Assessment of Water Resources Carrying Capacity Based on Principal Component Analysis in Handan City

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Abstract: The carrying capacity of water resources is the important indicator of sustainable development of the nature, economy and society. The aim of researching is to solve the contradiction between the present water resources carrying capacity and the load of water resources carrying capacity. Applying principal component method to evaluate water resources carrying capacity in Handan City according to indicators from 2006 to 2012, this paper analysis the reason for the carrying capacity of water resources changing to find out the main influencing factors. It is useful for policy-makers, environment protection and sustainable utilization of water resources.

Keywords: Handan city, principal component analysis, visual analysis, water resources carrying capacity.

1. INTRODUCTION

At present, the study on water resources carrying capacity has become a fundamental issue of sustainable development and water resources safety strategy research have attracted more attention from the academic circles [1-7]. The water resources in Handan are grossly deficient and the available water resources are woefully inadequate, so there is very evident contradiction between supply and demand of water. In recent years, the economy of Handan city is developing rapidly. The GDP in 2012 reached 302429 millions yuan, that is 2.2 times the 135946 millions yuan in 2006. Water resources are the physical support for social and economic development. Water resources carrying capacity is the major constraint on the regional economic and social sustainable development.

According to the economic development and water resources data of "Handan Statistical Yearbook" and the "Handan City water resources bulletin", this paper used principal component factor analysis method and SPSS software, analyzed the influence of the water resources carrying capacity changing. The result will provide a theoretical basis for rational utilization and sustainable development of water resources in Handan City.

2. RESEARCH MEHTODS

Principal component analysis is a multivariate statistical method which can divide multiple variables into a few comprehensive indicators [8-10]. From the perspective of mathematics, this is a dimensionality reduction technique to process high-dimensional variable space. Its essence is to integrate and simplify high dimension variable systems, and can objectively determine the weight of each index in the evaluation, so as to avoid the subjectivity of human. Under the assumption that ensure the minimum loss of original data information, this method can reflect the characteristics of the research object more concentrated and more typically. It is suitable for the study of the system with a large number of evaluation indexes, such as the water resources carrying capacity.

Principal component analysis method combines P original indexes which has certain correlation to independent index as a linear combination. The variance of the first principal component F1 is larger, the more information that F1 contains. So the variance of the first principal component is the largest. If the first principal component is not sufficient to represent the information of original P indexes, then select the second linear combinations and cov (F1, F2)=0. The third, fourth principal component can be constructed, and so on.

The model of the principal component is shown below,

$$\begin{cases} F_1 = a_{11}X_1 + a_{21}X_2 + \cdots + a_{p1}X_p \\ F_2 = a_{12}X_1 + a_{22}X_2 + \cdots + a_{p2}X_p \\ \ldots\ldots \\ F_p = a_{1p}X_1 + a_{2p}X_2 + \cdots + a_{p2}X_p \end{cases} \quad (1)$$

The following conditions are satisfied.

a. Quadratic sum of all the principal components is 1, that is $a_{1i}^2 + a_{2i}^2 + \cdots a_{pi}^2 = 1 (i = 1, 2, \cdots m)$;

b. The principal components are uncorrelated, that is $\mathrm{cov}(F_i, F_j) = 0$;

c. The variance of principal components decreases, that is $Var(F_1) \geq Var(F_2) \geq Var(F_p)$.

Based on the premise of ensuring the minimum loss of original data information, the primitive variables reduced to several new variables reflected the characteristics of the research objects better [2].

3. ASSESSMENT OF WATER RE-SOURCES CARRYING CAPACITY

The assessment of water resources carrying capacity in Handan City is as follows.

3.1. The General Situation of Research Area

Handan is located in the most southern part of Hebei Province, east of Taihang mountain. The main surface water includes the Qingzhang river, Zhuozhang river and Fuyang River, the main underground water are Heilong Cave spring of the western mountainous areas, Dongfeng Lake area and the eastern plain. For many years the average total amount of water resources production in Handan is 1330 million m^3, the average yearly rainfall is 523 mm, and the spatial-temporal distribution of water resources is not well balanced. The water resources per capita amount in Handan is only 157 m^3, the bottom of the list in Hebei province. Handan is the extreme water-lack area, and the contradiction between the supply and the requirement of the water resources stands out increasingly. For decades, Handan has constructed a large group of water conservancy works and 80 reservoirs existing. Because of many old enterprises, backward production technology of wastewater treatment in Handan City, there are large amounts of untreated or substandard industrial and living sewage efflux. In addition, there are many problems such as water shortage, overdraft of groundwater, serious waste of water.

3.2. The Influence Factors Selection

This paper uses principal component analysis to analyze water resources carrying capacity and the actual influence of evaluating indexes. It is important to consider reliability, mensurability, independence and independence of the index system.

According to the economic development and water resources data of "Handan Statistical Yearbook" and the "Handan City water resources bulletin", this paper selected the dynamic comprehensive evaluation of 16 indicators of 2006-2012 years of water resources carrying capacity in Handan. X_1 is the population (ten thousand people), X_2 is the proportion of urban population (%), X_3 is GDP (hundred million yuan), X_4 is fixed-asset investment (hundred million yuan), X_5 is per capita living expenditure (yuan), X_6 is total water utilization (hundred million m^3), X_7 is the annual precipitation (hundred million m^3), X_8 is domestic water (hundred million m^3), X_9 is per capita daily water consumption (dm^3), X_{10} is agricultural water (hundred million m^3), X_{11} is effective irrigation area (thousand hectare), X_{12} is industrial water consumption (hundred million m^3), X_{13} is water consumption per unit of GDP (m^3), X_{14} is water consumption per ten thousand yuan industrial added value (m^3), X_{15} is total amount of water resources (hundred million m^3), X_{16} is total amount of waste water (hundred million m^3). The 16 effect factors are listed in Table **1**.

3.3. The Result Analysis

3.3.1. Visual Analysis of the Data

From the data in Table **1** intuitively, Handan City has stable growth of population in recent years, currently nearly 10 million. GDP growth is rapid, amounted to 302429 million yuan in 2012, 2.22 times in 2006 135946 million yuan. But the water resources data is not ideal, such as the per capita daily water consumption (X_9) were significantly lower. The daily water consumption per capita living values of Hebei province is 85-140 dm^3 according to the national ministry of construction issued in "Standard for City Residents Living Water" of 2002. In the table the lower value X_9 suggests concept of water conservation within Handan community, and it reflects the water resources in Handan City is extremely scarce. In addition, the water consumption per unit of GDP X_{13} and the water consumption per ten thousand yuan industrial added value X_{14} have been decreasing gradually, which mean the way of water resources utilization shift from extensive to intensive form, utilization efficiency of water resources has improved. But it is still a distant to advanced city, such as Zhejiang Wenling City the water consumption per unit of GDP X_{13} has decreased from 57.6 m^3 in 2009 to 47.6 m^3 in 2013, Shanghai City has dropped from 163 m^3 in 2003 to 41 m^3 in 2013. It can be seen from the table, the water consumption per ten thousand yuan industrial added value X_{14} in Handan is 18.89 m^3, the mean is slightly lower in Hebei province 19 m^3, but much higher than the neighboring provinces and cities, such as Beijing 14 m^3, Tianjin 8 m^3, Shandong 12 m^3. To close the gap, it should constantly work on elimination of high water consumption enterprises, promoting industrial

Table 1. The original data of evaluating indexes in Handan city.

Year	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}
2006	884.12	30.88	1359.46	599.52	7121	18.6010	50.65	2.2758	70.52	13.3716	816.7	2.9536	136.83	47.02	8.0586	2.3868
2007	896.36	31.95	1608.1	805.92	7687	18.7066	55.75	2.2145	67.69	13.6797	811.3	2.8124	116.33	42.04	9.1794	1.3629
2008	928.08	32.29	1990.4	1048.99	8357	17.1055	62.96	2.2718	67.06	12.4194	795.64	2.4144	85.94	24.18	12.0960	1.5230
2009	942.77	33.36	2015.28	1466.90	8691	17.2295	63.87	2.2634	65.78	12.4041	842.2	2.5620	85.49	25.66	12.5297	0.8777
2010	963.50	31.31	2361.56	1835.13	9438	17.9981	56.96	2.5010	71.12	13.0551	812.1	2.4420	76.21	21.05	9.8795	0.8554
2011	979.95	31.48	2789.03	1985.40	11756	18.4416	62.51	2.9813	83.35	12.8852	819.1	2.5751	66.12	18.47	10.8560	1.0882
2012	993.1	31.04	3024.29	2383.55	12413	20.7192	60.61	2.9791	82.19	14.9567	825.7	2.7833	68.51	18.89	10.8360	1.1862

Table 2. The standardized data of evaluating indexes in Handan city.

Year	Z_1	Z_2	Z_3	Z_4	Z_5	Z_6	Z_7	Z_8	Z_9	Z_{10}	Z_{11}	Z_{12}	Z_{13}	Z_{14}	Z_{15}	Z_{16}
2006	-1.38697	-1.02009	-1.33527	-1.28524	-1.10777	0.16653	-1.74563	-0.65045	-0.27726	0.13403	-0.05836	1.49707	1.75301	1.63014	-1.53846	2.01483
2007	-1.08916	0.22226	-0.92262	-0.97203	-0.82672	0.25412	-0.68506	-0.82979	-0.66764	0.48257	-0.43613	0.80315	0.9727	1.19908	-0.82949	0.07056
2008	-0.31741	0.61703	-0.28814	-0.60319	-0.49401	-1.07384	0.81429	-0.66215	-0.75454	-0.94312	-1.53167	-1.15278	-0.18407	-0.34685	1.01541	0.37457
2009	0.04001	1.85939	-0.24685	0.03098	-0.32816	-0.97099	1.00353	-0.68673	-0.93111	-0.96043	1.72555	-0.42741	-0.2012	-0.21874	1.28975	-0.85078
2010	0.54437	-0.52083	0.32785	0.58975	0.04278	-0.33351	-0.43344	0.0084	-0.1945	-0.224	-0.38017	-1.01714	-0.55443	-0.61778	-0.38664	-0.89313
2011	0.94461	-0.32344	1.03729	0.81778	1.19382	0.03433	0.72071	1.41358	1.49253	-0.41619	0.10953	-0.36303	-0.93849	-0.8411	0.23104	-0.45107
2012	1.26455	-0.83432	1.42773	1.42195	1.52007	1.92337	0.3256	1.40714	1.33252	1.92714	0.57125	0.66014	-0.84752	-0.80474	0.21839	-0.26498

water economizing, optimization of water circulation system and the projects of high-volume water consumption should be under strict control.

3.3.2. Software Analysis with SPSS

With SPSS 19.0, the calculations adopting principal component analysis of the water resources carrying capacity were done. The procedures are as follows.

The data in Table **1** were standardized (see Table **2**) by standard deviation and derived correlation matrix of water resources carrying capacity factor in Handan. Then calculate the eigenvalues, the contribution rate and the cumulative contribution rate of principal components (see Table **3**). Result of factor analysis and scree plot is shown in Fig. (**1**).

The cumulative contribution rate of the first 3 principal components is 92.564%>85%, and the first 3 factors will summarize the most information in the scree plot. So we can use 3 principal components to reflect the characteristic of Handan water resources carrying capacity instead of the original 16 variables.

Table 3. Total variance explained.

Component	Eigenvalues	% of Variance	Cumulative %
1	8.623	53.891	53.891
2	4.817	30.108	83.999
3	1.370	8.565	92.564

The eigenvalues of 3 principal components are 8.623, 4.817, 1.370. Calculate their eigen vectors and the load of variables on the principal component. The component matrix is shown in Table **4**.

It can be seen from Table **4** that X_1, X_3, X_4, X_5, X_7, X8, X_9 are significant positive correlation with the first principal component U_1 and X_6, X_{10}, X_{12}, X_{16} are positive correlation with the second component U_2, X_2, X_{13}, X_{14}, X_{15} are positive correlation with the third component U_3.

The first principal component U_1 has 53.891% contribution rate. It is the impact of population and the production activity of industry or agriculture on the water resource. It is the main control factor which controls other factors. The second principal component U_2 has 30.108% contribution rate and it is the condition of water supply. The third principal component U_3 has 8.565% contribution rate. It is socioeconomic status which affect the carrying capacity of water resources in turn.

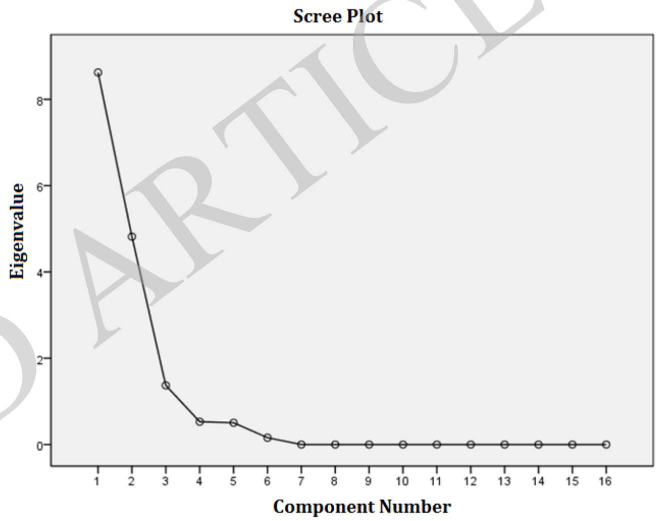

Fig. (1). Scree plot of factor analysis.

The value of principal components load matrix is divided by the square root of corresponding characteristic data, then get the index coefficient of the three principal components, namely the eigenvectors. Multiply the eigenvectors and the standard data Z to obtain expression of principal component. According to the principle of the principal component, U_1, U_2, U_3 score and comprehensive score of U can be expressed as the following linear combination (see Table **5**).

$$U_1=0.991Z_1-0.023Z_2+0.983Z_3+0.969Z_4+0.947Z_5 +0.323Z_6+0.709Z_7+0.844Z_8+0.710Z_9+0.219Z_{10} +0.284Z_{11}-0.457Z_{12}-0.964Z_{13}-0.941Z_{14}+0.573Z_{15} -0.731Z_{16}$$

$$U_2=0.049Z_1-0.880Z_2+0.169Z_3+0.156Z_4+0.301Z_5 +0.888Z_6-0.609Z_7+0.475Z_8+0.611Z_9+0.852Z_{10} -0.002Z_{11}+0.766Z_{12}+0.230Z_{13}+0.267Z_{14} -0.721Z_{15}+0.427Z_{16}$$

$$U_3=-0.024Z_1+0.430Z_2-0.063Z_3+0.060Z_4+0.002Z_5 +0.194Z_6+0.102Z_7-0.085Z_8+0.108Z_9+0.202Z_{10} +0.896Z_{11}+0.415Z_{12}+0.120Z_{13}+0.168Z_{14} +0.156Z_{15}-0.168Z_{16}$$

$$U=0.53891U_1+0.30108U_2+0.08565U_3 \quad (2)$$

Table 4. Component matrix.

Impact Factor	The First Principal Component U_1	The Second Principal Component U_2	The Third Principal Component U_3
X_1	0.991	0.049	-0.024
X_2	-0.023	-0.880	0.430
X_3	0.983	0.169	-0.063
X_4	0.969	0.156	0.060
X_5	0.947	0.301	0.002
X_6	0.323	0.888	0.194
X_7	0.709	-0.609	0.102
X_8	0.844	0.475	-0.085
X_9	0.710	0.611	-0.108
X_{10}	0.219	0.852	0.202
X_{11}	0.284	-0.002	0.896
X_{12}	-0.457	0.766	0.415
X_{13}	-0.964	0.230	0.120
X_{14}	-0.941	0.267	0.168
X_{15}	0.573	-0.721	0.156
X_{16}	-0.731	0.427	-0.168

Table 5. Comprehensive evaluation of water resources carrying capacity in Handan city.

Year	Ul	Sorting	U2	Sorting	U3	Sorting	U	Sorting
2006	-13.1374	7	4.871786	2	-0.01916	4	-5.61471	7
2007	-8.27231	6	1.234724	3	0.31464	3	-4.05933	6
2008	-1.83127	5	-5.46567	6	-1.92273	7	-2.79717	5
2009	0.866454	4	-6.68546	7	2.145082	1	-1.36219	4
2010	2.794612	3	-0.86603	5	-1.24142	6	1.138971	3
2011	8.925173	2	0.735581	4	-0.33312	5	5.002802	2
2012	10.65471	1	6.175087	1	1.056721	2	7.691633	1

It can be seen from Table **5** that the first principal component score is increasing year by year which mean the population and economic level increased yearly. The second and the third principal components fluctuate obviously. The second component is mainly due to the influence of water resources affected by natural climate and the economic development. The third component is due to the economy-society-resource coupling unstable influence of water resources development and utilization. In general, the score of water resource carrying capacity of Handan City in 2006-2012 is an upward trend.

The population growth rate was slow in recent years, and the rapid development of economy, GDP, fixed-asset investment, industrial water consumption showed a rising trend. Because of the development of science and technology, improving the quality of people to promote water saving ability, the water resources carrying capacity increased yearly.

CONCLUSION

In the complicated case, principal component analysis from a large number of statistical data finds common factors and special factors affecting the object of study. With this method, the three principal components effecting water resources carrying capacity in Handan City which are derived from the 16 indicators, are the impact of population and the production activity of industry and agriculture on the water resource, the condition of water supply, socioeconomic status. We should rationally adjust system structure of water resources carrying capacity and vigorously develop water-saving agriculture, promote the technique of water saving irrigation and cut down the cost. It is also very important to adjust the industrial production mode, adopt new technology and equipment, and improve the ability of sewage disposal. At the same time, we should pay attention to the increasing of recycling water and raise the utilization of water resources.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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