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Evaluation and Forewarning Management of Regional Resources and Environment Carrying Capacity: A Case Study of Hefei City, Anhui Province, China

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Abstract: The evaluation of resources and environment carrying capacity (RECC) is the basis of strategic policy for the development and utilization of regional resources, economic development, and environmental protection. The magnitude of carrying capacity of resources and environment is the result of the balance of multiple aspects including economy, resources, and society. In order to reflect this multi-dimensional vector relationship, a multi-level and multi-targeted evaluation index system needs to be constructed. The paper, adopting the analytic hierarchy process and including PM2.5 (Particulate matter with diameter less than or equal to 2.5 microns in the atmosphere) into the index system, establishes the evaluation system of regional RECC and analyzes the trend of RECC in Hefei city with the index system to put forward the countermeasures of forewarning management. The results are shown as follows: (1) Overall, the RECC in Hefei city presents a declining trend, with a reduction from a middle to lower level during the year 2009 to 2013, of which the year 2010 to 2011 showed the fastest decline and the year 2013 witnessed a slight increase; (2) from the perspective of mutual influence of indexes, the main reason causing the decline of RECC in Hefei city is that the natural resources and environment carrying capacity was in a declining trend from the year 2009 to 2013, respectively declining from middle and high levels to a lower level, while the social economy carrying capacity in Hefei city was in an increasing trend as a whole from the year 2009 to 2013, with an increase from lower level to middle level. From the perspective of the forewarning management of RECC, it focuses on improving the forewarning response system of regional resources and environment carrying capacity, establishes the sharing mechanism of RECC monitoring data and improves the responsibility assigning mechanism of RECC. The study enriches the evaluation index system of RECC and proves that it is reasonable and efficient to build a differentiated index system to scientifically recognize RECC in different regions, having reference value to evaluate similar regional RECC.

Keywords: resources; environment; carrying capacity; analytic hierarchy process; evaluation index

1. Introduction

Resources and the environment, as the foundation of human development, carry all social and economic activities of humans. With insufficient storage of resources, the basic life of humans cannot be guaranteed, and the environmental condition has a direct influence on the life quality of humans.

Although the resource use efficiency in China has improved in recent years, there are still many problems [1]. Taking the utilization of water resources as an example, the agricultural water consumption accounts for 65% of total water consumption in China, but the average effective utilization ratio of agricultural irrigation with water resources is about 50% in China, compared with more than 70% in developed countries [2]. In addition, the emission of "three wastes" has polluted a large area of soil, air, surface and underground water, seriously restricting the development of the population and social economy. Sustainability is a process or state that can sustain for the long term. The sustainability of human society consists of ecological sustainability, economic sustainability, and social sustainability, and the three are mutually related and indivisible. Ma Shijun, based on many years of study on ecology and in-depth thoughts of population, food, resources, energy, the environment, and other critical ecological and economic issues faced by human society, put forward the concept of "complex ecosystem of Society-Economy-Nature" in 1984, i.e., a complex system that is formed by human-centered society, the economic system, and the natural ecosystem through synergistic effect within a specific region [3,4]. The complex ecosystem is a complex system in which humans and nature are interdependent and symbiotic. Currently, the study on the response of the social–economic–natural complex ecosystem, taking resources and the environment as the core to human activities, has been widely conducted in the world, and the attention paid to sustainable development issues has been increasing. A series of concepts, theories, and approaches proposed for sustainable development have been applied to simulate the ecological environment effect brought by the coupling of humans and natural systems [5]. The concept "resources and environment carrying capacity (RECC)" covers the connotation of multiple dimensions, including resource, environment, ecology, disaster, society, and economy. In terms of the resource dimension, carrying capacity refers to the capacity of resources to supply the environmental system and human needs [6–10]; in terms of the environment dimension, carrying capacity refers to the maintenance function of good environmental quality with the dilution and self-purification of pollution; in terms of the ecology dimension, carrying capacity refers to the capacity to provide supply, adjustment, culture, and support for the existence of humans [11–14]; in terms of the social and economic dimension, carrying capacity refers to the intensity, scope, and relevant threshold of natural resources and environment to carry humans and social and economic activities of humans and, within the threshold system, the resource and environment system will not sustain obvious degeneration or collapse [14–17]. In addition, from the perspective of disaster response, there is the concept of disaster carrying capacity which refers to the overall resistance capacity of disaster carrying systems, including resources and the environment, to natural disasters [18,19]. In the recent 10 years, the problem of over carrying capacity of urban development has been spreading, and how to provide urban residents with a high-quality living environment has become a big challenge for urban planners and administrators. The interaction between urban development and the RECC is a typical form of human-land relationship [5]. Fortunately, the Chinese government has constructed a carrying capacity monitoring forewarning mechanism as an important mission of comprehensively deepening the institutional reform of ecological civilization.

Carrying capacity is originally derived from the field of ecological research, referring to the maximum amount of existence of certain species that certain ecological system can maintain [20]. In 1798, Malthus published the famous article *An Essay on the Principle of Population* [21], which not only gave the modern connotation for the concept of carrying capacity but also had profound influences on the research of demography and economics in the 20th century [22]. The paper *Economic Growth, Carrying Capacity and the Environment* published in *Science* by Arrow et al. in 1995 led the research on the evaluation of the comprehensive carrying capacity of an economy-resource-environment system from the perspective of resources and environment restriction [23], which drew extensive attention from academic circles [24]. The regional RECC has the characteristics of objectivity, variability, limitation, and controllability [25]. In terms of a region, the resources and environment system will not be the qualitative change in the structure and function, and the supply capacity of resources and environmental capacity are constant in a certain period of time. Therefore, the RECC is a relatively fixed and objective existing value. The change in the structure of regional resources and environment system may change the RECC, which is caused by the reason that, on one hand, carrying capacity is related to the motion and variation of resources and the environment system, and on the other hand, carrying capacity is related to the effect imposed by humans on resources and the environment. From the perspective of the system, there is a certain limit to the supply capacity of resources and the environmental capacity of the region. The variation of regional RECC can be largely controlled by human activities. Moreover, humans can conduct purposeful transformation for resources and environment in accordance with the actual needs of production and life based on the understanding of the rule of motion and variation of resources and environment system, keeping RECC in a controllable range. It is noted that the effect imposed by humans on resources and the environment must be limited and should not be extravagant without restriction. Therefore, the monitoring and early warning for RECC must be implemented.

The evaluation of RECC is the crucial means to identify and measure the degree of resources and environment restriction in the land development process and the basis of the strategic policy and its planning for the development and utilization of regional resources, economic development, and environmental protection [26,27]. Currently, whether in view of the current situation of resources and the environment in China or from the perspective of the national policy of China, it is necessary to conduct relevant research on RECC and to alleviate the resource and environment carrying pressure. While the establishment of the evaluation index system of RECC is an important link to judge whether the RECC of the researched region is overloaded, only if the evaluation result is calculated scientifically can the current situation of the RECC of the researched region be comprehensively understood. Conducting coordinated planning for current natural resources by introducing long-term mechanisms and implementing reasonable development and utilization within appropriate RECC scopes, the contradiction of the region between social economy and resources and environment can be alleviated, promoting social and economic development and improving people's living standards while protecting resources and the environment.

For the research on comprehensive RECC, the comprehensiveness, locality, and man-earth relationship are part of the important theoretical framework to support the development of the research, and it is a hot topic in recent years on how to construct a comprehensive evaluation system that allows the research to have application value in both research and practice. The research on regional carrying capacity targeting the complex of resources and environment elements in China began in 1990s when scholars attempted to evaluate the condition of regional RECC by establishing a comprehensive evaluation model from the perspective of the support of natural resources, the support of environmental production, and the social, economic, and technical levels [22,28–31]. In the 21st century, the research on RECC has developed as comprehensive research integrating resources, the environment, ecology, and RECC from single research on land resource carrying capacity and water resource carrying capacity to gradually realizing the transition from classified, static, qualitative, and basic research to comprehensive, dynamic, quantitative, and practical research. However, the threshold definition and key parameter calibration, standardized evaluation and comprehensive measurement of RECC are still the difficult points for comprehensive research [10], which can be reflected by more extensive contents contained in the index system of comprehensive RECC research [5]. According to the different carrying objects, researchers have set different object levels or element levels from the aspects of the economy, society, the environment and resource conditions. For example, for large-scale coal mining areas, Wu Liangxing (2009), applying the comprehensive evaluation method, constructed the evaluation index system of RECC of the mining area through analysis of the current situation of resources and the environment of the research area [32], including eight aspects of mineral resources, water resources, land resources, forest resources, tourism resources, atmosphere environment, water environment, and soil environment, and evaluated the level of RECC by selecting 20 major evaluation indexes, such as the reserve and production ratio, coal resource share per capita, agricultural acreage share per capita, percentage of forest coverage, annual passenger flow volume per unit area, annual total amount of CW emission, total amount of COD emission, and disposal and utilization rates of industrial solid waste. Yao Zhihua et al. (2010) constructed an evaluation index system of geological environment carrying capacity from four aspects of resource, environment, adjustment and social economy, based on the concept of geological environment carrying capacity, and evaluated the geological environment carrying capacity in Daqing city with a set pair analysis model based on entropy-AHP [33]. In terms of offshore environments, Lin et al. (2011) quantitatively characterized the RECC through the integrated, comprehensive indexes by selecting four elements of water resources, atmosphere, surface water and the offshore environment in 13 cities around the Bohai Rim Region, which has rapidly developed in the transition of China [34]. With the development of i-cities and the implementation of the Industry 4.0 strategy, the spatiotemporal dynamics study of regional RECC shows a research trend of integration of long-term monitoring results and multifactor prediction [5] and will pay more attention to the resource study and special environmental requirements on the development of emerging industries, research on new environmental impacts, and the RECC change brought by the recycling economy [35,36]. These research indicate that the construction of the evaluation index system of RECC is trending towards comprehensiveness, locality and universality, providing study bases for the design and index selection of the paper, and providing a reference for the forewarning management of the RECC as well.

In sum, currently, the academic circles are short of a relatively mature and perfect evaluation system of RECC, and it has not formed the relatively uniform calculation method for determining the index weight. The paper, based on the existing research, combined with the relevant Chinese policies and plans in recent years, constructs the evaluation system of regional RECC, including PM2.5 in the index system to evaluate the situation of RECC in Hefei city from the year 2009 to 2013 and then proposes the countermeasures of forewarning management, not only enriching the evaluation index system of the RECC but also providing a reference for the research of RECC of other regions.

2. Method and Data

2.1. Research Area Characteristics

As the capital of Anhui province, Hefei city is the exchange center and the major development area of the main functional area in Anhui province. From the perspective of resources and the environment, located in 116°41′–117°53′ E and 31°4′–32°38′ N, and with the total area of 11,445.1 square meters, Hefei city is located between the Yangtze River and integrates the characteristics of south and north resources and environmental areas of Anhui province [37], with four distinctive seasons, moderate climate, abundant streams, and diversified geomorphic types. From the view of social economy, Anhui province established the Hefei Metropolitan Circle with Hefei city as the center, injecting an emerging power for the social economy of Anhui province and leading the social and economic development of Anhui province; the "Hefei Model", which can be duplicated in the development of other cities in China, has been gradually formed [38]. Therefore, Hefei city is representative of multiple aspects.

2.2. Research Method

Analytic hierarchy process (AHP) is a systematized and hierarchical analysis method proposed by T.L. Saaty, the famous American operational research expert and professor of University of Pittsburgh in the early 1970s [39], which is a decision-making method for qualitative and quantitative analyses based on decomposing the elements related to decision-making into multiple levels, such as target, norm and index [40].

AHP, as a method to handle multilevel complex system problems, is essentially a mode of thinking for decision-making, reflecting people's thinking characteristics of "decomposition-adjustment-combination", which is a process for people to carry out deliberation and repetitive comparison in decision-making, such as the development plan decision-making for population, traffic, the economy and the environment, and other fields. The main process of AHP in solving problems includes the following steps, that is, decomposing the complex system into several constitute elements, and then dividing these elements into a ordered hierarchical structure model in accordance with the dominant relationship and affiliation relationship to compare the relative importance of elements in the hierarchy with the method of expert consultation and grading by the public, and finally determining the importance and status of elements by combining the value of elements [25]. According to the characteristics of RECC and the availability of data required for the index system calculating RECC, AHP can be used to research, calculate, and evaluate RECC.

2.3. Construction of Evaluation Index System of Regional RECC

There are many factors influencing the RECC, and the magnitude of carrying capacity of resources and the environment is the result of the balance of multiple aspects, including economy, resources and society. In order to reflect this multi-dimensional vector relationship, a multi-level and multi-targeted evaluation index system and a set of evaluation index systems which can comprehensively reflect the influence relationship need to be constructed. The constructed index system should reflect various carrying capacity indices of the resources and environment researched, i.e., the index of land resources carrying capacity, water resources carrying capacity, mineral resources carrying capacity, and environment carrying capacity. The index set with different attributes, which are formed according to the characteristics of different resources, should have the function of describing the current situation of the RECC [41,42]. The study, following the principles of scientific nature, locality, practicality and dominance, screens out 30 representative indexes to construct the evaluation index system of regional RECC (Table 1) by combining with the national plan for main functional area in China, the strategy of ecological civilization construction of Anhui province, the current situation of resources and environment in Hefei city and the characteristics of Hefei city, comprehensively considering air pollution, water pollution, green coverage and other factors which have great impact on Hefei's environment, and fully drawing on experts' opinions and relevant research outcomes. The target layer (A) is the overall target of the index system, that is, the regional RECC; the norm layer (B) is the index established in accordance with the influence factor of regional RECC, including the three aspects of natural resources, social economy and environment; the index layer (C), based on the norm layer, selects the index parameters closely related to the norm layer, and then selects the feasible basic index (D) by combining with the regional condition.

Table 1. The evaluation index system of resources and environment carrying capacity (RECC).

Target Layer	Norm Layer	Index Layer	Basic Index	Unit	Index Property
RECC (A)	Natural Resource Carrying Capacity (B1)	Land Resource (C1)	Arable land per capita (D1)	hectare/person	Positive correlation
			Construction land area per capita (D2)	m^2/person	Moderate
			Intensity of territorial development (D3)	%	Moderate
		Water Resource (C2)	Water resource per capita (D4)	m^3/person	Positive correlation
			Annual rainfall (D5)	mm	Positive correlation
			Utilization ratio of water resource development (D6)	%	Moderate
		Mineral Resource (C3)	Consumption of main mineral resource (D7)	10,000 tons	Negative correlation
			Energy consumption per GDP (D8)	ton of standard coal/10,000 yuan	Negative correlation
		Forest Resource (C4)	Green coverage ratio in established area (D9)	%	Positive correlation
			Percentage of forest coverage (D10)	%	Positive correlation
			Forest growing stock (D11)	10,000 m^3	Positive correlation
	Social Economy Carrying Capacity (B2)	Level of social development (C5)	Population density (D12)	person/km^2	Negative correlation
			Social dependency ratio (D13)	%	Negative correlation
			Urbanization rate (D14)	%	Positive correlation
		Level of social development (C6)	GDP per capita (D15)	yuan/person	Positive correlation
			Contribution rate of primary industry (D16)	%	Positive correlation
			Industrial contribution rate (D17)	%	Positive correlation
			Contribution rate of strategic emerging industry (D18)	%	Positive correlation

Environment Carrying Capacity (B3)	Land Environment (C7)	Number of geological disaster (D19)	time	Negative correlation
		Consumption of chemical pesticides (D20)	ton	Negative correlation
	Water Environment (C8)	Discharge of industrial waste water (D21)	10,000 tons	Negative correlation
		Discharge of municipal domestic sewage (D22)	10,000 tons	Negative correlation
		COD emission (D23)	10,000 tons	Negative correlation
		Ammonia nitrogen emission (D24)	10,000 tons	Negative correlation
		Water qualification rate of the source of drinking water (D25)	%	Positive correlation
	Atmosphere Environment (C9)	SO_2 emission (D26)	10,000 tons	Negative correlation
		Annual average concentration of PM_{10} (D27)	mcg/m^3	Negative correlation
		Annual average concentration of $PM_{2.5}$ (D28)	mcg/m^3	Negative correlation
		NO_2 emission (D29)	10,000 tons	Negative correlation
		Proportion of days with AQI above level II (D30)	%	Positive correlation

2.3.1. Standardization and Normalization

The index dimensionless, also known as the standardization and normalization of index data, is a method to eliminate the dimensional effect of original indexes through mathematical manipulation. The range transformation method applied in the paper is a relatively simple and common linear standardization method. Supposed that there is a linear variation relation between the index value and the corresponding standard value, the index of positive correlation is Equation (1) and the index of negative correlation is Equation (2) [43], which are as follows:

Index of positive correlation:

$$y_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)} \tag{1}$$

Index of negative correlation:

$$yi_j = \frac{\max(x_j) - x_{ij}}{\max(x_j) - \min(x_j)} \tag{2}$$

where, i,j = 1,2,3……, the result of y_{ij} is in the range (0, 1), and the appropriateness index is considered as the positive correlation by default.

2.3.2. Weights Calculation

There are generally two methods for the establishment of evaluation index weight, that is, subjective weighting and objective weighting. The subjective weighting method, including the Delphi method and AHP, largely applies qualitative components and calculates the index weight based on the subjective preference or experience of decision marker, with the evaluation result relatively close to the actual condition of the research region, which has been relatively perfect in China [42,44,45], while the objective weighting method, including the entropy evaluation method and the mean-square deviation decision method, mainly determines the index weight by quantitative method, which is a rigorous method with relatively subjective evaluation results [46,47]. In order to make the evaluation result closer to the actual conditions in Hefei city, the paper selects AHP to implement subjective weighting for the evaluation index of RECC in Hefei city. Using AHP to decompose the complex problems to be identified into several hierarchies, experts and decision makers then judge and score the listed index hierarchy by hierarchy based on their relative importance, and determine the contribution degree of the lower index to the upper index by using the eigenvectors of the calculated judgment matrix so as to get the ranking result of the importance of the base index to the overall target or the comprehensive evaluation index [44]. Although this method is subjective to some extent, it is one of the most commonly used methods.

3. Evaluation Results

Using the above index system to evaluate the RECC of Hefei City between 2009 to 2013, the following results were obtained: in these five years, the RECC of Hefei city declined from medium to weak, except the carrying capacity of social economy increased from weak to medium, both the natural resources and environment carrying capacity of Hefei city declined in different degrees from medium and strong to weaker, respectively, of which the environment carrying capacity had the larger decline. Therefore, it is urgently required by the administrative departments of the government to enhance monitoring forewarning management to seek development coordinated by the regional economy, society and population, resources and the environment to ensure the realization of the target of sustainable development strategy.

3.1. Standardized Processing of Index Data

The research is based on the relevant statistical data of Hefei city from the year 2009 to 2016, which is from the statistical yearbook of Anhui province (2010–2014) and the statistical yearbook of Hefei city (2010–2014). Because the calculation method of indexes is different, it is required to firstly conduct standardized processing for the index data. As the data dimensionless is the prerequisite to realize information synthesis integration, scholars have put forward multiple feasible and effective dimensionless methods [48–55], while the linear dimensionless method is the primary index processing method used for most evaluations. The specific values of standardized processing are as follows (Table 2):

Table 2. The standardized values of the RECC evaluation index in Hefei city from 2009 to 2013.

	2009	2010	2011	2012	2013		2009	2010	2011	2012	2013
D1	1.0000	0.5556	0.2593	0.0370	0.0000	D16	0.5255	0.0000	0.4380	1.0000	0.4526
D2	0.0000	0.4291	0.6848	0.9580	1.0000	D17	0.4506	0.8378	1.0000	0.0000	0.1490
D3	0.8681	1.0000	0.0000	0.0766	0.0936	D18	0.3867	0.0953	0.0000	0.9317	1.0000
D4	0.0000	1.0000	0.2262	0.2563	0.1725	D19	0.5000	0.0000	0.5000	1.0000	1.0000
D5	0.1637	1.0000	0.0654	0.3043	0.0000	D20	1.0000	0.8422	0.1269	0.0000	0.3910
D6	1.0000	0.0000	0.7800	0.5584	0.7296	D21	0.9855	1.0000	0.6850	0.0098	0.0000
D7	1.0000	0.7877	0.4362	0.1549	0.0000	D22	0.9892	1.0000	0.3467	0.2633	0.0000
D8	0.0000	0.1304	0.7391	0.9130	1.0000	D23	1.0000	0.9397	0.6412	0.0000	0.0653
D9	0.0000	0.1247	0.7914	0.9890	1.0000	D24	1.0000	0.9524	0.3095	0.0000	0.0714
D10	1.0000	0.0000	0.3067	0.3567	0.8033	D14	0.0000	0.0000	0.0000	0.0000	0.0000
D11	0.0000	0.2990	0.4309	0.5869	1.0000	D15	0.2500	1.0000	0.0000	0.5000	0.5000
D12	0.0596	0.0000	1.0000	0.9639	0.9538	D27	0.2500	0.0000	0.1875	0.5625	1.0000
D13	0.1540	1.0000	0.2000	0.0610	0.0000	D28	-	-	-	-	0.5156
D14	0.0000	1.0000	0.1220	0.5610	0.9024	D29	1.0000	0.0000	0.5000	0.2500	0.5000
D15	0.0000	0.3367	0.3483	0.6809	1.0000	D30	1.0000	0.7059	0.2588	0.9765	0.0000

Data Source: Statistical Yearbook of Anhui Province (2010–2014), Statistical Yearbook of Hefei City (2012–2014). Note: because Hefei city started to monitor $PM_{2.5}$ from 2013, original data from the year 2009 to 2012 could not be acquired.

3.2. Establishment of Index Weight by AHP

The basic principle of AHP is based on the nature of the problem and target. According to the mutual influence of the factors and the membership of hierarchical clustering combinations, it requires experts to give a quantitative scale to the relative importance of the factors of each hierarchy in the model on individual judgement to objective reality, and by determining the the weight of relative importance order of all factors at each hierarchy and through the comprehensive calculation of relative importance weights of various factors, to get the combination weights of the relative importance order [56]. The study scores in accordance with the experiences of experts and the requirements for the development of main areas in the main functional area of Anhui province to determine the relative importance of each two indexes in Level B and Level A, Level C and Level B, Level D and Level C in the evaluation index system of RECC in Hefei city. Then, two indexes of the same level with each other shall be compared in pairs based on the scoring result to respectively build and calculate the decision matrix, with 13 decision matrices in total. Taking the decision matrix (Table 3) calculating the RECC in Hefei city as an example, the relative importance of three indexes, B1, B2, B3, is decided by comparing pairs.

Table 3. The decision matrix of RECC in Hefei city (A).

A	B1	B2	B3
B1	1	1/3	1/5
B2	3	1	1/3
B3	5	3	1
λ max = 3.0387, CI = 0.0193, CR = 0.0334			

Through the calculation, the consistency of decision matrices is less than 0.1, which conforms to the consistency inspection. Therefore, the weight of all indexes are decided (Table 4).

Table 4. The evaluation weight of RECC in Hefei city.

Target Layer	Norm Layer	Weight 1	Index Layer	Weight 2	Basic Index	Weight 3
A	B1	0.1046	C1	0.0349	D1	0.0203
					D2	0.0038
					D3	0.0108
			C2	0.0349	D4	0.0203
					D5	0.0038
					D6	0.0108
			C3	0.0174	D7	0.0058
					D8	0.0116
			C4	0.0174	D9	0.0025
					D10	0.0075
					D11	0.0075
	B2	0.2586	C5	0.0647	D12	0.0073
					D13	0.0116
					D14	0.0459
			C6	0.1940	D15	0.0158
					D16	0.0196
					D17	0.0793
					D18	0.0793
			C7	0.1592	D19	0.0265
					D20	0.1327
	B3	0.6368	C8	0.3184	D21	0.0314
					D22	0.0561
					D23	0.0998
					D24	0.0998
					D14	0.0314
			C9	0.1592	D15	0.0252
					D27	0.0252
					D28	0.0700
					D29	0.0252
					D30	0.0137

3.3. Comprehensive Evaluation of RECC in Hefei City

All indexes are calculated in accordance with the standard values and weight results of all indexes (Tables 2 and 4), and the evaluation results are as follows (Table 5):

Table 5. The RECC index results in Hefei city from 2009 to 2013.

	2009	2010	2011	2012	2013		2009	2010	2011	2012	2013
D1	0.0203	0.0113	0.0053	0.0008	0.0000	D16	0.0103	0.0000	0.0086	0.0196	0.0089
D2	0.0000	0.0016	0.0026	0.0036	0.0038	D17	0.0357	0.0664	0.0793	0.0000	0.0118
D3	0.0094	0.0108	0.0000	0.0008	0.0010	D18	0.0307	0.0076	0.0000	0.0739	0.0793
D4	0.0000	0.0203	0.0046	0.0052	0.0035	D19	0.0133	0.0000	0.0133	0.0265	0.0265
D5	0.0006	0.0038	0.0002	0.0012	0.0000	D20	0.1327	0.1118	0.0168	0.0000	0.0519
D6	0.0108	0.0000	0.0084	0.0060	0.0079	D21	0.0309	0.0314	0.0215	0.0003	0.0000
D7	0.0058	0.0046	0.0025	0.0009	0.0000	D22	0.0555	0.0561	0.0194	0.0148	0.0000
D8	0.0000	0.0015	0.0086	0.0106	0.0116	D23	0.0998	0.0938	0.0640	0.0000	0.0065
D9	0.0000	0.0003	0.0020	0.0025	0.0025	D24	0.0998	0.0950	0.0309	0.0000	0.0071
D10	0.0075	0.0000	0.0023	0.0027	0.0060	D14	0.0000	0.0000	0.0000	0.0000	0.0000
D11	0.0000	0.0022	0.0032	0.0044	0.0075	D15	0.0063	0.0252	0.0000	0.0126	0.0126
D12	0.0004	0.0000	0.0073	0.0070	0.0070	D27	0.0063	0.0000	0.0047	0.0142	0.0252
D13	0.0018	0.0116	0.0023	0.0007	0.0000	D28	-	-	-	-	0.0361
D14	0.0000	0.0459	0.0056	0.0257	0.0414	D29	0.0252	0.0000	0.0126	0.0063	0.0126
D15	0.0000	0.0053	0.0055	0.0108	0.0158	D30	0.0137	0.0097	0.0035	0.0134	0.0000

Based on the evaluation results of all indexes and Equation (3), the comprehensive evaluation results of RECC (A) in Hefei city are finally calculated, which are shown in Table 6.

$$A = \sum_{i=1}^{n} \left(W_i \times B_i \right) \quad (3)$$

Table 6. The comprehensive evaluation results of RECC in Hefei city from 2009 to 2013.

	2009	2010	2011	2012	2013		2009	2010	2011	2012	2013
C1	0.0297	0.0237	0.0079	0.0052	0.0048	B1	0.0544	0.0565	0.0398	0.0386	0.0438
C2	0.0114	0.0241	0.0133	0.0124	0.0114	B2	0.0789	0.1368	0.1086	0.1377	0.1642
C3	0.0058	0.0061	0.0111	0.0115	0.0116	B3	0.4835	0.4230	0.1868	0.0881	0.1785
C4	0.0075	0.0026	0.0075	0.0095	0.0160	A	0.6168	0.6163	0.3352	0.2644	0.3865
C5	0.0022	0.0575	0.0152	0.0335	0.0484	-	-	-	-	-	-
C6	0.0767	0.0793	0.0934	0.1042	0.1158	-	-	-	-	-	-
C7	0.1460	0.1118	0.0301	0.0265	0.0784	-	-	-	-	-	-
C8	0.2860	0.2763	0.1358	0.0151	0.0136	-	-	-	-	-	-
C9	0.0515	0.0349	0.0209	0.0465	0.0865	-	-	-	-	-	-

It is known from the evaluation results of RECC in Hefei city (Line A in Table 6) that the RECC in Hefei city from the year 2009 to 2013 was in a declining trend, reaching the lowest value in 2012 and showing a slight increase in 2013. The main cause of the decline of RECC in Hefei city was the contradiction between social economy and resources and the environment; that is, the rapid development of industrialization and urbanization in Hefei city resulted in the degradation of natural resources and environment carrying capacity. Moreover, the improvement of monitoring technology will relatively narrow the error range of original monitoring data, making the evaluation results closer to the actual conditions.

From the perspective of natural resources (B1), the RECC in Hefei city from the year 2009 to 2013 has fluctuated. However, in general, the natural resources carrying capacity in Hefei city from the year 2009 to 2010 was better than that from the year 2011 to 2013, with a slight improvement in 2013 than in 2012. From the year 2009 to 2013, the land resources carrying capacity showed a larger decline due to the reduction of arable land per capita year by year and the increase of construction land area per capita year by year; the water resources carrying capacity has risen and fallen, caused by the influence of annual rainfall and reached the strong water resources carrying capacity in 2010 and presented a stable overall status; the mineral resources and forest resources carrying capacity were basically in a rising trend, indicating that Hefei city has made certain achievements in the change of economic development mode and the afforestation in the period.

From the perspective of social economy carrying capacity (B2), except for the large fluctuation caused by the social development level in 2010, the social and economic development level in Hefei city from the year 2009 to 2013 had rapidly improved, resulting in the rising trend for the social economy carrying capacity in Hefei city, which conformed to the positioning of the main functional area in the development of major areas in Hefei city. As population is an important influence factor for social development levels, the rapid population urbanization in the past ten years may be one of the reasons causing the larger change of social economy carrying capacity in Hefei city.

From the perspective of environment carrying capacity (B3), the environment carrying capacity in Hefei city showed a declining trend, with a slight improvement in 2013. In 2013, Hefei city took the lead in Anhui province to monitor PM2.5 concentrations, and evaluated air quality with a new national standard for air quality (*Ambient Air Quality Standards* ; GB3095-2012); because there was no data of $PM_{2.5}$ concentration included in the calculation of the evaluation from the year 2009 to 2012, it caused a certain influence on the final evaluation result of environment carrying capacity. The main cause of the decline of environment carrying capacity in Hefei city was the sharp decline of water environment quality; the land environment was effectively controlled and improved in 2013.

In order to better understand the RECC in Hefei city, the index weights of resources and environmental carrying capacity, natural resources carrying capacity, social economy carrying capacity, and environment carrying capacity in Hefei city are divided into four levels, which are respectively weak, relatively weak, medium, and strong (Table 7).

Table 7. The carrying capacity classification.

Carrying Capacity Classification	Resources and Environment Carrying Capacity (0, 1)	Natural Resources Carrying Capacity (0, 0.1046)	Social Economy Carrying Capacity (0, 0.2586)	Environment Carrying Capacity (0, 0.6368)
Weak	(0, 0.25)	(0, 0.0262)	(0, 0.0647)	(0, 0.1592)
Relatively Weak	(0.25, 0.5)	(0.0262, 0.0523)	(0.0647, 0.1293)	(0.1592, 0.3184)
Medium	(0.5, 0.75)	(0.0523, 0.0785)	(0.1293, 0.1940)	(0.3184, 0.4776)
Strong	(0.75, 1)	(0.0785, 0.1046)	(0.1940, 0.2586)	(0.4776, 0.6368)

According to Tables 6 and 7, the RECC in Hefei city from the year 2019 to 2013 reduced from a medium level to a relatively weak level; except that the social economy carrying capacity rose to a medium level from a relatively weak level, the natural resources carrying capacity and environment carrying capacity in Hefei city showed declining trends in different degrees, reducing respectively from medium level and strong level to a relatively weak level, of which the environment carrying capacity witnessed the larger decline.

4. Forewarning Management

The change of regional resources and environment carrying capacity, especially the change in a declining trend, imposes an urgent demand for enhancing monitoring and forewarning management. The authors consider that it should focus on the following aspects.

4.1. Make Efforts to Improve the Forewarning Response System of Regional Resources and Environment Carrying Capacity

RECC is the restrictive index to determine space resources and environmental capacity and the foundation and prerequisite for the planning of the main functional area, land utilization and urban construction. Currently, it speeds up the construction of the monitoring and forewarning platform of RECC and build the resources and environment evaluation and forewarning model. Moreover, it carries out the calibration and verification of monitoring results and forecast results of the monitoring, forewarning system and optimizes model parameters to finalize the framework of the monitoring, evaluation, and forewarning system. Then, a platform for the dynamic monitoring and forewarning technology system, which is leading both at home and abroad with a perfect system and strong practicality, is formed through the analysis of internal mechanisms, the development of key technologies, and the demonstration of popularization and application.

4.2. Establish the Sharing Mechanism of RECC Monitoring Data

In view that the administration, such as the department of natural resources, department of water conservancy, department of environmental protection and meteorological department, have their own monitoring systems, in order to avoid repetitive construction and reduce the waste of resources, including manpower, materials, and financial resources, the relevant functional departments in the region should carry out data integration and processing by combining with the index system in the paper, based on existing monitoring data, and build a uniform exchange and sharing platform for information resources within the region, thereby acquiring the effective monitoring data of RECC within the administrative scope. Meanwhile, it should strengthen the operation maintenance and updates of the monitoring database and realize the dynamic management and sharing of RECC monitoring data to ensure the effectiveness and timeliness of monitoring data, promoting the coordinated planning of the monitoring and forewarning system of RECC.

4.3. Improve the Accountability Mechanism of RECC

A sound retrospective accountability mechanism should be established for the decision-making and implementation of environmental protection policies and major local projects, which, more importantly, serves as a warning. It will improve the preparation system of a balance sheet of natural resources, step up the off-office audit of natural resource assets for leading officers, and strengthen the lifelong accountability system for the liability of damaging ecological environments, making officers in all levels stick to the ecological bottom line in order to realize the sustainable utilization of natural resources and sound development of the region. The quantitative assessment evaluation for each index should be implemented, and the off-office audit and post-assessment system for ecological performance should be determined to firmly bind the officers' responsibilities to environmental protection. Moreover, it enhances the policymaker's assumption of responsibility that corresponds to the assessment result whether the policymaker has changed positions or is on duty. In case that the ecological environment deteriorates due to decision-making mistakes, it must trace the liability and impose punishment until the criminal responsibility is investigated. It should establish a strict scientific and democratic decision-making system to keep decision-making under all-round social supervision at any time and to make regional decision-makers keep protection and green development first in mind.

5. Conclusion

There are many systems, such as resources, environment, ecology, and social economy, that are involved in the evaluation index of the RECC, and the evaluation index of different systems will impact and interact with each other. The paper, adopting the analytic hierarchy process and including $PM_{2.5}$ into the index system, enriches the evaluation index system of RECC. It shows that the problem of over carrying capacity of Hefei city has already appeared, using the index system to evaluate the RECC in Hefei city from the year 2009 to 2013. Furthermore, the evaluation results of the social and economic carrying capacity show that the regional RECC can be maintained and improved by the government adjusting the industrial structure, promoting the optimal allocation of resources, and reasonably guiding urban planning, which many pieces of research on the relationships between humans and land on the RECC have also proved [5]. Therefore, the paper also proves that it is reasonable and efficient to build a differentiated index system to scientifically recognize the RECC in different regions, having reference value to evaluate similar regional RECC.

From the conclusion of this paper, the evaluation results conform to the actual development situation of Hefei city. With the development of globalization, and the continuous enhancement of the research on the correlation between different scales and the interaction between resources and the environment of different regions, paying more attention to the research on temporal dynamics and spatial interaction of the RECC in future is required.

6. Discussion

We must acknowledge that there are limitations in the research. Firstly, the AHP focuses on choosing the best from all the alternative plans to the problem, so it fails to put forward new plans to settle the problem, lacking creativity [57]. Secondly, the AHP needs a judgment matrix with multiple structural hierarchies and large scales. However, the increased indexes have made it more difficult to judge the relative importance of pairs; furthermore, the eigenvector (weight) calculated by the constructed judgment matrix may not be reasonable. In addition, the AHP of weight measurement scored by experts is more subjective, which will affect the recognition of the analysis conclusion.

So far, the research on the RECC has achieved abundant results. However, the interaction between natural resources and the environment, economic and social development is very complex in a medium-sized region, which has time dynamics and spatial differentiation. At the same time, it is affected by cross-scale factors, which makes the research of RECC face severe challenges. With the popularization and wide use of big data, data distribution and sharing, GIS and other software, some fields also need to be strengthened, such as big data management, data mining, comprehensive evaluation and simulation model construction, and decision support tool development for RECC.

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