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Evaluation of China industrial water efficiency based on DAGF method

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ABSTRACT

Raising the efficiency of industrial water has become a hot topic in economic development and environmental governance. Based on DAGF method – a combination of Delphi method, analytic hierarchy process, gray relational analysis, and Fuzzy comprehensive evaluation – this paper evaluated the industrial water efficiency of 22 samples selected from China. The main conclusions are as follows: the overall efficiency of industrial water use in China is good but unbalanced, and the gap between regions is relatively large. Compared with areas which have resource-based water shortage and of which the economy is relatively backward, industrialized areas are more prone to industry water inefficiencies. Finally, according to the evaluation results, the following suggestions were put forward to improve the efficiency of industrial water use: the government should strengthen its guidance through establishing incentive and restraint mechanisms and enterprises should improve industrial water efficiency by developing water-saving technologies and accelerating the transformation of production mode.

Keywords: Industrial water efficiency; Evaluation index system; DAGF method; Industrial water suggestions

1. Introduction

Water shortage is one of the thorny issues faced with the development of China. Although the total freshwater resources of China reach 2.8 trillion m^3, accounting for 6% of the world's water resources and ranking the fourth, its huge population makes it the world's largest water-consuming country and one of the poorest countries in terms of water resources per capita. With the economic and social development, water consumption in China has also raised greatly with industrial water consumption accounting for most of the total consumption. The security and efficiency of industrial water are of great significance. In 2015, the State Council issued the "Made in China 2025" circular to confirm China's goal of transforming to powerful manufacturing country from big manufacturing country, pointing out that China should significantly reduce water consumption per unit of industrial added value. In 2017, the leaders of 19th CPC National Congress had set forth the strategic goal of building an all-round socialist modernization country. Studying and improving industrial water efficiency is of positive significance for promoting the development of a green and high-quality industry.

According to present researches, industrial water efficiency and industrial development will influence each other. Balancing the relationship between economic development and industrial water use has become an important issue for China [1]. Some countries experienced rapid industrialization, which may stimulate substantial increases in their

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future industrial water use [2]. Urban areas, especially cities, are facing the challenge of having direct water needs from local sources [3]. Water resources elasticity coefficient should be further increased to improve the contribution of unit water consumption for industrial growth, so improving industrial water efficiency was one of the most important aspects [4]. The driving forces of changes in industrial water use are output, technological, and structural forces [2]. Masanet and Walker [5] studied the water efficiency of the U.S. energy and industrial steam. Accurate prediction of water use efficiency is very important to water management [6]. To improving water efficiency, the government and citizens should focus on pollution reduction, water conservation, industrial restructuring, and so on [7]. Decrease in the share of the secondary industry in the national economy is a precondition for the stabilization and decline in industrial water use [8].

The efficiency of industrial water can be improved through the using of new technologies, water conservation, and industrial restructuring. An efficient industrial water management system can yield obvious water-saving benefits [9]. Government should decrease the export volume of industrial products which contained too much water, so as to use water resource in a sustainable and effective way [10]. Reuse technologies have seen increasing adoption in recent years [11]. Improving the industrial structure is an effective way of reducing water consumption and water pollutants [12]. Water charges may be an effective instrument for water conservation [13]. Zhelev et al. [14] took a new view of water solutions management, especially when processes experience difficulties for direct heat recovery. The systematic strategy for sustainable utilization of water resource is necessary for water saving and regulating watercourses [15]. New method of industrial water recycling can ease the contradiction between supply and demand of water resources [16].

This paper evaluated industrial water efficiency using Delphi method [17,18], analytic hierarchy process (AHP) method [19,20], fuzzy comprehensive evaluation method [21], and gray relational analysis method [22,23]. Analytic hierarchy process and fuzzy comprehensive evaluation method can be conducted to establish the evaluation index and evaluation system [24]. By analyzing the influence of various factors, the countermeasures to improve the efficiency of industrial water use were put forward.

2. Evaluation method

2.1. Industrial water efficiency evaluation index system

By consulting experts, AHP and Delphi method are adopted to determine the three-level evaluation index system. The first level is the total target: industrial water efficiency. The second level is divided into three factors including unit output value of water use, total water use, and water-saving indicator; then the second-level indicators are decomposed to obtain the third-level indicators.

2.2. Determination of the weight of indicators at all levels

First, we invited experts to evaluate the various indicators of the factors set, and we drew the expert evaluation matrix. Then, the consistency of the evaluation matrix was checked, and the weight vector of the matrix was further obtained to judge the importance of each index to the upper level indicator.

Taking the weight of the second-level index as an example, we calculated its expert rating matrix as follows:

$$A = \begin{bmatrix} 1 & 2 & 1/2 \\ 1/2 & 1 & 1/2 \\ 2 & 2 & 1 \end{bmatrix} \quad (1)$$

Aiming at the expert evaluation matrix A, we used MATLAB software to find the weight vector, the largest eigenvalue, and to test the consistency.

Indicator weight vector is $W = \{0.3108, 0.1958, 0.4934\}$.

The maximum eigenvalue is $\lambda_{max} = 3.0536$.

The consistency test result is CI = 0.0268 and CR = 0.0516.

The consistency test result shows CR < 0.1, therefore, the consistency of the matrix is acceptable, and the index weight is reasonable. Using the same method, we can calculate the weight of other indicators, and the weights of indicators at all levels are shown in Table 2.

2.3. Sample selection and dimensionless treatment

The evaluation index system in this paper is suitable for most of the samples for industrial water efficiency evaluation. We selected 22 samples from 34 provincial-level administrative regions of China for the evaluation of industrial water efficiency in 2016. These regions are as follows: Beijing, Tianjin, Shanghai, and Chongqing, which are municipalities; Liaoning, Jiangsu, Anhui, Fujian, Jiangxi, Shandong, Hubei, Hunan, Guangdong, Hainan, Sichuan, Yunnan, Shaanxi, Gansu, and Qinghai, which are provincial regions; and Inner Mongolia, Guangxi, and Ningxia, which are autonomous regions. The distribution of these 22 samples were analyzed from the geographic area: there is one in northeastern area, four in North China, six in the east, four in the southeast, three in the southwest, and four in the northwest. The sample data selected in this paper are very time-oriented. They are basically from the government-issued water resources bulletin of 2016.

The sample data in the evaluation index were dimensionless sized to form an optimized sample matrix. In this evaluation index system, U_1 and U_2 are reverse indicators, and U_3 is forward indicator. Therefore, the sample data should be dimensionless sized using Eqs. (2) and (3).

- For forward indicators, the dimensionless formula is as follows:

$$b_{ij} = \frac{d_j - \min d_{ij}}{\max d_j - \min d_j} (i = 1, 2, ..., m;\ j = 1, 2, ..., n) \quad (2)$$

where $\max d_j$ and $\min d_j$ represent the maximum and minimum of each evaluation value in the index set U; d_j represents the actual value; and b_{ij} represents dimensionless sized values.

- For reverse indicators, the dimensionless formula is as follows:

Table 1
Industrial water efficiency evaluation index system

Goal	Factors	Indicators
Industrial water efficiency, U	Unit output value of water use, U_1	Water consumption per 10,000 Yuan GDP, U_{11}
		Water consumption per 10,000 Yuan industrial added value, U_{12}
	Total water use indicator, U_2	Total industrial use of water, U_{21}
		The rate of industrial water use, U_{22}
		Industrial water consumption, U_{23}
		The rate of industrial water consumption, U_{24}
	Water-saving indicator, U_3	The rate of water use reduction per 10,000 Yuan industrial added value, U_{31}
		The rate of industrial water reduction, U_{32}

Table 2
Indicators at all levels of weight

Goal	Factors	Weight vector	Indicators	Weight vector
U	U_1	0.3108	U_{11}	0.4
			U_{12}	0.6
	U_2	0.1958	U_{21}	0.0741
			U_{22}	0.2751
			U_{23}	0.1376
			U_{24}	0.5132
	U_3	0.4934	U_{31}	0.6667
			U_{32}	0.3333

Table 3
Sample data after the non-dimensionalization

	U_{11}	U_{12}	U_{21}	U_{22}	U_{23}	U_{24}	U_{31}	U_{32}
BJ	0.71	0.48	0.99	0.92	0.57	0.81	0.84	0
TJ	0.71	1	0.98	0.68	0.98	0.05	0.6	0.21
SH	1	0.47	0.72	0	0.57	0.81	0.39	0.52
CQ	0.93	0.5	0.76	0.18	0.71	0.49	0.94	0.56
LN	0.71	0.48	0.86	0.82	0.85	0	0.84	0.7
JS	0.83	0.61	0	0.43	0.71	0.81	0.65	0.37
AH	0.49	0	0.27	0.4	0.73	0.85	0.68	0.33
FJ	0.79	0.42	0.47	0.3	0.57	0.81	0.9	0.57
JX	0.34	0.07	0.52	0.56	0.66	0.38	0.6	0.33
SD	0.71	0.48	0.77	0.82	0.73	0.86	0.84	0.2
HB	0.68	0.22	0.28	0.39	0.61	0.69	0.78	0.43
HN	0.57	0.17	0.3	0.52	0.73	0.72	0.64	0.41
GD	0.86	0.69	0.14	0.56	0.62	0.82	0.8	0.47
HI	0.47	0.32	0.99	0.99	1	1	0.88	1
SC	0.71	0.53	0.57	0.66	0	0.18	0	0.32
YN	0.59	0.39	0.85	0.83	0.87	0.92	0.83	0.69
SN	0.91	0.48	0.91	0.8	0.88	0.81	0.84	0.5
GS	0.23	0.35	0.93	0.94	0.94	0.11	0.64	0.5
QH	0.59	0.74	1	0.93	1	0.94	0.9	0.78
NM	0.62	0.83	0.88	0.95	0.78	0.89	0.73	0.65
GX	0.27	0.23	0.62	0.75	0.09	0.23	1	0.76
NX	0	0.6	0.99	1	0.95	0.87	0.71	0.32

Note: For abbreviations of each province please refer to "China Internet Domain Name System."

$$b_{ij} = \frac{\max d_j - d_{ij}}{\max d_j - \min d_j} (i = 1, 2, ..., m; j = 1, 2, ..., n) \tag{3}$$

Here, we take the first sample data U_{111} of indicator U_{11} as an example to calculate the optimized data d_{ij}.

In the sample data of indicator U_{11}, $\max(U_{ij})$ = 206, $\min(U_{ij})$ = 31, and U_{111} = 81. So the equation is as follows:

$$d_{11} = \frac{\max(U_{ij}) - U_{111}}{\max(U_{ij}) - \min(U_{ij})} = \frac{206 - 81}{206 - 31} = 0.71 \tag{4}$$

Other sample data can be optimized by the same method as shown in Table 3.

2.4. Calculation of the gray evaluation coefficient

We adopted gray relational analysis method to determine the evaluation gray e and definite weighted functions f_e, then calculated the gray evaluation coefficient of each indicator according to f_e.Finally, the gray evaluation coefficients of each gray were summed to get the total evaluation coefficient X. We set four gray grades, denoted e = 1, 2, 3, 4.The definite weighted functions determined according to gray class are shown in Table 4.

The formula of total gray evaluation coefficient of a certain sample in the evaluation index U_{ij} is as follows:

$$X_{ij} = \sum_{e=1}^{4} f_e(d_i) \tag{9}$$

Based on the sample matrix after dimensionless processing, the gray evaluation coefficient and the total evaluation coefficient were calculated, and the gray fuzzy evaluation matrix was obtained. As this paper seeks to obtain comparisons between samples, it is necessary to calculate the final score for each sample separately. According to Eqs. (5)–(8), we take the sample Beijing as an example, and the calculation process are as follows:

For the indicator U_{11} of Beijing, the statistics X_e for four gray categories are as follows:

$$\left.\begin{aligned} e = 1, x_1 = f_1(1) = 1 \\ e = 2, x_2 = f_2(1) = 0.21429 \\ e = 3, x_3 = f_3(1) = 0 \\ e = 4, x_4 = f_4(1) = 0 \end{aligned}\right\} \tag{10}$$

Table 4
Definite weighted functions

Gray class	Gray evaluation coefficient	Definite of weighted function
$e = 1$	$\otimes_1 \in [0, 0.5, 1]$	$f_1(d_i) = \begin{cases} d_i / 0.5, d_i \in [0,0.5] \\ 1, d_i \in [0.5,1] \\ 0, d_i \notin [0,1] \end{cases}$ (5)
$e = 2$	$\otimes_2 \in [0, 0.4, 0.8]$	$f_2(d_i) = \begin{cases} d_i / 0.4, d_i \in [0,0.4] \\ (0.8 - d_i) / 0.4, d_i \in [0.4,0.8] \\ 0, d_i \notin [0,0.8] \end{cases}$ (6)
$e = 3$	$\otimes_3 \in [0, 0.3, 0.6]$	$f_3(d_i) = \begin{cases} d_i / 0.3, d_i \in [0,0.3] \\ (0.6 - d_i) / 0.3, d_i \in [0.3,0.6] \\ 0, d_i \notin [0,0.6] \end{cases}$ (7)
$e = 4$	$\otimes_4 \in [0, 0.2, 0.4]$	$f_4(d_i) = \begin{cases} 1, d_i \in [0,0.2] \\ (0.4 - d_i) / 0.2, d_i \in [0.2,0.4] \\ 0, d_i \notin [0,0.4] \end{cases}$ (8)

According to Eq. (9), the total evaluation coefficient X of the indicator U_{11} in Beijing can be calculated as follows. Similarly, the gray coefficient and the total number of other indicators can be calculated.

$$x = x_1 + x_2 + x_3 + x_4 = 1.21429 \quad (11)$$

2.5. Calculation of gray weight vector and weight matrix

We obtained the gray coefficient and the total evaluation coefficient of each indicator, and we can further get the gray evaluation weight vector r and weight matrix R of each indicator according to Eq. (12).

$$r_{ij} = \left(\frac{f_1,(d_i)}{X_{ij}}, \frac{f_2,(d_i)}{X_{ij}}, \frac{f_3,(d_i)}{X_{ij}}, \frac{f_4,(d_i)}{X_{ij}} \right) \quad (12)$$

We still take the indicator U_{11} of Beijing as example to calculate the weight vector and weight matrix. According to Eq. (12), the weight of indicator U_{11} is r_{11}=(0.82353, 0.17649, 0, 0).

Similarly, we can calculate the weights of eight indicators such as r_{12}, r_{21}, r_{22}, …, r_{32}. We can get the gray fuzzy evaluation matrix of U_1, U_2, U_3 according to the calculation above, which are R_1, R_2, R_3 in turn.

$$R_1 = \begin{bmatrix} r_{11} \\ r_{12} \end{bmatrix} = \begin{bmatrix} 0.82353 & 0.17647 & 0 & 0 \\ 0.43936 & 0.37185 & 0.18879 & 0 \end{bmatrix}$$
$$R_2 = \begin{bmatrix} r_{21} \\ r_{22} \\ r_{23} \\ r_{24} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0.60626 & 0.34196 & 0.05178 & 0 \\ 1 & 0 & 0 & 1 \end{bmatrix} \quad (13)$$
$$R_3 = \begin{bmatrix} r_{31} \\ r_{32} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

2.6. Calculation of the second-level indicator evaluation vector

We determined the weight evaluation vector and weight evaluation matrix of the third-level indicator. Here, we take the indicator U_1 of Beijing as an example to calculate the second-level indicator evaluation vector B_1.

$$B_1 = W_1 \cdot R_1 = [0.59303 \quad 0.2937 \quad 0.11327 \quad 0] \quad (14)$$

Similarly, the evaluation vectors of U_2, U_3 are B_2, B_3. Further, we obtained the fuzzy evaluation matrix R of the second-level indicator:

$$R = \begin{bmatrix} B_1 \\ B_2 \\ B_3 \end{bmatrix} = \begin{bmatrix} 0.59303 & 0.2937 & 0.11327 & 0 \\ 0.94582 & 0.04705 & 0.00712 & 0 \\ 0.6667 & 0 & 0 & 0.3333 \end{bmatrix} \quad (15)$$

2.7. Calculation of fuzzy comprehensive evaluation value

Through the steps above, we obtained the weight vector W of the second-level indicators relative to the first-level indicator, then determined the score set C = [90, 70, 50, 30], and also obtained the fuzzy evaluation matrix R of the second-level indicators. And then, the fuzzy comprehensive evaluation value of each sample can be acquired. We still take Beijing as an example to calculate the total score Z of industrial water efficiency evaluation.

$$Z = W \cdot R \cdot C^T = 79.6591 \quad (16)$$

Similarly, the total score of industrial water efficiency of other sample cities can be calculated. See Table 5 for details.

3. Evaluation results analysis and countermeasures

3.1. Evaluation results analysis

As can be seen from Table 5, the scores of the provinces varied greatly indicating that there is a wide gap between the efficiencies of industrial water in all provinces of China, and the industrial water efficiency is uneven among different regions. From the rankings, we can see that the first and second places are Qinghai and Inner Mongolia, respectively. Although they are inland water-scarce and economically underdeveloped areas, their industrial water efficiency ranks ahead of Guangdong.

Throughout the rankings, we can see that in areas where water resources are scarce and economic development is relatively backward, the efficiency of industrial water is not necessarily low. However, in some industrially developed and water-rich areas, there may be inefficiencies in industrial water. Upon this, all provinces should focus on improving industrial water efficiency, especially industrialized areas in which industrial water consumption is relatively larger, to ensure the improvement of water use quality.

According to the analytic hierarchy process, we can see that water-saving indicators and unit output water indicators account for a relatively high proportion of 49.34% and 31.08%, respectively, while total water indicators account for only a low of 19.58%. Among the third-level indicators, water consumption per 10,000 Yuan GDP, water consumption per 10,000 Yuan industrial added value, the rate of industrial water consumption, the rate of water reduction per 10,000 Yuan industrial added value account for relatively high weights. Therefore, in the process of developing industrial production, we must continuously reduce the amount of water consumed per unit output value and pay attention to water-saving technologies and water-saving industries.

At the same time, the total water consumption cannot be ignored, and industrial production should bid farewell to the era of extensive water use. Specifically speaking, water consumption per 10,000 Yuan of GDP and water consumption per 10,000 Yuan industrial added value should be reduced, so as to create more industrial value per unit of water. Meanwhile, we should pay attention to the purification and reuse of industrial wastewater.

Table 5
Comprehensive evaluation results

Sample	Score	Grade	Ranking
QH	88.4093	Excellent	1
NM	87.2907	Excellent	2
GD	85.4466	Excellent	3
SX	84.9992	Good	4
YN	84.7006	Good	5
SC	83.7631	Good	6
FJ	83.0126	Good	7
HI	82.8123	Good	8
CQ	82.1929	Good	9
JS	81.4291	Good	10
SD	80.5144	Good	11
LN	80.0870	Good	12
HB	77.4828	Good	13
TJ	77.0869	Good	14
BJ	76.6591	Good	15
NX	75.4917	Good	16
HN	75.1093	Good	17
SH	74.9866	Moderate	18
GX	74.2507	Moderate	19
GS	72.5843	Moderate	20
AH	69.5615	Moderate	21
JX	68.1602	Moderate	22

Note: For abbreviations of each province please refer to "China Internet Domain Name System."

3.2. Strengthening of guidance by the government

The government should take actions to establish incentives and restraints to improve the efficiency of industrial water. On the one hand, the government should enhance water conservation and water use efficiency by strengthening the legal system construction and administration. For example, according to the existing laws, regulations to improve the efficiency of industrial water should be studied and formulated. To strengthen the supervision over the water used for industrial production, the government should step up education and even take necessary punitive measures. On the other hand, the government should take proactive measures to encourage industrial enterprises to improve water use efficiency. For those enterprises that use wastewater as their raw material for industrial production, the government should give preferential policies.

Authority shall establish a water rights trading system to improve the efficiency of resource allocation of industrial water. First of all, it is necessary to clarify the property right of water resources. All regions shall develop and utilize water resources in accordance with the water rights theory, operate water rights in accordance with market principles, and allocate water resources to places where water resources are scarce and can bring higher benefits. At the same time, it is necessary to establish a reasonable price system of water resources and effectively suppress overconsumption of industrial water in the upper reaches of rivers.

Water-saving technology research should be combined with industrial production. On the one hand, the government should strongly support relevant research institutes to improve the efficiency of industrial water. On the other hand, the government should provide technical assistance about water saving to industrial enterprises, help them with efficient water use methods and advanced management experience, and raise their efficiency in industrial water.

3.3. Active participation of the enterprise

Enterprise should develop industrial water-saving technologies and apply them to industrial production practices. On the one hand, enterprises should guarantee the funds for R&D of water-saving technologies, make continuous investments in projects that can improve the efficiency of industrial water, and overcome short-sighted behaviors of enterprise. On the other hand, enterprises should actively promote and use water-saving technologies in industrial production with reference to the "Outline of China's Water-saving Technical Program."

Enterprise should pay attention to accelerate the transformation of development mode so as to achieve a green and efficient development. First, speed up industrial restructuring and upgrading, those with large water demand or large sewage discharge should change backward production methods; second, backward production capacity must be eliminated. Enterprises should conduct inspections on internal production processes, resolutely eliminate outdated production capacity, effluent discharge that is not up to standard on environmental protection, and actively cultivate and construct water-efficient production capacity to improve industrial water efficiency, achieve green coordination of high-quality development.

Enterprises should also insist on innovation. On the one hand, enterprises should innovate the concept of economic development, abandon the concept of extensive use of water, and implement the concept of water conservation in the industrial production of enterprises; on the other hand, enterprises should innovate industrial production water technologies.

4. Conclusions

Through the analysis above, we can see DAGF method – a combination of Delphi method, analytic hierarchy process, gray relational analysis, and Fuzzy comprehensive evaluation – used in this paper can effectively evaluate the industrial water efficiency. We can obtain industrial water efficiency scores and grades through this method. If there are multiple samples involved, we can also adopt a unified standard to compare the situation among multiple samples and rank the advantages and disadvantages among the samples. According to the evaluation index system in this paper, we can make concrete suggestions to improve the efficiency of industrial water. Therefore, the method used in this paper is not limited to evaluation, but also has the practical significance of improving the efficiency of industrial water use. For the purpose of this study, the authors only used cross-sectional data and in future studies they will try to use panel data to make the conclusions more accurate.

References

[1] Y. Zhang, A. Gu, B. Pan, Relationship between industrial water consumption and economic growth in China based on environmental Kuznets curve, Energy Procedia, 105 (2017) 3557–3564.

[2] Y. Shang, S. Lu, L. Shang, X. Li, Y. Wei, X. Lei, C. Wang, H. Wang, Decomposition methods for analyzing changes of industrial water use, J. Hydrol., 543 (2016) 808–817.

[3] M.A. Renouf, S.J. Kenway, Evaluation approaches for advancing urban water goals, J. Ind. Ecol., 21 (2017) 995–1009.

[4] F. Zhang, H. Xue, H. Wang, H. Dong, Industrial growth path under the restriction of water resources in China, Procedia Eng., 174 (2017) 934–940.

[5] E. Masanet, M.E. Walker, Energy-water efficiency and U.S. industrial steam, AIChE J., 59 (2013) 2268–2274.

[6] X.H. Fan, C. Ning, A hybrid ARIMA and BP neural network model to forecast industrial water efficiency, Adv. Mater. Res., 1010–1012 (2014) 1042–1046.

[7] L. Zhao, C. Sun, F. Liu, Interprovincial two-stage water resource utilization efficiency under environmental constraint and spatial spillover effects in China, J. Cleaner Prod., 164 (2017) 715–725.

[8] S. Jia, H. Yang, S. Zhang, L. Wang, J. Xia, Industrial water use Kuznets curve: evidence from industrialized countries and implications for developing countries, J. Water Resour. Plann. Manage., 132 (2006) 183–191.

[9] J. Liu, C. Yang, J.P. Zhang, Study on industrial water-saving system—taking the Ningdong energy and chemical base as an example, Appl. Mech. Mater., 212–213 (2012) 658–663.

[10] A.M. Tian, N. Dong, A.X. Jiang, Water resource sustainable utilization study of based on water footprint, Adv. Mater. Res., 347–353 (2011) 2949–2956.

[11] B.M. Berhanu, M. Blackhurst, M.J. Kirisits, P. Jamarillo, D. Carlson, Feasibility of water efficiency and reuse technologies as demand-side strategies for urban water management, J. Ind. Ecol., 21 (2017) 320–331.

[12] X. Zhang, Z. Dong, B. Luo, Industrial structure optimization based on water quantity and quality restrictions, J. Hydrol. Eng., 18 (2013) 1107–1113.

[13] S. Kumar, Analysing industrial water demand in India: an input distance function approach, Water Policy, 8 (2004) 15–29.

[14] T. Zhelev, K. Semkov, E. Mooney, T. Majozi, A. Korobeinikov, Industrial heat utilization through water management, Heat Transfer Eng., 34 (2013) 1191–1201.

[15] Z. Liu, On water saving agriculture and water resource sustainable utilization in Northeastern China, Ying Yong Sheng Tai Xue Bao, 15 (2004) 1737.

[16] X.F. Yang, B.X. Zhang, Y.Z. Shi, M.Y. Fan, H.J.Liu, Study on high efficiency technology of industrial circulating water in Yellow River estuary area, Appl. Mech. Mater., 737 (2015) 719–722.

[17] A.F. Jorm, Using the Delphi expert consensus method in mental health research, Aust. N. Z. J. Psychiatry, 49 (2015) 887–897.

[18] A. Paraskevas, M.N. Saunders, Beyond consensus: an alternative use of Delphi enquiry in hospitality research, Int. J. Contemp. Hosp. Manage., 24 (2012) 907–924.

[19] S. Ierace, S. Cavalieri, An analytic hierarchy process based model for the selection of decision categories in maintenance systems, Manage. Prod. Eng. Rev., 4 (2013) 37–49.

[20] B. Kittel, A. Kaczynski, S. Bethge, A.C. Mühlbacher, Was braucht der neueLandarzt?—Ein analytic hierarchy process (AHP), Gesundh ökon Qual manag, 21 (2015) 137–144.

[21] A. Afful-Dadzie, E. Afful-Dadzie, S. Nabareseh, Z.K. Oplatková, Tracking progress of African Peer Review Mechanism (APRM) using fuzzy comprehensive evaluation method, Kybernetes, 43 (2014) 1193–1208.

[22] S.B. Wang, Research of factors of regional product quality based on gray relational analysis, Adv. Mater. Res., 1079–1080 (2014) 1189–1193.

[23] R. Fang, R. Shang, M. Wu, C. Peng, X. Guo, Application of gray relational analysis to k-means clustering for dynamic equivalent modeling of wind farm, Int. J. Hydrogen Energy, 42 (2017) 20154–20163.

[24] S. Fang, Y. Cai, AHP-Fuzzy comprehensive evaluation model of venture investment and financing system: based on the case of incubation base in Anhui, Can. Soc. Sci., 11 (2014) 148–153.