Ecological security of economic belt from the symbiosis perspective--a case study of the Yangtze river economic belt

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Abstract. As an advanced stage of the urbanization process and the main force driving the high-quality development of China's economy, the economic belt has caused the emergence of ecological security problems in the economic belt while its economic growth. In this paper, the Yangtze River Economic Belt, a national strategic layout area, is used as an empirical research. Based on the symbiosis theory, the Lotka-Volterra model for ecological security measurement of symbiotic development is constructed, and according to the actual conditions of 11 provinces and cities in the Yangtze River Economic belt, comprehensive evaluation of the ecological security of its are conducted.The research results show that: (1) From 2008 to 2017, the overall ecological carrying capacity of the Yangtze River Economic Belt was low, and the regional ecological conditions have improved but not obvious; (2) Through the reverse decoupling of indicators, it was found that the resources along the Yangtze River were over-exploitation, the serious pollution of industries and agriculture, and the base of pollutant emissions is large; (3) To improve the resources and ecological environment of the Yangtze River Economic Belt, it is necessary to strengthen source prevention, comprehensively promote pollution remediation, repair damaged ecology, and promote green sustainability development.

1. Introduction

The economic belt relies on specific geographical location, natural environment, resource endowment, transportation context, etc., taking them as a long-term development axis, and taking several economically developed areas on this development axis as the core, give full play to the agglomeration function of and radiation driving function of economic development, promote the economic development of the underdeveloped areas of different sizes around the surrounding area, thus forming a dot-shaped economic area that integrates longitudinally extending production, manufacturing, and circulation with densely distributed dots, omnidirectional radiation. At present, the economic belt has become the main force for the transformation of China's economic development from high speed to high quality in the new era. The high-quality economic development in the economic belt must be oriented towards green development, take into account the balance of economic, social and ecological interests, and realize sustainable development. At present, China is facing the shrinking of total resources and the degradation of the ecosystem and the maintenance of ecological security is placed in an increasingly prominent position. The ecological security of the economic belt also reflects the

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competitiveness of the region and the whole country. Therefore, the study of ecological security is of great necessity.

At present, ecological security, as a new security concept, has become increasingly clear in its connotation and function, and has gradually attracted the attention of various countries[1]. Ecological security was proposed by Lester. R. brown in the 1970s [2], then some scholars constantly enriched and expanded the content of ecological security. In the 1990s, the International Institute of Applied Systems Analysis gave a definition of ecological security that is still in use today, that is, ecological security refers to the protection of the health and integrity of the ecosystem for human survival and development[3]. At present, the academic circle has a wide range of research contents on ecological security, such as: global ecological security [4], national ecological security [5-6], regional ecological security [7-8], land ecological security [9-10], forestry ecological security [11-12], water resource ecological security [13], marine ecological security [14-15], etc. In terms of research topics, there are: research on the spatio-temporal evolution trend of ecological security[16-17], ecological security evaluation [18-19], measurement and analysis of ecological efficiency [20-21], and research on the sustainability of natural resources and ecological security system [22], etc. The research methods include: fuzzy mathematical model [23], neural network model [24-25], lotka-volterra model [26], DPSIR index evaluation system [27-28], AHP analysis [29], comprehensive index evaluation [30], etc. Based on the above literature review, it is found that although there are abundant research achievements on ecological security, there are few studies on ecological security in the "economic belt" formed by the collection of specific regions. "Economic belt" is a multi-level and diversified economic regional unit gradually formed based on the regional division of social labor. Due to the characteristics of multi-level, diversification, openness and variability of economic belt, its ecological security problem is more complex and prominent. How to solve the ecological security problem in economic belt and ensure the coordinated development of regional economic in economic belt has become the key problem to be solved in the process of economic belt development.

As the main force leading China's high-quality economic development, the Yangtze river economic belt has obvious economic capacity. However, the rapid economic growth has resulted in multiple ecological problems such as the bottomless abuse of natural resources along the Yangtze River, and the sharp decline in biodiversity. The premise of restoring and building the green ecological corridor of the Yangtze river is to grasp the current ecological security situation of the Yangtze river economic belt in terms of time and space. Therefore, it is particularly important to study the spatial and temporal evolution pattern of ecological security in the Yangtze river economic belt.

Based on symbiosis theory in ecology, combined with the actual condition of the Yangtze river economic belt, the ecological security of eleven provinces and cities in the Yangtze River Economic belt from 2008 to 2017 were measured by building a L-V measure model of the ecological security to study and judge the ecological security of the Yangtze River Economic belt, and analyze the cause of the ecological security problems, and put forward the suggestion, so as to provide a reference for the restoration and sustainable development of ecological security in the Yangtze River Economic belt.

2. Research methods

The Yangtze River Economic belt has a vast area, which is not only a golden waterway connecting various regions, but also a core belt for regional construction. The belt-shaped city cluster centered on Chongqing, Wuhan and Shanghai is distributed along the river, and the development of industry and ecology is closely linked and mutually influenced. The orderly development of social economy and resource ecology has formed a coordinated symbiotic organism within the Yangtze River Economic belt. Therefore, this paper studies the ecological security of the Yangtze River Economic belt based on the symbiotic mechanism.

2.1. *Constructing a symbiotic model of economic belt according to the symbiotic mechanism*

Symbiosis is a common phenomenon in the biological world, which refers to the phenomenon that two species live together and depend on and influence each other. Later, it was introduced into the field of social science to provide new ideas and methods for solving some complex system problems. The ecological security system of economic belt is composed of socioeconomic subsystem and resource ecological subsystem. The symbiosis and competition of the two subsystems are similar to the symbiotic relationship between organisms. On the one hand, the resource ecosystem provides the socioeconomic system with the resource base for growth and development, such as water resources and atmospheric resources, etc. After the social and economic system gradually develops and strengthens relying on the support of the resource ecosystem, it has the ability to better maintain and utilize the resource ecosystem, and the two have reached a state of harmonious coexistence. But on the other hand, if the expansion of the socioeconomic system in the economic belt unrestrictedly stretches resources from the resource ecosystem in economic belt, it will cause pressure on the ecological environment and cause damage to the ecosystem. Then the resource ecosystem will in turn inhibit and hinder the development of the socioeconomic system of the economic belt, and the two are in a state of confrontational competition. In other words, there is a relationship of antagonistic symbiosis between the socioeconomic subsystem and the resource ecological subsystem in the economic belt in the enjoyment of natural resources.

According to the mechanism of symbiotic model described above, there is a complex relationship of competitive symbiosis between the economic system of economic belt and the resource ecosystem. Therefore, the L-V symbiosis model of social economy and natural ecology is expressed by the following formula: (subsystem I: economic system of economic belt; Subsystem II: resource ecosystem of economic belt)

$$\frac{dF(t)}{dt} = r_F F(t) \frac{C - F(t) - \alpha E(t)}{C} \tag{1}$$

$$\frac{dE(t)}{dt} = r_E E(t) \frac{C - E(t) - \beta E(t)}{C} \tag{2}$$

Due to the limitation of space, this paper omits the description and derivation of the Lotka-Volterra symbiosis model and only briefly describes its basic formula. In the formula, $F(t)$ represents the development level index of subsystem I; $E(t)$ represents the ecological level index of subsystem II; C is the environmental capacity index; r_F is the growth rate of socioeconomic development level; r_E is the growth rate of the ecological level of the natural environment;" $\alpha(\beta)$" is the competition coefficient, which represents the promoting or hindering effect of subsystem I on subsystem II (subsystem II on subsystem I); t is the time variable.

2.2. *Construct DPSIR model and ecological security index system*

Through DPSIR model, ecological security index system is constructed to accurately measure social development level index F(t), natural ecological level index E(t) and environmental capacity index C. DPSIR model mainly reflects the relationship between human activities, economic development and natural ecological environment from five aspects of driving force, pressure, state, impact and response. The driving force of social economic system (D) in economic belt improves the resource and environmental situation of the resource ecosystem in the economic belt (S), and the pressure (P) of socioeconomic system in the economic belt negatively destroys the state of the resources ecosystem in the economic belt (S). Therefore, The driving force (D) and pressure (P) can be used to construct the measurement index of the socioeconomic development level index F(t)of the economic belt; the state (S) and impact (I) represent the impact of the socioeconomic driving force and pressure on the natural ecological environment, which can be used to construct the measurement index of ecological level index E(t). Human response (R) represents the positive actions taken by humans to protect the ecology and the behaviors that damage and harm the ecological environment. It can be used to construct the measurement index of environmental capacity index C together with the state (S) of the resource ecosystem in the economic belt. In this paper, according to relevant scholars' studies on the evaluation index system of ecological security in the Yangtze river economic belt, based on DPSIR model, the evaluation index system of ecological security in the Yangtze river economic belt was constructed. Besides, clustering analysis method and coefficient of variation method were used to quantitatively select indexes. Finally, the weight of each index after screening was determined according to the entropy weight method. The final determined indicator system and its specific meaning and weight are shown in table 1.

Table 1. DPSIR model index construction and index weight

Target layer	Criterion layer	Index layer	Index meaning	Index attribute	Index weight
Ecological security	Driving force (D)	Resident consumption level	Reflect the driving force of residents' consumption capacity to regional development	+	0.0449
		GDP growth rate	Reflect the level of social and economic development and the ability to improve the natural environment	+	0.2314
		Number of domestic invention patent applications granted	Reflect the drive of regional innovation to social development	+	0.0872
		Contribution rate of final consumption expenditure	Reflect the driving force of regional consumption expenditure on the economy	+	0.0299
	Pressure (P)	Regional population growth rate	Reflect the pressure of regional population growth on the natural environment	-	0.0297
		Total regional water consumption	Reflect the pressure of water resources demand for regional social and economic development	-	0.0187
		Proportion of secondary industry	Reflect the pressure of industrial and construction industry development on regional resources and environment	-	0.0366
		Energy consumption per unit of GDP	Reflect the energy consumption per unit of economic output value and the pressure and intensity of energy demand	-	0.0095
		Land area purchased by real estate companies	Reflect the pressure of regional commercial and residential land on land resources	-	0.0123
	State (S)	Built-up area	Reflect the state of urban construction	-	0.0216
		Forest stock	Reflect the status of regional forestry resources	+	0.0955
		Food output per capita	Reflect regional food security state	+	0.0250
		Population density	Reflect the current regional population carrying state	-	0.0298
	Response (R)	Internal expenditure on research and experimental development	Reflect the ability of regional scientific research to improve ecology	+	0.0652
		Total afforestation area	Reflect the forestry response to the protection of ecological security	+	0.0544
		Environmental protection investment	Reflect the overall attention to environmental protection	+	0.0687
		Harmless treatment capacity of household garbage	Reflect the response of residents' life and urban construction	+	0.0542
	Impact (I)	Number of parks	Reflect the impact of ecological construction on the urban environment	+	0.0509

Sulfur dioxide emissions	Reflect the impact of social and economic development on the atmospheric environment	-	0.0240
Affected area	Reflect the impact of social and economic development on natural disasters	-	0.0103

2.3. *Measurement of basic index and competition intensity coefficient*

The calculation formulas of environmental capacity index C, socioeconomic development level index F and natural ecology level index E are as follows:

$$\theta = \Sigma^{n}_{i=1} x^{*}_{i} w_{i} \tag{3}$$

In the formula, θ represents the basic indices; X^{*}_{i} is the standardized value of the i-th index; W_{i} represents the combined weight.

To calculate the competition coefficient, formula (1) and (2) are discretized in this paper, and year k is taken as the discretized time variable. Assuming that the environmental capacity and the competition coefficient are constant near year k, formula (3) and (4) can be changed into:

$$F(k+1)-F(k)=\frac{F(k)-F(k-1)}{F(k-1)}F(k)\frac{C(k)-F(k)-\alpha(k)E(k)}{C(k)} \tag{4}$$

$$E(k+1)-E(k)=\frac{E(k)-E(k-1)}{E(k-1)}E(k)\frac{C(k)-E(k)-\beta(k)F(k)}{C(k)} \tag{5}$$

In the formula, each symbol is the value of year k, year k-1 and year k+1, and its meaning is the same as that of formula (1) and (2).So,

$$\alpha(k)=\frac{[\varphi_{\mathrm{F}}(k)C(k)-F(k)]}{E(k)} \tag{6}$$

$$\beta(k)=\frac{[\varphi_{\mathrm{E}}(k)C(k)-E(k)]}{F(k)} \tag{7}$$

$$\varphi_{\mathrm{F}}(k)=1-\frac{F(k+1)-F(k)}{F(k)}\times\frac{F(k-1)}{F(k)\text{-}F(k-1)}=1-\frac{r_{\mathrm{F}}(k+1)}{r_{\mathrm{F}}(k)} \tag{8}$$

$$\varphi_{\mathrm{E}}(k)=1-\frac{E(k+1)-E(k)}{E(k)}\times\frac{E(k-1)}{E(k)-E(k-1)}=1-\frac{r_{\mathrm{E}}(k+1)}{r_{\mathrm{E}}(k)} \tag{9}$$

According to the above calculation principle and the measurement index system constructed and the weight calculated by the entropy weight method, the environmental capacity index C, the social and economic development level index F, the natural ecology level index E, as well as the competition coefficient α and β can be obtained from 2009 to 2016.

2.4. *Construction of symbiosis index and ecological security criterion of economic belt*

According to competition coefficient α and β , driving force index of socioeconomic system of economic belt to resource ecosystem $S_F(k)$[$S_F(k)$= -α(k)] and the pressure index of the economic system of the economic belt endured by the resource ecosystem $S_E(k)$[$S_E(k)$= -β(k)] can be obtained respectively. Construct a symbiosis index to judge the pros and cons of the symbiotic relationship between the socioeconomic subsystem and the resource ecological subsystem of the economic belt on the basis of $S_F(k)$ and $S_E(k)$.

$$S(k)=\frac{S_{\mathrm{F}}(k)+S_{\mathrm{E}}(k)}{\sqrt{S_{\mathrm{F}}^{2}(k)+S_{\mathrm{E}}^{2}(k)}} \qquad (10)$$

Compared with the socioeconomic development level index F, ecological level index E and environmental capacity index C, the symbiosis index $S(k)$ can better represent the ecological and economic significance of the economic belt and reflect the internal reasons for the ecological security of the economic belt, which is conducive to the governance and regulation of policy makers. According to the principle that the denominator of formula 10 is greater than 0, the value range of $S(k)$ can be calculated as $[-\sqrt{2},\sqrt{2}]$. In this range, the greater the $S(k)$ value is, the better the symbiotic relationship between the socioeconomic subsystem of the economic belt and the resource ecological subsystem will be, and the higher the degree of mutual benefit will be; while the smaller the $S(k)$ value is, the worse the symbiotic relationship between the two subsystems will be, and the higher the degree of mutual harm will be. Therefore, the natural ecological pressure index $S_E(k)$ and symbiosis index $S(k)$ are used to evaluate the ecological security state and security level of the economic belt, and divides the ecological security state of the economic belt into 7 categories, corresponding to 7 ecological security levels (mark grade area with color: seven-color diagram), as shown in table 2.

Table 2. Ecological security status and security levels of the economic belt

Sequence number	Ecological pressure index $S_E(k)$	Symbiosis index $S(k)$	Symbiotic relationship	security state	Grade color
1	$S_E(k)<0$	$-\sqrt{2}<S(k)<-1$	The social economy and ecology are competing and damaging each other	Extreme risk	Red indicates hazard
2	$S_E(k)<0$	$-1<S(k)<0$	Socioeconomic earns little and there is serious ecological damage	Significant risk	Black indicates risk
3	$S_E(k)<0$	$0\le S(k)<1/3$	Socioeconomic earns more and there is serious ecological damage	General risk	Yellow indicates risk
4	$S_E(k)>0$	$-1\le S(k)<0$	Serious socioeconomic losses and small ecological gains	Lower risk	Orange indicates risk
5	$S_E(k)<0$	$1/3\le S(k)<1$	Socioeconomic earns more and there is small ecological loss	Low risk	Purple indicates risk
6	$S_E(k)>0$	$0\le S(k)<1$	Small socioeconomic losses and ecology benefits more	Safe	Blue indicates security
7	$S_E(k)>0$	$1\le S(k)\le\sqrt{2}$	Social economy and ecology are mutually beneficial and harmonious	Extremely safe	Green indicates security

3. Overview of the study area and data sources

As one of the "three strategies" to promote regional development in China, the Yangtze river economic belt geographically includes backward provinces in the west such as Sichuan, Yunnan and Guizhou, developed provinces and cities such as Shanghai and Zhejiang, and central provinces and cities such as Hubei, Chongqing and Jiangsu. Although the land area of Yangtze river economic belt only accounts for 21.4% of the country, its population and GDP account for 42.9% and 44.1% of the country's total population and GDP respectively, playing an important engine role in China's economic development. Relying on the golden waterway of the Yangtze River, the Yangtze River Economic belt has a unique advantage for inland navigation. Moreover, the Yangtze River Economic Belt has developed transportation, dense population, abundant resources, high degree of urbanization, and considerable consumer demand. In addition, the Yangtze river delta urban agglomeration and urban agglomeration in the middle reach of Yangtze river, the Chengdu-chongqing urban agglomeration are closely linked with dense population and high urbanization degree, and consumer demand is considerable. Therefore, the economic growth space of the Yangtze river economic belt is huge, but the ecological security situation is very serious, restricting the high-quality development of the region.

The data required in this paper are from "China's statistical yearbook", "China's statistical bulletin", national data, and the statistical yearbook and bulletin of 11 provinces and cities under the jurisdiction of the Yangtze river economic belt from 2008 to 2017. For some missing data, the average value and interpolation method of adjacent recent years are adopted to calculate and supplement.

Materials and Methods should be described with sufficient details to allow others to replicate and build on published results. Please note that publication of your manuscript implicates that you must make all materials, data, computer code, and protocols associated with the publication available to readers. Please disclose at the submission stage any restrictions on the availability of materials or information. New methods and protocols should be described in detail while well-established methods can be briefly described and appropriately cited.

Research manuscripts reporting large datasets that are deposited in a publicly available database should specify where the data have been deposited and provide the relevant accession numbers. If the accession numbers have not yet been obtained at the time of submission, please state that they will be provided during review. They must be provided prior to publication.

Interventionary studies involving animals or humans, and other studies require ethical approval must list the authority that provided approval and the corresponding ethical approval code.

4. Research results and analysis

4.1. *Comprehensive evaluation results of ecological security in the Yangtze river economic belt*

The higher the ability of harmonious symbiosis between socioeconomic system and resource ecosystem in economic belt, the safer the ecological environment will be. According to the above studies, the symbiosis index S(k) can represent the symbiosis relationship between the two subsystems. Therefore, after measuring the ecological security of the Yangtze river economic belt from 2008 to 2017, this paper made a judgment on the state and level of ecological security of the economic belt by combining the ecological level index and the symbiosis index.

Based on the empirical analysis of the ecological security situation of the Yangtze river economic belt from 2008 to 2017, the basic indexes such as socioeconomic system development level index, resource ecosystem development level index and environmental capacity index are obtained, as shown in figure 1.

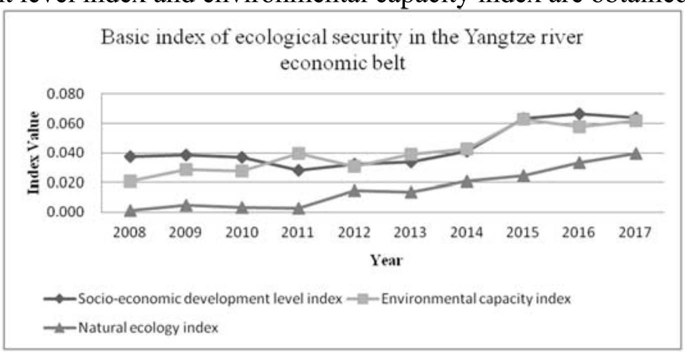

Figure 1. Basic index of ecological security in the Yangtze river economic belt

As can be seen from figure 1, since 2008 the socioeconomic development level index of the Yangtze river economic belt showed an rising trend. The reasons for the rise in the level of socioeconomic development mainly include two aspects, On the one hand, the three major opening-up strategies implemented by China in the 1990s promoted the comprehensive opening up of the Yangtze River Basin. After 20 years of long-term accumulation, the Yangtze River Economic Belt has become the world's leading industrial belt; On the other hand, the alleviation of socio-economic development pressure is also contributing to the growth of the socio-economic development level. The investment in science and technology and the upgrading of the industrial structure have caused the energy consumption per unit of GDP to continue to decline, and the economic growth mode is healthier, so the overall social and economic development level index is on the rise.

The overall level of natural ecological construction in the Yangtze River Economic Belt is relatively low, but the trend is rising. The main reason for this trend is that since 2000, the local "GDP-only" extensive economic growth mode has led to the large-scale occupation of ecological land, the reduction of vegetation coverage, and the ability of the original ecosystem to conserve water and fix carbon and reduce emissions Greatly weakened, the level of ecological construction is at a very low level, especially in the middle and lower reaches of the Yangtze River, where the population is dense, but the manufacturing industry and industry are still the main industries driving its economic growth. Over time, it will only make seriouly ecological damage. However, in recent years, the country has placed ecological civilization in an important strategic position and actively repaired the ecological environment in the Yangtze River Economic Belt. Technology has led to changes in the industrial structure and lifestyle, while the development of environmentally friendly and healthy lifestyles and high-tech industries have also reacted to the aquatic ecology, land ecology and atmospheric environment of the economic belt, forming a benign ecological cycle.

The environmental capacity index of the Yangtze river economic belt showed an overall upward trend from 2008 to 2017. Although the upward range was obvious, the upward process fluctuated slightly. Because the development of social economy is supported by the consumption of natural resources, the natural resources in the river basin are limited. With the urbanization of the Yangtze River Economic Belt, the built-up area and population density continue to increase, and the per capita water consumption rises, resulting in per capita water resources decrease, but as the government continues to increase investment in science and technology, technological progress and industrial structure upgrades have been achieved, resources and environmental conditions such as per capita grain output have also improved.

Based on the measurement results of the three basic indexes above, the ecological security state of the Yangtze river economic belt from 2009 to 2016 are comprehensively evaluated in the following part, and the corresponding security level is given, as shown in figure 2.

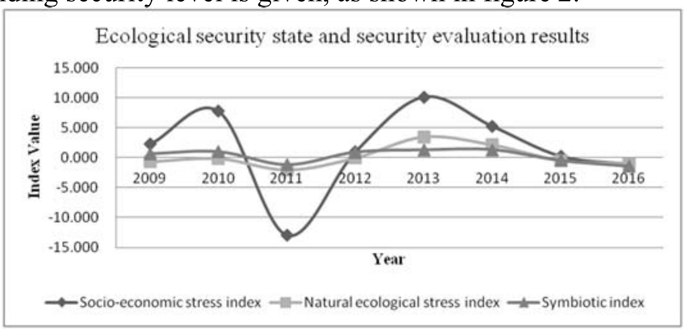

Figure 2. Ecological security state and security evaluation results

As can be seen from figure 2, except for 2011 and 2016, the socioeconomic stress index S (F) of the Yangtze river economic belt was greater than zero, indicating that the resource ecological subsystem can promote the development of the socioeconomic subsystem. Natural ecological stress index S (E) was greater than zero only in 2013 and 2014, which is affected by the positive force of socioeconomic subsystem. In 2013 and 2014, symbiotic index were greater than 1, showing that the resource ecosystem and the socioeconomic development system coexist in harmony and promote each other, and the ecological state is in the safest state. But in the rest of the years, the resource ecosystem and socioeconomic subsystem were in a state of confrontation or obstruction, especially in 2011, 2015, symbiotic index was less than zero, indicating that the ecological condition is in a high-risk or medium-risk state, and the ecological environment has deteriorated.

Therefore, through the above analysis, it can be seen that the interaction between the socioeconomic subsystem of the economic belt and the resource ecological subsystem, that is, the symbiosis degree of the two systems determines the final state of ecological security.In 2008 and 2009, ecological security along the Yangtze river economic belt has been in a state of low risk, namely resources ecosystem was slightly damaged, but the socioeconomic system benefited more. if the human can response to alleviate the ecological pressure in time, the Yangtze river economic belt is expected to be towards a harmonious symbiosis of green and safe state.

4.2. *Evaluation results of ecological security of provinces and cities in the Yangtze river economic belt*
Based on the above studies, this paper specifically measured the stress status and symbiosis index of ecological security of 11 provinces and cities in the Yangtze river economic belt from 2009 to 2016, and obtained the evaluation results of their ecological security state and security grade as shown in figure 3- figure 4 and table 3. Due to space limitations, this article only analyzes the ecological security status of major provinces in the Yangtze River Economic Belt.

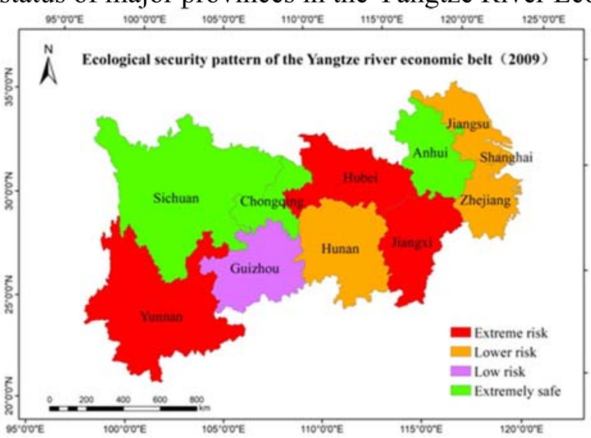

Figure 3. Ecological security pattern of the Yangtze river economic belt (2009)

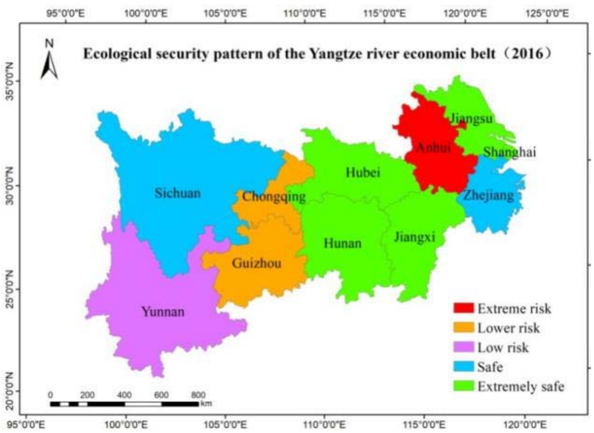

Figure 4. Ecological security pattern of the Yangtze river economic belt (2016)

The figure 3 shows that the ecological pattern of the provinces and cities in the Yangtze River Economic belt as a whole shows a good trend. There are nearly 1/2 provinces and cities whose ecological security status is in a green security state. Only Anhui province shows signs of ecological deterioration. The overall pattern of ecological security has shifted from being more dangerous in the central and eastern regions and southwestern regions, being more safe in the northwest region, being more safe in the eastern region, and weaker in the western region. According to Table 3, in 2016, Shanghai, Jiangsu, Jiangxi, Hunan and Hubei were all in a green and safe state, that is, $S(E)$ >, $1<S(k)<\sqrt{2}$. The socioeconomic subsystem and the resource ecological subsystem promote each other and coexist harmoniously.

The basic ecological security index from 2009 to 2016 in the region was analyzed to obtain its evolution trend of ecological security. From the stress index $S(F)$ of socioeconomic subsystem, Shanghai, Jiangsu, Jiangxi, Hunan, Hubei are rising, showing that the socioeconomic subsystem has been positively supported by the resource ecological subsystem, which has promoted its rapid development. Moreover, as the economic center of China, Shanghai has been leading and driving the development of the Yangtze River Economic belt. Combined with natural ecological level index and symbiotic index, the built-up area and the land area purchased by real estate companies in Jiangsu province continued to increase in 2010, but there was no significant change in the green coverage, forest volume, and urban sewage treatment capacity of the built-up area, resulting in the occupation of ecological land in Jiangsu province and the reduction of the total area, and the ecological ability of land and water conservation is greatly reduced. However, after 2012, human beings realized that the ecological security was at risk, so they took corresponding ecological restoration actions in a timely manner, making the ecological security situation in Jiangsu province gradually improve from 2012 and turn to a green security state. The natural ecological level index of Shanghai, Hunan and Hubei provinces has been rising rapidly from 2008 to 2017, realizing the crossing from the general risk state to the high-level security state. However, there are fluctuation and drops in some years, which is a normal phenomenon of the development of ecological security.

Table 3. Evaluation results of ecological security grades of provinces and cities in the Yangtze river economic belt

Region	2009	2010	2011	2012	2013	2014	2015	2016
Shanghai	Orange danger	Green safe	Green safe	Orange danger	Blue safe	Orange danger	Green safe	Green safe
Jiangsu	Orange danger	Green safe	Purple danger	Black danger	Orange danger	Green safe	Green safe	Green safe
Zhejiang	Orange danger	Green safe	Green safe	Blue safe	Orange danger	Blue safe	Green safe	Blue safe
Jiangxi	Red harm	Purple danger	Orange danger	Green safe	Orange danger	Green safe	Orange danger	Green safe
Anhui	Green safe	Orange danger	Green safe	Green safe	Purple danger	Blue safe	Purple danger	Red harm
Hunan	Orange danger	Orange danger	Green Safe	Purple danger	Black danger	Blue safe	Orange danger	Green Safe
Hubei	Red harm	Purple danger	Green safe	Green safe	Purple danger	Green safe	Orange danger	Green safe
Chongqing	Green safe	Purple danger	Green safe	Green safe	Purple danger	Blue safe	Green safe	Orange danger
Sichuan	Green safe	Red harm	Green safe	Black danger	Red harm	Blue safe	Green Safe	Blue safe
Yunnan	Red harm	Orange danger	Red harm	Green safe	Purple danger	Red harm	Red harm	Purple danger
Guizhou	Purple danger	Purple danger	Yellow danger	Green safe	Purple danger	Green safe	Purple danger	Orange danger

In 2016, the ecological security belt was in the red hazard state ($S_E(k)<0$, $-\sqrt{2}<S_E(k)<-1$) in Anhui province, indicating that the socioeconomic subsystem and the resource ecological subsystem of Anhui province were in the mutual harmful mode of mutual obstruction and inhibition. The change of the ecological security index of Anhui from 2009 to 2016 showed that in addition to 2010, the ecological security state from 2009 to 2012 in Anhui province was safe, mainly because most cities in Anhui province are inland cities, the industrial structure was relatively backward, there were few large-scale industrial enterprises with serious pollution, the ecosystem was relatively intact, water resources per capita, environmental protection investment amount and other states and response indicators all showed a growing trend; But after 2012, the ecosystem of Anhui province changed from a safe state to a general risk state, and finally entered an extremely risky state. With the development of economy, the urbanization process is accelerated, the life pollution and industrial pollution is

IOP Conf. Series: Earth and Environmental Science **568** (2020) 012008 doi:10.1088/1755-1315/568/1/012008

aggravating, the level of human response failed to catch up with the speed of ecological destruction, suggesting that the development of socioeconomic subsystem pose a threat to the development of resource ecological subsystem, and resources ecosystem is destroyed, obstructing and inhibiting the development of socioeconomic subsystem. The economic growth mode of Anhui province still belongs to the mode of economic development at the expense of ecological environment.

In 2016, the provinces and cities where the ecological security was between the extreme risk state and the security state are mainly Zhejiang, Sichuan, Chongqing, Yunnan, Guizhou, of which Zhejiang and Sichuan are in a blue security state ($S_E(k)>0$, $0\leq S(k)<1$), that is, there is small economic loss and ecology benefits more, and ecological security is in good condition. Through the analysis of the change of ecological security index from 2009 to 2016 in Zhejiang and sichuan, it is found that the ecological security state of Zhejiang and Sichuan have experienced a reciprocating process from harmony to danger to harmony. Sichuan is located in the upper reaches of the Yangtze River, with sufficient sunlight, abundant rainwater, abundant mineral resources and forest biological resources, and has a good ecological foundation. Therefore, before 2011, Sichuan's ecological security state was in a state of mutualism and symbiosis. After 2011, due to ignoring the deterioration of the ecological environment in the early stage and illegally developing and constructing various projects, mining natural resources, developing heavy industries such as steel manufacturing and non-ferrous metals, extensive tourism development that destroys the natural environment, and the acceleration of the urbanization process aggravated the damage to the ecological environment to varying degrees, so the ecological security situation in Sichuan province finally entered a high-risk state in 2013. After 2013, the government realized the severe situation faced by the ecological environment, and it started to adjust industrial layout, introduced high-tech incubation enterprises, increased the urban green coverage rate and forest coverage rate, improve the capacity of household waste treatment, gradually improving the ecological environment.

5. Conclusion and suggestion

5.1. *Conclusion*

The characteristics index method and the index system method are used to construct the ecological security measurement model of the Yangtze river economic belt in this paper to measure and analyze the ecological security state of the Yangtze river economic belt. Based on this, this paper draws the following conclusions:

(1) From the point of time evolution, from 2008 to 2017, the socioeconomic development level index and natural ecological index of the Yangtze river economic belt showed a rising trend in fluctuation. The starting point of the ecological index is low and the rate of rise is slow. It shows that the overall ecological carrying capacity of the Yangtze River Economic belt is low. While the economy is developing rapidly, the regional ecological situation has improved but not obvious. From the interaction between socioeconomic subsystem and resources ecological subsystem, from 2009 to 2016, the stress direction of social economy in the Yangtze river economic belt is positive, while the stress direction of natural ecology is mostly negative, indicating that the harmful pattern of social and economic development hindering and infringing on the development of natural ecology has not been changed. If this development pattern continues for a long time, it will not only cause the deterioration of regional ecological security, but also inhibit economic development.

(2)Through the reverse decoupling of the indicators, it is found that the over-exploitation of natural resources along the Yangtze river, the serious pollution of the intensive chemical industry in the downstream and the large emission base of pollutants have become the important reasons hindering the improvement of ecological security in the Yangtze river economic belt. On the other hand, urbanization development and construction in some areas severely occupy the ecological space of rivers and lakes with serious domestic pollution and agricultural pollution. There are prominent conflicts between economic development and ecological protection.

(3) Due to the large span of the Yangtze river economic belt, the spatial difference of ecological security is particularly significant. In 2016, the ecological security of Shanghai, Jiangsu, Jiangxi, Hunan, Hubei and other places has been in a state of harmonious symbiosis, while the ecological security of Anhui, Yunnan, Guizhou and other places is still in a dangerous or fragile state.

5.2. *Suggestions*

(1) The primary task of the Yangtze river economic belt is to solve the problem of industrial distribution, and the provinces should focus on optimizing the industrial distribution along the river. It should be guided by the strategic direction of protecting ecology and harmonious development and the path orientation of protecting first and then developing. Define the red line of ecological protection, the bottom line of environmental quality and the resources utilization.

(2) Ecological restoration of the Yangtze River Economic belt requires comprehensive promotion of pollution control, and increase the intensity of natural protection of the ecological compensation and protection of drinking water sources. Increase investment in pollution control funds and scientific and technological support to areas with excessive pollutant emissions, and encourage and support the relocation of polluting enterprises.

(3) Promote green development and strengthen source prevention. The development of green and high quality needs to vigorously promote the development of the environmental protection industry, adjust the industrial structure from the source of pollution damage, strictly control the scale and number of high-pollution enterprises, and cultivate new growth momentum.

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IOP Conf. Series: Earth and Environmental Science **568** (2020) 012008 doi:10.1088/1755-1315/568/1/012008

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