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Water resources management in China based on coordinated development index

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ABSTRACT

To develop an applicable indicators system and a reasonable model to evaluate water resources management in China, this paper explored adaptation relationship and weights between the bottom indicators and subsystems based on global principal component analysis method. Additionally, this paper obtained coordination degree and coordinated development index though simulation and applied *K*-means to reveal the law of coordinated development. The empirical results showed that (i) water efficiency, water supply, water demand, and water structure were four subsystems in evaluation indicators system, and the scores of water supply subsystem were the lowest among them; (ii) research samples were divided into five clusters according to the coordinated development index, and the overall water resources in the east and south were abundant, while in the west and north were poor; and (iii) water efficiency was relatively high in regions with shortage of water resources or more developed economies. Thus, it can be concluded that the distribution of water resources was uneven, and water efficiency was the key subsystem to improve coordinated development of water resource management.

Keywords: Water resource management; Indicators system; Simulation; Coordinated development index; *K*-means

1. Introduction

Rapid population growth and industrialization, coupled with climate changes during the past few decades have caused increasing pressure on water resources [1]. Experts estimate that nearly 50% of the global population will live in water-scarce countries till 2080, and water resources management will be faced with more complex problems pertaining to the issues of society, economy, environment, ecology, etc. [2] Sustainable water management has been a prevalent strategy to solve the problems [3]. In the light of this philosophy, water resources must be managed as a context-dependent natural resource based on prediction of observable water resources and the total outcomes from hydrology, society, and economy [4,5]. The main challenge for extant sustainable water management is to formulate a reasonable quantitative assessment method, which can be used to develop reliable guidelines for water resources management [6]. Most studies have focused on biophysical assessments, economic value [7,8], and the social assessment [9]. Some scholars regarded sustainable water resources management as a system and constructed evaluation index systems, varying from two-dimensional subsystem to five-dimensional subsystem, such as Pan and Chen [10] constructed a coordinated development decoupling evaluation model to evaluate the coordination relationship between water consumption and economic growth, and Bao and He [11] discussed the shortage and utilization of water resources in Beijing-Tianjin-Hebei. Jiang et al. applied

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the coupling degree model to analyze the relationship among water resources, society, and economy system [12]. Zang et al. [13] established the index system of coordinated development from the four dimensions of population, water resources, environment, and economy. Yu and Han [14] introduced an evaluation index system for sustainable utilization of water resources based on the driving–pressure–state–impact–response model. A few studies adopted the integrated models to depict the human-hydrology-coupled systems, such as river basin models, groundwater coupled systems, and even global agricultural production and trade models, to make the systematic evolutionary prediction [15–17].

However, the extant studies have ignored some critical issues. Firstly, the optimal dimension the indicators system needs to be verified due to the divergent subsystems. Secondly, the linkage between the bottom indicators and subsystems is intricate and one bottom indicator is likely attributed to more than one subsystems. For example, water resource consumption by gross domestic product (GDP) is always categorized as the bottom indicators of the water resources subsystem, but it may be related to the economic or other subsystems, namely stratified interleaving in this case.

Therefore, focusing on the above concerns, the objectives of this paper are as follows: (i) put forward a reasonable and applicable evaluation indicators system, (ii) propose an evaluation model on the coordinated development of water resources with an interdisciplinary perspective, and (iii) apply these methods to a case study in China.

2. Methodology

2.1. Data standardization

The piecewise function method was used to standardize the data as follows:

$$x_{ij}^{+}=\begin{cases}\dfrac{x_{ij}-\min\{x_i\}}{x_i-\min\{x_i\}}\times 0.59+0.01 & \text{if } \min\{x_i\}\le x_{ij}\le \overline{x}_i\\[2ex] \dfrac{x_{ij}-\overline{x}_i}{\max\{x_i\}-\overline{x}_i}\times 0.4+0.6 & \text{if } \overline{x}_i\le x_{ij}\le \max\{\overline{x}_i\}\end{cases} \tag{1}$$

$$x_{ij}^{-}=\begin{cases}\dfrac{\overline{x}_i-x_{ij}}{\overline{x}_i-\min\{x_i\}}\times 0.4+0.6 & \text{if } \min\{x_i\}< x_{ij}\le \overline{x}_i\\[2ex] \dfrac{\max\{x_i\}-x_{ij}}{\min\{x_i\}-\overline{x}_i}\times 0.59+0.01 & \text{if } \overline{x}_i\le x_{ij}\le \max\{x_i\}\end{cases} \tag{2}$$

where x_{ij}^{+} and x_{ij}^{-} are normalized values; $\overline{x}_i$ is the average of all samples of the index i, i = 1, 2, …, e; e is the original index, j = 1, 2, …, f; f is the total number of all samples, and $\max\{x_i\}$ and $\min\{x_i\}$ are the maximum and minimum of samples.

2.2. Adaptation relationship between bottom indicators and the subsystems

The complex system method could better solve the problems in development [18,19]. Because each subsystem may cover more than one bottom indicator, the same indicator may be attributed to multiple subsystems with the different degree of affiliation. Yang and Zhang [20] applied principal component analysis to each subsystem and the underlying indicators. Based on this, the adaptation relationship is shown in Fig. 1. There are two typical basic types of adaptation relationship between the subsystems and the bottom indicators, namely sequenced decomposition and stratified interleaving. Sequenced decomposition means that each indicator is only affiliated to a specific subsystem, and the linkage between subsystems and bottom indicators is straight-lined. On the contrary, bottom indicators in the stratified interleaving can be affiliated with multiple subsystems at the same time, and the linkage between the subsystems and the indicators is intersectional.

2.3. Adaptation relationship model

Among all kinds of existing evaluation methods, principal component analysis is an important and recognized multivariate statistical method. However, the indicators system in this paper is a panel data containing indicators data of different provinces and cities in a certain period of time. If the principal component analysis is carried out separately according to the cross-sectional data, the unity, integrity, and comparability of the system analysis cannot be guaranteed. Namely, it needs a unified and simplified space for all cross-sectional data. Therefore, from the overall perspective, the comprehensive effect of the space is the best. To ensure the uniformity, integrity, and comparability of panel data analysis, the global principal component analysis (GPCA) method is introduced. Namely, before carrying out the traditional principal component analysis, all indicators of the same city are arranged according to the time sequence. The GPCA method is a bottom-up method that sorts the rotated component coefficient display format by size, and based on this, the bottom indicators are divided into corresponding principal components. As Fig. 1 indicates, the adaptation relationship between the subsystems and bottom indicators is not a single type. Additionally, the expression formula of eigenvector of principal component reveals that the relationship between the bottom indicators and principal components is stratified and interlaced. The adaptation relationship between the bottom indicators and subsystems is obtained, combining the results of GPCA with following classification criteria.

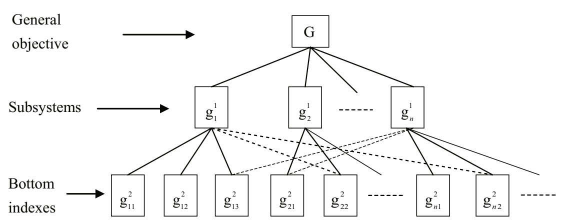

Fig. 1. Adaptation relationship model (The solid line means an indicator only attributed to a certain subsystem and the dotted line means an indicator also related to additional subsystems. The thickness of the line means the level of the linkage between the bottom indicator and the subsystem.).

(i) If an indicator has the maximum load on a specific principal component and the load coefficient is greater than M, then the index is directly attributed to the principal component.

(ii) If an indicator load is less than M, but it cannot be ignored due to its specific economic and social connotation, then the index is attributed to additional related principal component meantime.

2.4. Weight calculation

The optimal dimension of the subsystem is determined by the first k principal component of GPCA. Therefore, the weights of the subsystems can be derived from the following formula:

$$W_h = \frac{\alpha_h}{\alpha(k)} \tag{3}$$

where α_h is contribution rate of a certain principal component, and $\alpha(k)$ is cumulative contribution rate of the first k principal components, $h = 1, 2, \ldots, k$.

The essence of eigenvector is the complete weight coefficient between each indicator and each principal component. Consequently, the weights of bottom indicators can be calculated by the following formulae:

$$a_j = \frac{l_j}{\sqrt{\lambda_h}} \tag{4}$$

$$W_j = \frac{a_j}{\sum_{j=1}^{n_k} a_j} \tag{5}$$

where α_j is eigenvector of bottom indicators, l_j is load coefficient, λ_h is latent root, and n_k is the number of bottom indicators in the first k subsystem.

2.5. Coordinated development evaluation model

Based on subsystem coupling theory [21–24], two formulae are obtained as follows:

$$c_x = \left\{ \frac{s_1 \times s_2 \cdots \times s_u}{\frac{s_1 + s_2 + \cdots + s_u}{u}} \right\}^{\frac{1}{u}} \tag{6}$$

$$c_g = \left\{ \frac{s_1 \times s_2 \cdots \times s_v}{\left[\frac{s_1 + s_2 + \cdots s_v}{v} \right]^v} \right\}^2 \tag{7}$$

where u and v are the number of subsystems, the value of u and v are 2, 3, 4, and 5 in this paper.

Although the values of Eqs. (6) and (7) are 0 and 1, we cannot judge which one is better to reflect the distribution of all the values. Following the extant study by Yang et al. [25], the simulation method is adopted to calculate the value distribution of coordination degree model, which facilitated the judgment of an optimal model. The simulation results of Eqs. (6) and (7) are shown, respectively, in Figs. 2 and 3.

From Fig. 2, C_x is blank in (0, 0.35), which means it cannot cover all values. Whereas in Fig. 3, C_g is (0, 1), and it can cover all the cases. And thus, C_g is chosen as the optimal coordination degree model.

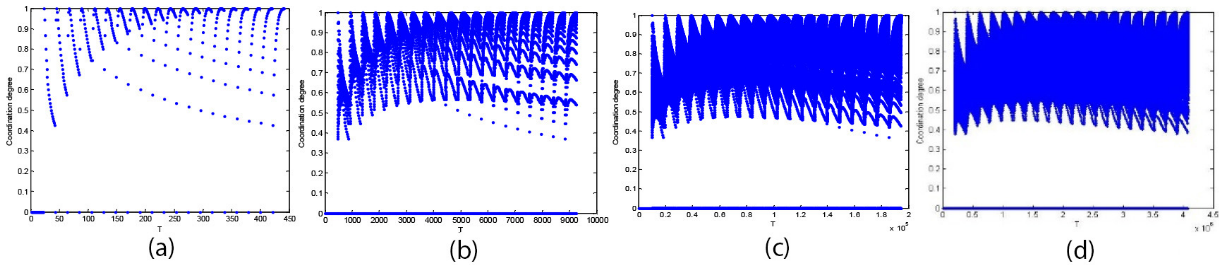

Fig. 2. The simulation results of C_x: (a) two subsystems, (b) three subsystems, (c) four subsystems, and (d) five subsystems.

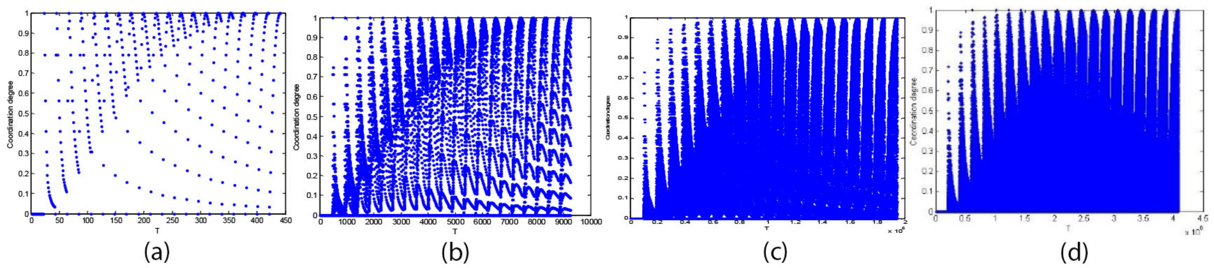

Fig. 3. The simulation results of C_g: (a) two subsystems, (b) three subsystems, (c) four subsystems, and (d) five subsystems.

The coordinated development includes both coordination and development. The degree of development indicates the adequacy of development, and the degree of coordination indicates the imbalance of development. The formula of the development degree (R) and the coordinated development index (CD) are constructed as the following formulae:

$$R = S_1W_1 + S_2W_2 + \ldots + S_hW_h \tag{8}$$

$$\text{CD} = \sqrt{C_g \times R} \tag{9}$$

3. Results and discussion

3.1. Adaptation relationship analysis

A water resources system is the entirety of hydrologic, infrastructure, ecologic, and human processes pertaining to water [26]. According to the availability and reliability of the data, this paper takes 31 provinces and cities regions as the research sample; the time span of the data is 2007–2016 and eventually selects 27 initial indicators related to water resources in the National Bureau of statistics of China.

According to the correlation coefficients of 27 initial indicators, the indicators with correlation coefficient larger than 0.7 are deleted. The following bottom indicators are retained, namely, total water resources (V1), cultivated land area (V2), forest coverage (V3), GDP (V4), green coverage of urban construction area (V5), urban daily water consumption (V6), urban water penetration rate (V7), the proportion of second industry added value to GDP (V8), reservoir capacity (V9), total water supply (V10), natural population growth (V11), water consumption per unit GDP (V12), and water utilization rate (V13). The correlation matrix of 13 bottom indicators is shown in Table 1.

After determining the 13 bottom indicators, the GPCA method is carried out, and the results indicate that Bartlett's spherical test is passed at a significance level of 0.05. The total variance explanation is shown in Table 2, and the cumulative variance percentage of four principal components is 67.846%. According to load coefficients in Table 3, M is set to 0.6. And then, by referring to the meaning of the bottom index with load coefficients that are larger than 0.6, the four principal components correspond to four subsystems, namely, water efficiency, water supply, water demand, and water structure. Further, taking classification criteria (ii) into account, water consumption per unit GDP can also be attributed to the water efficiency subsystem, urban water penetration rate can also subordinate to the water supply, and urban daily water consumption can also pertain to the water demand subsystem. Finally, the adaptation relationship and weight between the bottom indicators and subsystems are obtained as shown in Fig. 4.

3.2. Comprehensive evaluation of coordinated development level

Based on Eqs. (7)–(9), comprehensive evaluation scores of coordinated developments of 31 provinces and cities are calculated and exhibited in Table 4.

Table 1
Correlation matrix

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13
V1	1.00												
V2	–0.07	1.00											
V3	0.29	0.05	1.00										
V4	–0.02	0.15	0.15	1.00									
V5	–0.17	–0.09	0.39	0.50	1.00								
V6	0.55	–0.48	0.27	0.08	0.13	1.00							
V7	–0.30	–0.23	0.00	0.34	0.40	–0.06	1.00						
V8	–0.18	0.26	–0.10	0.14	–0.07	–0.37	0.04	1.00					
V9	0.20	0.22	0.37	0.24	0.05	0.18	0.08	0.15	1.00				
V10	0.16	0.39	0.10	0.51	0.22	0.19	0.12	0.19	0.33	1.00			
V11	0.38	–0.34	–0.07	–0.24	–0.11	0.41	–0.10	–0.18	–0.04	0.05	1.00		
V12	0.31	0.01	–0.26	–0.41	–0.41	0.17	–0.27	–0.13	–0.13	0.27	0.56	1.00	
V13	–0.38	–0.23	–0.40	–0.07	0.09	–0.10	0.11	0.01	–0.32	–0.15	0.05	0.08	1.00

Table 2
Total variance explanation

Variable	Initial eigenvalue			Quadratic sum of rotational loads		
	Eigenvalue	Percentage of variance	Cumulation %	Eigenvalue	Percentage of variance	Cumulation %
1	2.81	21.612	21.612	2.314	17.797	17.797
2	2.568	19.755	41.367	2.283	17.561	35.358
3	1.979	15.22	56.587	2.122	16.322	51.679
4	1.464	11.259	67.846	2.102	16.167	67.846

Table 3
Rotated factor matrix

Variation	Factors			
	1	2	3	4
Green coverage of urban construction area	0.784[a]	0.104	–0.185	–0.180
GDP	0.779[a]	0.210	–0.020	0.260
Urban water penetration rate	0.690[a]	–0.233[b]	–0.131	–0.080
Water utilization rate	0.169	–0.758[a]	0.055	–0.106
Forest coverage	0.206	0.753[a]	–0.182	–0.210
Reservoir capacity	0.211	0.608[a]	0.086	0.241
Total water resources	–0.210	0.597[a]	0.514	–0.237
Water consumption per unit GDP	–0.388[b]	–0.177	0.803[a]	0.055
Natural population growth	–0.114	–0.074	0.728[a]	–0.364
Total water supply	0.282	0.249	0.562[a]	0.122
Cultivated land area	–0.130	0.251	–0.083	0.820[a]
The proportion of second industry added value to GDP	0.070	–0.090	–0.086	0.629[a]
Urban daily water consumption	0.195	0.371	0.509[b]	–0.592[a]

[a]Adaptation relationship is divided according to classification criteria (i).
[b]Adaptation relationship is divided according to classification criteria (ii).

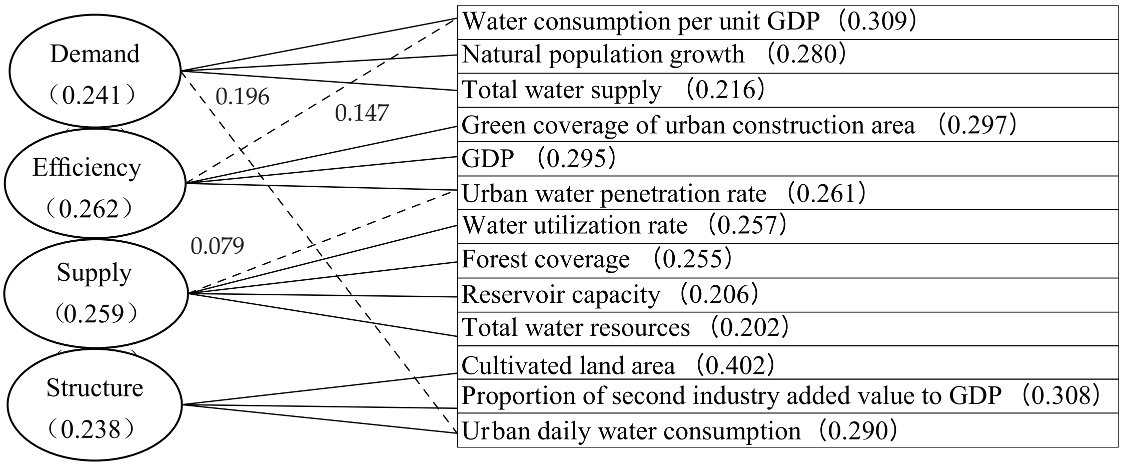

Fig. 4. Adaptation relationship and weight between the bottom indicators and subsystems (The data in parentheses is the weight of the subsystems and the bottom indicators. The dotted line indicates that an indicator is not only attributed to a certain subsystem but also subordinates to additional subsystem.).

In general, the results coincide with the actual development of economic, social, and ecological development of all provinces and cities. The coordinated development of water resources in the east and south of China is higher than other regions. For example, in Zhejiang, Guangdong, and Fujian provinces, the water resources supply and demand are relatively balanced, the water structure is reasonable, and the water efficiency is high, so that the water resource coordination is very high. On the contrary, in Ningxia, Gansu, and Tibet, the water resources coordinated development are low due to the lack of water resources, the slow economic development, the lagging of urban infrastructure construction, and the low utilization efficiency of water resources. China is in the transitional development stage. The coordinated development of water resources must establish a set of flexible transformation mechanism to determine the optimal opportunity of the water resources development, break the inertia of endogenous modes of coordinated development of water resources, and optimize the coordinated development of water resources.

To facilitate regional comparative analysis, *K*-means algorithm is used to maximize the similarity among the objects that are divided into the same cluster, while the similarity between different clusters is the smallest. The clustering algorithm is based on two rules. Firstly, the number of clusters is moderate. Secondly, the average contour value of the sample has better as high as possible. For a cluster with only 31 samples, the appropriate number of categories is 2–7. The average contour values of different classes and the clustering results are shown in Figs. 5 and 6, respectively.

From Fig. 5, there is a maximum average contour value when the number of samples clustering is five, and thus the optimal number of clusters is five. Moreover, according to the clustering results by *K*-means in Fig. 6, Cluster 1 includes

Table 4
Comprehensive evaluation scores of coordinated development of water resources

	Water efficiency	Water supply	Water demand	Water structure	Development degree (R)	Coupling degree (C_g)	Coordinated development (CD)
Anhui	0.624	0.493	0.599	0.521	0.559	0.939	0.724
Beijing	0.820	0.436	0.625	0.860	0.683	0.755	0.718
Chongqing	0.584	0.356	0.640	0.669	0.559	0.775	0.658
Fujian	0.726	0.579	0.603	0.653	0.641	0.963	0.785
Gansu	0.382	0.282	0.540	0.626	0.452	0.679	0.554
Guangdong	0.772	0.598	0.652	0.585	0.653	0.949	0.787
Guangxi	0.527	0.584	0.503	0.544	0.540	0.969	0.723
Guizhou	0.435	0.462	0.543	0.649	0.519	0.880	0.676
Hainan	0.497	0.397	0.374	0.767	0.506	0.705	0.597
Hebei	0.773	0.458	0.686	0.557	0.619	0.853	0.726
Heilongjiang	0.492	0.523	0.735	0.440	0.546	0.841	0.678
Henan	0.618	0.452	0.732	0.510	0.577	0.868	0.707
Hubei	0.665	0.597	0.647	0.539	0.613	0.968	0.770
Hunan	0.609	0.565	0.602	0.579	0.589	0.987	0.762
Jiangsu	0.831	0.417	0.762	0.514	0.632	0.730	0.678
Jiangxi	0.651	0.592	0.553	0.573	0.593	0.976	0.761
Jilin	0.493	0.470	0.718	0.572	0.560	0.877	0.701
Liaoning	0.706	0.514	0.775	0.586	0.644	0.898	0.760
Nei Monggol	0.548	0.362	0.727	0.534	0.540	0.749	0.635
Ningxia	0.439	0.347	0.395	0.700	0.467	0.732	0.585
Qinghai	0.476	0.328	0.412	0.646	0.463	0.777	0.599
Shaanxi	0.631	0.371	0.633	0.536	0.542	0.833	0.671
Shandong	0.837	0.446	0.721	0.519	0.632	0.771	0.698
Shanghai	0.750	0.309	0.666	0.779	0.623	0.612	0.617
Shanxi	0.614	0.304	0.651	0.597	0.539	0.705	0.616
Sichuan	0.592	0.495	0.688	0.509	0.570	0.918	0.723
Tianjin	0.667	0.295	0.692	0.746	0.596	0.613	0.603
Tibet	0.295	0.296	0.247	0.739	0.389	0.409	0.396
Xinjiang	0.495	0.394	0.438	0.600	0.480	0.889	0.653
Yunnan	0.539	0.513	0.598	0.633	0.569	0.959	0.738
Zhejiang	0.786	0.609	0.686	0.632	0.680	0.960	0.807

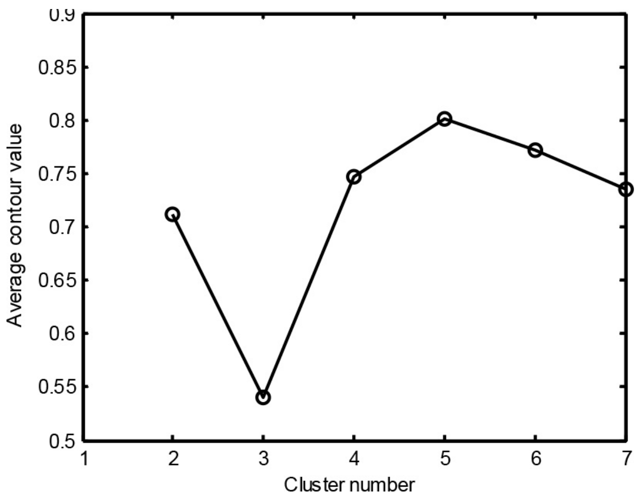

Fig. 5. Average contour values of different classes.

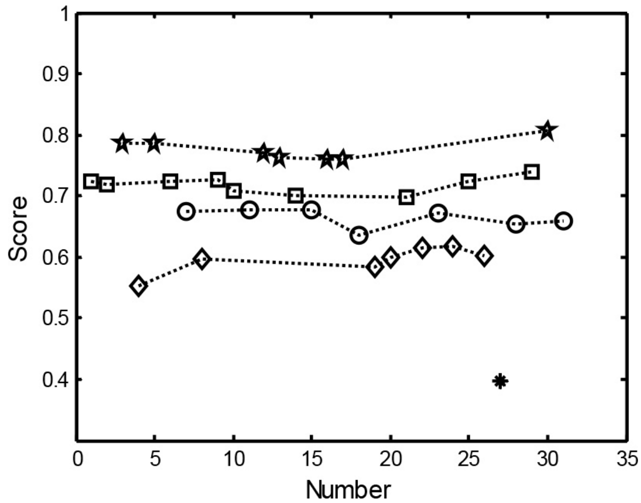

Fig. 6. Clustering results by K-means.

Hubei, Zhejiang, Jiangxi, Hunan, Fujian, Guangdong, and Liaoning; Cluster 2 contains Shandong, Henan, Anhui, Yunnan, Guangxi, Jilin, Hebei, Beijing, and Sichuan; Cluster 3 embodies Heilongjiang, Xinjiang, Jiangsu, Guizhou, Shaanxi, Neimonggol, and Chongqing; Cluster 4 involves Shanxi, Ningxia, Hainan, Tianjin, Qinghai, Gansu, and Shanghai; and Cluster 5 consists of Tibet.

The coordinated development of water resources system in all regions from 2007 to 2016 is calculated to analyze the spatial distribution of the coordinated development. And then based on the results of *K*-means clustering, the coordinated development of water resources in all regions is divided into five levels as represented by a different color, shown in Fig. 7.

From Fig. 7, the per capita water resource is small though the total water resources are abundant in China. Meanwhile, the distribution of water resources is uneven. The overall water resources in the east and south are abundant while in the west and north are poor. Specifically, the runoff of Yangtze River basin and its south branches covers 80% of water resources and the nearly 40% of cultivated land area. The area of Yellow River basin, Huaihe River basin, Haihe River basin, and northwest inland covers 50% of China, while the amount of water resources is only 12%. The lack of water resources has become the critical obstacle of the local economic development in western and northern China. Moreover, water supply subsystem is taking a negative impact on the level of coordinated development. For some cities with a geographical disadvantage, such as Beijing, Shanghai, and Tianjin, the scores of forest coverage, reservoir capacity, and total water resources are pretty low, which pulls down the overall level of coordinated development. For the areas that are economically undeveloped and with weak infrastructure, including Qinghai, Ningxia, and Gansu, the scores of both water efficiency and water supply are in low levels.

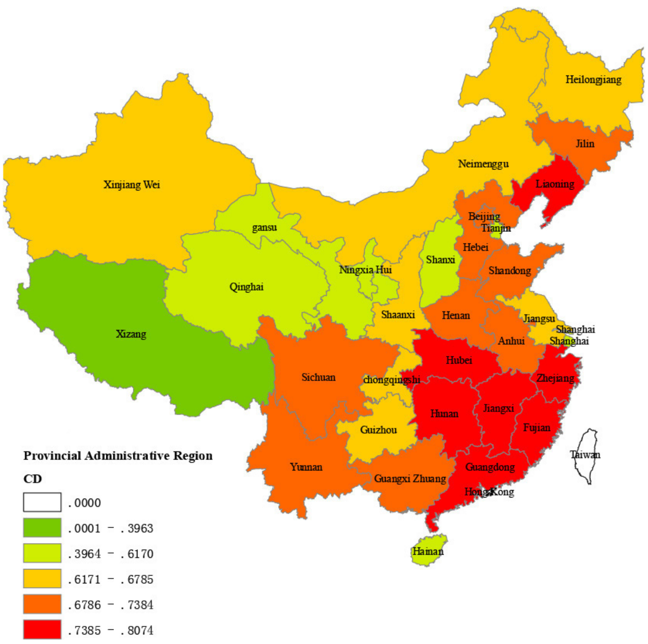

Fig.7. Spatial distribution of coordinated development level.

3.3. Discussion on coordinated development of water resources management

The regional differences of water resource management are generally significant in China. Water efficiency is high in regions with shortage of water resources or developed economies, including Beijing (0.820), Hebei (0.773), Shandong (0.837), Jiangsu (0.831), and Zhejiang (0.786), where the GDP water consumption score is higher than 0.8. The score of water supply subsystem is the lowest among the four subsystems, especially in the west and the north of China, due to the contribution of geographical location to the low scores of forest coverage and the total amount of water resources. The scores of the water demand subsystem is less fluctuated, with the average value of 0.6 for 31 provinces and cities. It is very important to improve water efficiency in the management of water resource.

Regional sustainable development requires availability of different resources and their efficient application [27]. From the past practice of water resources management in China, water resources management strategies have historically relied on supply-side management, which increases the availability of water through the expansion of water infrastructure and the acquisition of new sources. Sustainable urban development requires detailed assessment of economic, environmental, and social impacts borne by major stakeholders [28].With the rapid population growth and economic expansion, however, urban areas have exceeded the limits of local water supplies. It is beneficial for water resource sustainability to conduct the demand-side management. The adaptations and decisions of consumers and policymakers create feedback loops within the water resources system that may significantly influence the sustainability of the urban water supply. The dynamics and adaptations of the interactions among consumers, policy makers, and natural and engineered water resources systems have an impact on the system-wide sustainability of water resources for a long-term planning horizon, which may delay or expedite the need for new supplies [29].

Consequently, the following policy recommendations are put forward to improve the water resources management in China.

Firstly, it is imperative to strengthen the construction of water-saving facilities and vigorously promote the reuse of industrial water technologies to improve the reuse of industrial water. Wastewater is not a disaster, but a kind of resource. It is necessary to recycle the useful substances in wastewater and the water resources themselves, so as to solve the water crisis and control the environmental pollution effectively. On the other hand, a reasonable evaluation index system of water resources management should be constructed, and the risk awareness of water shortage can be improved due to its early-warning role.

Secondly, it is indispensable to make full use of different water sources to increase water supply. On one hand, implementing effective water resources policy to improve the capacity of regional water resources, for example, to speedup the process of cross basin water diversion project. On the other hand, implementing sponge city and green city to enhance the urban water ecosystem as it can minimize water consumption and reduce the pollutant emissions, and eventually achieve a healthy water cycle in urban systems. Furthermore, artificial floating islands have been adopted to help purify water and provide a suitable environment for many living beings to survive and breed.

Thirdly, it is important to optimize the industrial structure, actively develop low-water consumption industries, reduce the construction of new high water-consuming projects in areas with low water resources economic inefficiency, and emphasize water resources efficiency standards for the layout of high water-consumption industries. Additionally, to avoid ecological and environmental issues arising, in some regions, where there are problems of overdevelopment of groundwater, water utilization volume approximating or exceeding water resources development, fragile of ecology and environment, the new irrigation area should not be developed.

Finally, it is necessary to correctly handle the relationship between social benefits, ecological benefits, and economic benefits. Under the constraints of a limited water supply, water resources management requires reasonable planning to efficiently and sustainably meet demands for life, production, and ecology in all regions.

4. Conclusion

This paper presented an experimental study on the coordinated development of water resources management, it can be drawn that water resources management was a complex system and could be analyzed from four aspects, namely, water efficiency, water supply, water demand, and water structure. By calculating the scores of the four subsystems and the coordinated development index, it indicated that due to disadvantage of geographical location, the scores of water supply subsystem were the lowest, and the scores of both water demand and water structure were reasonable and stable. Importantly, water efficiency was crucial in terms of improving the coordinated development of water resource management. Additionally, the distribution of water resources was uneven though the total water resources were abundant, in this regard, some measures should be taken effectively to strengthen water resources management, for example, construction of water-saving facilities, the reuse of industrial water, the development of the sponge city, and the optimization of industrial structure.

Originality of this paper lies on the following: (i) Based on the GPCA method, the optimal dimension of subsystems was obtained, and the adaptation relationship and weight between the bottom indicators and subsystems were explored. Eventually, a reasonable evaluation indicators system for coordinated development of water resources management was obtained. (ii) By using the simulation method, the optimal coordination degree model was determined, and the coordinated development index was further proposed. (iii) Combining *K*-means with geographic information system, 31 provinces and cities were divided into five clusters to analyze the spatial distribution of the coordinated development in China. It is believed that the discoveries can provide guidelines for decision makers to improve water resources management.

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