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 development and utilization of resources, the strategic planning of the and economic development in 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 km², the medium-term development area is about 200 km² and the long-term control area is about 2000 km². 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 km², 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 km², accounting for 61.4%, the urban and rural construction land is 310.70 km², accounting for 19.91%, the wetland area with Baiyangdian as the main body is 194.26 km² (only referring to the
The wetland area of the New Area is 194.26 km², 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 km², 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 m³ and 567 mm respectively, including 1620 billion m³ of surface water resources and 2223 billion m³ of groundwater resources. In 2016, the per capita water resources of Baoding city was 287 m³ [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 km², 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 m³, including 11 million m³ surface water resources, 169 million m³ groundwater resources and 7 million m³ 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 m³, which is lower than that of Baoding city (282 m³) and Beijing-Tianjin-Hebei in the same period (248 m³).

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

|                  | 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》)
### Table 3 Comparison of water resources utilization sustainability in Xiong’an New Area, Hebei and Beijing in 2018

| Area               | Total water resources (100 million m³ 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          |

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 m³, of which the development and utilization of groundwater is 232 million m³, 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 m³, and the sustainability of water resources is 0.623. By comparison, Beijing and Hebei have larger deficits. 384 million m³ and 1838 million m³ 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 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 m³) | GDP (100 million yuan) | Water consumption per 10000 yuan of GDP (m³) |
|---------------|-----------------------------------------|------------------------|-------------------------------------------|
| Xiong’an New Area | 2.58                                    | 184.5                  | 139.84                                    |
| Hebei         | 182.42                                  | 36010                  | 50.66                                     |

4) Low efficiency of water resources output

In 2018, water consumption per 10000 yuan of GDP in the New Area is 139.84 m³, higher than 50.66 m³ in Hebei, and far higher than 12.96 m³ 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.
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 70000 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. 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.

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 |

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.

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.
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 |
|-------------------------------------------|----------------------------------------------------------|----------------------------------------------------------|----------------------------------------------------|----------------------|
| Land resources                            | per capita cultivated land area (m² per capita)         | Cultivated land area / Total population                   | +                                                  |
|                                           | per capita construction land area (m² per capita)        | Construction land area / Total population                 | +                                                  |
|                                           | per unit cultivated land productivity (t per km²)        | Crop yield / Cultivated land area                         | +                                                  |
|                                           | construction land area per 10000 yuan of GDP(m² per 10000 yuan) | Construction land area / GDP                              | -                                                  |
|                                           | increased rate of construction land (%)                  | Increased construction land area / Total construction land area | +                                                  |
| Evaluation index system of resource carrying capacity of Xiong'an New 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 km²)                | GDP / Total land area                                    | +                                                  |
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 area 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.

| 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       |
Table 8 Rotated Component Matrix

| Component                                              | Component 1 | Component 2 | Component 3 | Component 4 |
|--------------------------------------------------------|-------------|-------------|-------------|-------------|
| per capita cultivated land area                        | 0.919       | 0.288       | -0.224      | 0.149       |
| per capita construction land area                       | 0.912       | 0.224       | -0.072      | 0.338       |
| per unit cultivated land productivity                   | 0.364       | 0.928       | 0.044       | -0.072      |
| construction land area per 10000 yuan of GDP            | 0.254       | 0.634       | 0.198       | -0.155      |
| increased rate of construction land                     | -0.815      | -0.524      | 0.236       | 0.073       |
| land utilization rate                                   | 0.998       | 0.055       | -0.037      | 0.003       |
| land development intensity                              | 0.542       | 0.235       | -0.237      | 0.035       |
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 Analysis
Rotation Method: Varimax with Kaiser Normalization
a. Rotation converged in 5 iteration

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: \( U = \{U_1, U_2, U_3, \ldots, U_m\} \), \( U_m = \{U_{m1}, U_{m2}, U_{m3}, \ldots, U_{mn}\} \), \( m, n > 0 \).

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 \( v = \{v_1, v_2, v_3, \ldots, v_n\} \) 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, \( v_2 \) level of non-carrying state and \( v_3 \) 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 \( k_2 \), and the point value in the \( v_1 \) level interval is \( k_1 = (k_1 + k_2) / 2 \).

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 Formula 1.

\[
\begin{align*}
    u_{v1} &= \begin{cases} 
    0 & U_i \leq k_1 \\
    0.5[1+(k_1-U_i)/(k_2-U_i)] & U_i > k_1 \\
    \end{cases} \\
    u_{v2} &= \begin{cases} 
    0.5[1+(U_i-k_1)/(k_2-k_1)] & k_2 < U_i \leq k_1 \\
    0.5[1+(U_i-k_1)/(k_2-k_1)] & U_i > k_1 \\
    \end{cases} \\
    u_{v3} &= \begin{cases} 
    0.5[1+(U_i-k_3)/(k_2-k_3)] & k_2 < U_i \leq k_1 \\
    0 & U_i > k_3 \\
    \end{cases} \\
\end{align*}
\]
Through the above Formula 1 and Formula 2, the membership \( r_{ij} \) of each evaluation index corresponding to each level can be calculated,

\[
    r_{ij} = u_{v1}(U_i), \quad r_{i2} = u_{v2}(U_i), \quad r_{i3} = u_{v3}(U_i), \quad (i = 1, 2, 3 ... m).
\]

Secondly, establish fuzzy relation matrix. Through calculation of membership, the fuzzy relation matrix \( R_{mo} \) is established:

\[
    R_{mo} = (r_{ij}) = \begin{pmatrix}
        r_{11} & r_{12} & r_{13} \\
        r_{21} & r_{22} & r_{23} \\
        \vdots & \vdots & \vdots \\
        r_{m1} & r_{m2} & r_{m3}
    \end{pmatrix}
\]

\( r_{ij} = (r_{i1}, r_{i2}, ..., r_{im}) \) 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:

\[
    B = W \ast R = (w_1, w_2, w_3, ..., w_m) \ast (b_1, b_2, b_3, ..., b_n) = (b_{ij})
\]

The evaluation result \( B \) is a fuzzy subset of \( v \), \( B = \{b_1, b_2, ..., b_n\}, 0 \leq b_j \leq 1 \), \( b_j \) 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.

\[
    \alpha = \frac{\sum_{j=1}^{3} b_j \alpha_j}{\sum_{j=1}^{3} b_j}
\]

\( b_j \) is the \( j \)-th value of the result matrix, \( \alpha \) 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
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 index | Component 1 | Component 2 | Component 3 | Component 4 |
|------|------------------|-------------|-------------|-------------|-------------|
|      | Per capita cultivated land area (Mu per capita) | >1.5 | 1.5 ~ 0.8 | <0.8 |           |
|      | Per capita construction land area (m² per capita) | >300 | 300 ~ 250 | <250 |           |
| Land resources | Per unit cultivated land productivity (t/km²) | >650 | 650 ~ 550 | <550 |           |
|      | Land use rate (%) | >75 | 75 ~ 60 | <60 |           |
|      | Unit land output (million yuan/km²) | >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 \( v_1 \) 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 9.

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

| Name | Evaluation index | \( v_1 \) | \( v_2 \) | \( v_3 \) |
|------|------------------|-------------|-------------|-------------|
| Per capita cultivated land area (Mu per capita) | >1.5 | 1.5 ~ 0.8 | <0.8 |
| Per capita construction land area (m² per capita) | >300 | 300 ~ 250 | <250 |
| Per unit cultivated land productivity (t/km²) | >650 | 650 ~ 550 | <550 |
| Land use rate (%) | >75 | 75 ~ 60 | <60 |
| Unit land output (million yuan/km²) | >1200 | 1200 ~ 950 | <950 |

According to 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 \( k_2 \) as 0.8. 2. **Per capita construction land area.** The national per capita construction land area is 284.78 m² per capita, and the per capita construction land area of Xiong'an New Area is 278.85 m² per capita, which is far higher than the level of 84 m² per capita in developed countries and 83 m² per capita in the world average level. Combined with the relevant research results, so \( k_1 \) is selected as 300 and \( k_2 \) as 250. 3. **Per unit cultivated land productivity.** The average per unit cultivated land productivity is 650 t/km² in China, and the per unit cultivated land productivity in Xiong'an New Area is 560.64 t/km². Combined with relevant research results and expert opinions, so \( k_1 \) is selected as 650 and \( k_2 \) 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 \( k_2 \) as 60. 5. **Unit land output.** According to the national average level of land efficiency of 9.3781 million yuan/km², and the unit land output of Xiong'an New Area of 11.8258 million yuan/km², combined with the 13th five year plan for national economic and social development, so \( k_1 \) is selected as 1200 and \( k_2 \) 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.
Factor loads

| Index                      | Factor Load | Factor Load | Factor Load | Factor Load |
|----------------------------|-------------|-------------|-------------|-------------|
| Per capita cultivated land area (Mu per capita) | 0.919       | 0.288       | -0.224      | 0.149       |
| Per capita construction land area (m² per capita) | 0.912       | 0.224       | -0.072      | 0.338       |
| per unit cultivated land productivity (t/km²)    | 0.364       | 0.928       | 0.044       | -0.072      |

Coefficient in linear combination

| Index                      | Coefficient | Coefficient | Coefficient | Coefficient |
|----------------------------|-------------|-------------|-------------|-------------|
| Per capita cultivated land area (Mu per capita) | 0.359       | 0.168       | -0.169      | 0.133       |
| Per capita construction land area (m² per capita) | 0.356       | 0.131       | -0.054      | 0.301       |
| per unit cultivated land productivity (t/km²)    | 0.142       | 0.542       | 0.033       | -0.064      |

Coefficient in comprehensive score model

| Index                      | Coefficient |
|----------------------------|-------------|
| Unit land output (million yuan/km²) | -0.026 | 0.574 | 0.130 | -0.004 |

Indexes weight

| Index                      | Weight |
|----------------------------|--------|
| 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 |

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:

| $R_{2014}$ | | | |
|----------|----------|----------|----------|
| 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        | |

| $R_{2015}$ | | | |
|----------|----------|----------|----------|
| 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        | |
Secondly, calculate the comprehensive evaluation matrix. Through fuzzy transformation, take 2014 as an example, get the comprehensive evaluation matrix \( R \) of land resources system in Xiong'an New Area:

\[
R_{2014} = (r_{ij}) = \begin{bmatrix}
0.4143 & 0.5857 & 0 \\
0 & 0.9876 & 0.0124 \\
0.1937 & 0.8063 & 0 \\
0 & 0.2976 & 0.7024 \\
0.7690 & 0.2310 & 0
\end{bmatrix}
\]

\[
B_{2014} = W \ast R = (0.212, 0.224, 0.193, 0.160) \ast [0.1419, 0.8581, 0] = (0.2855, 0.4778, 0.2367)
\]

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 |
|------------------|------|-----------------------------|----------------------------|-----------------------------|---------------------------------|
|                  | 2014 | 0.2855                      | 0.4778                     | 0.2367                      | 0.5220                          |
|                  | 2015 | 0.2361                      | 0.5934                     | 0.1705                      | 0.5295                          |
| Xiong’an New Area| 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 m³ are water rich areas, those with per capita water resources of 1000-2000 m³ are vulnerable areas, those with per capita water resources of 500-1000 m³ are in short supply areas, and those with per capita water resources of less than 500 m³ are water poor areas. The national per capita water resources level is 1956 m³, Baoding city is 287 m³ and Xiong’an New Area is 144 m³. Referring to international standards and relevant literature, so \( k_1 \) is selected as 2000 and \( k_2 \) as 1000.

2. **Per unit effective irrigation area.** The national per unit...
effective irrigation area is 700 m²/t. Hebei province is 2400 m²/t and Xiong'an New Area is 4300 m²/t. Combined with the relevant research results, so \( k_1 \) is selected as 3000 and \( k_3 \) as 100. 

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/m³ and Xiong'an New Area is 61.71 yuan/m³. 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.

| Name | Evaluation indexes | Evaluation classification | \( v_1 \) | \( v_2 \) | \( v_3 \) |
|------|--------------------|---------------------------|----------|----------|----------|
|      | Per capita water resources (m³ per capita) | >2000 | 2000~1000 | <1000 |
| Water resources | Per unit effective irrigation area (m²/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: 

\[
B_{2014} = (0.2094, 0.4338, 0.3568), \quad B_{2015} = (0.2221, 0.4389, 0.3390), \quad B_{2016} = (0.2285, 0.4024, 0.3691), \quad B_{2017} = (0.2285, 0.4024, 0.3691), \quad B_{2018} = (0.2810, 0.3837, 0.3353).
\]

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.

| Area name | Year | Evaluation results \( v_1 \) | Evaluation results \( v_2 \) | Evaluation results \( v_3 \) | Comprehensive evaluation results |
|-----------|------|-----------------------------|-----------------------------|-----------------------------|--------------------------------|
|           | 2014 | 0.2094                      | 0.4338                      | 0.3568                      | 0.4337                          |
|           | 2015 | 0.2221                      | 0.4389                      | 0.3390                      | 0.4474                          |
| Xiong’an New Area | 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 5.6 million t/km², Hebei province is 6.25 million t/km² and Xiong’an New Area is 792.70 t/km². 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 175.9 million t/year, and that in Hebei province is 5.2 million 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, \( k_i \) 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.

| Name                  | Evaluation indexes                                                                 | Evaluation classification | v1  | v2  | v3  |
|-----------------------|------------------------------------------------------------------------------------|----------------------------|-----|-----|-----|
| 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.

| 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.

\[
Z = \sum w_i * B_i
\]

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](image)

**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 selected 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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