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Research on the Coupling Coordinated Development of Ecological Environment Pressure State and Response in City

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Abstract: This paper constructs an ecological carrying capacity index for ecological environment based on the pressure-state-response (PSR) framework model, discusses the coupling coordination of ecological environment pressure, state and response subsystem of the city in china from 2011 to 2021. Through establishing the ecological carrying capacity index and the urban ecological coupling model, predicated the security warning degree of each year. The calculation result indicates that the coordination degree of urban ecological development in Suzhou has been improved year by year, the ecological carrying capacity security index shows an upward tendency from the overall view, and the security warning degree rises from comparative Insecurity to comparative security. The analysis shows that in the process of national ecological civilization construction demonstration zone construction, the ecological resources and environmental policies adopted by Suzhou city have played a great role in promoting ecological security. However, ecological security index in Suzhou is still below 0.6, far from the high security level (0.75), and the government and the public still need to do a lot to improve ecological security.

1. Introduction

In recent years, with the rapid development of the economy, issues from resources and the environment have been continuously highlighted, especially in the areas of the Yangtze River Economic Belt (YREB) in china where there are more severe hazy weather and serious pollution. The pressure on the coordinated development of the economy, population, resources and environment is enormous, and the evaluation and early warning of urban ecological carrying capacity (UECC) have become increasingly important as the essential work of urban ecological management. It is very urgent to carry out safety early warning research on (UECC). Therefore, this paper selects Suzhou city in china as a case to build an early warning system of urban ecological carrying safety through data collection-quantitative assessment-dynamic forecasting-graded early warning to provide a reference for the city's ecological management policy formulation [1].

The concept of “carrying capacity” was lent from engineering mechanics and concept was first introduced into the study of human ecology research by Park Burgess (1921) [2]. It refers that under a particular environmental condition (mainly refers to the combination of living space, nutrients, sunlight and other ecological factors), the maximum number of a certain individual exists in the environment. The changing trend and speed of ecological carrying capacity and its coordinated development with social economy lay a solid foundation for effective regulation and coordination of ecological systems and sustainable development. Therefore, it is not only the main means of ecological carrying capacity research, but also one of the main contents and directions of ecological carrying capacity research in recent years[3,4].Ecological carrying capacity should include two factors: the first meaning that the ecosystem has the ability to sustain development, especially the system can self-regulate; the second meaning that the various subsystems in the ecosystem have the ability to develop independently. [5]. In this paper, the early warning of urban ecological carrying capacity mainly refers to the evaluation, prediction and early warning of the current status and future development of UECC.

The city is a unified spiral composite system of "socio-economic-environment". How to effectively protect the ecological environment while achieving economic and social development is an important value of urban ecological security research. Since the 1980s, ecological security assessment has gradually become a hot issue in ecosystem management and regional environmental management [6]. In recent years, many researchers have proposed quantitative and qualitative evaluation methods of urban ecological security from different perspectives. From the literature review, the more influential methods of ecological security evaluation include comprehensive index evaluation methods[7, 8], landscape ecology evaluation methods[9-11], economic evaluation methods[12], ecosystem service value evaluation methods[13-15], and ecological footprint evaluation methods[16,17].

Many scholars have studied UECC by different methods [18-22]. In terms of early warning and regulation of ecological carrying capacity, although the early warning theory of many countries (such as the United States and the United Kingdom) has a relatively complete concept system and systematic operation methods, however, the theory of urban composite ecosystems has been studied in China relatively late. Research results on ecological carrying capacity are not abundant. Such as Tian (2018) constructs an evaluation framework of the comprehensive carrying capacity of the Yangtze River Economic Belt, and analyzes its dynamic relationship through spatial metrology methods[23]; Zhang (2018) has constructed a comprehensive evaluation index system containing 18 indicators, such as water carrying capacity, land carrying capacity, atmospheric environmental carrying capacity, energy carrying capacity, and solid waste environmental carrying capacity. These indicator systems reflect the supporting and restrictive role of resources and environment in the process of human development, and reflect the dynamic changes of urban environmental carrying capacity [24].

2. Using PSR Model to Establish Safety Early Warning Evaluation Index System of Ecological Carrying Capacity

2.1 PSR model

Since the Organization for Economic Co-operation and Development (OECD) and the United Nations Environment Program UNEP) proposed the stress-state-response (PSR) model in 1993, this model has been commonly used to study the sustainability of resources and the environment. [25]. The PSR framework mainly studies the balance of the system through pressure indicators, environmental condition indicators, and social response indicators. It studies the causality and interaction between the three indicators to derive the carrying capacity in the region. Now it is used worldwide to study the ecosystem health conditions [26-30].

It is assumed that there is an interactive relationship between human social-economic activities and the natural environment. Human beings acquire various biological resources from the natural environment and discharge them into the natural environment through production and consumption, thereby changing the number of resources and the quality of the environment. Changes in resources and the environment, in turn, affect human social activities and welfare. Each element interacts to form a "pressure-state-response" relationship between human activities and the natural environment. The “stress” indicator describes the direct pressure or load caused by human activities and natural disasters in an area’s ecological environment. It mainly reflects the impact of human activities on the ecological environment; the “state” indicator refers to the current state of the system; and the “response” indicator stands for the countermeasures and measures taken by humans to mitigate, prevent, restore and prevent the negative impact of human activities on the ecological environment. This model reflects the interaction between human and natural ecosystems and has a very clear causal relationship. The basic idea is that the influence of human activities on the environment and natural resources will affect the quality of the environment and resources, while the society will formulate environmental, economic, and land policies or measures to respond to these changes and reduce the impact of human activities on the environment through human consciousness and activities.

The pressure–state–response (PSR) model emphasizes that human production and living conditions play a key role in the sustainable development of the regional environment. The model divides the indicators of ecological carrying capacity into three categories: stress, state and response. It is assumed that there is an interactive relationship between human social-economic activities and the natural environment [31, 32]. In the process of production and consumption, human beings need to obtain various biological resources from the natural environment and eventually discharge by-products into the natural environment, thereby changing the number of resources and the quality of the environment. Changes in resources and the environment, in turn, affect human social activities and welfare. Due to the mutual constraints and interactions between these three factors, a pressure-state-response relationship has formed between human activities and the natural environment. The “stress” indicator describes the direct pressure or load caused by human activities and natural disasters in an area’s ecological environment. It mainly reflects the impact of human activities on the ecological environment; the “state” indicator refers to the current state of the system; and the “response” indicator stands for the countermeasures and measures taken by humans to mitigate, prevent, restore and prevent the negative impact of human activities on the ecological environment. This model reflects the interaction between human and natural ecosystems and has a very clear causal relationship. The influence of human activities on the environment and natural resources will affect the quality of the environment and resources, while the society will formulate environmental, economic, and land policies or measures to respond to these changes and reduce the impact of human activities on the environment through human consciousness and activities.

2.2 Pre-Warning Evaluation Index System of UECC

Urban ecosystems are based on human-centered ecosystems. The safety early warning evaluation index system of UECC is a comprehensive system of resources, environment, economy, society and human resources [33]. Combining the definition of ecological carrying capacity, and referring to the research results of relevant scholars and follow the basic principles of the construction of the following index system: scientific principle, systematic principle, reference principle, and operational principle, and based on the pressure-state-response model, this paper constructed the safety early warning evaluation index system for UECC represented by Suzhou City in the Table 1.

Table. 1 Pre-Warning Evaluation Index System and the Security Standard Value of UECC

Target Layer	System Layer	Indicator Layer	unit	Property	Weight
Prewarning indicators of Urban Ecological Carrying Capacity	Pressure f(x)	population density x_{01}	unit	negative	0.004547
		population growth rate x_{02}	%	negative	0.049704
		Rate of urbanization x_{03}	%	negative	0.000311
		Proportion of primary industry x_{04}	%	negative	0.014964
		Unit area Agricultural Chemical Insecticides x_{05}	kg/hm^2	negative	0.071536
		Unit area Chemical Fertilizer x_{06}	kg/hm^2	negative	0.071736
		Unit area Volume of Industrial Smoke (Powder) Dust Emission x_{07}	t/km^2	negative	0.081769
		Unit area Volume of Industrial Wastewater Discharged x_{08}	t/km^2	negative	0.093279
		Unit area Volume of Sulphur Dioxide Emission x_{09}	t/km^2	negative	0.080257
	State g(y)	soil erosion x_{10}	%	negative	0.001951
		Per capita arable land x_{11}	hm^2	positive	0.019175
		Grain output per unit area x_{12}	t/hm^2	positive	0.005444
		the per capita floor space x_{13}	m^2	positive	0.019165
		per capita area of Roads x_{14}	m^2	positive	0.007308
		per capita Park green area x_{15}	m^2	positive	0.015200
		GDP unit energy consumption x_{16}	ton	negative	0.023619
		GDP unit electric energy consumption x_{17}	kW ħ	negative	0.016736
		Engel's coefficient x_{18}	%	negative	0.024187
	Response h(z)	Total Power of Agricultural Machinery x_{19}	kW/hm^2	positive	0.010124
		Per million with public transport vehicles x_{20}	unit	positive	0.073428
		industrial solid waste comprehensively utilization rate x_{21}	%	positive	0.228175
		Proportion of tertiary industry x_{22}	%	positive	0.003557
		per capital GDP x_{23}	yuan	positive	0.001253
		Treatment Rate of Sewage x_{24}	%	positive	0.014764
		rate of no harm disposal of garbage x_{25}	%	positive	0.035179
		The proportion of investment in environmental pollution in GDP x_{26}	%	positive	0.007560
		The proportion of education expenditure in budget expenditure x_{27}	%	positive	0.025075

2.3 Determination of safety standard values

The determination of the safety standard values of each evaluation index is the prerequisite and basis for the safety prewarning evaluation of UECC. Based on the previous literature and research results, considering the factors of sustainable development, this study identified the following indicators:

(1) Scientific principle

The security of ecological carrying capacity is both a theoretical and a practical problem. The safety evaluation of ecological carrying capacity should select certain correlation and stability indexes, data, calculation and summary, etc., all of which should pay attention to the scientific nature, should be based on the scientific foundation, and reflect the environmental attributes as comprehensively, completely and accurately as possible.

(2) Systematic principle

Urban ecosystem is a comprehensive system of coordinated development of social and economic systems, ecosystems and other systems. Therefore, its index system should not only reflect the ecological environment and resources, but also have development indexes that reflect the social and economic systems, paying attention to systematisms.

(3) Operational principle

The data collection should be convenient, measurable and comparable. In the actual investigation, the index data should be collected through statistical data or directly obtained from the relevant departments.

(4) Reference principle.

The index system refers to the methods of previous researchers and selects relevant indicators. Based on the results of previous researches, security standard value of the index system of the security prewarning UECC [19, 34-38].

2.4 Method

2.4.1 Standardization of quantitative indexes

Because the units of the data are quite different, the data must be standardized, and the data reflect different properties and can be divided into two groups. “positive (larger desirable response)” and “negative (smaller desirable response)”. Standardization of positive effect indexes: for some indexes, the higher their values are, the greater the positive effect they will bring to city ecological security, which means this index is much less risky for ecological security. And the original sequence can be standardized as:

$$x_{ij}^{'} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}} \qquad \text{(positive)}$$

$$x_{ij}^{'} = \frac{\max_i x_{ij} - x_{ij}}{\max_i x_{ij} - \min_i x_{ij}} \qquad \text{(negative)}$$

x_{ij} is the pre-treated value of the J-th evaluation index in year i. x_{ij} and $x_{ij}^{'}$ respectively represent the original value and the standardized value of index j in year i. $\max_i x_{ij}$ and $\min_i x_{ij}$ represent the maximum and minimum values of the j-th index, respectively.

In this study, according to the meaning of each indicator, the properties of each indicator are shown in Table 1. After the above processing method, the values of all indicators can all be converted into values in the range[0, 1].

2.4.2 The calculation of the safety index of ecological carrying capacity and the determination of the evaluation standard of alarm degree

This paper uses gray-weighted correlation method to calculate the ecological carrying capacity safety index. The specific calculation steps are as follows:

(1) Determine the pre-processed optimal value of each indicator x, pre-processed the j-th evaluation index.

(2) Determination of index weight

The evaluation of UECC involves multiple factors, and the contribution of each evaluation index to the evaluation target is different. Although there are many methods to determine the weight of indicators, in order to minimize the error of weight determination, the article uses the coefficient of variation method to determine the weight W_i.

$$\delta_i = \frac{D_i}{\overline{X_i}}$$

$$W_i = \frac{\delta_i}{\sum_{i=1}^{n} \delta_i}$$

δ_i, D_i, $\overline{X}_i$, W_i represents the coefficient of variation, mean variance, mean value and weight value of index. Table 1 shows the weight of each index calculated.

Step 3: calculating the correlation coefficient

$$\varphi_{ij} = \frac{v_{min} + \omega v_{max}}{\left|x_j^* - x_{ij}'\right| + \omega v_{max}}$$

$v_{min} = \min_i \min_j \left|x_j^* - x_{ij}'\right|$, $v_{max} = \max_i \max_j \left|x_j^* - x_{ij}'\right|$, ω is distinguishing coefficient, in this paper, ω=0.5.

Step 4:

Calculate the gray weighted association degree of each level of the evaluation object. The formula is as follows:

$$r_i = \frac{1}{n}\sum_{j=1}^{n} W_k \omega_{ij}$$

According to the grey correlation coefficient method, we can get the ranking of urban ecological carrying early warning index E. The higher the index, the higher the urban ecological carrying capacity.

Step 5: Urban ecological coupling model

Coupling degree refers to the degree of interaction between two or more systems through their interaction with the external environment. When analyzing the three systems of urban ecological environment pressure, state, and response, the coupling degree model can be expressed as:

$$C = \left[\frac{f(x) \times g(y) \times h(z)}{[(f(x) + g(y) + h(z))/3]^3}\right]^{1/k}$$

In the formula: C is the coupling degree, $0 \le C \le 1$; *k* is the adjustment coefficient, which is selected as 3 in this paper, *f(x), g(y), h(z)* represents the development index of ecological environment pressure, state, and response. When the coupling degree C becomes larger, it indicates that the pressure, state and response of ecological environment are more coordinated, Otherwise, it means lack of coordination.

Step 6: Urban ecological coordinated development model

Although the degree of coupling can better reflect the degree of coordination between the ecological environment pressure, the state, and the response system, it is difficult to reflect the level of overall coordinated development between the systems. Therefore, we construct a coordinated development model to reflect the coordinated development of the systems as follows:

$$T = \alpha f(x) + \beta g(y) + \gamma h(z)$$

$$D = \sqrt{C \times T}$$

In the formula: D is the urban ecological coordination index, which indicates the level of coordinated ecological development; T is the comprehensive development index of urban ecological environmental pressure, state and response; α, β, and γ are undetermined coefficients, we assume that the ecological environment pressure, state, and response are equally important in the system, so we take $\alpha = \beta = \gamma = 1/3$.

3. Sample and Data sources

Suzhou is 80km away from Shanghai. It is one of the important cities in the Yangtze River Delta. After 30 years of rapid development, Suzhou has made great improvements in economy and society. According to the "Consideration of the Domestic Economic and Social Development of Suzhou in 2021", Suzhou 's GDP per capita exceed 25,000 USD in 2021, and won the title of National Ecological City, International Garden City, etc.

During the rapid development of cities, some urban diseases have appeared, such as air pollution, water pollution, transportation problems, and domestic garbage problems. These problems have hindered the healthy development of cities and reduced their capacity for urban development. The Suzhou municipal government has realized that these problems will hinder the development of the city and has formulated some solutions to improve UECC. This study describes the development trend of UECC in Suzhou in recent years.

The authors collected raw data on the safety and early warning assessment indicators for the ecological carrying capacity in Suzhou from 2011 to 2021. The data were sourced from the china statistical yearbook on environment（2012-2021）, Jiangsu statistical yearbook（2012-2022）, Suzhou statistical yearbook （2012-2022） and Suzhou environmental bulletin （2012-2021） china statistical yearbook on environment， and some raw data come from the web of Suzhou statistics bureau.

3.1 Determine the criteria for ecological early warning

Table. 2 Security warning degree division standard of UECC

Composite index value	**Level**	**System characteristics**
0.75-1.0	High security	The various elements in the urban ecosystem coexist in harmony, and the system has self-regulating ability and a reasonable organizational structure.
0.55-0.75	Comparative security	The urban ecosystem is relatively well-preserved. There is no ecological abnormality; Harmonious relationship between man, nature and ecology. The system is stable and sustainable.
0.45-0.55	Basal security	The urban ecosystem is affected to a certain extent, there are some ecological anomalies. The function of the system is affected, but basic operations can still be maintained, and the relationship between people, nature and ecology is facing certain threats.
0.35-0.45	Comparative Insecurity	The urban ecosystem is affected to a certain extent, The function of the system has been greatly affected, the relationship between humans, nature and ecosystems has been threatened, and human activities have a greater impact on resources and the environment. There are some ecological anomalies.
0-0.35	Insecurity	The urban ecosystem is damaged to a certain extent, There are many ecological anomalies The relationship between people, nature and ecosystems has been unbalanced, and human activities pose serious threats to resources and the environment.

According to the impact of human activities on resource use, environmental development, and the coordination relationship between humans and urban ecosystems, and the degree of damage to ecosystems, and with reference to the research results of relevant researchers, in the table 2, this article determines the UECC standard [39].

4. Results

4.1 Analysis on the ecological carrying capacity of urban city

From 2011 to 2021, the ecological carrying capacity safety index and the urban ecological coordination index of Suzhou city in each year can be calculated, as shown in table 3.

Table. 3 Change Trend of ecological capacity safety index and the urban ecological coordination index (2011-2021)

year	**Pressure system safety index f(x)**	**State System safety index g(y)**	**Responsive system safety index h(z)**	**Ecological capacity safety index (E)**	**Urban Ecological Coordination Index (D)**
2011	0.4694	0.3600	0.3692	0.3995	0.1954
2012	0.5319	0.3681	0.4082	0.4361	0.2102
2013	0.5395	0.3876	0.4137	0.4469	0.2165
2014	0.6058	0.3844	0.4584	0.4829	0.2289
2015	0.6060	0.4038	0.4582	0.4894	0.2341
2016	0.6249	0.4059	0.5028	0.5112	0.2440
2017	0.6279	0.4279	0.5024	0.5194	0.2502
2018	0.6567	0.4682	0.5485	0.5578	0.2710
2019	0.668	0.4725	0.5506	0.5636	0.2736
2020	0.669	0.473	0.5523	0.5699	0.2749
2021	0.6702	0.4766	0.5539	0.5737	0.2820

In the Table 3, the ecological capacity safety index of the Suzhou city showed a rising trend. The index rose from 0.3995 in 2011 to 0.5737 in 2021. Correspondingly, the alarm degree of ecological security is comparative security, and the warning level is getting lighter and lighter with a good trend. When the economy is developing rapidly, Suzhou pays attention to the protection of urban ecological environment, put forward a lot to improve ecological policy, increase of urban ecological construction, such as increasing urban green space construction and urban water treatment facilities, reduce pollution enterprises and so on, these measures to improve UECC and promote sustainable development.

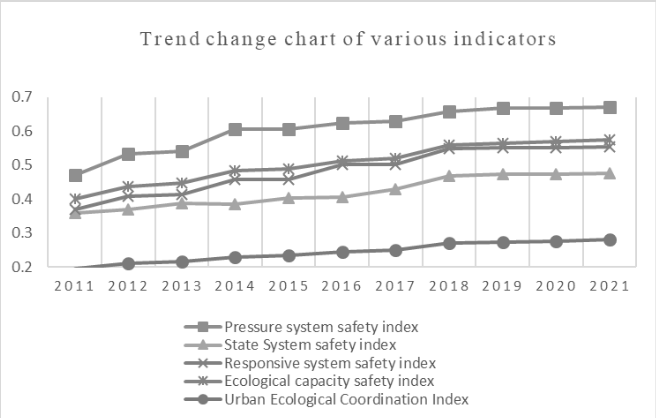

Figure 1 Trend change chart of various indicators

In the Fig.1, we can be seen from the urban ecological coordination Index and the urban ecological coordination index of the Suzhou city continues to grow, but growth rate is not high, the same period of the growth of the Ecological capacity safety index are basically the same, in addition, Urban Ecological Coordination Index at lower levels, shows that in the process of economic development, still need to pay attention to ecological environment protection.

4.2 Analysis on pressure system safety

The “pressure” indicator represents the direct pressure or load imposed by human activities and natural disasters on the regional ecological environment. It mainly reflects the impact of human activities on the ecological environment. The Fig.1 shows the safety index showed a rising trend of fluctuation from 0.4694 to 0.6702 from 2011 to 2021, with an increase of 42.78%. From the perspective of the pressure system, the corresponding safety alarm of pressure system is reduced from Sub-healthy to Generally healthy, especially in recent years, it means that the UECC in Suzhou City is continuously upgrade, especially in the latest year, and the pressure system safety index has been rising faster than in previous years.

4.3 Analysis on State System safety

The system safety index from 2011 to 2021 showed an increasing trend of fluctuation, rising from 0.3600 to 0.4766, with an increase of 32.39%. Although the value is in an upward trend, it is still in an ordinary range, because the "state" indicator represents the current state of the system, indicating that the ecological environment of Suzhou is still not optimistic.

In the process of development in recent years, Suzhou has witnessed a rapid economic development, has been attaching great importance to environmental protection. It has made great investment in urban green construction, such as the construction of urban Green Island and the expansion of the number and area of urban parks. As Suzhou is a typical energy-importing city, it attaches great importance to the improvement of energy efficiency and the proportion of green energy in the development process, and at the same time, it is gradually eliminating some enterprises with high energy consumption.

4.4 Analysis on Responsive system safety

From the perspective of the response system, the response system index increased significantly from 0.3692 to 0.5539. Accordingly, the ecological security alarm degree responding to the system was changed from generally unhealthy to sub-healthy .Since the "response" index represents the countermeasures and measures taken by human beings when ecological and environmental problems occur, including preventing the occurrence of environmental problems and reducing the impact of human production and life on the urban environment. This shows that as a demonstration area of ecological civilization construction, Suzhou has taken active and effective measures to promote the construction of ecological city.

5. Conclusion

(1) In recent years, the ecological load bearing index and ecological coordination index of Suzhou city are not high on the whole, but they show an increasing trend, and the coupling and coordination between subsystems are also improving. This is mainly because Suzhou has taken innovative measures to promote the healthy and sustainable development of the ecological environment, such as eliminating high-energy enterprises, vigorously developing low-pollution enterprises, improving the urban green area, and building urban parks. It can be predicted that the ecological carrying capacity of Suzhou city and the ecological coordination among its subsystems will be continuously improved.

(2) Although the index system of urban ecological carrying capacity is constructed in this study, which involves pressure, state and response, all of them adopt statistical indicators and lack indicators of residents' subjective feelings. Although the urban ecology study of coordination and its influencing factors of other subsystems, choose endogenous variable such as treatment rate of sewage, but did not consider industrial policy, exogenous variables such as green taxes, property rights system, and the interaction effect between variables and the space effect.

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