Evaluation of Carrying Capacity of Land Resources Based on Perspective of "Production-Living-Ecological" Space in Chahar Right Back Banner

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Abstract

Land resources are indispensable resources for human survival and development. The spatial pattern of "production-living-ecological" land and carrying capacity of land resources is not only related to control of wind and sand but also affect the ecological environment in regions. Taking Chahar Right Back Banner of Inner Mongolia as the study area, building up an evaluation index system of the carrying capacity of land resources including production, living and ecological from 2003 to 2018 by using the methods of entropy-weight and TOPSIS. Then, using the Spatial Lorentz curve and Gini coefficient to analyze the spatial pattern of "production-living-ecological" land in 2018. The results show that: (1) The weight value of the carrying capacity of the living subsystem was the higeset, which was mainly affected by employment per land and number of beds in health institutions per 10000 people; the weight value of the carrying capacity of the ecological subsystem was the lowest, which was mainly affected by per capita cultivated land area and electricity consumed in rural area; (2) During the study period of 2003-2018, the carrying capacity of land resources in Chahar Right Back Banner was rising after fluctuating, increased by 0.442. The carrying capacity of the ecological subsystem decreased slightly by 0.079 compared with the beginning of the study period. Furthermore, the carrying capacity of the production subsystem and the living subsystem increased by 0.411 and 0.848, respectively; (3) The degree of specialization of ecological land in Honggertu township was the lowest, but the degree of specialization of production land was the highest; Xile township was not only the township with the lowest degree of specialization of production land, but also the township with the lowest degree of specialization of living land. Meanwhile, it was the township with the highest degree of specialization of ecological land; Baiyinchagan township was the township with the highest degree of specialization of living land among all townships; (4) The distribution of ecological land was absolutely average; the distribution of living land was relatively average, and the distribution of production land was relatively reasonable. The distribution of production land, living land and ecological land is above reasonable, and the carrying capacity of land resources still has some improvement room in Chahar Right Back Banner. There is little difference in living environment and economic development between townships in study area. Along with the continues development of economy and people's living standard is improved, the carrying capacity of the production subsystem and the living subsystem is increased, which is closely related to the rapid growth of summary item on the national economy, such as the GDP per land, the total investment in fixed assets per land and the income of residents and so on, which causes the ecological environment to be destroyed, so that the carrying capacity of the ecological subsystem decreases.

Keywords

"Production-Living-Ecological" Space; Land Resources Carrying Capacity; Spatial Lorentz Curve; Gini Coefficient; Methods of Entropy-Weight and TOPSIS; Chahar Right Back Banner.

1. Introduction

Land resources play an indispensable role in the process of human survival and development [1], as an important production factor, providing humans with the production function of food, fresh water, timber and other raw materials necessary for survival; as a key resource for human activities, providing humans with living functions such as housing, leisure and recreation; because of its inherent properties, providing humans with important ecological protection functions [2,3]. Therefore, the "production-living-ecological" functions of production, living and ecology are gradually formed. The concept is not clearly defined in foreign countries, but its research theories are highly consistent with the "production-living-ecological".

For the first time, SENSOR [4] summarized land use functions as social, economic and environmental functions. Land use function studies mostly focus on urban space [5,6], agricultural landscape [7,8] and other studies, aiming to solve the problems between urban life, agricultural production and environmental management. Since the 18th National Congress of the Party, various scholars have begun to analyze land use function delineation [2,9,10,11], spatial pattern evolution [12,13], suitability evaluation [14,15] and so on from macroscopic to microscopic perspectives, and rich theoretical results have been formed.

Land resource carrying capacity is one of the core elements of resource and environmental carrying capacity evaluation. Ilaria et al. [16] analyzed the geomorphological characteristics of extended coast and combined with questionnaire survey to calculate beach carrying capacity. Majid Ebrahimi et al. [17] identified the land suitability and ecological carrying capacity of tourist areas in Iran based on AHP and GIS. China's research on the carrying capacity of land resources can be traced back to the end of the twentieth century [18], and with the strengthening of the awareness of ecological environmental protection, it gradually shifted from single-factor research to multi-factor research. For the classification system of evaluation index system of land resource carrying capacity, China has not yet formed a unified standard, various scholars have conducted studies based on different priorities, but the research focus can be summarized into three perspectives of ecology, production and living. At present, there are relatively few studies on the carrying capacity of land resources in the northern agricultural-pastoral interlacing zone in China, and the existing studies are relatively single and do not analyze the current situation of each land use function, therefore, the study will be carried out in the case of Chahar Right Back Banner in Inner Mongolia, which is one of the key agricultural-pastoral staggered belt areas in the north and is a wind and sand control ecological function area. Constructing a land resource carrying capacity evaluation index system from the perspective of "production-living-ecological" to evaluate the land resource carrying capacity of the region from 2003 to 2018, which provides scientific basis for wind and sand control and ecological protection of Chahar Right Back Banner.

2. Overview of the Study Area

Chahar Right Back Banner is located in the north-central part of Ulanqab City, Inner Mongolia Autonomous Region, with the geographical coordinates of 112°42′-113°30′E, 40°03′-41°59′N. It has 8 townships, with an area of 3910km^2. The topography is undulating, with rolling hills in the north, high mountains in the southwest, and flat topography in the middle, that is, the whole topography decreases from south to north and is slightly rectangular. It is a medium-temperate semi-arid continental monsoon climate, the soil is mainly chestnut calcium soil, short and sparse rivers, less water, seasonal characteristics are obvious, the type of vegetation is semi-arid grassland type.

3. Data Sources and Research Methods

3.1 Data Sources

Cloud 0.08, Landsat OLI_TIRS satellite image data of May 15, 2018 from the geospatial data cloud platform and Google Earth image data with resolution above 10m were selected to obtain the Chahar Right Back Banner’s land use data in 2018 through supervised classification and manual visual interpretation. Socio-economic data were obtained from Inner Mongolia Statistical Yearbook, Inner

Mongolia Yearbook and China City Statistical Yearbook, and some missing data were completed by interpolation method.

3.2 Research Methods

3.2.1 Land use function delineation

According to the classification of the "three surveys" database, the actual situation of the study area and the existing classification system [19,20,21], the land in the Chahar Right Back Banner was divided into 26 secondary categories, and the current land use data were connected with the "production-living-ecological" and reclassified according to the principle of "bottom-up and functional classification" to establish the classification system of the "production-living-ecological" land use based on land use classification, see Table 1.

Table 1 The classification system of “Production-living-ecological” land

Class 1 functional land	Class 2 functional land	Classification of land use status
Ecological land	Forest ecological function land	Forest/Shrub land/Other woodlands
	Pasture ecological function land	Natural pastureland/Artificial pastureland/Other grassland
	Water ecological function land	Lake/River/Reservoir/Swag/Inland beach
	Other ecological function land	Sand/Bare land
Production land	Agricultural production function land	Dry land/Irrigable land/Facilities of agricultural land/Ditch/Hydraulic construction land
	Industrial and mining production function land	Industrial land/Mining lease
Living land	Urban living function land	Urban residential land/Highway
	Rural living function land	Rural residence land/Rural road
	Other living function land	Scenic and special land/Railroad

3.2.2 Construction of Evaluation Index System

Based on the principles of scientificity, controllability, hierarchy and feasibility, drawing on the existing research results [22,23,24]and combining with the local actual situation of Chahar Right Back Banner, selecting 23 indicators from three subsystems of ecology, production and living to construct a land resource carrying capacity evaluation index system, see Table 2.

3.2.3 Entropy Weight TOPSIS Model

The entropy weight method can be used for the comprehensive evaluation of multiple objects and indicators, which is an objective assignment method, and the TOPSIS (Technique for order Preference by Similarity to ideal solution) method is based on the expert evaluation method to determine the index weights, which is more subjective [25].Therefore, the two are improved to evaluate the land resource carrying capacity status by entropy weight TOPSIS model, which makes the results more objective. Its calculation process is:

(1) Data standardization

According to the positive and negative attributes of the indicators, the data are standardized using the extreme value method. r_{ij}' refers to the standardized indicator value; x_{ij} is the original data value of the j^{th} indicator in the i^{th} year, i=1, 2,..., m, m is the number of evaluation years, j=1, 2,..., n, n is the number of evaluation indicators; $max(x_{ij})$, $min(x_{ij})$ denote the maximum and minimum values of the j^{th} indicator in m years, respectively.

$$\text{Positive indicators: } r_{ij}' = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})} \quad (1)$$

$$\text{Negative indicators: } r_{ij}' = \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})} \quad (2)$$

Table 2 The evaluation index system of carrying capacity of land resources of Chahar Right Back Banner

Target layer	Criteria layer	Index layer	Calculation of Index	Index attributes	Weight
land resources Carrying capacity	Ecological subsystem A1	Consumption of chemical fertilizer per unit of cultivated land area/($t \cdot hm^{-2}$) A11	Consumption of chemical fertilizer/Cultivated land area	-	0.034
		Sulfur dioxide emissions/kt A12	Using the representative of sulfur dioxide emissions in UlanQab	-	0.030
		Electricity consumed in rural area/10^4 Kwh A13	Statistical yearbook available	-	0.035
		Per capita cultivated land area/hm^2 A14	Cultivated land area/Total population	+	0.065
		Coverage of forest/% A15	Statistical yearbook available	+	0.034
	Production subsystem B1	GDP per land/(10^4 Yuan$\cdot km^{-2}$) B11	Gross Domestic product/Area of administration	+	0.034
		Proportion of tertiary industry /% B12	Tertiary industry/Gross Domestic product	+	0.033
		Yield of grain per unit of cultivated land area /($t \cdot hm^{-2}$) B13	Yield of grain/Cultivated land area	+	0.025
		Total investment in fixed assets per land/(10^4 Yuan$\cdot km^{-2}$) B14	Total investment in fixed assets/Area of administration	+	0.047
		Per capita yield of grain/($t \cdot person^{-1}$) B15	Yield of grain/Total population	+	0.027
		Per capita total sown area/hm^2 B16	Total sown area/Total population	+	0.047
		Total power of agricultural machinery/10^4 Kw B17	Statistical yearbook available	+	0.025
		Output of pork, beef & mutton per land/($t \cdot km^{-2}$) B18	Output of pork, beef & mutton/Area of administration	+	0.041
		Per capita total livestock at the year-end/heads B19	Total livestock at the year-end/Total population	+	0.063
		Total retail sales of consumer goods per land/(10^4 Yuan$\cdot km^{-2}$) B20	Total retail sales of consumer goods/Area of administration	+	0.037
	Living subsystem C1	Proportion of non-agricultural population/% C11	(Total population-Rural)/Total population	+	0.046
		Per capita net income of peasant & herdsman/Yuan C12	Statistical yearbook available	+	0.042
		Disposable income of urban residents/Yuan C13	Statistical yearbook available	+	0.037
		Total length of highways/km C14	Statistical yearbook available	+	0.023
		Number of beds in health institutions per 10^4 person C15	Statistical yearbook available	+	0.067
		Medical technical presonnel/person C16	Statistical yearbook available	+	0.048
		Employment per land/(Person$\cdot km^{-2}$) C17	Employment/Area of administration	+	0.116
		Average wage of staff & workers employed in/Yuan C18	Statistical yearbook available	+	0.042

(2) Calculation of index weights

$$P_{ij} = \frac{r_{ij}'}{\sum_{i=1}^{m} r_{ij}'} \tag{3}$$

$$e_j = -\frac{\sum_{i=1}^{m}\left(P_{ij} \cdot \ln P_{ij}\right)}{\ln(m)} \tag{4}$$

$$w_j = \frac{1-e_j}{\sum_{j=1}^{n}(1-e_j)} \tag{5}$$

$$v_{ij} = r_{ij}' \cdot w_j \tag{6}$$

P_{ij} is the weight of the j^{th} indicator in year i. If $r_{ij}'=0$, then $P_{ij} \cdot \ln P_{ij}=0$; e_j is the entropy value of the j^{th} indicator; w_j is the weight of the j^{th} indicator; v_{ij} is the weighted value.

(3) Determining the positive and negative ideal solution

Positive ideal solution:

$$V^+ = \{\max_{1 \le i \le m} v_{ij} \mid j = 1,2,3,\ldots\ldots,\ n\} = \{v_1^+,\ v_2^+,\ v_3^+,\ldots\ldots,\ v_n^+\} \tag{7}$$

Negative ideal solution:

$$V^- = \{\min_{1 \le i \le m} v_{ij} \mid j = 1,2,3,\ldots\ldots,\ n\} = \{v_1^-,\ v_2^-,\ v_3^-,\ldots\ldots,\ v_n^-\} \tag{8}$$

(4) Calculate distance

The Euclidean distance is used to calculate the distance of each indicator from the positive ideal solution and the negative ideal solution.

$$D_i^+ = \sqrt{\sum_{j=1}^{n}(v_j^+ - v_{ij})^2} \tag{9}$$

$$D_i^- = \sqrt{\sum_{j=1}^{n}(v_j^- - v_{ij})^2} \tag{10}$$

(5) Calculation of closeness

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{11}$$

The C_i indicates the closeness of the evaluation object to the optimal target, $C_i \in [0, 1]$, when the C_i value is larger, the higher the carrying capacity of land resources, the lower the reverse.

3.2.4 Spatial Lorentz Curve

Location entropy, also known as specialization rate, is used to measure the spatial distribution of factors in a region [26], and usually $Q > 1$ indicates a high proportion of factors in the region.

$$Q = (A_1 / A_2)/(A_3 / A_4) \tag{12}$$

In the formula: Q is the location entropy, A_1 is the area of a certain land type in a township, A_2 is the area of a certain land type in the study area, A_3 is the land area of a township, and A_4 is the total land area in the study area.

The Spatial Lorentz Curve is formed by borrowing the Lorentz curve to analyze the spatial distribution of a certain land type. The ranking is plotted from low to high by location entropy, and inflection points are used to determine the degree of specialization of a township's land type.

3.2.5 Gini coefficient

The Gini coefficient, also known as the "Lorentz coefficient", indicates the degree of equilibrium of income distribution [27]. The Gini coefficient is used to quantitatively analyze the degree of equilibrium of each category.

$$G = \sum_{i=1}^{n}(M_{i+1}Q_i - M_iQ_{i+1}) \tag{13}$$

In the formula: G is the Gini coefficient, Mi is the cumulative percentage of area of a certain land category in a township, and Q_i is the cumulative percentage of total land area. There are 8 townships under the Chahar Right Back Banner, so the value of i is $0<i<8$, and it takes an integer. When the

Gini coefficient is less than 0.2, it means absolute average, between 0.2 and 0.3 means relatively average, between 0.3 and 0.4 means relatively reasonable, between 0.4 and 0.5 means a large gap, and greater than 0.5 means a wide gap [28].

4. Result Analyses

4.1 Evaluation of the Carrying Capacity of Land Resources

4.1.1 Indicator Impact Analysis

The indicator weights of ecological subsystem, production subsystem and living subsystem are 0.198, 0.380 and 0.422 respectively. The indicators with the highest and lowest weights in each subsystem are cultivated land area per capita, sulfur dioxide emission; Per capita total livestock at the year-end, the total power of agricultural machinery; employment per land and total length of highways.

4.1.2 Analysis of Land Resource Carrying Capacity Assessment Value

Combined with the evaluation index weights in Table 2, equations 1-11 were applied to calculate the assessed value of the carrying capacity of land resources in 2003-2018 in the Chahar Right Back Banner, see Fig. 1.

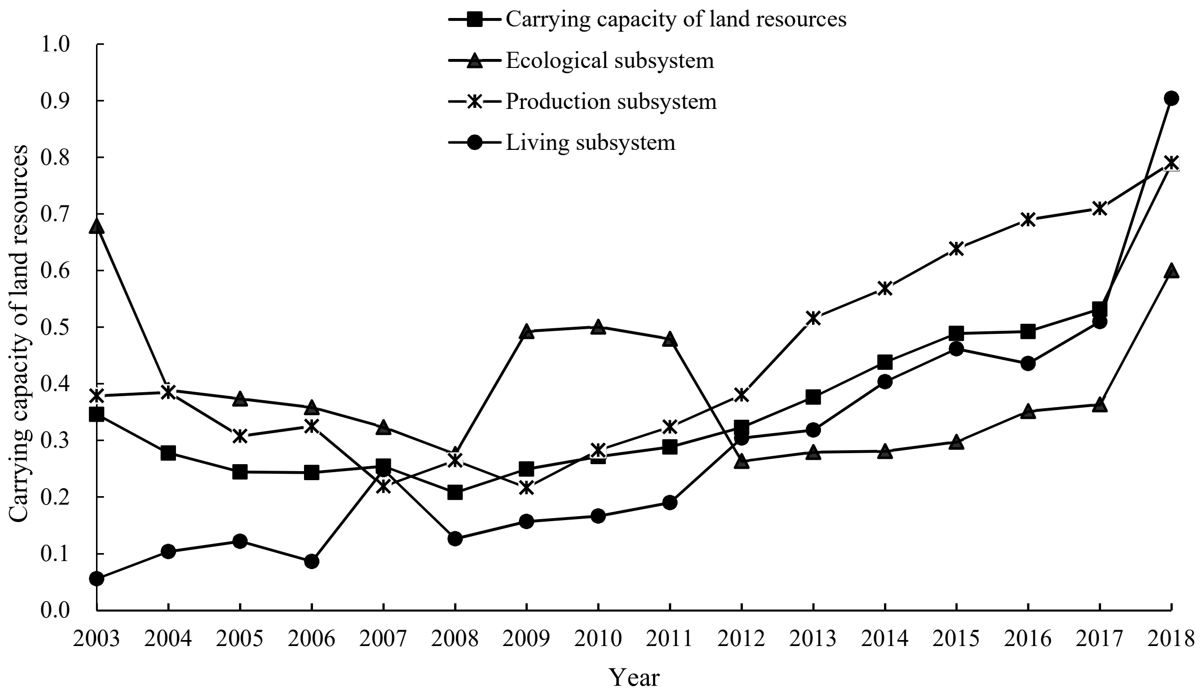

Fig. 1 Evaluation value of carrying capacity of land resources of Chahar Right Back Banner from 2003 to 2018

(1) Subsystem evaluation

The evaluation value of ecological subsystem fluctuates in a “W” shape, and the fluctuation fluctuates greatly. The evaluation value eventually returns to its initial level after declining. During the study period, the continuous economic development of Chahar Right Back Banner led to the destruction of the ecological environment. With the improvement of environmental protection awareness, people began to pay attention to the ecological environment, Chahar Right Back Banner focused on the implementation of the national ecological construction of Beijing-Tianjin wind and sand source control, returning farmland to forest (grass) project, as evidenced by the sulfur dioxide emissions decreased from 74.312 kilotons to 21.999 kilotons, the forest coverage rate increased from 8.49 percent to 30.37 percent.

After fluctuations, the production subsystem evaluation value reached a minimum value of 0.217 in 2009, affected by serious natural disasters. The evaluation value continued to rise in the later period and reached the maximum value of 0.790 in 2018. The Chahar Right Back Banner vigorously develops the individual private economy and attracts investment, with the three largest contributions from the GDP per land (up 6.17 times), total investment in fixed assets per land(up 17.56 times) and total retail sales of consumer goods per land (up 12.34 times).

The living subsystem evaluation value has changed the most among the three subsystems, with the evaluation value increased from 0.056 in 2003 to 0.904 in 2018, and the level of carrying capacity becoming higher. The per capita net income of peasant and herdsman increased by 5.65 times in 15 years, the disposable income of urban residents increased by more than 20,000 yuan, the road mileage increased by 4.56 times, the average salary of on-the-job workers increased by 7.49 times, and the people's living standard improved, laying the foundation for the withdrawal of the Chahar Right Back Banner from the ranks of poor counties in 2019.

(2) Comprehensive evaluation

The carrying capacity of land resources in Chahar Right Back Banner is on an upward trend, and its comprehensive assessment value increased from 0.346 in 2003 to 0.788 in 2018, with an average annual growth of 0.028, basically experiencing two stages of decline (2003-2008) - rise (2008-2018). Turning point in 2008, with a minimum value of 0.208 in that year, mainly due to the Chahar Right Back Banner experienced a major drought in 2007 and a financial crisis broke out in 2008, which seriously affected the crop production and economic development of the Chahar Right Back Banner. The value of the comprehensive evaluation increased year by year since 2008, reaching a maximum value of 0.788 in 2018.

4.2 Spatial Pattern of "production-living-ecological" Land Use

4.2.1 Analysis of Specialization

According to the location entropy and cumulative percentage of each category of the "production-living-ecological" land use to draw the spatial lorentz curves of each category in Chahar Right Back Banner, see Fig. 2.

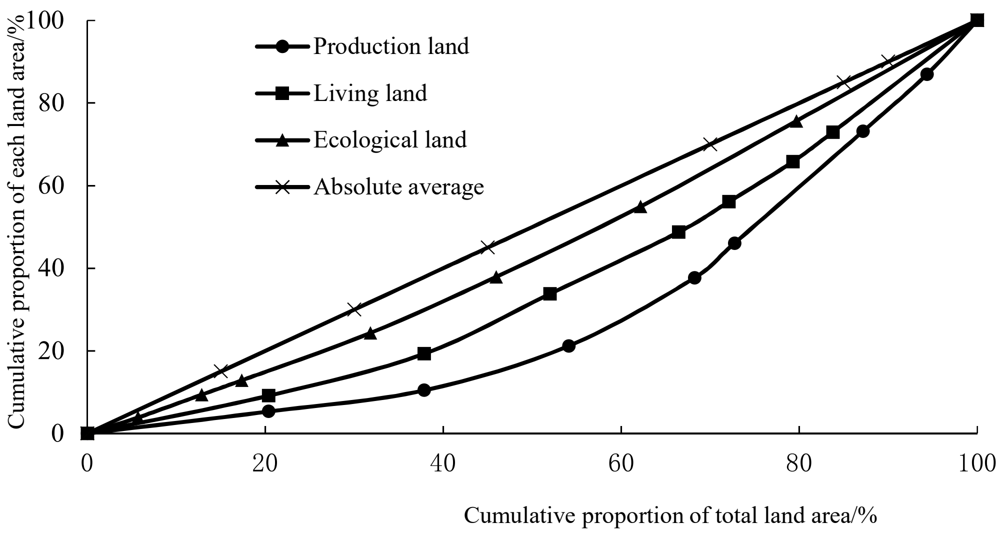

Fig. 2 The Spatial Lorentz curves of Chahar Right Back Banner

For the production land: Honggertu township Q>2, Benhong township, Tumuertai township, Daliuhao township, Danglanghudong township Q>1, the distribution ratio of production land is high, among which Honggertu town has 5.672% of the total land area of the banner, occupying 13.102% of the production land of the banner, and is the township with the highest distribution ratio of production land; Baiyinchagan township, Ulanhada township, Xile township Q<1, the distribution ratio of production land is low, among which Xile township has the largest proportion of land area in the whole banner and only 5.315% of the production land, which is the township with the lowest distribution ratio of production land.

For the living land: Baiyinchagan township, Daliuhao township, Benhong township, Honggertu township, Tumuertai township and Danglanghudong township Q>1, the proportion of living land distribution is high, among which Baiyinchagan township has 16.246% of the land area of the whole banner, occupying the most living land, and is the township with the highest proportion of living land distribution; Ulanhada township and Xile township Q<1, the proportion of living land distribution is low, among which Xile township has the largest proportion of land area in the whole banner, with 9.129% of living land, and is the township with the lowest proportion of productive land distribution.

For the ecological land: Xile township, Ulanhada township, Baiyinchagan township Q>1, with a high proportion of ecological land distribution, of which Xile township has the largest proportion of land area and ecological land, and is the township with the highest proportion of ecological land distribution; Danglanghudong township, Tumuertai township, Daliuhao township, Benhong township, Honggertu township Q<1, with a low proportion of ecological land distribution, of which Honggertu township has the Banner down two, ecological land only accounted for 3.860%, is the lowest proportion of ecological land distribution township.

4.2.2 Uniformity analysis

According to the distance of the Lorentz curve of each category from the absolute average curve, the uniformity of distribution of each category: ecological land > living land > production land. The degree of uniformity of each category of land in Chahar Right Back Banner is divided into three grades: ecological land-absolutely average distribution (Gini coefficient 0.100); living land-relatively average distribution (Gini coefficient 0.247); production land-relatively reasonable distribution (Gini coefficient 0.397).

5. Conclusion

(1) The index weights of living subsystem > production subsystem > ecological subsystem in the land resource carrying capacity evaluation index system.

(2) From 2003 to 2018, the annual average land resources carrying capacity assessment values of ecological, production and living subsystems in Chahar Right Back Banner were 0.394, 0.437 and 0.287, respectively. The assessment values of production and living subsystems had an upward trend, while the assessment value of ecological subsystems experienced fluctuations and eventually had a slight downward trend. The comprehensive carrying capacity of land resources basically showed an upward trend.

(3) The degree of specialization of production land: Honggertu township > Benhong township > Tumuertai township > Daliuhao township > Danglanghudong township > Baiyinchagan township > Ulanhada township > Xile township; the degree of specialization of living land: Baiyinchagan township > Danglanghudong township > Benhong township > Honggertu township > Tumuertai township > Danglanghudong township > Ulanhada township > Xile township; the degree of specialization of ecological land: Xile township > Ulanhada township > Baiyinchagan township > Danglanghudong township > Tumuertai township > Danglanghudong township > Benhong township > Honggertu township.

(4) The distribution of ecological land in Chahar Right Back Banner was absolutely average; the distribution of living land was relatively average; the distribution of production land was relatively reasonable.

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