Contents lists available at YXpublications

International Journal of Applied Mathematics in Control Engineering

Journal homepage: http://www.ijamce.com

Research on Theoretical Analysis Method Based on Maximizing Deviation

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ARTICLE INFO

Article history:
Received 7 March 2020
Accepted 13 May 2020
Available online 19 May 2020

Keywords:
maximizing deviation
theoretical analysis
weighted mean
spatial difference
temporal difference

ABASRACT

In the face of the multi-type and multi-feature mass data, the conventional information analysis method faces the challenge. Pointing at the mass data set of multi-group time series and spatial series and the information analysis method based on maximizing deviation technology is proposed. A comprehensive evaluation index system is established, and the water use efficiency of China is taken as an example to verify. The objective weight of each index of water use efficiency is obtained by the method of maximizing dispersion. The weighted average method is used to calculate the comprehensive weight of each index, and the evaluation model for evaluating water use efficiency is constructed. Finally, a quantitative evaluation is made by analyzing the scores of the comprehensive indicators. The results show that the significant spatiotemporal differences of water resources utilization efficiency in eastern, central and western China have been investigated: in terms of time, a trend of declining is shown in eastern, western China and the whole country, while a trend of increasing is shown in central China; and in terms of space, eastern China has the highest water using efficiency, followed by western China, and the water using efficiency of central China is the lowest.

1. Introduction

Water is a crucial natural factor for the survival and development of human beings, and also an important medium for the origin and evolution of life on the earth. But the shortage of water resources is serious in today's world. Currently, one sixth of the world's population, namely about one billion people, are in short of water. The situation of water resources in China is not optimistic [1], with the per capita water resources of 2,200 m3, which is about only one quarter of the world average and one fifth of the US average. China ranks 121 in the world, making it one of the world's thirteen most urgent countries for shortage of water resources per capita [2]. Water shortage has seriously affected the economic and social development of China. Thus, the analysis of water resources utilization efficiency is of great priority. To achieve sustainable and harmonious development of economy and society, sustainable and efficient water usage solutions will be aroused with investigation of factors affecting utilization efficiency of water resources in urban areas [3].

2. System Modeling

2.1 The basic principle of maximizing deviation

For the decision-making problem consisting of multiple attribute groups, scheme set is $X=\{x_1,x_2,\ldots,x_3\}$, attribute set is $Q=\{q_1,q_2,\ldots,q_m\}$, and decision maker set is $R=\{r_1,r_2,\ldots,r_t\}$. Assuming that decision maker $r_k\in R$, for known scheme $x_i\in X$ under attribute $Q_i\in Q$, the attribute value is $a_{ij}^k(a_{ij}^k>0, i\in N=\{1,2,\cdots,n\}$; $j\in M=(\omega_1,\omega_2,\cdots\omega_m)$; $k\in T=\{1,2,\ldots,t\}$), constituting the decision matrix ω_k. Normally, attribute values can be divided into positive benefit type and negative cost type. Normalized decision matrix can be obtained by dimensionless processing with the method described below. $\mathbf{R_k}=\left(\mathbf{r_{ij}^k}\right)n\times m$. Assume that the weight vector of attributes $\omega=\left(\omega_1,\omega_2\ldots,\omega_\mathbf{m}\right)$, $\omega_i\geq 0$, and it satisfies the unitization constraints $\sum_{i=1}^m\omega_i^2=1$. Assume that the weight of t'th decision maker is $\lambda=(\lambda_1,\lambda_2,\ldots,\lambda_t)$, and it satisfies $0\leq\lambda_k\leq 1,\sum_{k=1}^t\lambda_k^2=1$.

For the decision-making problem with multiple attributes, the normalized decision matrix of a decision maker is assumed to be

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$Y = \cdot(y \cdot ij \cdot) \cdot n \times m$. If attribute Q_j (the j'th attribute) is consistent to all alternatives, the rank of alternatives will not be influenced by Q_j. Then let the weight coefficient of attributes be zero. Otherwise, if there are large differences in attribute values generated by Q_j in different alternatives, then the ranking of alternatives will be greatly influenced by those attributes. Thus, a large weight coefficient should be given to Q_j. For attribute Q_j, $L_{ij}(X)$ represents deviations between scheme s i and all the other schemes, and it is defined as $L_{ij}(\omega) = \sum_{l=1}^{n} | r_{ij}\omega_i - r_{lj}\omega_j |$. Then $L_j(\omega)$ is defined as $L_j(\omega) = \sum_{i=1}^{n} r_{ij}\omega_i = \sum_{i=1}^{n}\sum_{l=1}^{n} | r_{ij} - r_{lj} |\omega_j$. $L_j(\omega)$ represents the summation of deviations between each scheme and all the other schemes. Based on this idea of maximizing deviation, the solution of weight vector ω can be transformed to the following optimized model [4,5,6]:

$$\begin{cases} \max L(\omega) = \sum_{j=1}^{m}\sum_{i=1}^{n}\sum_{l=1}^{n} \left| y_{ij} - y_{lj} \right| \omega_j \\ s.t.\ \ \omega_j \geq 0, j \in M, \sum_{j=1}^{m} \omega_j^2 = 1 \end{cases} \tag{1}$$

By solving the above model and carrying out normalization processing, the weight of attributes [7] can be presented as follows:

$$\omega_j = \frac{\sum_{i=1}^{n}\sum_{l=1}^{n} \left| y_{ij} - y_{lj} \right|}{\sum_{j=1}^{m}\sum_{i=1}^{n}\sum_{l=1}^{n} \left| y_{ij} - y_{lj} \right|} \tag{2}$$

2.2 The basic principle of weighted mean method

In the weighted mean method [8], values are multiplied by the corresponding weights, and added up to obtain the total value. Then the total value will be divided by the total number of units to obtain the weighted mean. In the calculating process, weight represents the proportion of each component in the whole system. A larger weight means more importance to the whole system, giving more significant influence to the weighted mean. The formula is as follows:

$$Y = \sum_{i}^{n} y_i \omega_j = \sum_{i=1}^{n} \frac{x_i}{x_l} \omega_j \tag{3}$$

where Y is the synthetical index needed to be calculated for comprehensive assessment; y_i is the individual index of the i'th evaluation indicator, which is actually a dimensionless evaluation value acquired by comparing the actual value and the evaluation standard of the i'th indicator, and the meaning and calculating method of y_i is shown in the expansion of y_i; x_i is the actual value of the i'th evaluation indicator; $\overline{x}_1$ is the evaluation standard of the i'th evaluation indicator (in this paper, the average of each indicator is adopted as the evaluation standard); and ω_j is the weight of i'th evaluation indicator in the comprehensive assessment.

2.3 The construction of water resources utilization efficiency model

1) The dimensionless processing of raw data: due to different meanings, calculation methods and dimensions of indicators, comparing them directly is unfeasible. Standardization of indicators is necessary before building up the maximizing deviation model. For the positive benefit indicators where larger values are better, the standardization is as follows [9]:

$$\text{Positive indicator: } r_{ij} = \frac{x_{ij}}{x_{ij}} \tag{4}$$

For negative cost indicators where smaller values are better, the standardization is as follows:

$$\text{Negative indicator: } r_{ij} = \frac{\overline{x_{ij}}}{x_{ij}} \tag{5}$$

where x_{ij} is the raw data of indicators, and $\overline{x_{ij}}$ is the average of raw data of indicators.

2) Obtaining the weight of dimensionless indicators by maximizing deviation: based on the idea of maximizing deviation, the solution of weight vector ω can be transformed to the optimized model:

$$\begin{cases} \max L(\omega) = \sum_{j=1}^{m}\sum_{i=1}^{n}\sum_{l=1}^{n} \left| y_{ij} - y_{lj} \right| \omega_j \\ s.t.\ \ \omega_j \geq 0, j \in M, \sum_{j=1}^{m} \omega_j^2 = 1 \end{cases} \tag{6}$$

By solving the above model and carrying out normalization processing, the weight of attributes is presented as follows:

$$\omega_j = \frac{\sum_{i=1}^{n}\sum_{l=1}^{n} \left| y_{ij} - y_{lj} \right|}{\sum_{j=1}^{m}\sum_{i=1}^{n}\sum_{l=1}^{n} \left| y_{ij} - y_{lj} \right|}, j \in M \tag{7}$$

where $L_{ij}(X)$ represents deviations between scheme s i and all the other schemes, and $Y = (y_{ij})_{n \times m}$ is the normalized decision matrix.

3) The construction of synthetically evaluation index by the weighted mean method: dimensionless values are multiplied by the corresponding weights, and added up to obtain the comprehensive score. The formula is presented as follows:

$$Y = \sum_{i}^{n} y_i \omega_j = \sum_{i=1}^{n} \frac{x_i}{\overline{x}_l} \omega_j \tag{8}$$

where Y is the synthetically index needed to be calculated for comprehensive assessment, y_i is the dimensionless index of the i'th evaluation indicator, x_i is the actual value of the i'th evaluation indicator, $\overline{x}_i$ is the evaluation standard of the i'th evaluation indicator, and ω_j is the weight of i'th evaluation indicator in the comprehensive assessment.

3. Example Verification

3.1 Selection of indicators

When analyzing and assessing the water resources utilization efficiency of China, the water using efficiency of economic and social development needs to be considered. Moreover, in order to conduct an overall assessment of China's water resources utilization efficiency from whole to part, the water using efficiency of industrial and domestic water consumption has to be evaluated respectively according to different types of water consumption. Therefore, considering the above comprehensive factors, with the help of Song Guojun's indicator selection experience from his research of benchmarking construction for the water resources utilization efficiency of China, four indicators [10,11] for water resources utilization efficiency are selected: water consumption per 10,000 yuan of GDP, which reflects the water using efficiency of city's economy development; overall water consumption per capita, which reflects the water using efficiency of city's society; water consumption per 10,000 yuan of industrial gross output, which reflects the water using efficiency of city's industrial production; and domestic water consumption per capita, which reflects the water using efficiency of city's residential use.

1) Calculation formula for water consumption per 10,000 yuan of GDP: water consumption per 10,000 yuan of GDP = total water supply/GDP in 10,000 yuan.

According to the indicator explanation on the website of National Bureau of Statistics of China, total water supply refers to the total water supply from public waterworks and social units with their own water sources throughout the year, which consists of not only the effective water supply, but also the water supply loss except the agricultural and domestic water loss[12,13]. Water consumption per 10,000 yuan of GDP indicates the water resources needed to be consumed for economic aggregate growth per unit.

2) Water consumption per 10,000 yuan of industrial gross output = total industrial water consumption/industrial gross output.

This reveals the water resources consumed for every increased 10,000 yuan within the gross industrial output in the municipal area, reflecting the water-saving efficiency of industrial production to some extent. For statistics collection, the data of industrial water consumption are unavailable in the municipal area. Thus, in this paper, the total industrial water consumption is calculated by min using total water supply with domestic water consumption and water supply loss.

3) Calculation formula for overall water consumption per capita: overall water consumption per capita = total water supply/population of the municipal area.

This indicator reflects the distributed amount of overall social water consumption per capita in the city. The item "population of urban area" only refers to urban residents, and rural residents are excluded so as to better reflect the actual comprehensive allocation of water supply services in municipal areas [14,15].

4) Calculation formula for domestic water consumption per capita: domestic water consumption per capita = total domestic water consumption/population of the municipal area.

Domestic water consumption is composed of water consumption for daily use and public water consumption of urban residents, such as their drinking water and their daily using water in catering industry, construction industry, hotels, fire departments, public institutions, governments, shopping malls, bathing industry, medical services, beauty industry, training institutions, etc.

3.2 Sources of the data

The statistics used in this paper are all from China City Statistical Yearbook, China Urban Construction Statistical Yearbook in 2007 to 2015, and Water Resources Bulletin published on the website of water resources departments of provinces and municipalities directly under the central government. In this paper, the city scope is limited to the municipal districts and counties or county-level cities under the jurisdiction are not included. The statistics used in this paper are total water supply, total GDP, urban population, domestic water consumption, total industrial water consumption and industrial gross output.

3.3 Experimental process

Step one: standardization of indicators.

The four selected indicators of water consumption per 10,000 yuan of GDP, overall water consumption per capita, water consumption per 10,000 yuan of industrial gross output and domestic water consumption per capita in 2007 to 2015 are negatively correlated with water utilization efficiency of cities above prefecture level. Therefore, negative indicator standardization method [16,17] is employed for dimensionless processing. The formula is as follows:

$$r_{ij} = \frac{\overline{X}_{ij}}{X_{ij}}$$

where x_{ij} is the raw data of indicators, and $\overline{x}_{ij}$ is the average of raw data of indicators.

Step two: by the maximizing deviation method, the weights of each city's four water resources indicators in 2007 to 2015 in cities above prefecture level are calculated.

Table 1. The weights of each city's water resources indicators in 2007 to 2015 in cities above prefecture level

YEAR	WCGDP	WCGIOV	PCCWS	WCPC
2007	0.16169162	0.3976974	0.19776794	0.242843
2008	0.15381218	0.4511505	0.17330696	0.22173
2009	0.16685909	0.4129723	0.20167542	0.218493
2010	0.17027475	0.4101266	0.2083724	0.211226
2011	0.16473896	0.4417174	0.20415434	0.189389
2012	0.18686163	0.3944855	0.21263099	0.206022
2013	0.17941182	0.4759525	0.18072105	0.163915
2014	0.19155427	0.4884705	0.16947837	0.150497
2015	0.18601736	0.481156	0.17546025	0.157366

Step three: the comprehensive evaluation scores of water resources utilization efficiency in cities above prefecture level are calculated using the weighted mean method.

Since there are 287 cities above prefecture level in China, the data are too much and the factors influencing the water utilization efficiency are complicated, which makes it difficult to analyze regularities of the result. Thus, in this paper, the data are further processed into comprehensive evaluation scores of water resources utilization efficiency in the provincial level. As the raw data of indicators in Tibet from 2007 to 2012 are unavailable, only the data in 2013 to 2015 is collected. Thus, there are data of 30 provincial regions from 2007 to 2012, and data of 31 provincial regions from 2013 to 2015. The results of provincial regions are listed in the following table:

Table 2. The comprehensive scores of water resources utilization efficiency in provincial regions of China

province	2007	2008	2009	2010	2011	2012	2013	2014	2015
BJ	2.01602624	1.925655	1.689426	1.6772506	1.581217	1.547771	1.648978	1.296018	1.341443
TJ	3.06895664	3.368935	3.200923	3.350426	3.207173	2.73371	2.633236	2.628543	2.949497

HeB	1.77375307	1.821219	1.635947	1.522007	1.465028	1.47086	1.518111	1.756534	1.811798
SanX	2.14728525	1.61442	1.496396	1.7593	1.703636	1.453721	1.405826	1.216064	1.283354
NMG	1.8132956	1.904204	1.589166	1.426047	1.578657	1.96963	2.015406	1.605927	1.704441
LN	1.73372668	1.660994	1.67469	1.580877	1.633499	1.488194	1.315173	1.348129	1.233701
JL	2.70995904	2.220003	2.459837	2.401916	1.864299	1.817883	1.749956	1.994508	2.401379
HLJ	1.36707025	1.34462	1.319021	1.335672	1.259801	1.158445	0.934832	0.891656	0.88725
SH	1.37029997	1.375308	1.23593	1.415278	1.160151	1.481412	1.213127	1.116735	1.182086
JS	2.19896901	2.382785	1.804088	1.608126	1.500534	1.42487	1.892401	3.699684	2.190797
ZJ	1.89261228	2.003148	1.834195	1.575455	1.544097	1.440247	1.441399	1.456513	1.410386
AH	1.26766616	1.314528	1.460214	1.187914	1.21196	1.209444	1.36097	1.464898	1.5375
FJ	1.78148596	1.738393	1.545884	1.771138	1.754717	1.64845	1.366715	1.686553	1.978395
JX	1.02345001	1.293497	1.280132	1.266746	1.22139	1.285338	1.517623	1.812714	2.049417
SD	2.63127376	2.788773	2.586387	2.272363	2.133659	1.988543	2.210784	2.039123	2.037074
HeN	1.55314951	1.557341	1.444654	1.460113	1.439844	1.310129	1.417017	1.354411	1.611038
HuB	0.95537357	1.042879	1.088218	1.199214	2.22711	1.339969	1.601916	1.582903	1.693433
HuN	1.15903354	1.193439	1.162278	1.184565	1.092163	1.004134	1.183665	1.197166	1.292398
GD	2.29325585	3.905447	2.478216	2.316218	2.360579	1.46004	1.854708	1.568241	1.723454
GX	1.1773054	1.115874	1.071575	1.167297	1.461455	1.066227	1.439123	1.409951	1.54117
HaiN	0.61223038	0.572858	0.606877	0.336686	0.421792	0.410888	0.396989	0.458699	0.47459
CQ	2.30271275	2.898193	2.142152	1.946635	1.959015	1.953045	1.628294	1.790614	2.028223
SC	1.59099392	1.696773	1.6852	1.706767	1.771386	1.761774	1.84847	2.100558	1.934607
GZ	1.42541591	1.477794	1.64158	1.670773	1.494709	1.389873	1.891684	1.667128	1.655238
YN	2.04576703	2.107058	1.910664	1.741342	1.67523	1.762003	1.574564	1.616224	1.590957
XZ							0.256243	0.311787	0.232757
ShanX	2.80842905	2.759252	1.998753	2.206148	2.039199	1.957037	3.141107	2.445634	2.292966
GS	2.03838752	1.857538	1.678925	1.742136	1.726574	1.801054	1.901911	1.74683	1.591424
QH	0.81824626	0.792412	0.863351	0.87683	0.741199	0.760053	0.718898	0.779047	0.838421
NX	2.45179029	2.29422	2.364612	2.527646	2.142274	1.11312	1.42618	1.296393	1.265038
XJ	1.64881341	1.333483	1.1475	1.112101	1.01315	0.977061	1.030481	1.185218	0.866969

Step four: temporal difference analysis of water resources utilization efficiency in China.

According to the regional division of National Bureau of Statistics of China, the above provincial regions are further grouped into eastern, central and western China. Guangdong, Hebei, Shandong, Jiangsu, Liaoning, Zhejiang, Fujian, Hainan, Shanghai, Tianjin and Beijing are included in eastern China. Henan, Hunan, Anhui, Hubei, Jiangxi, Heilongjiang, Shanxi and Jilin are included in central China. Sichuan, Guangxi, Yunnan, Guizhou, Shaanxi, Chongqing, Gansu, Xinjiang, Inner Mongolia, Ningxia and Qinghai are included in western China.

The average scores of water resources utilization efficiency in three major parts of China from 2007 to 2015 are listed in the following table:

Table 3. The average scores of water resources utilization efficiency in the three major parts of China from 2007 to 2015

Region	Eastern Region	Central region	Western Region	Whole Country
2007	1.94296271	1.52287342	1.8291961	1.765011
2008	2.14031956	1.44759095	1.83970921	1.809207
2009	1.84477857	1.46384363	1.64486171	1.651161
2010	1.76598394	1.47443002	1.64761109	1.629342
2011	1.70567707	1.50252534	1.60025895	1.60282
2012	1.55408949	1.32238298	1.50098878	1.459154
2013	1.59014731	1.3964756	1.57269675	1.519773
2014	1.7322519	1.43929001	1.49627588	1.555939
2015	1.66665641	1.5944711	1.46185091	1.574326

To better observe the temporal trends of eastern, central and western China, the data in Table 3 are transformed into the broken-line graph, as shown below:

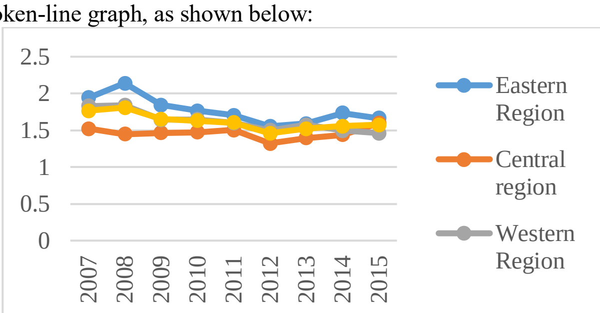

Fig.1. Broken-line graph for temporal trends of water resources utilization efficiency in the three major parts of China from 2007 to 2015

As shown in the temporal trend graph, from 2007 to 2015, water resources utilization efficiency of eastern China has always been higher than the national average. The score of western China is close to the national average in 2007 to 2013, but lower than the national average in 2014 to 2015. On the contrary of western China, the score of central China is always lower than the national average while it is slightly higher than the national average and even higher than western China in 2015. As for the varying trend with time, the score shows a decreasing trend in eastern, western China and the whole country while it shows an increasing trend in central China, which is consistent with the research of most scholars [18,19,20].

Step five: spatial difference analysis of water resources utilization efficiency in China.

To better observe the spatial trends of eastern, central and western China, the data of Table 3 are transformed into the broken-line graph shown below:

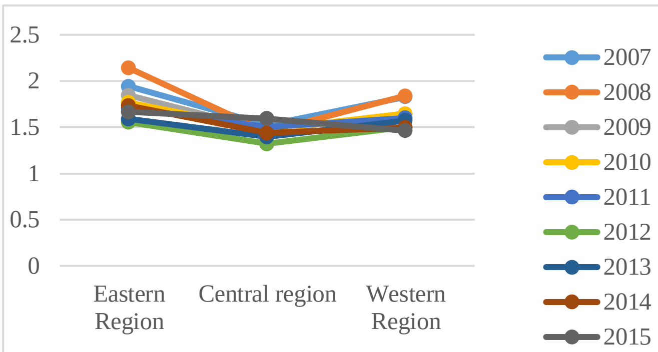

Fig. 2. Broken-line graph for spatial trends of water resources utilization efficiency in three major parts of China from 2007 to 2015

As shown in the above broken-line graph, from 2007 to 2014, the water resources utilization efficiency of eastern China is higher than that of western China, while the score of western China is higher than that of central China, which is highly consistent with the analysis of Gong Mingli [21,22] in her A Study on the Efficiency of Urban Water Resource System in

China Based on the Analysis of Network BAM Model. In 2015, the water resources utilization efficiency of eastern China is still higher than that of central and western China, but the score of central China is higher than that of western China. This may be attributed to the location advantage of eastern China, which brings together abundant human and financial resources. In addition, the technologies in eastern China might be more advanced, bringing about higher efficiency of water using during production or sewage disposal. Therefore, the overall water using efficiency of the system in eastern China is superior to central and western China. As for central China, the efficiency is low in some of the central provinces such as Heilongjiang and Hubei. This drags down the overall water resources utilization efficiency of cities in central China, and leads to its lower comprehensive efficiency than that of western China.

4. Conclusion

Maximizing deviation method is employed to calculate the weight of dimensionless indicators. The comprehensive scores of water resources utilization efficiency in cities above prefecture level are obtained by the weighted mean method. Then, the spatial and temporal differences of water using efficiency in China are analyzed with the comprehensive scores. As shown in the temporal trend graph of water resources utilization efficiency, the water using efficiency of eastern China is the highest, and it's also higher than the national average. The efficiency of western China is close to the national average, and the efficiency of central China is lower than the national average. The water utilization efficiency of all three major parts of China varies with time. The utilization efficiency is decreasing gradually in both eastern and western China, while it grows gradually in central China. As shown in the spatial trend graph of water resources utilization efficiency, the efficiency of eastern China is the highest, followed by western China, and the efficiency of central China is the lowest.

Acknowledgements

This work Supported by the Hebei Science and Technology Support Project (Grant:17210105D).

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