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Comprehensive Land Carrying Capacities of the Cities in the Shandong Peninsula Blue Economic Zone and their Spatio-Temporal Variations

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Abstract: The comprehensive land carrying capacities of seven cities in the Shandong Peninsula Blue Economic Zone between 2007–2014 were assessed using a multi-criterion comprehensive evaluation approach and an index of 27 indicators, and cluster analysis was conducted to identify the spatial-temporal variations of the cities' comprehensive land carrying capacities. The results showed that the carrying capacity of the water and soil resources of the cities had declined except Dongying City; in contrast, the carrying capacities of the eco-environment, the social resources and the economy and technology of the seven cities had all arisen. The carrying capacities of social resources of Dongying and Weihai were markedly higher than the other five cities. The carrying capacities of economy and technology of Qingdao and Dongying were high, the capacities of Weihai and Yantai were moderate, and the capacities of Weifang, Rizhao, and Binzhou were low. In general, the comprehensive land carrying capacities of the eastern cities were higher than those of the western cities, which was similar to the spatial pattern of the economy development of those cities. In addition, positive correlations were identified between the comprehensive land carrying capacity and the per capita land for construction, areal proportion of wetland to total land, percentage of green space to build up area, per capita public green space, comprehensive utilization rate of industrial solid waste residues, urbanization rate, area of per capita urban road, per capita GDP, economy density, fixed-assets investment per area, etc. However negative correlations were discovered between the comprehensive land carrying capacity and the discharge of industrial waste water per 10,000 Yuan RMB GDP, as well as the proportion of added value of the primary industry to total GDP. Finally, we discussed measures to improve the comprehensive land carrying capacities of the cities, such as elevating the intensive land utilization and economic development, decreasing the proportion of added value of the primary industry to total GDP, promoting energy saving and emission reduction, etc.

Keywords: comprehensive land carrying capacity; multi-criterion comprehensive evaluation; analytic hierarchy process; standard deviation; weight; spatial variation

1. Introduction

Population explosion and land resource shortage are two important constraints on current economic development of the world [1]. By the early 19th century, scientists started to realize that the relationship of social economic activities with the land resources should be coordinated, and that is when the line of research on land carrying capacity began. During the period of 1970s to 1980s, research on land carrying capacity was mainly based on the ecological limiting factors, potential land capacity for natural production, grain yield and relationship of man and grain to confirm the land's population carry capacity. For example, the research of land carrying capacity for Australia on the perspective of the restriction imposed on population by all types of resources [2], the determination of land population carrying capacity by using Agricultural Ecology Zone method proposed by FAO in 1997 [3,4]. The enhancement of carrying capacity options (ECCO) put forward by Slessor in the early 1980s took thorough consideration of the relation between population change and land carrying capacity [5]. Furthermore, research of land resource production capacity, especially grain output and land's population carrying capacity of China were also carried out by the Commission for Integrated Survey of Natural Resources, China [6].

Since the 1990s, with the progress of economic globalization, the land carrying capacity research on the relationship between human and grain showed its limitation in effectively explaining and guiding human activities. Research on land carrying capacity evaluation gradually developed from the application of single grain index to comprehensive index, from the evaluation of land's population carrying capacity to the evaluation of comprehensive land carrying capacity by considering all kinds of human activities rather than merely focusing on population. The index composed by cost and benefit indicators, which belong to four subsystems of water and soil resources, eco-environment, society, economy, and technology, is put forward for evaluating comprehensive land carrying capacity of eastern China [1,7–12]. The comprehensive land carrying capacity of major grain-producing areas, Heilongjiang Province in northeastern China and its risk factors were also researched [13]. The weights of the indicators were mainly constructed using only objective weighting methods, and short of the evaluator's professional experience and subjective judgment, the methods of system dynamic, ecological footprint, projection pursuit, pair analysis, variables fuzzy assessment method began been used in the research [1,7–15]. In this period, the research on land's population or livestock carrying capacity, water resources carrying capacity, and ecological carrying capacity were also carried out [14,16–19], however the aims of and index used by these studies were different from the evaluation of comprehensive land carrying capacity. The comprehensive land carrying capacity is the threshold of human activities that the ecological-economic-social system formed mainly by land can bear at a particular state, or limiting factors of land reached their maximum value or minimum value. It is composed of the carrying capacity of water and soil resources, the carrying capacity of eco-environment, the carrying capacity of social resources and the carrying capacity of economy and technology.

"The Plan to Develop the Shandong Peninsula Blue Economic Zone" approved by the state council of China in 2011 indicated that Shandong Peninsula Blue Economic Zone takes the accumulation area of modern marine industry with high international competitiveness, the world's leading core area of marine science and technology and marine education, the national marine economic reform and open zone and the marine ecological civilization demonstration area as its construction goals [20]. The total population of the area had increased to 3691.4×10^4 by 2014. Such large population and shortage of land resource per capita gave high pressure on the land, which has become the main obstacles for the region. This research aims to provide theoretical basis for the development of marine industry, the coordinated development of inland and coastal area, and the adjustment and optimization of land utilization, as well as improve the quality of regional eco-environment by studying the spatio-temporal variations and the influences of the comprehensive land carrying capacity in the Shandong Peninsula Blue Economic Zone. In regard to research methods, determining the weight of indicators is the key technology of evaluating the comprehensive land carrying capacity. Previous studies showed defects on subjective or objective empowerment of evaluating indicators, therefore this paper tries to determine the weight of indicators for evaluation by using the multi-criterion comprehensive evaluation model to compensate the shortage of subjective evaluation or objective evaluation, and in order to get more scientific and accurate results.

2. Research methods

2.1. Research Area

Shandong Peninsula Blue Economic Zone includes the 6 cities of Qingdao City, Dongying City, Yantai City, Weifang City, Weihai City, Rizhao City, and Wudi County and Zhanhua County in Binzhou City of Shandong Province as well as the regional offshore waters, it has land area of 6.4×10^4 km^2, sea area of 15.95×10^4 km^2 and coastline of 3345 km in length. The warm temperate continental monsoon climate of the research area is characterized by precipitation concentrated in summer and autumn, the temperature of spring lower than that of autumn. The terrain is characterized by higher altitudes in the southern and northern regions than that in the central region, and the regional average altitude is less than 300 m. The land area comprises mainly mountains and hills of granite, as well as alluvial plains and marine-deposition plains partially. The soils are classified as brown soil, cinnamon soil, fluvo-aquic soil, cultivated soil, alluvial-salty soil, saline soil, etc. The zonal vegetation of the region is temperate deciduous broad-leaved forest. With excellent location, rich marine resources and favorable eco-environment, Shandong Peninsula Blue Economic Zone has seen rapid regional social and economic development. By 2014, the population of the cities of Qingdao, Dongying, Yantai, Weifang, Weihai, Rizhao and Binzhou were 904.62×10^4, 209.91×10^4, 700.23×10^4, 924.72×10^4, 280.92×10^4, 287.05×10^4, and 383.96×10^4, and each had increased 7.86, 5.43, 0.11, 4.65, 0.34, 5.42, and 4.59% respectively. The total population had increased 4.27% during the period of 2007–2014. By 2014, the regional gross domestic product (GDP) reached 2.77×10^{12} Yuan RMB and gross ocean product (GOP) reached 1.04×10^{12} Yuan RMB, accounting for 46.64% and 17.50% of the GDP and GOP of Shandong Province respectively. The per capita GDP of the research area was 81,656.38 Yuan RMB, which was 34.51% higher than that of Shandong Province.

2.2. Establish Evaluation Index System

With the principles of comprehensiveness, hierarchy and regional particularity, the evaluation index system of comprehensive land carrying capacity of Shandong Peninsula Blue Economic Zone based on multi-objective comprehensive evaluation model is composed of three layers of target, criterion and index [10,18,21,22]. The target layer is the comprehensive land carrying capacity of Shandong Peninsula Blue Economic Zone, the criterion layer is composed by four supporting land carrying capacity subsystems, namely the carrying capacity of the water and soil resources, the carrying capacity of eco-environment, the carrying capacity of social resources and the carrying capacity of economy and technology, the index layer includes 22 benefit indictors and 5 cost indictors [23], the benefit indictors include cultivated land area per capita, effective irrigation rate of cultivated land, and water resources per capita, etc., which are positively correlated with the comprehensive land carrying capacity, and the cost indictors negatively related to the comprehensive land carrying capacity, which include the proportion of value added of primary industry to total GDP, discharge of industrial waste water per 10 thousand Yuan RMB GDP, density of population, registered urban unemployment rate, and natural population growth rate.

2.3. Data Source and Processing Method

In order to make the indictors used in the research comparable, the 7 cities of Rizhao, Qingdao, Weihai, Yantai, Weifang, Dongying, and Binzhou were selected as evaluation units; the original data of the 27 indictors of the cities in 2007–2014 for evaluation were collected from China's City Statistical Almanacs, Shandong Statistical Almanacs, and the Statistical Almanacs of the seven cities during the period of 2008–2015.

Due to data of the indicators of the seven cities is not comparable for the difference of dimensions and units, the original data should be normalized, the method of normalizing original data is to bring the original data of benefit indictors and cost indictors in the index layer of the seven cities in the period of 2007–2014 into formula (1) or (2), then the normalized value of the indicators is obtained.

In the data series of a given benefit indictor in 2007–2014, the largest normalized value of the seven cities is 1, the smallest normalized value is 0, and the cost indicators are reversed.

The benefit indictor is

$$Z_{ij} = \frac{x_{ij} - x_{j\min}}{x_{j\max} - x_{j\min}}, \tag{1}$$

The cost indictor is

$$Z_{ij} = \frac{x_{j\max} - x_{ij}}{x_{j\max} - x_{j\min}}, \tag{2}$$

where x_{ij} is the original data of the indicators, i is the sample number of the indicators, j is the number of the indicators, Z_{ij} is the normalized value of the jth indicator, $0 \le Z_{ij} \le 1$; X_{jmin} and X_{jmax} are the minimum values and maximum values respectively of the original data of the jth indicator.

2.4. Determining the Weight of the Indicators

There are three methods of determining the weights of the indicators for carrying capacity evaluation, which include subjective weighting method, objective weighting method, and multi-criterion comprehensive weighting method. The subjective weighting method determines the weights of the indicators according to the evaluator's professional experience and the relative importance of the indicators, and the weights have some subjective meaning; the objective weighting method determines the weights of the indicators according the amount of information contained in the indicators by using mathematical model, but the evaluator's subjective understanding and professional experience were ignored [24–26]. The multi-criterion comprehensive weighting method possesses the advantages of both subjective weighting method and objective weighting method, and avoids their disadvantages. The weights of indicators reflect both the evaluator's subjective understanding and the amount of information content of the indicators [27]. The process of calculating the indicators' weights using the multi-criterion comprehensive weighting method is as follows:

The weight of each indicator was determined by the analytic hierarchy process and the standard deviation method. Analytic hierarchy process is a combination of subjective method and objective method for determining weights of indicators, to determine the weights of indicators by using analytic hierarchy process, we firstly establish hierarchical structure model of index, and a judgment matrix is constructed to calculate the weights of indicators of all levels, coupled comparing and ranking all indicators in each level respectively, and then the consistency test of the indicators' weights is performed, the indicators in each level are sorted declining according their weights, and ranking the total indicators on their weights [28]. However, the standard deviation method only uses objective mathematical model to determine the weights of indicators, the average value and standard deviation of the indicators are calculated by using formula (3) or (4) respectively, and then normalize the standard deviations of each indicators to obtain the weights of the indicators by using formula (5) [29].

The average value of the indicators is calculated by

$$\overline{Z_j} = \frac{1}{n}\sum_{i=1}^{n} Z_{ij}, \tag{3}$$

The standard deviation of the indicators is

$$\sigma_j = \sqrt{\sum_{i=1}^{n} (Z_{ij} - \overline{Z_j})}, \tag{4}$$

The weight of the indicators is

$$q_j = \frac{\sigma_j}{\sum\limits_{j=1}^{m} \sigma_j}, \tag{5}$$

After calculating the weights of the indicators by using the analytic hierarchy process and standard method separately, the paper combines the two results of calculation, the weight of every indicator is further determined by using multi-criterion comprehensive method. Assume the comprehensive weight of the jth indicator is w_j, the value of w_j can be calculated using formula (6).

The comprehensive weight of the jth indicator is

$$w_j = k_1 p_j + k_2 q_j, \tag{6}$$

where p_j and q_j are the weight of the jth indicator calculated by using analytic hierarchy process and standard deviation method respectively, k_1 and k_2 are the undetermined constant.

Establishing objective function in formula (7), when the value of the objective function is maximum and the formula (7) meet the demands of $k_1 > 0$, $k_2 > 0$ and $k_1^2 + k_2^2 = 1$, we obtain k_1 and k_2 by using formulae (8) and (9) according to the Lagrange extreme value principle

$$\sum_{i=1}^{n} y_i = \sum_{i=1}^{n} \sum_{j=1}^{m} (k_1 p_j + k_2 q_j) Z_{ij}, \tag{7}$$

$$k_1 = \frac{\sum\limits_{i=1}^{n} \sum\limits_{j=1}^{m} p_j Z_{ij}}{\sqrt{(\sum\limits_{i=1}^{n} \sum\limits_{j=1}^{m} p_j Z_{ij})^2 + (\sum\limits_{i=1}^{n} \sum\limits_{j=1}^{m} q_j Z_{ij})^2}}, \tag{8}$$

$$k_2 = \frac{\sum\limits_{i=1}^{n} \sum\limits_{j=1}^{m} q_j Z_{ij}}{\sqrt{(\sum\limits_{i=1}^{n} \sum\limits_{j=1}^{m} p_j Z_{ij})^2 + (\sum\limits_{i=1}^{n} \sum\limits_{j=1}^{m} q_j Z_{ij})^2}}, \tag{9}$$

The results of the calculation are k_1 = 0.6956 and k_2 = 0.7184, substituting the value of k_1, k_2, and the weights of the indicators calculated by using analytic hierarchy process and the standard method respectively into formula (6), calculate their normalization to get the weight of the indicators by using the multi-criterion comprehensive method (Table 1).

Table 1. Weight of the indicators for assessing the comprehensive land carrying capacities of Shandong Peninsula Blue Economic Zone.

Target Layer	Criterion Layer	Index Layer	Subjective Weight Calculated by Analytic Hierarchy Process	Objective Weight Calculated by Standard Deviation Method	The Weight Calculated by Multi-Criterion Comprehensive Method
Comprehensive land carrying capacities of cities in Shandong Peninsula Blue Economic Zone	Carrying capacity of water and soil resources/C_1	Cultivated land per capita C_{11}/(hm^2/capita)	0.0770	0.0376	0.0570
		Effective irrigation rate of cultivated land C_{12}/(%)	0.0376	0.0354	0.0365
		Water resource per capita C_{13}/(m^3/capita)	0.0199	0.0367	0.0284
		Intensity of land exploitation C_{14}/(%)	0.0247	0.0357	0.0303
		Land for construction per capita C_{15}/(m^2/capita)	0.0550	0.0367	0.0457
		Proportion of wetlands to total land area C_{16}/(%)	0.0177	0.0348	0.0264
		Coordination of water and land C_{17}/(%)	0.0422	0.0375	0.0398

Table 1. *Cont.*

Target Layer	Criterion Layer	Index Layer	Subjective Weight Calculated by Analytic Hierarchy Process	Objective Weight Calculated by Standard Deviation Method	The Weight Calculated by Multi-Criterion Comprehensive Method
	Carrying capacity of eco-environment/C_2	Percentage of green space to built up area C_{21}/(%)	0.0365	0.0339	0.0352
		Public green space per capita C_{22}/(m^2/capita)	0.0252	0.0357	0.0305
		Forest coverage rate C_{23}/(%)	0.0712	0.0357	0.0532
		Proportion of environment protection investment to GDP C_{24}/(%)	0.0116	0.0406	0.0263
		Comprehensive utilization rate of industrial solid waste residues C_{25}/(%)	0.0134	0.0411	0.0275
		Urban sewage treatment rate C_{26}/(%)	0.0180	0.0353	0.0268
		Discharge of industrial wastewater per 10,000 Yuan RMB GDP C_{27}/(t)	0.0180	0.0414	0.0299
	Carrying capacity of social resources/C_3	Population density $C3_1$/(capita/m^2)	0.0537	0.0312	0.0423
		Natural population growth rate C_{32}/(%)	0.0105	0.0394	0.0252
		Registered urban unemployment rate C_{33}/(%)	0.0195	0.0395	0.0297
		Urbanization rate C_{34}/(%)	0.0314	0.0402	0.0359
		Proportion of technology and education investment to total GDP C_{35}/(%)	0.0105	0.0315	0.0212
		Urban road area per capita C_{36}/(m^2)	0.0074	0.0390	0.0235
	Carrying capacity of economy and technology/C_4	GDP per capita C_{41}/($\times10^4$ Yuan RMB)	0.1142	0.0359	0.0744
		Economy density C_{42}/($\times10^4$ Yuan RMB/m^2)	0.0792	0.0348	0.0566
		Growth rate of GDP C_{43}/(%)	0.0615	0.0415	0.0513
		Fixed assets investment per area C_{44}/($\times10^4$ Yuan RMB/hm^2)	0.0549	0.0397	0.0472
		Yield of grain per area C_{45}/(kg/hm^2)	0.0398	0.0374	0.0386
		Proportion of value added of the primary industry to total GDP C_{46}/(%)	0.0211	0.0414	0.0314
		Proportion of value added of the secondary industry to total GDP C_{47}/(%)	0.0284	0.0305	0.0295

Note: The indicators of C_{11}, C_{13}, C_{15}, C_{31}, and C_{41} are calculated according to the permanent residents, C_{14}, C_{21}, C_{22}, and C_{36} are the statistical data of urban areas, among them, C_{14} is the proportion of land for construction to total urban land, and C_{24} is the proportion of the budget of environment protection investment to GDP, C_{35} is the proportion of technology and education investment to GDP in the fiscal budgets of the cities, and C_{44} is the ratio of total fixed assets investment to acreage of agricultural and construction land.

2.5. Calculation of the Indicators of Comprehensive Land Carrying Capacity

Putting the normalized value of the indicators and the weights of the indicators calculated by using multi-criterion comprehensive method into formula (10), we get the indicators of comprehensive land carrying capacity of each evaluating unit y_i ($0 \le y_i \le 1$) (Table 2). The value of the indicator is bigger, the comprehensive land carrying capacity is higher.

$$y_i = \sum_{j=1}^{m} w_j Z_{ij} = \sum_{j=1}^{m} (k_1 p_j + k_2 q_j) Z_{ij}\,, \tag{10}$$

where y_i is the indicator of the comprehensive land carrying capacity, Z_{ij} is the normalized value of the indicators, w_j is the weight of the indicators.

Then analyze the overall spatial difference of the comprehensive land carrying capacities of the seven cities in Shandong Peninsula Blue Economic Zone in 2007–2014 by using cluster analysis method.

3. Results of Evaluation and Analysis

3.1. Annual Changes and Spatial Differences of the Supporting Land Carrying Capacity Subsystems

We obtain the indicators' value of comprehensive land carrying capacity of the seven cities in Shandong Peninsula Blue Economic Zone in the period of 2007–2014 (Table 2) and analyze the annual changes and spatial differences of the supporting land carrying capacity subsystems.

Table 2. Comprehensive land carrying capacities of the seven cities in Shandong Peninsula Blue Economic Zone in the period of 2007–2014

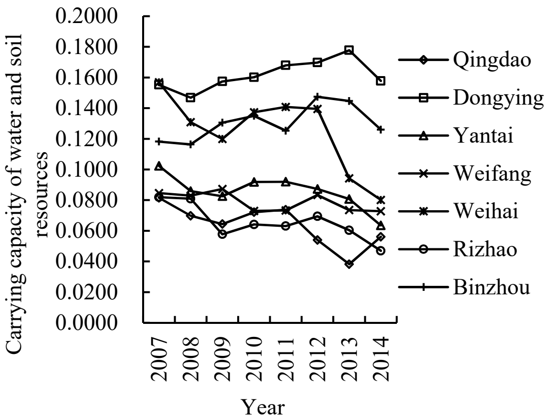
City	2007	2008	2009	2010	2011	2012	2013	2014
Qingdao	0.424	0.435	0.456	0.482	0.508	0.506	0.513	0.521
Dongying	0.500	0.506	0.514	0.555	0.590	0.612	0.626	0.652
Yantai	0.417	0.405	0.423	0.468	0.475	0.477	0.474	0.451
Weifang	0.311	0.331	0.369	0.384	0.392	0.418	0.433	0.428
Weihai	0.555	0.515	0.526	0.591	0.584	0.608	0.577	0.590
Rizhao	0.345	0.370	0.362	0.386	0.414	0.429	0.422	0.422
Binzhou	0.351	0.371	0.404	0.428	0.460	0.471	0.476	0.471

With the economy development and the population growth in the period of 2007–2014, the land carrying capacity of soil and water resources of six cities except for Dongying showed a slow decrease due to the decrease of land and water resource per capita, the land carrying capacity of soil and water resources of Dongying, Weifang, and Weihai were higher than those of the other four cities (Figure 1a).

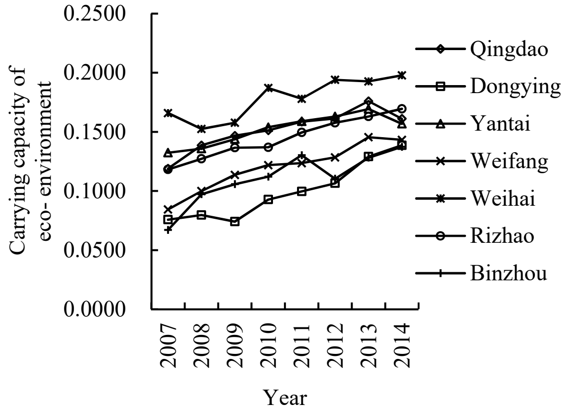
The land carrying capacity of eco-environment of the seven cities rose significantly because the increase of percentage of green space to urban built up area, the public green space per capita, the forest coverage rate, the proportion of environmental protection investment to GDP, the comprehensive utilization rate of industrial solid waste residues and the urban sewage treatment rate, as well as the decrease of discharge of industrial wastewater per 10,000 Yuan RMB GDP. The carrying capacity of eco-environment of Weihai was in high level, those of Qingdao Rizhao and Yantai were in middle level, and those of Weifang, Dongying, and Binzhou were low (Figure 1b).

The land carrying capacity of social resource of the seven cities had increased to a small extent, and the increase of Dongying and Weihai was obvious higher than the others five cities, due to the cities showed increase of the population density, natural population growth rate, registered urban unemployment rate, urbanization rate, proportion of technology and education investment of total GDP, the urban road area per capita, etc., however, the growth rate of the three benefit indicators, such as the urbanization rate were higher than that of the three cost indicators which include the population density (Figure 1c).

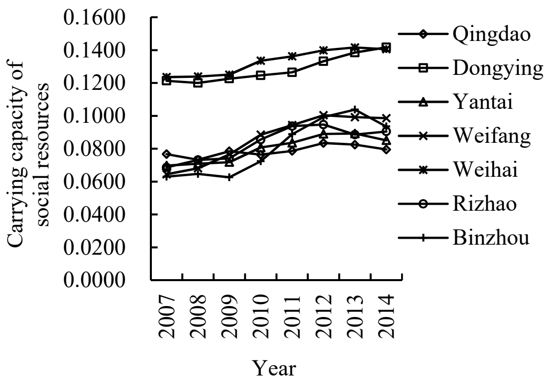
The cultivated land per capita of the cities had decreased, however with the improvement of agricultural technology, the yield of grain per area had increased significantly, which partly makes up for the decrease of cultivated land per capita and improves the population carrying capacity of land resource; the GDP per capita, economy density and fixed assets investment per area of the seven cities had been constantly increasing, the land use intensification has been continuously improved, the carrying capacity of economy and technology of the seven cities had increased. The carrying capacity of economy and technology of Qingdao and Dongying were in high level, those of Weihai and Yantai were in middle level, and those of Rizhao, Weifang, and Binzhou were low (Figure 1d).



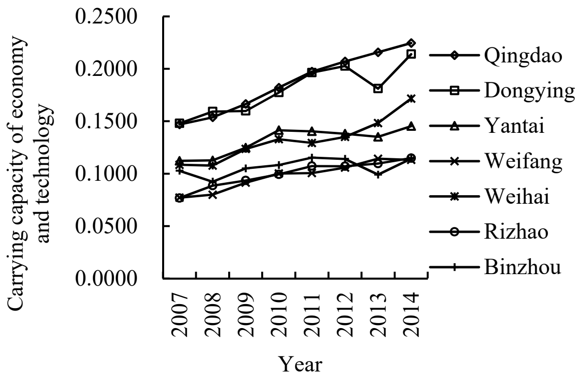
(a) Carrying capacities of water and soil resources of the seven cities and their changes.



(b) Carrying capacities of eco-environment of the seven cities and their changes.



(c) Carrying capacities of social resources of the seven cities and their changes.



(d) Carrying capacities of economy and technology of the seven cities and their changes.

Figure 1. The sub-systems' indexes of land carrying capacities of the seven cities in Shandong Peninsula Blue Economic Zone and their spatiotemporal variations in the period of 2007–2014.

3.2. Annual Changes of the Comprehensive Land Carrying Capacity

The comprehensive land carrying capacity of the seven cities had kept been continual or fluctuant rising in the period of 2007–2014, which reveal the seven cities attach great importance to the management of land use, and constantly improve the type structure and spatial distribution of land use, overall planning of land utilization, as well as improve the intensity of land exploitation, strengthen prime cropland construction, protect cultivated land, and coordinate the relationship between land use and protection of eco-environment. Since 2011, the growth rate of comprehensive land carrying capacities of the 6 cities except for Dongying had decreased because the growth of economy slowed down and the carrying capacities of water and soil resources decreased (Figure 2).

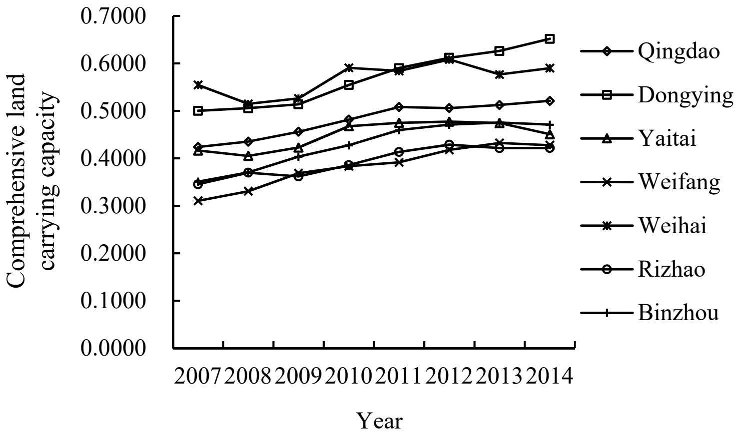


Figure 2. Comprehensive land carrying capacities of the seven cities in Shandong Peninsula Blue Economic Zone and their changes in the period of 2007 and 2014.

3.3. Spatial Differences of the Comprehensive Land Carrying Capacity of the Seven Cities

In order to understand the spatial differences of comprehensive land carrying capacity of the seven cities in Shandong Peninsula Blue Economic Zone in the period of 2007–2014, the software of SPSS 19.0 and clustering methodology were used for calculating the comprehensive land carrying capacities of the seven cities in the period of 2007–2014, and the comprehensive land carrying capacities of the cities were divided into three grades of I, II, and III from high to low. The average situation of the comprehensive land carrying capacity of the seven cities in the period of 2007–2014 shows roughly the spatial difference characteristics of east-high and west-low which similar to the regional differences of economy growth: the east Weihai and central Dongying belonged to the region of grade I, their comprehensive land carrying capacities were high; Qingdao and Yantai belonged to the region of grade II, their comprehensive land carrying capacities were intermediate, the west cities of Weifang, Rizhao, and Binzhou belonged to the region of grade III, and their comprehensive land carrying capacity level were low (Figure 3).

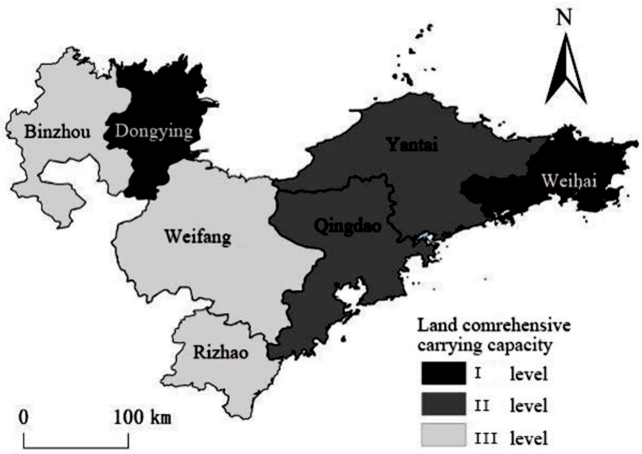


Figure 3. Grades of comprehensive land carrying capacities and their spatial difference of the seven cities in Shandong Peninsula Blue Economic Zone in the period of 2007–2014.

The region of grade I includes Dongying and Weihai. The comprehensive land carrying capacities of the two cities were higher than those of the other five cities, the comprehensive land carrying capacity of Dongying was the highest in the seven cities. The indexes of all supporting land carrying capacity subsystems were relatively high, and the indicators were well coordinated, or some indicators have significant advantages to compensate for the disadvantages of other indicators. For example, the proportion of environment protection investment to GDP and forest coverage rate of Dongying were relatively poor, which caused a low regional carrying capacity of eco-environment, however the carrying capacity of water and soil resources, the carrying capacity of economy and technology of the city were relatively high.

The region of grade II includes Qingdao and Yantai. The comprehensive land carrying capacities of the two cities were slightly lower than those of the two cities of grade I. The indexes of all supporting land carrying capacity subsystems were intermediate, and the supporting subsystems were well coordinated, for example, Qingdao had developed economy, effective eco-environment governance, high efficiency of input and output in the process of land resource exploitation, and relatively high indicators of carrying capacity of eco-environment, carrying capacity of social resources as well as carrying capacity of economy and technology. However, the indicators of carrying capacity of soil and water resources were relatively low limited by the large population, shortage of cultivated land, and water resource per capita.

The region of grade III includes Rizhao, Weifang, and Binzhou. The comprehensive land carrying capacities were low, the supporting subsystems lacked prominent advantages and were poorly coordinated with each other. For example, the carrying capacity of soil and water resources and carrying capacity of social resources of Binzhou were at a medium level, and more seriously, its carrying capacity of eco-environment and carrying capacity of economy and technology were low.

4. Conclusions and Discussion

4.1. Conclusions

The comprehensive land carrying capacity of the seven cities in Shandong Peninsula Blue Economic Zone from 2007 to 2014 was evaluated by using multi-criterion comprehensive evaluation method, and the spatio-temporal variations and the factors which influenced the evaluating result were analyzed.

The comprehensive land carrying capacities of the seven cities had been rising either continuously or with a fluctuation. In addition, it and shows a great regional difference that cities in the east demonstrated higher comprehensive land carrying capacity than the cities in the west during 2007–2014. The seven cities were consequently divided into three grades, among which Dongying and Weihai belonged to the region of grade I and their comprehensive land carrying capacities were high; Qingdao and Yantai belonged to the region of grade II, the comprehensive land carrying capacities of the two cities were slightly lower than those of Dongying and Weihai; Rizhao, Binzhou, and Weifang belonged to the region of grade III, their comprehensive land carrying capacities were lower than those of Qingdao and Yantai.

4.2. Discussions

The index used in this paper was adapted from references [7–10], however it is optimized by adding new effective indicators, such as intensity of land exploitation, proportion of wetlands to total land area, urbanization rate, etc. Additionally, several ineffective indicators in the previous index were removed. The indicators' weights were determined by using multi-criterion comprehensive weighting method, and the evaluator's subjective thoughts and the indicators intrinsic information were significantly reflected, avoiding the disadvantages of both subjective and objective weighting method. There is still a shortage of missing the data in the latest two years; however, after a preliminary analysis of the new data of 2015 and 2016, we adding data of the two years would not overt change of the research conclusion.

It has to be noted that even clean service economics, such as tourism, would have negative impacts on the land system [30]. It seemed that one of the research results, the comprehensive land carrying capacities of the seven cities should had been decreasing for many economic indicators had been increasing. However, the truth is that the capacities had kept been increasing. The main reason is that we regarded most economic indicators as benefit indicators which have positive impacts on comprehensive land carrying capacity; however, we also accounted for their negative impacts in the evaluation index by using the five cost indicators and a few benefit indicators, maybe we underestimate negative impacts of economic indicators on land.

Due to the marine industry and marine eco-environment play an important role on the regional economic development, therefore the indicators for evaluation which reflect the marine economy development, the status of marine resources exploitation and the characteristics of marine eco-environment can be added to further optimize the index system of evaluation, in order that the results of evaluation can reflect the impact of marine industry development and marine eco-environment on the comprehensive land carrying capacity.

We should take countermeasures such as improving intensive land use, strengthening regional eco-environment governance, enhancing urban economy growth rate, improving the energy use efficiency, reducing the proportion of added value of the primary industry to total GDP, as well as reducing greenhouse gas emissions to improve the comprehensive land carrying capacities of the cities in research area.

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