A Fuzzy Comprehensive Evaluation Method of Area Resource Carrying Capacity

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Abstract— The evaluation of resource carrying capacity of Xiong'an New Area can clearly recognize the endowment characteristics, carrying capacity and carrying level of resources in Xiong'an New Area, which could provide certain theoretical guidance for the sustainable development of economy, society and ecology in the New Area. Based on the analysis of the current situation of resources in the New Area, following the main principles of scientific, dynamic, reflecting the coordination of human land relationship and sustainable development, from three aspects of land resources, water resources and mineral resources, 13 indexes of the per capita cultivated land area, per capita construction land area, per unit cultivated land productivity, per capita water resources, per unit effective irrigation area, utilization rate of water resources, water use efficiency, ore production per unit land use and geothermal field area are selected to build the evaluation index system of resource carrying capacity of the New Area. Based on the fuzzy comprehensive evaluation method, the resource carrying capacity of Xiong'an New Area from 2014 to 2018 is evaluated with the administrative areas of Xiong county, An'xin county and Rongcheng county (including Baiyangdian water area) as the main evaluation unit, which could provide policy guidance for the land, water and mineral resources management of the New Area.

Keywords— Resource carrying capacity evaluation, fuzzy comprehensive evaluation method, Xiong'an New Area, land resources capacity, water resources capacity, mineral resources capacity.

I. INTRODUCTION

The establishment of Xiong'an New Area is a millennium plan and a national event. In April of 2018, the planning outline of Xiong'an New Area in Hebei province was officially promulgated, which clearly pointed out that "adhere to the rigid constraints of resource carrying capacity, and scientifically determine the development boundary, population scale, land use scale and development intensity of the new area". Therefore, the objective and accurate evaluation of the resource carrying capacity of the New Area can provide countermeasures for the coordinated development of the resource system and the social economic system, and walk out a path of resource saving, environment-friendly regional green development and sustainable development. Based on the evaluation index system of resource carrying capacity of the New Area, in this paper the fuzzy comprehensive evaluation method is used to evaluate the resource carrying capacity of the New Area dynamically, which provides the basis for the development and utilization of resources, the strategic planning of the and economic development in the New Area.

II. ANALYSIS ON THE RESOURCES OF XIONG'AN NEW AREA

Xiong'an New Area is positioned as a second-class city, which is planned to be developed first with a specific area as the starting area. The starting area is about 100 km^2, the medium-term development area is about 200 km^2 and the long-term control area is about 2000 km^2. The New Area has obvious location advantages, convenient transportation, excellent ecological environment, low level of existing development, abundant development space, and basic conditions of high starting point and high standard development and construction. The current situation of resources in the New Area is analyzed from three aspects: land resources, water resources and mineral resources.

A. Analysis on the land resources of Xiong'an New Area

In 2017, the total land area of Xiong, An'xin and Rongcheng county under the jurisdiction of Xiong'an New Area is 1560.70 km^2, and the land use structure shows the characteristics of "six fields, two constructions, one water and half forest". Among them, the cultivated land area is 958.16 km^2, accounting for 61.4%, the urban and rural construction land is 310.70 km^2, accounting for 19.91%, the wetland area with Baiyangdian as the main body is 194.26 km^2 (only referring to the administrative boundary of the New Area Wetland area), accounting for 12.45%, forest land area is 97.58 km^2, accounting for 6.25%.

1) The dynamic change of land use is sharp, which is higher than the average level of Beijing-Tianjin-Hebei region.

From 2000 to 2018, the dynamic change area of the first-class land use type in three counties of Xiong'an New Area is 219.50 km^2, accounting for 13.93% of the area, which is higher than the average level of Beijing-Tianjin-Hebei in the same period by 7.21%, as shown in Table 1.

Table 1 Land use area change of three counties in Xiong'an New Area from 2000 to 2018 (unit: km^2)

Land change	Cultivated land	Wood land	waters	Urban and rural industrial and mining residential land	Non cultivated land in cultivated land
Newly added	54.11	6.36	59.18	70.06	29.79
Reduce	90.56	0.46	83.69	0.28	44.50
Net change	-36.45	5.90	-24.51	69.78	-14.71

（Note: the above data source from《Xiong'an New Area Development Research Report》）

2) The cultivated land resources are abundant, but the quality and utilization intensity are quite different.

The cultivated land area of the Xiong'an New Area accounts for more than 60%, which provides enough space for the adjustment of human and land relationship. However, the cultivated land quality and utilization intensity of the three counties are quite different. The cultivated land quality of An'xin and Rongcheng county is good, and the multiple cropping index is high, reaching 1.92 and 1.87 respectively, winter wheat and summer maize are planted in turn on most cultivated land, with high utilization intensity. However, the cultivated land quality of Xiong county is relatively poor, and the multiple cropping index is obviously low, only 1.32, most of the cultivated land is mainly planted with corn and potato crops in summer, and the planting area of winter wheat is small [1].

3) The saving and intensive potential of construction land is great.

The existing urban and rural construction land in the New Area is nearly 290 km^2, accounting for nearly 20% of the land area. Among them, the total built-up areas (state-owned construction land) of Xiong, An'xin and Rongcheng county is about 35 km^2, accounting for 10% of the construction land area of the New Area. The permanent population of the county is 243000, and the per capita construction land area is 123.5 m^2. The collective construction land area of rural (including towns) is 252.17 km^2, with a population of 884000, and the per capita construction land area is 285 m^2, and the rural construction land has great saving and intensive potential [2].

4)The distribution of wetland and forest land is less, and the ecological space needs to be optimized.

The wetland area of the New Area is 194.26 km^2, about 92% of which is under the jurisdiction of An'xin county. Baiyangdian is the main part of the wetland in the New Area, which is of great significance to maintain the ecological security and improve the landscape diversity. The woodland area of the New Area is 97.58 km^2, the forest coverage is only 6.3%, and the fast-growing poplar is the main forest species [3]. From the perspective of planning and building a livable city, for the New Area, there is a huge space to improve forest coverage and optimize forest species structure in the future.

B. Analysis on the water resources of Xiong'an New Area

The total water resources and annual average precipitation of Baoding city where the Xiong'an New Area is located are 2978 billion m^3 and 567 mm respectively, including 1620 billion m^3 of surface water resources and 2223 billion m^3 of groundwater resources. In 2016, the per capita water resources of Baoding city was 287 m^3 [4]. Xiong'an New Area is rich in water systems, including Baiyangdian, which is the largest freshwater lake in North China. Baiyangdian is located in the middle and lower reaches of the Daqing River system, with a water area of about 366 km^2, which includes 143 lakes and more than 3700 ditches.

1) Total water resources and per capita water resources are insufficient

In recent years, the average precipitation of the New Area is 516 mm, and the total amount of water resources is 173 million m^3, including 11 million m^3 surface water resources, 169 million m^3 groundwater resources and 7 million m^3 repetition, as shown in Table 2. In 2018, the population of the New Area is nearly 1.2 million, and the per capita water resource is only 144 m^3, which is lower than that of Baoding city (282 m^3) and Beijing-Tianjin-Hebei in the same period (248 m^3).

Table 2 Annual average water resources of three counties in Xiong'an New Area

County name	Rainfall (mm per year)	Surface water resources (100 million m^3 per year)	Groundwater resources (100 million m^3 per year)	Total water resources (100 million m^3 per year)
Xiong county	518	0.0232	0.4413	0.4522
Rongcheng county	514	0.0569	0.5797	0.6200
An’xin county	517	0.0282	0.6667	0.6546
Total	1549	0.1083	1.6877	1.7268

（Note: the above data source from《Xiong'an New Area Development Research Report》）

2) Serious over exploitation of water resources has approached the carrying limit of water resources

In 2018, the total water consumption of the three counties in the New Area is 258 million m^3, of which the development and utilization of groundwater is 232 million m^3, accounting for 90% of the total water consumption [5]. It can be seen that due to the influence of geographical location and local economic structure, the groundwater in three counties has been overexploited to varying degrees, which makes the water depth deeper and deeper. From 2006 to 2015, the underground water depth of Xiong county is decreased from 17.8 m to 19.2 m, An’xin county from 7.8m to 10.8m, Rongcheng county from 19.2 m to 22.5 m.

3) Significant water deficit and low sustainability

In 2018, the deficit of water resources in the New Area is 85 million m^3, and the sustainability of water resources is 0.623. By comparison, Beijing and Hebei have larger deficits, 384 million m^3 and 1838 million m^3 respectively. But the sustainability of water resources in Beijing and Hebei is slightly higher than that in the New Area, 0.706 and 0.685 respectively, as shown in Table 3. Beijing and Hebei (including the New Area) is generally a region lacking water resources, and the sustainability of water resources is relatively low.

Table 3 Comparison of water resources utilization sustainability in Xiong'an New Area, Hebei and Beijing in 2018

Area	Total water resources (100 million m^3 per year)	Total water consumption (100 million m3 per year)	Water deficit (100 million m3 per year)	Sustainability
Xiong’an New Area	1.73	2.58	0.85	0.623
Beijing	35.46	39.3	3.84	0.706
Hebei	164.04	182.42	18.38	0.685

（Note: the above data source from《Beijing Water Resources Bulletin》,《Hebei Water Resources Bulletin》,

《Xiong'an New Area Development Research Report》）

4) Low efficiency of water resources output

In 2018, water consumption per 10000 yuan of GDP in the New Area is 139.84 m^3, higher than 50.66 m^3 in Hebei, and far higher than 12.96 m^3 in Beijing, as shown in Table 4. This shows that the efficiency of water resources output in the New Area is relatively low, and it is necessary to introduce science, technology and water-saving industries to improve the efficiency of water resources output .

Table 4 Comparison of water consumption per 10000 yuan of GDP in Xiong'an New Area, Hebei and Beijing in 2018

Area	Total water consumption (100 million m^3)	GDP (100 million yuan)	Water consumption per 10000 yuan of GDP (m^3)
Xiong’an New Area	2.58	184.5	139.84
Hebei	182.42	36010	50.66

Beijing	39.3	30320	12.96

（Note: the above data source from《Beijing Statistical Yearbook》,《Hebei Economic Yearbook》,《Beijing Water Resources Bulletin》,《Hebei Water Resources Bulletin》）

5) Water resource gap continues to increase

In terms of per capita water consumption, Beijing is 178.6 m^3 in 2016, while Hebei is 245.2 m^3 in the same period. In the future, if there are 500000 people in Xiong'an New Area, the annual water demand is 89.3 million m^3. If there are 1 million people in the new area, the annual water demand is 178.6 million m^3, which is basically the same as the total water resources in the New Area. According to the overall planning of the New Area, the population development scale will reach 2-2.5 million in the medium term in the future. If calculated according to per capita water consumption of Beijing, it will need 357~450 million m^3 and the water resource gap will reach 180~280 million m^3 [6].

C. Analysis on the mineral resources of Xiong'an New Area

Xiong'an New Area has unique advantages in oil, natural gas, geothermal and other mineral resources. Xiong county is the main production area of Huabei oilfield, with more than 1200 oil wells, with an annual output of 700000 t crude oil and 18 million m^3 natural gas. The building sand and stone materials in the New Area are mainly distributed in Taihang Mountain and Yanshan area, while the brick clay is distributed in the plain area in the middle and eastern part of Hebei, including 150 cement limestone with an annual output of 39.6 million tons, 308 construction stone limestone with an annual output of 19.7 million tons, 21 construction sand with an annual output of 39.6 million tons, 634 brick clay with an annual output of 11.5 million tons, 367 dolomites for construction with an annual output of 65.5 million tons [7].

The New Area is rich in geothermal resources. As of 2019, the bedrock thermal storage area of Xiong county is 320 km^2, accounting for 61% of the total area of the county, accounting for 50% of the total area of the geothermal field in Niutuo town. The geothermal water reserve is 82.178 billion m^3, equivalent to 6.63 billion tons of standard coal.

III. Design of evaluation index system of resource carrying capacity in Xiong'an New Area

A. Design idea

Combined with the resource situation of Xiong'an New Area, in this paper, the evaluation index system of resource carrying capacity of the New Area is designed from the three dimensions of land resources, water resources and mineral resources, to select the several second-class indexes according to the actual situation of the development of the New Area, and optimize the selection of each characteristic index by using the correlation analysis and principal component analysis of SPSS. Finally, the evaluation index system of resource carrying capacity of the New Area is designed to meet the regional characteristics.

A. Design principles

The design of evaluation index system of resource carrying capacity of Xiong'an New Area follows five main principles [8][9]: ① Scientific principle. The evaluation indexes should be able to objectively and truly reflect the regional development status, fully reflect the essential characteristics of resources of Xiong'an New Area, at the same time the index requires clear concept, data availability and statistical norms, to ensure objective, scientific and effective evaluation results. ② Dynamic principle. Xiong'an New Area is in the initial planning and development stage, and the resource carrying capacity will continue to be changed dynamically. Therefore, the evaluation indexes should be able to fully describe and evaluate the operation mode and development state of the resource system in the New Area. ③ Reflecting the coordination of human land relationship. The regional resource carrying capacity is an important carrier of the study of human land interaction. Therefore, it is necessary to base on the objective reality of the evaluation area, fully reflect the human land relationship characteristics of the resource carrying capacity of Xiong'an New Area, and depict the human land interaction mechanism of the New Area. ④ Sustainable development principle. The selection of indexes should consider the sustainable utilization of regional resources, and the evaluation results should reflect the sustainable development capacity of resource system in Xiong'an New Area.

B. Design of evaluation index system

Based on the first-class indexes of land resources, water resources and mineral resources, a total of 28 second-class indexes that best reflect the resource characteristics of Xiong'an New Area and statistical data can be checked or calculated are selected to initially build the evaluation index system of resource carrying capacity of the New Area [10][11], as shown in Table 5.

Table 5 Preliminary construction of evaluation index system of resource carrying capacity of Xiong'an New Area

Name	First-class indexes	Second-class indexes
Evaluation	land resources	total land area, per capita cultivated land area, per capita construction land area, per

index system of resource carrying capacity of Xiong'an New Area		unit cultivated land productivity, construction land area per 10000 yuan of GDP, increased rate of construction land, land utilization rate, land development intensity, per unit land output, per capita grain occupancy
	water resources	Total water resources, average precipitation, surface water resources, per capita water resources, per capita water resources demand, proportion of agricultural water use, per unit effective irrigation area, sustainability of water resources, utilization rate of water resources, water use efficiency
	mineral resources	Number of mining enterprises, annual ore production, ore production per unit land use, actual mining capacity per unit land use, annual crude oil production, annual natural gas production, geothermal field area, geothermal water reserves

In the following, the paper uses the correlation analysis and principal component analysis of SPSS to optimize the evaluation indexes of resource carrying capacity in Xiong'an New Area.

Step 1: Based on the correlation analysis of SPSS.

Firstly, the statistical data of 28 indexes of land resources, water resources and mineral resources in Xiong'an New Area from 2014 to 2018 are standardized. Secondly, the correlation analysis method of SPSS tools is used to test the correlation, and significant correlation indexes (the absolute value of correlation coefficient is greater than 0.8) are found, for example, the index of total land area is significantly related to three indexes: land utilization rate, land development intensity and per unit land output, the index of total water resources is significantly related to three indexes of surface water resources, per capita water resources and proportion of agricultural water use. Finally, combined with the expert scoring method (invite 10 relevant experts to score), it is to exclude 8 indexes with lower weight scores, including total land area, per capita grain occupation, total water resources, average precipitation, sustainability of water resources, number of mining enterprises, actual mining capacity per unit land use and geothermal water reserves. In Table 6, it is shown the evaluation indexes (including 20 second-class indexes) of resource carrying capacity of Xiong'an New Area screened by correlation analysis.

Table 6 Evaluation indexes of resource carrying capacity of Xiong'an New Area after correlation analysis

Name	First-class Indexes	Second-class indexes	Index meaning	Positive or negative
Evaluation index system of resource carrying capacity of Xiong'an New Area	Land resources	per capita cultivated land area (m^2 per capita)	Cultivated land area / Total population	+
		per capita construction land area (m^2 per capita)	Construction land area / Total population	+
		per unit cultivated land productivity (t per km^2)	Crop yield / Cultivated land area	+
		construction land area per 10000 yuan of GDP(m^2 per 10000 yuan)	Construction land area / GDP	-
		increased rate of construction land (%)	Increased construction land area / Total construction land area	+
		land utilization rate (%)	Used land area / Total land area	+
		land development intensity (%)	Total construction land / Total land area	+
		per unit land output (10000 yuan per km^2)	GDP / Total land area	+

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Water resources	surface water resources (100 million m^3 per year)		+
	per capita water resources (m^3 per capita)	Total water resources / Total population	+
	per capita water resources demand (m^3 per capita)	Total water demand / Total population	-
	proportion of agricultural water use (%)	Total agricultural water consumption / Total water resources	+
	per unit effective irrigation area (m^2 per ton)	Irrigation area / Water consumption of cultivated land	+
	utilization rate of water resources (%)	Water consumption / Available water resources	-
	water use efficiency (yuan per m^3)	GDP / Water supply	+
Mineral resources	ore production per unit land use (10000 tons per km^2)	Annual ore output / Mining land area	+
	annual crude oil production (ton per year)		+
	annual natural gas production (10000 m^3)		+
	geothermal field area (km^2)		+
	geothermal water reserves (100 million m^3)		+

Step 2: Based on the principal component analysis of SPSS.

Firstly, standardize the statistical data of 20 indexes of land resources, water resources and mineral resources in Xiong'an New Area from 2014 to 2018. Secondly, use the principal component analysis method of SPSS tools for analysis. In Table 7, the characteristic values of the first four principal components of the resource carrying capacity index are all greater than 1, and the cumulative contribution rate is more than 80%, indicating that these four principal components can basically represent the original index to evaluate the resource carrying capacity of Xiong'an New Area. Finally, the related indexes are extracted based on the principal components. In Table 8, by analyzing the rotated factor load matrix, 13 indexes of the per capita cultivated land area, per capita construction land area, per unit cultivated land productivity, land utilization rate, per unit land output, per capita water resource, per unit effective irrigation area, utilization rate of water resources, water use efficiency, ore production per unit land use, annual crude oil yield, annual natural gas yield, geothermal field are extracted from the four main components to construct the evaluation index system of resource carrying capacity of Xiong'an New Area, as shown in Fig 1.

Table 7 Total Variance Explained

Component	Initial Eigenvalues			Rotation Sums of Squared Loading		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	6.549	42.743	42.743	6.549	42.743	42.743

2	2.932	24.659	67.402	2.932	24.659	67.402
3	1.759	8.797	76.199	1.759	8.797	76.199
4	1.260	6.802	83.001	1.260	6.802	83.001
5	0.918	5.172	88.173			
6	0.772	4.875	93.048			
7	0.517	3.115	96.163			
8	0.348	1.825	97.988			
9	0.177	0.928	98.916			
10	0.078	0.537	99.453			
11	0.042	0.329	99.782			
12	0.025	0.216	99.998			
13	0.018	0.194	100.000			
14	6.221E-16	3.111E-15	100.000			
15	5.532E-16	2.766E-15	100.000			
16	3.727E-16	1.863E-15	100.000			
17	1.954E-16	9.769E-16	100.000			
18	-4.206E-16	-2.103E-15	100.000			
19	-5.042E-16	-2.521E-15	100.000			
20	-1.390E-15	-6.949E-15	100.000			

Extraction Method: Principal Component Anaylsis

Table 8 Rotated Component Matrix [a]

	Component			
	1	2	3	4
per capita cultivated land area	.919	.288	-.224	.149
per capita construction land area	.912	.224	-.072	.338
per unit cultivated land productivity	.364	.928	.044	-.072
construction land area per 10000 yuan of GDP	.254	.634	.198	-.155
increased rate of construction land	-.815	-.524	.236	-.073
land utilization rate	.998	.055	-.037	.003
land development intensity	.542	.235	-.237	.035

per unit land output	-.066	.983	.172	-.005
surface water resources	-.254	.447	.175	-.840
per capita water resources	-.288	.380	.813	.049
per capita water resources demand	-.856	-.165	-.484	.080
proportion of agricultural water use	.413	-.264	-.854	.173
per unit effective irrigation area	.755	.098	.643	.085
utilization rate of water resources	-.161	.067	.968	.181
water use efficiency	.961	.157	-.078	.212
ore production per unit land use	.582	.809	.064	-.055
annual crude oil production	-.131	.719	.504	-.346
annual natural gas production	.975	.218	-.024	.015
geothermal field area	.626	-.101	-.144	.759
geothermal water reserves	.677	.553	.268	.406

Extraction Method: Principal Component Anaylsis

Ratation Method:Varimax with Kaiser Normalization

a.Ratation converged in 5 iteratio

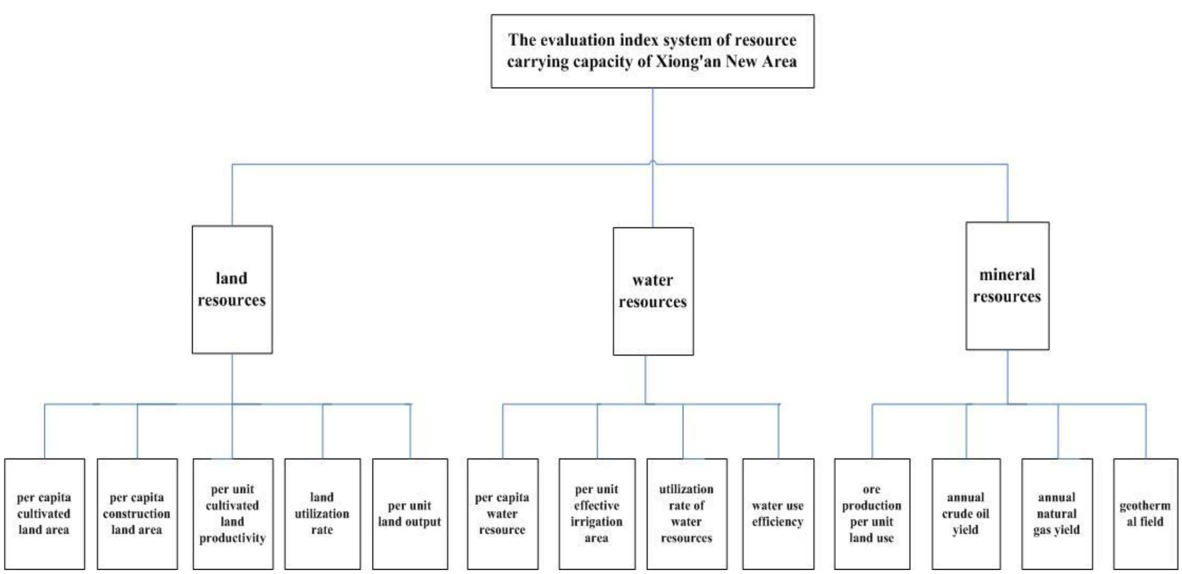

Fig.1 The evaluation index system of resource carrying capacity of Xiong'an New Area

IV. Fuzzy Comprehensive Evaluation Method

A. Overview of fuzzy comprehensive evaluation method

Fuzzy comprehensive evaluation method is a comprehensive evaluation method based on fuzzy mathematics. According to the membership degree theory of fuzzy mathematics, qualitative evaluation is transformed into quantitative evaluation. That is to say, fuzzy mathematics is used to make an overall evaluation of things or objects restricted by various factors. It has the characteristics of clear results and strong systematization, which can solve the fuzzy and difficult to quantify problems and is suitable for solution of various kinds of uncertain problems. The evaluation of regional resources and environment carrying capacity is a very complex problem. All kinds of factors will affect the evaluation effect of resources and environment carrying capacity, and the way and size of the influence are different and fuzzy. The fuzzy comprehensive evaluation method can objectively reflect these effects, so it is more scientific and feasible.

B. Main steps of fuzzy comprehensive evaluation method

Main steps of fuzzy comprehensive evaluation method include [12]:

Step 1: Determine the factor set.

The factor set is divided into target level, first-class evaluation factor and second-class evaluation factor, namely: $U=(U_1,U_2,U_3,...,U_m)$, $U_m=(U_{m1},U_{m2},U_{m3},...,U_{mn})$, $m,\ n>0$ 。

Step 2: Determine the evaluation set.

In general, according to the characteristics of the selection of evaluation factors whose possible values are intervals in the comprehensive evaluation factor set, the evaluation set $v=\{v_1,v_2,v_3,...,v_n\}$ is set as {very good, good, general, poor, very poor}, and the evaluation is carried out by combining the limit optimal value or multiple schemes to compare the optimal value. In this paper, according to the influence degree of the evaluation index on resource carrying capacity of Xiong'an New Area, the evaluation index is divided into three levels: v_1 level of ideal carrying state, v_3 level of non-carrying state and v_2 level of carrying state (between v_1 and v_3).

Step 3: Building fuzzy matrix.

Firstly, build fuzzy membership function. Membership indicates the degree of membership corresponding to the evaluation result and the level standard. In this paper, according to the characteristics of resource evaluation, in order to eliminate the jump phenomenon that the value difference between different levels is not big and the evaluation level is one level different, it is to make the membership function smoothly transition between different levels and is to be blurred. Now, the critical value of the v_1 and v_2 level is k_1 , the critical value of the v_2 and v_3 level is k_3 , and the point value in the v_2 level interval is k_2 , $k_2=(k_1+k_3)/2$.

For the evaluation factors with higher index value and higher resource carrying capacity level, the calculation formula of relative membership function of each level is as follows in Formula1.

$$u_{v1}=\begin{cases} 0.5[1+(k_1-U_i)/(k_2-U_i)] & U_i>k_1 \\ 0.5[1-(U_i-k_1)/(k_2-k_1)] & k_2<U_i\le k_1 \\ 0 & U_i\le k_2 \end{cases}$$

$$u_{v2}=\begin{cases} 0.5[1-(k_1-U_i)/(k_2-U_i)] & U_i>k_1 \\ 0.5[1+(U_i-k_1)/(k_2-k_1)] & k_2<U_i\le k_1 \\ 0.5[1+(k_3-U_i)/(k_3-k_2)] & k_3<U_i\le k_2 \\ 0.5[1-(k_3-U_i)/(k_2-U_i)] & U_i\le k_3 \end{cases} \qquad (1)$$

$$u_{v3}=\begin{cases} 0.5[1+(k_3-U_i)/(k_2-U_i)] & U_i<k_3 \\ 0.5[1-(U_i-k_3)/(k_2-k_3)] & k_3\le U_i<k_2 \\ 0 & U_i\ge k_2 \end{cases}$$

For the evaluation factors with smaller index value and higher resource carrying capacity level, the calculation formula of relative membership function of each level is as follows in Formula 2.

$$u_{v1}=\begin{cases} 0.5[1+(k_1-U_i)/(k_2-U_i)] & U_i<k_1 \\ 0.5[1-(U_i-k_1)/(k_2-k_1)] & k_1\le U_i<k_2 \\ 0 & U_i\ge k_2 \end{cases}$$

$$u_{v2}=\begin{cases} 0.5[1-(k_1-U_i)/(k_2-U_i)] & U_i<k_1 \\ 0.5[1+(U_i-k_1)/(k_2-k_1)] & k_1\le U_i<k_2 \\ 0.5[1+(k_3-U_i)/(k_3-k_2)] & k_2\le U_i<k_3 \\ 0.5[1-(k_3-U_i)/(k_2-U_i)] & U_i\ge k_3 \end{cases} \qquad (2)$$

$$u_{v3}=\begin{cases} 0.5[1+(k_3-U_i)/(k_2-U_i)] & U_i\ge k_3 \\ 0.5[1-(U_i-k_3)/(k_2-k_3)] & k_2\le U_i<k_3 \\ 0 & U_i<k_2 \end{cases}$$

Through the above Formula 1 and Formula 2, the membership r_{ij} of each evaluation index corresponding to each level can be calculated,

$$r_{i1} = u_{v1}(U_i),\ r_{i2} = u_{v2}(U_i),\ r_{i3} = u_{v3}(U_i),$$
$$(i = 1,2,3...m).$$

Secondly, establish fuzzy relation matrix. Through calculation of membership, the fuzzy relation matrix $R_{m\times n}$ is established:

$$R_{m\times n} = (r_{ij}) = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & r_{m3} \end{bmatrix}$$

$r_{ij} = (r_{i1}, r_{i2}, ..., r_{in})$ is the single index evaluation result of the *i-th* index U_i in the matrix *R*.

Step 4: Determine weight.

The weight vector is a set corresponding to the factor set, which is used to display the weight value of each index.

$$W = (w_1, w_2, w_3, ... w_m)$$

$$w_m \geq 0,\quad \sum w_m = 1$$

The evaluation index system of resource carrying capacity of Xiong'an New Area is a total of two-class indexes. Therefore, the expert scoring method and principal component analysis method are selected to determine the weights of the evaluation indexes.

The first-class evaluation index of resource carrying capacity evaluation index system in Xiong'an New Area uses expert scoring method to determine the weight. The specific method is to invite ten experts to fill in the questionnaire of index weight independently according to the requirements, and do not discuss or have any horizontal contact with each other. The principle of selecting experts is scholars who are proficient in relevant research, and the number of experts is selected to exclude personal subjective factors and the operability of investigation.

Principal component analysis method is used to determine the weight of the second-class evaluation index system of resource carrying capacity in Xiong'an New Area. The specific steps are: firstly calculate the coefficient of the index in the linear combination of the principal components, secondly calculate the variance contribution rate of the principal components, finally normalize the index weight.

Step 5: Select fuzzy operator pairs.

Select the fuzzy operator pair, that is, the weight vector *W* and its corresponding fuzzy matrix *R* for fuzzy transformation, and get the comprehensive evaluation results:

$$B = W * R = (w_1, w_2, w_3, \cdots, w_m) * \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1j} \\ r_{21} & r_{22} & \cdots & r_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mj} \end{bmatrix} = (b_1, b_2, b_3, \cdots, b_j)$$

The evaluation result *B* is a fuzzy subset of v, $B = \{b_1, b_2, ..., b_j\}$, $0 \leq b_j \leq 1$, b_j is the membership of the fuzzy subsets *B* obtained from the comprehensive evaluation v_j, which represents the results of the comprehensive evaluation. The weight vector $w = \{w_1, w_2, ..., w_m\}$ represents the weight index of the importance of each evaluation index to the comprehensive evaluation. According to the different influence degree of each evaluation index on the resource carrying capacity, each evaluation index is given different weights, to satisfy $w_1 + w_2 + ... + w_m = 1$.

Score 0-1 interval for v_1, v_2 and v_3, the higher the index score value corresponding to the stronger carrying capacity, the scoring value corresponding to the grading indexes of v_1, v_2 and v_3 is a_1, a_2, a_3, take a_1=0.95, a_2=0.5 and a_3=0.05, and the calculation formula of comprehensive evaluation score is as follows in Formula 3.

$$a = \frac{\sum_{j=1}^{3} b_j \alpha_j}{\sum_{j=1}^{3} b_j} \qquad (3)$$

b_j is the *jth* value of the result matrix, *a* represents resource carrying capacity in the region, and a_j is between 0 and 1. The closer the value of a_j is to 1, the greater the potential of resource carrying capacity is, the higher the regional resource carrying capacity is. The closer the value of a_j is to 0, the smaller the potential of resource carrying capacity is, the lower the regional resource carrying capacity is.

V. Evaluation of Resource Carrying Capacity of Xiong'an New Area Based on Fuzzy Comprehensive Evaluation Method

A. *Definition of evaluation unit in Xiong'an New Area*

Taking Xiong county, An’xin county and Rongcheng county administrative area (including Baiyangdian water area) of Xiong’an New Area as the main evaluation unit, the research data is the statistical index data of the New Area from 2014 to 2018, all of which are from Hebei Economic Yearbook, Statistical Bulletin of National Economic and Social Development of Baoding, Hebei Economic Development

Report, Website of Hebei Bureau of Statistics, Official Website of Xiong'an New Area, official websites of Xiong county, An'xin county and Rongcheng county, and to investigate or calculate the actual data.

B. Evaluation of land resources carrying capacity in Xiong'an New Area

Step 1: Set grading standard of evaluation index.

Based on the relevant policy documents such as urban system planning, urban land classification and planning and construction land standard, land use master plan, Xiong'an New Area Master Plan (2018~2035), combined with national land use level, actual land use situation and land use level of the New Area, referring to relevant literature, it has formulated the grading standards for each evaluation index of the land resources carrying capacity in the New Area.

① **Per capita cultivated land area**. At present, China's per capita cultivated land area is 1.499 Mu, just for one third of the world, and the per capita cultivated land area of Xiong'an New Area is 1.30 Mu, lower than the national average. According to the world recognized standard, the international warning line is 0.8 Mu per capita. Combined with relevant literature and expert advice, so k_1 is selected as 1.5 and k_3 as 0.8. ② **Per capita construction land area**. The national per capita construction land area is 284.78 m^2 per capita, and the per capita construction land area of Xiong'an New Area is 278.85 m^2 per capita, which is far higher than the level of 84 m^2 per capita in developed countries and 83 m^2 per capita in the world average level. Combined with the relevant research results, so k_1 is selected as 300 and k_3 as 250. ③ **Per unit cultivated land productivity**. The average per unit cultivated land productivity is 650 t/km^2 in China, and the per unit cultivated land productivity in Xiong'an New Area is 560.64 t/km^2. Combined with relevant research results and expert opinions, so k_1 is selected as 650 and k_3 as 550. ④ **Land use rate**. Compared with the average level of 73.95% of the national land use rate, the land use rate of Xiong'an New Area is 62.8%. Referring to the master plan of Xiong'an New Area in Hebei Province (2018-2035), so k_1 is selected as 75 and k_3 as 60. ⑤ **Unit land output**. According to the national average level of land efficiency of 9.3781 million yuan/km^2, and the unit land output of Xiong'an New Area of 11.8258 million yuan/km^2, combined with the 13th five year plan for national economic and social development, so k_1 is selected as 1200 and k_3 as 950. Through the above grading standard selection process, determine the grading standard of land resources carrying capacity evaluation index in Xiong'an New Area, as shown in Table 9.

Table 9 The grading standard of land resources carrying capacity evaluation index in Xiong'an New Area

Name	Evaluation indexes	Evaluation classification v		
		v_1	v_2	v_3
Land resources	Per capita cultivated land area (Mu per capita)	>1.5	1.5~0.8	<0.8
	Per capita construction land area (m^2 per capita)	>300	300~250	<250
	per unit cultivated land productivity (t/km^2)	>650	650~550	<550
	Land use rate（%）	>75	75~60	<60
	Unit land output（million yuan//km^2）	>1200	1200~950	<950

According to different degrees of influence of the above five indexes on the regional land resources carrying capacity, it is divided into three grades of v_1, v_2 and v_3, which v_1 means better and the regional land has larger carrying capacity, and which v_3 means worse and the carrying capacity of land resources has become saturated, the further development potential is small. v_2 is between v_1 and v_3, which has certain development potential, but the potential is limited.

Step 2: Determine the weight of each index.

In this paper, principal component analysis is used to determine the weight of second-class evaluation indexes, as shown in Table 10.

Table 10 Weight of each evaluation index of land resources in Xiong'an New Area

Name	Evaluation indexes	Component 1	Component 2	Component 3	Component 4

Factor loads	Per capita cultivated land area (Mu per capita)	0.919	0.288	-0.224	0.149
	Per capita construction land area (m^2 per capita)	0.912	0.224	-0.072	0.338
	per unit cultivated land productivity (t/km^2)	0.364	0.928	0.044	-0.072
	Land use rate（%）	0.998	0.055	-0.037	0.003
	Unit land output（million yuan//km^2）	-0.066	0.983	0.172	-0.005
Characteristic roots of principal components		6.549	2.932	1.759	1.260
Coefficient in linear combination	Per capita cultivated land area (Mu per capita)	0.359	0.168	-0.169	0.133
	Per capita construction land area (m^2 per capita)	0.356	0.131	-0.054	0.301
	per unit cultivated land productivity (t/km^2)	0.142	0.542	0.033	-0.064
	Land use rate（%）	0.390	0.032	-0.028	0.003
	Unit land output（million yuan//km^2）	-0.026	0.574	0.130	-0.004
Coefficient in comprehensive score model	Per capita cultivated land area	0.228			
	Per capita construction land area	0.241			
	per unit cultivated land productivity	0.227			
	Land use rate	0.207			
	Unit land output	0.171			
Indexes weight	Per capita cultivated land area	0.212			
	Per capita construction land area	0.224			
	per unit cultivated land productivity	0.211			
	Land use rate	0.193			
	Unit land output	0.160			

The weight matrix W of evaluation index of land resources carrying capacity in Xiong'an New Area = (0.212, 0.224, 0.211, 0.193, 0.160).

Step 3: Evaluate the carrying capacity of land resources.

First of all, the evaluation matrix R of membership function is calculated. According to the evaluation index rating standard of land resources in Xiong'an New Area in Table 12, the basic data of five indexes of per capita cultivated land area, per capita construction land area, per unit cultivated land productivity, land use rate and unit land output from 2014 to 2018 are substituted into Formulas 1, and the fuzzy matrix R of land resources system in the New Area from 2014 to 2018 is obtained as follows:

$$R_{m\times n2014} = (r_{ij}) = \begin{bmatrix} 0.65 & 0.35 & 0 \\ 0 & 0.6138 & 0.3862 \\ 0.1419 & 0.8581 & 0 \\ 0 & 0.2219 & 0.7781 \\ 0.7360 & 0.2640 & 0 \end{bmatrix}$$

$$R_{m\times n2015} = (r_{ij}) = \begin{bmatrix} 0.4571 & 0.5429 & 0 \\ 0 & 0.8646 & 0.1354 \\ 0.0972 & 0.9028 & 0 \\ 0 & 0.2737 & 0.7263 \\ 0.7417 & 0.2583 & 0 \end{bmatrix}$$

$$R_{m\times n2016}=(\mathrm{r_{ij}})=\begin{bmatrix}0.4143 & 0.5857 & 0\\ 0 & 0.9876 & 0.0124\\ 0.1937 & 0.8063 & 0\\ 0 & 0.2976 & 0.7024\\ 0.7690 & 0.2310 & 0\end{bmatrix}$$

$$R_{m\times n2017}=(\mathrm{r_{ij}})=\begin{bmatrix}0.1857 & 0.8143 & 0\\ 0.1032 & 0.8968 & 0\\ 0 & 0.922 & 0.078\\ 0 & 0.58 & 0.42\\ 0.5417 & 0.4583 & 0\end{bmatrix}$$

$$R_{m\times n2018}=(\mathrm{r_{ij}})=\begin{bmatrix}0.0429 & 0.9571 & 0\\ 0.8102 & 0.1898 & 0\\ 0 & 0.9083 & 0.0917\\ 0 & 0.6867 & 0.3133\\ 0.0768 & 0.9232 & 0\end{bmatrix}$$

Secondly, calculate the comprehensive evaluation matrix. Through fuzzy transformation, take 2014 as an example, get the comprehensive evaluation matrix *B* of land resources system in Xiong'an New Area:

$$B_{2014}=W*R$$

$$=(0.212,0.224,0.211,0.193,0.160)*\begin{bmatrix}0.65 & 0.35 & 0\\ 0 & 0.6138 & 0.3862\\ 0.1419 & 0.8581 & 0\\ 0 & 0.2219 & 0.7781\\ 0.7360 & 0.2640 & 0\end{bmatrix}$$

$$=(0.2855,0.4778,0.2367)$$

In this way, the comprehensive evaluation Matrix *B* of the land resource system in Xiong’an New Area from 2015 to 2018 is calculated in turn: B_{2015}=(0.2361, 0.5934, 0.1705), B_{2016}=(0.2517, 0.61, 0.1383), B_{2017}=(0.1491, 0.7378, 0.1131), B_{2018}=(0.2029, 0.7173, 0.0798).

In summary, based on Formula 3, the evaluation results of land resources carrying capacity in Xiong’an New Area from 2014 to 2018 are as follows in Table 11, the evaluation results of land resource carrying capacity in Xiong’an New Area have a higher degree of subordination for v_1 and v_2, indicating a higher development potential. From the analysis of comprehensive evaluation results, the carrying capacity of land resources in the new district fluctuated between 0.51 and 0.56 from 2014 to 2018, which increased by 6.4% compared with 2014.

Table 11 Evaluation results of land resources carrying capacity in Xiong'an New Area from 2014 to 2018

Area name	**Year**	***Evaluation results*** v_1	***Evaluation results*** v_2	***Evaluation results*** v_3	***Comprehensive evaluation results***
Xiong’an New Area	2014	0.2855	0.4778	0.2367	0.5220
	2015	0.2361	0.5934	0.1705	0.5295
	2016	0.2517	0.61	0.1383	0.5511
	2017	0.1491	0.7378	0.1131	0.5162
	2018	0.2029	0.7173	0.0798	0.5554

C. Evaluation of water resources carrying capacity in Xiong'an New Area

Step 1: Set grading standard of evaluation index.

① **Per capita water resources**. According to international general standards, those with per capita water resources of more than 2000 m^3 are water rich areas, those with per capita water resources of 1000-2000 m^3 are vulnerable areas, those with per capita water resources of 500-1000 m^3 are in short supply areas, and those with per capita water resources of less than 500 m^3 are water poor areas. The national per capita water resources level is 1956 m^3, Baoding city is 287 m^3 and Xiong'an New Area is 144 m^3. Referring to international standards and relevant literature, so k_1 is selected as 2000 and k_3 as 1000. ② **Per unit effective irrigation area**. The national per unit effective irrigation area is 700 m^2/t, Hebei province is 2400 m^2/t and Xiong'an New Area is 4300 m^2/t. Combined with the relevant research results, so k_1 is selected as 3000 and k_3 as 1000. ③ **Utilization rate of water resources**. According to the international general standards, the utilization rate of water resources is about 15% in the wet area, about 15%~25% in the vulnerable area, about 25% ~ 50% in the short area, and more than 50% in the poor water area. The national average utilization rate of water resources is about 25%, while the utilization rate of Xiong'an New Area is 127%, so k_1 is selected as 25 and k_3 as 50. ④ **Water use efficiency**. The national average level of water use efficiency is 57 yuan/m^3 and Xiong'an New Area is 61.71 yuan/m^3. Combined with relevant references and expert opinions, so k_1 is selected as 100 and k_3 as 50. Through the above grading standard selection process, determine the grading standard of water resources carrying capacity evaluation index in the New Area, as shown in Table 12.

Table 12 The grading standard of water resources carrying capacity evaluation index in Xiong'an New Area

Name	**Evaluation indexes**	**Evaluation classification** v		
		v_1	v_2	v_3
Water resources	Per capita water resources (m^3 per capita)	>2000	2000~1000	<1000
	Per unit effective irrigation area (m^2/t)	>3000	3000~1000	<1000
	Utilization rate of water resources (%)	<25	25~50	>50
	Water use efficiency（%）	>100	100~50	<50

Step 2: Determine the weight of each index.

Step 3: Evaluate the carrying capacity of water resources.

Through Step2 and Step3，in this way, the comprehensive evaluation Matrix B of the water resource system in Xiong'an New Area from 2014 to 2018 is calculated in turn: B_{2014}=(0.2094, 0.4338, 0.3568), B_{2015}=(0.2221, 0.4389, 0.3390), B_{2016}=(0.2285, 0.4024, 0.3691), B_{2017}=(0.2285, 0.4024, 0.3691), B_{2018}=(0.2810, 0.3837, 0.3353).

In summary, based on Formula 3, the evaluation results of water resources carrying capacity in Xiong'an New Area from 2014 to 2018 are as follows in Table 13, the evaluation results of water resources carrying capacity of Xiong'an New Area from 2014 to 2018 have a large degree of membership to v_2, indicating that there is a certain development potential, and the membership to v_1 shows an upward trend. From the analysis of the comprehensive evaluation results, as the economic development speed of the New Area increased in 2016, the amount of water resources used exceeded the load, which reduced the water resources carrying capacity to a certain extent. As a whole, as the New Area strengthened the management and utilization of water resources in 2017, the water resources carrying capacity is in a gradual upward trend.

Table 13 Evaluation results of water resources carrying capacity in Xiong'an New Area from 2014 to 2018

Area name	**Year**	***Evaluation results*** v_1	***Evaluation results*** v_2	***Evaluation results*** v_3	***Comprehensive evaluation results***
Xiong'an New Area	2014	0.2094	0.4338	0.3568	0.4337
	2015	0.2221	0.4389	0.3390	0.4474
	2016	0.2285	0.4024	0.3691	0.4367
	2017	0.2741	0.3980	0.3279	0.4758
	2018	0.2810	0.3837	0.3353	0.4756

D. Evaluation of mineral resources carrying capacity in Xiong'an New Area

Step1: Set grading standard of evaluation index

① **Ore production per unit land use**. The national ore production per unit land use is 5.6million t/km^2, Hebei province is 6.25 million t/km^2 and Xiong'an New Area is 792.70 t/km^2. Referring to relevant literature, k_1 is selected as 750 and k_3 as 600. ② **Annual crude oil production**. The annual crude oil production in China is 175.9million t/year, and that in Hebei province is 5.2million t/year, ranking the eighth. The annual crude oil production of Xiong'an New Area is 93.2t/year, which is higher than the average level of Hebei Province. Combined with relevant research results, k_1 is selected as 80 and k_3 as 50. ③ **Annual natural gas production**. The national annual natural gas production is more than 160 billion m^3, and Hebei province is 620 million m^3, ranking the 13th. The annual natural gas production of Xiong'an New Area is 2010 million m^3. Therefore, k_1 is selected as 2000 and k_3 as 1000. ④ **Geothermal field area**. The geothermal field in Xiong'an New Area is 670 km^2, far exceeding the national average standard of 280 km^2. In combination with relevant references and expert opinions, k_1 is selected as 500, and k_3 as 300. Through the above grading standard selection process, determine the grading standard of mineral resources carrying capacity evaluation index in the New Area, as shown in Table 14.

Table 14 The grading standard of mineral resources carrying capacity evaluation index in Xiong'an New Area

Name	Evaluation indexes	Evaluation classification v		
		v_1	v_2	v_3
Mineral resources	ore production per unit land use(10000 t per km^2)	>750	750~600	<600
	annual crude oil production(t per year)	>80	80~50	<50
	annual natural gas production(10000 m^3)	>2000	2000~1000	<1000
	geothermal field area (km^2)	>500	500~300	<300

Step 2: Determine the weight of each index.

Step 3: Evaluate the carrying capacity of mineral resources

Through Step 2 and Step 3，in this way, the comprehensive evaluation Matrix B of the mineral resource system in Xiong'an New Area from 2015 to 2018 is calculated in turn: B_{2014}=(0.6090, 0.3910, 0), B_{2015}=(0.6229, 0.3771, 0), B_{2016}=(0.6625, 0.3375, 0), B_{2017}=(0.6279, 0.3721, 0), B_{2018}=(0.6540, 0.3460, 0).

In summary, based on Formula 3, the evaluation results of mineral resources carrying capacity in Xiong'an New Area from 2014 to 2018 are as follows in Table 15, the evaluation results of mineral resources carrying capacity of the New Area from 2014 to 2018 have a large degree of subordination to v_1, indicating a large development potential. From the analysis of the comprehensive evaluation results, the mineral resources carrying capacity in the New Area shows an upward trend from 2014 to 2018.

Table 15 Evaluation results of minreal resources carrying capacity in Xiong'an New Area from 2014 to 2018

Area name	Year	*Evaluation results* v_1	*Evaluation results* v_2	*Evaluation results* v_3	*Comprehensive evaluation results*
Xiong'an New Area	2014	0.6090	0.3910	0	0.7741
	2015	0.6229	0.3771	0	0.7671
	2016	0.6625	0.3375	0	0.7981
	2017	0.6279	0.3721	0	0.7826
	2018	0.6540	0.3460	0	0.7943

E. Evaluation of resources carrying capacity in Xiong'an New Area

Using the expert scoring method, the corresponding weights of land resources, water resources and mineral resources of Xiong'an New Area are 0.4, 0.4 and 0.2 respectively. The Formula 4 as followed is used, w_i given to the evaluation value of land resources, water resources and mineral resources in the comprehensive evaluation, B_i represents the evaluation value of the carrying capacity of land resources, water resources and mineral resources.

$$Z = \sum w_i * B_i \tag{4}$$

The evaluation results of resource carrying capacity in Xiong'an New Area from 2014 to 2018 are obtained, as shown in Fig 2. The resource carrying capacity of Xiong'an New Area shows an upward trend from 2014 to 2018, and the value fluctuates from 0.53 to 0.58, so the resource carrying capacity is good. Since 2017, the construction of the New Area has been strengthened, and the resource carrying capacity is on the rise.

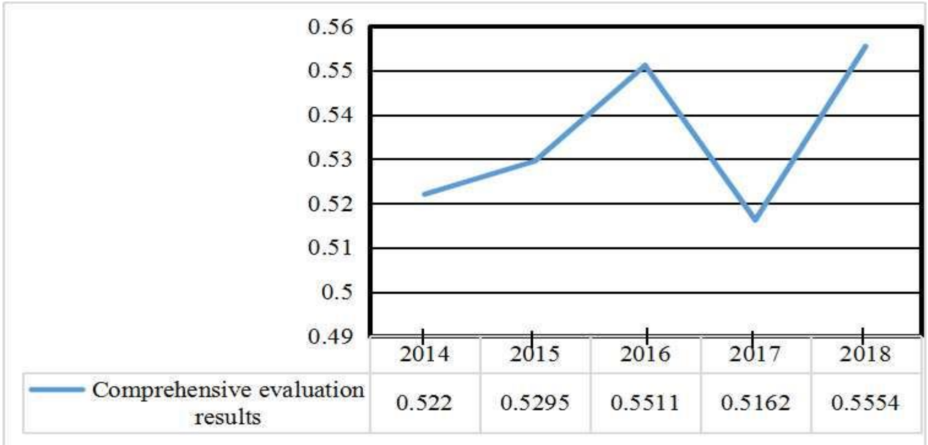

Fig. 2 The evaluation results of resource carrying capacity in Xiong'an New Area from 2014 to 2018

VI. Conclusion

Based on the analysis of the current situation of land resources, water resources and mineral resources in Xiong'an New Area, using the evaluation index system of resource carrying capacity in the New Area, the statistical data of 2014-2018 is seleted to analyze the carrying capacity of land resources, water resources and mineral resources. On this basis, it makes a comprehensive analysis of the carrying capacity of resources in the New Area. The conclusion is as follows:

1) From 2014 to 2018, the carrying capacity of land resources in Xiong'an New Area is 0.5220, 0.5295, 0.5511, 0.5162 and 0.5554 respectively. Compared with 2014, the land resources carrying capacity has increased 62.07% in 2018.

2) From 2014 to 2018, the water resources carrying capacity of Xiong'an New Area is 0.4337, 0.4474, 0.4367, 0.4758 and 0.4756 respectively. Due to the acceleration of economic development in 2016, the use amount of water resources is increased significantly, and the water resources carrying capacity decreased to a certain extent. On the whole, the water resources carrying capacity of the New Area is in a slow rising trend, maintaining an annual growth rate of about 2.5%.

3) From 2014 to 2018, the carrying capacity of mineral resources in Xiong'an New Area is 0.7741, 0.7671, 0.7981, 0.7826 and 0.7943 respectively, which is with great potential. Compared with 2014, the mineral resources carrying capacity increased by 2.61% in 2018.

4) From 2014 to 2018, the resource carrying capacity of the Area is 0.5371, 0.5442, 0.5547, 0.5533 and 0.5713 respectively, which belong to the medium level. As the New Area strengthened resource management from 2017, the resource carrying capacity showed an obvious upward trend, with an annual growth rate of 3.25%.

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