading industry is resources exploitation is rising. The State Department announced 141 resource based cities is in the well-developed stage. The well-developed resource based cities are the core cities for resource security. In recent years, people living standard enhances unceasingly, but the environment is getting worse and worse because of wasting resources. Many problems become more and more obvious, such as inefficiency of using resource, exhaustion of the traditional resource. These problems restrict the sustainable development of resource based cities. In order to solve the increasingly serious environmental problems and ensure the sustainable development of environment, first we should monitor the environment of resourced based cities, and establish an indices system; second we propose a comprehensive evaluation model to evaluate the sustainable development ability for resource based cities, then according to
the evaluation results, we find the problems of resource based cities. Finally, we give some advices for the sustainable development.

Recent years, the literature about the sustainable development of urban environment mostly focused on qualitative research \cite{1-4}. Because most of the literatures only build the index system, and not focus on the evaluation method for the sustainable environment development of resource based city, the paper choose the well-developed resource based cities to research, and build a new index system to evaluate the sustainable development of the environment by quantitative model.

INDEX SYSTEM CONSTRUCTION AND SAMPLE SELECTION

Index System Construction

There are two important problems in the Multi-attribute evaluation. One is how to set indicators and the other is how to give weight for indicators. So in this paper, we will consider environmental pollution and environmental management to evaluate the level of sustainable development. In order to construct index system, we review literatures \cite{5-7} about environmental sustainable development index system. Based on these literatures, we have constructed a new index system which shows in the table 1.

<table>
<thead>
<tr>
<th>First level index</th>
<th>Second level indexes</th>
<th>Third level indexes</th>
</tr>
</thead>
<tbody>
<tr>
<td>environmental sustainable development indicator</td>
<td>environmental pollution</td>
<td>unit industrial smoke dust discharge $X_1$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>unit industrial wastewater discharge $X_2$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>unit industrial SO$_2$ discharge $X_3$</td>
</tr>
<tr>
<td>environmental management</td>
<td>ratio of industrial smoke dust treatment $Y_1$</td>
<td>utilization rate of industrial waste $Y_2$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>centralized sewage treatment rate $Y_3$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>rate of MSW treatment $Y_4$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>green coverage rate in constructed areas $Y_5$</td>
</tr>
</tbody>
</table>

Formulation to calculate the values of the main indicators are as follows:

\[
\text{unit industrial smoke dust discharge} = \frac{\text{industrial smoke dust discharge}}{\text{cities' total area}}
\]

\[
\text{ratio of industrial smoke dust treatment} = \frac{\text{industrial smoke dust generation-industrial smoke dust discharge}}{\text{industrial smoke dust generation}}
\]

Sample Selection

Based on the availability and the accuracy of the data, we choose 44 well-developed resource based cities. All the data is from China Cities Statistical Yearbook 2014 and China Environmental Statistics Yearbook 2014.
RESEARCH METHOD

Index is not the more the better in the comprehensive evaluation. The general method is to select primary indicator for evaluating. Factor analysis is one of the most commonly used methods in multi-attribute evaluation. Factor analysis always gets more than a common factor, so it is difficult to make a comprehensive evaluation. How to combine multiple indicators into one indicator is a question. Guo Yajun\textsuperscript{[8]} proposed a new comprehensive evaluation which named Scatter Degree Method. He also proposed improved scatter degree method based on factor analysis, and testified the stability of the method\textsuperscript{[8,9]}. In this paper, we will use factor analysis to extract common factors, and then use the improved scatter degree method to evaluate the sustainable development of environment based on common factors, so as to avoid the subjectivity of the index weights.

The Basic Theory of the Improved Scatter Degree Method

Factor analysis is a normal method on evaluation. Its basic idea is to reduce dimensions. Scatter degree method is an objective method to reflect the difference between the evaluated objects. The basic idea of the method is to choose the weights to make the difference among the evaluated objects as large as possible. Scatter degree method is suitable for the evaluation problem with few indexes. So that based on common factor, we could use scatter degree method to solve this problem.

Model Formulation

If the evaluation object $i$ has $p$ indexes which noted that $x_{i1}, x_{i2}, \ldots, x_{ip}$, then we can gain the data matrix of the evaluation objects as follows:

$$
\begin{bmatrix}
x_{11} & x_{12} & \cdots & x_{1p} \\
x_{21} & x_{22} & \cdots & x_{2p} \\
\vdots & \vdots & \ddots & \vdots \\
x_{m1} & x_{m2} & \cdots & x_{mp}
\end{bmatrix}
$$

Without loss of generality, the data matrix was standardized at first, and then the common factors of environmental pollution and environmental management were extracted by factor analysis respectively. Let $F_{i}$ noted that common factor $i$ of environmental pollution, $F_{2i}$ noted that common factor $i$ of environmental management. Factor score models are as follows:

$$
\begin{align*}
F_{1i} &= a_{i1}x_{1i} + a_{i2}x_{2i} + \ldots + a_{ip}x_{pi} , \quad i = 1, 2, \ldots, m_1 \\
F_{2i} &= b_{i1}y_{1i} + b_{i2}y_{2i} + \ldots + b_{ip}y_{pi} , \quad i = 1, 2, \ldots, m_2
\end{align*}
$$

Note that $x_{i}$ is standardized data of the $i$ th environmental pollution index, $y_{i}$ is standardized data of $i$ th environmental management index. If the common factor has only one, then we can use the common factor to evaluate the effect of environmental pollution or environmental management respectively, but the common factor is always more than one, then how to evaluate becomes a difficult problem. Guo Yajun\textsuperscript{[9]} has proved that when the indexes are independent and standardized, then the scatter degree method loses its effectiveness. Common factors are independent, so we couldn’t
construct comprehensive indicators by using the scatter degree method. Considering
the different factors with different contributions, we can use variance as weight to
calculate comprehensive index. Let $F_1$ denote comprehensive factor of environmental
pollution, $F_2$ denote comprehensive factor of environmental management, $s_{ij}$ denote
variance of the $j$th common factors of the $i$th comprehensive factor, then the
comprehensive factor’s formulation is as follows:

$$
F_i = \sum_{j=1}^{m_i} s_{ij} F_i + \sum_{j=1}^{s} \frac{s_{ij}}{s} F_{i2} + \ldots + \sum_{j=1}^{s} s_j F_{im}
$$

Now there are only two comprehensive factors. In order to research the ability of
sustainable development, we should consider both environmental pollution and
environmental management. Scatter degree method is suitable for the evaluation
problem with few indexes, then we could use scatter degree method to construct
comprehensive index $F$ for sustainable development. According to the basic idea of
the scatter degree method, constructing a comprehensive index is to find the weight $\omega$
to make the gap between the evaluation objects as large as possible. It means that we
need to find the weight to maximize $\text{Var}(F)$, Let $F^{(i)}$, $i = 1, 2, \ldots n$ denote the factor
score of the $i$th evaluation object (the $i$th components of $F$), $\bar{F}$ is the mean of $F$.

$$
F = \omega_1 F_1 + \omega_2 F_2
$$

Obviously

$$
\text{Var}(F) = \frac{1}{n-1} \sum_{i=1}^{n} (F^{(i)} - \bar{F})^2
$$

If there is no restriction to weight, the value of $\text{Var}(F)$ is infinity. So the
optimization model is as follows:

$$
\text{Max} \quad \text{Var}(F)
\text{s.t.} \quad \omega^T \omega = 1
$$

In the model, $\omega = (\omega_1, \omega_2)^T$. If $F^{(i)}$ is standardized data, then $\bar{F} = 0$. Because

$$
F = (F_1, F_2)^T \begin{bmatrix} \omega_1 \\ \omega_2 \end{bmatrix} = H \omega,
\text{then } \text{Var}(F) = \frac{1}{n-1} \sum_{i=1}^{n} (F^{(i)} - \bar{F})^2 = \frac{1}{n-1} F^T F = \frac{1}{n-1} \omega^T H^T H \omega,
$$

the optimization model has changed as follows:

$$
\text{Max} \quad \frac{1}{n-1} \omega^T H^T H \omega
\text{s.t.} \quad \omega^T \omega = 1
$$

Theorem 1: The standard eigenvector corresponding with the max eigenvalue make
the model reach a maximum value.
The steps of the method are as follows:

1. Collect data for indexes and data preprocessing
2. Use factor analysis to extract common factors respectively
3. If the common factor has only one, then go to step (4), otherwise use
   formulation (3) to construct comprehensive index for environmental pollution or environmental management.
4. In order to construct comprehensive index for sustainable development, we
   will use scatter degree method to integrate environmental pollution and
environmental management into a comprehensive index for environmental sustainable development.

EMPIRICAL ANALYSIS

Due to data availability and the importance contribution of the well-developed resource based cities for economic development, we have chosen 44 well-developed resource based cities to research.

Data Preprocessing

Multiple indexes have different dimension, different type and structure of information. Firstly, the data are normalized to eliminate the influence of dimension, the normalized formulation is 

$$x'_j = \frac{x_j - \bar{x}_j}{s_j},$$

(\(\bar{x}_j\) means the mean of the \(j\) th index). The value of \(x'_j\) is the smaller the better, and the value of \(y'_j\) is the larger the better. To keep the consistency, let \(y'_j = 1 - y_j\), it means ratio of untreated.

Evaluation Process

FACTOR ANALYSIS FOR ENVIRONMENTAL POLLUTION

First, we use SPSS 23.0 to testify whether the data is suitable for factor analysis. The output is shown in table 2:

<table>
<thead>
<tr>
<th>Kaiser-Meyer-Olkin Measure of sampling Adequacy</th>
<th>.698</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bartlett’s Test of sphericity</td>
<td>31.361</td>
</tr>
<tr>
<td>df</td>
<td>3</td>
</tr>
<tr>
<td>sig</td>
<td>.000</td>
</tr>
</tbody>
</table>

From table 2, we find sig=0.000<0.05, so the indexes we chosen for environmental pollution is suitable for factor analysis.

Second, we use principal components method to extract common factor, the table 3 shows the results.

<table>
<thead>
<tr>
<th>Component</th>
<th>Initial eigenvalue</th>
<th>Extraction sums of squared loading</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>% of variance</td>
</tr>
<tr>
<td>1</td>
<td>2.044</td>
<td>68.118</td>
</tr>
<tr>
<td>2</td>
<td>0.495</td>
<td>16.488</td>
</tr>
<tr>
<td>3</td>
<td>0.462</td>
<td>15.395</td>
</tr>
</tbody>
</table>

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From the table 3, the first component’s variance contribution is 68.118%, so we extract only one common factor $F_1$, we named $F_1$ as environmental pollution factor, then we could use the factor score model to calculate the value of $F_1$. According to the factor score, the cities ranking is showed in table 4.

<table>
<thead>
<tr>
<th>city</th>
<th>result</th>
<th>city</th>
<th>result</th>
<th>city</th>
<th>result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ezhou</td>
<td>1</td>
<td>Handan</td>
<td>2</td>
<td>Xingtai</td>
<td>3</td>
</tr>
<tr>
<td>Changzhi</td>
<td>5</td>
<td>Yangquan</td>
<td>6</td>
<td>Jinan</td>
<td>7</td>
</tr>
<tr>
<td>Benxi</td>
<td>9</td>
<td>Guangzhou</td>
<td>10</td>
<td>Datong</td>
<td>11</td>
</tr>
<tr>
<td>Kehamuyi</td>
<td>13</td>
<td>Weinan</td>
<td>14</td>
<td>Linfen</td>
<td>15</td>
</tr>
<tr>
<td>Jinzhong</td>
<td>17</td>
<td>Jinzhong</td>
<td>18</td>
<td>Leihua</td>
<td>19</td>
</tr>
<tr>
<td>Heihe</td>
<td>21</td>
<td>Anshan</td>
<td>22</td>
<td>Pingliang</td>
<td>23</td>
</tr>
<tr>
<td>Jilin</td>
<td>25</td>
<td>Xinzhui</td>
<td>26</td>
<td>Shenyang</td>
<td>27</td>
</tr>
<tr>
<td>Yulin</td>
<td>29</td>
<td>Baotou</td>
<td>30</td>
<td>Baoshan</td>
<td>31</td>
</tr>
<tr>
<td>Baie</td>
<td>33</td>
<td>Zhangjiakou</td>
<td>34</td>
<td>Daqing</td>
<td>35</td>
</tr>
<tr>
<td>Dazhou</td>
<td>37</td>
<td>Chengdu</td>
<td>38</td>
<td>Guangyang</td>
<td>39</td>
</tr>
<tr>
<td>Yangzi</td>
<td>41</td>
<td>Chongqing</td>
<td>42</td>
<td>Puer</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heihe</td>
<td>44</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

From table 4, Ezhou is the most polluted cities in these cities, the minimum is Heihe. Through investigation China City Statistical Yearbook 2014, we calculate the value for $x_1, x_2, x_3$. The value of Heihe’s unit industrial smoke dust discharge is $0.14$ ton/km$^2$. The value of Heihe’s unit industrial wastewater discharge is $0.0175$ ton/km$^2$; the value of Heihe’s unit industrial SO$_2$ discharge is $0.465$ ton/km$^2$, but the value of Ezhou’s environmental pollution indexes are $12.913$, $1.417$, $2.38$ respectively. The Ezhou’s pollution indexes exceed Heihe’s by 80 times or more. In accordance with China City Statistical Yearbook 2014, we find that Ezhou’s GDP is about 63 billion RMB; GDP per capita is 57,358 RMB, and Heihe’s GDP is about 39 billion, GDP per capita is 22,654 RMB. That means Ezhou’s economic level is higher than Heihe’s. Actually, many cities sacrifice environment to improve economic development. So how to balances environment and economic is a very important problem.

**FACTOR ANALYSIS FOR ENVIRONMENTAL MANAGEMENT**

The process for analysis environmental management is similar with last section. In this section, we also extract common factors by principle component, and the table 5 shows the process of extraction.

<table>
<thead>
<tr>
<th>component</th>
<th>Initial eigenvalue</th>
<th>Rotation sums of squared of loading</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>% of variance</td>
</tr>
<tr>
<td>1</td>
<td>1.686</td>
<td>33.718</td>
</tr>
<tr>
<td>3</td>
<td>0.949</td>
<td>18.98</td>
</tr>
<tr>
<td>4</td>
<td>0.616</td>
<td>12.324</td>
</tr>
<tr>
<td>5</td>
<td>0.443</td>
<td>8.863</td>
</tr>
</tbody>
</table>
From table 5, we extract 3 common factors for environmental management. In order to evaluate environmental management comprehensively, we use formulation (3) to construct comprehensive index $F_2$, then the cities ranking is showed in table 6. Because of data preprocess, the value of $F_2$ is the larger the worse.

Table 6 shows that Xinzhou is the worst in managing environment, and Handan is the best in these cities. The relationship between $F_1$ and $F_2$ shows in figure 1.

From the figure 1, there is no correlation between them. The pearson correlation coefficient is 0.285 which means correlation is not significant. A few cities realized the seriousness of the environmental pollution, e.g. Handan, Xingtai. Many heavily polluted cities have not strengthened environmental protection. For example, Panzhihua’s environmental pollution factor score ranks 40, but it still ranks 28 in environmental management.

**SCATTER DEGREE METHOD FOR SUSTAINABLE DEVELOPMENT**

In this section, we construct a comprehensive index for sustainable development by using the scatter degree method. Note that the value of the factor is the smaller the
better. We use MATLAB to solve the optimal model, then calculate the weight of $F_1$, $F_2$ is (0.79, 0.21), then the comprehensive factor $F = 0.79F_1 + 0.21F_2$. The ranking for ability of sustainable development is as follows:

![Table 7: Sustainable Development Factor Ranking](image)

From the table 7, Heihe is the best cities in protecting environment among the 44 resource based cities, and Ezhou is the worst because of its terrible environment problem. In order to let variance reach maximum, we find the weight of $F_1$ is larger than the weight of $F_2$. It means that the variance of pollution factor is larger, so the contribution of $F_1$ is larger than $F_2$. The main idea of scatter degree method is to max the difference among evaluation objects. The weight explains that the difference of pollution is larger than management. Although many cities has terrible environment problem, they still pay no attention on environment problem. The ability of sustainable development is mostly decided by environmental pollution. There is obvious correlativity between the pollution factor and the ability of sustainable development. The correlation coefficient shows in the table 8.

![Table 8: Correlation](image)

CONCLUSIONS

The well-developed resource based cities are important part of the economic, but with the development of the economic, the environmental problem becomes more and more serious. In order to develop economic healthy, we must realize the seriousness of
the environmental pollution. In this paper, we construct a new indexes system to evaluate the sustainable of the environment development, and use scatter degree method based on factor analysis. The results are as follows:

(1) For environmental pollution problem, some cities sacrifice environment to improve economic development. So the government should monitor these cities who only take the economic development as goal.

(2) There was a weak relationship between environmental pollution and management. Although many cities’ environment problem are serious, they still didn’t pay more attention on environmental management.

(3) The different weight means the pollution for each cities vary great, but there isn’t a huge difference among the ability of environmental management of the cities.

Finally, we evaluate the sustainable of environment development by collecting only one year data, maybe there is a way to research ability of the sustainable of environment development by using a few years data so that we can find the trend of sustainable of environment development.

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