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Assessment of Forest Ecological Security in China Based on DPSIRM Model: Taking 11 Provincial Administrative Regions along the Yangtze River Basin as Examples

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Abstract: China's forest ecological problems are becoming increasingly serious, especially in the Yangtze River Basin (YRB) area. The basin has rich species resources and a well-developed natural forest management and conservation policy. Taking the YRB as the object, we combine the DPSIRM model to build a forest evaluation system containing 6 criterion layers and 24 indicator layers. The entropy weight method-TOPSIS and ArcGIS were combined to assess the forest state and the distribution characteristics of the 11 regions. Furthermore, grey relational analysis (GRA) was used to study the influencing factors of forest status. The results are as follows: (1) the comprehensive index of the YRB forests increased by 192.66% during the study period. The forest status showed the stage characteristics of small climb, basic flatness, and significant improvement. (2) The forest status varied significantly among provinces (cities), with Tibet (0.483) in the best condition and Qinghai (0.103) in a worse condition. (3) Except for Tibet, the rest of the regions are more influenced by the extent of development of the economy. (4) The factor most strongly correlated with the YRB is the forest response (R) indicator.

Keywords: forest; evaluation index system; watershed; entropy method-TOPSIS; GRA

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1. Introduction

Forests are the most biologically rich ecosystems on land and they have a very effective role in regulating biological homeostasis. Economic development cannot be at the expense of forest integrity, which is protected for the sake of sustainable economic development. Rapid economical and societal growth has led to the accelerating process of eco-industrialization and urbanization [1,2]. This has damaged the balance of the forest ecosystem to some extent. At the same time, crude economic growth threatens the survival of human, animals, and plants. It follows that maintaining the sustainability of forest ecosystems is particularly important. The Yangtze River Basin (YRB) is the world's third major basin and an important ecological security barrier in China [3]. With its massive river and river–lake aquatic system and distinct and integral natural biological ecosystem, the Yangtze preserves an essential treasure trove of biological genes in China. At the same time, the YRB has abundant water, soil, forest, and coal deposits, which guarantee the country's water security, food, and fuel security [4]. The governance and exploration of the basin has nurtured a population of about 459 billion and given birth to the Yangtze River conservancy. Since ancient times, the Yangtze River has played a vital role in China's economy, culture, and ecology [5].

Ecological security is defined as the state of healthy and intact ecosystems [6] and is an important component of national security [7]. Forest ecosystems are integrated ecosystems [8–10]. Forests not only provide tangible forest products for people's existence and growth, but also perform a significant function in air maintenance, water conservation and tourism recreation [11,12]. Forests are both an important natural resource and an irreplaceable environmental resource. Forests are the most important base for conservation biology. However, there are many threats to forest resources in China and even worldwide [13], such as indiscriminate logging, the illegal occupation of forest land, fires, and pest and rodent infestation [14]. These threats have upset the balance of the existing forest ecosystems and even caused the degradation of certain ecological functions. Especially in the YRB, urbanization and industrialization have accelerated in the last decades. This has led to frequent flooding, severe soil erosion, depletion of plant and animal resources, and an increasingly critical forest situation in the YRB. Under the above backdrop, there is a strong and real urgency to scientifically assess the forest status within the YRB.

Currently, research on forest ecological security (FES) is centered on two aspects: factors influencing forest systems, and spatial and temporal changes [15–17]. On the one hand, some scholars study which factors are more damaging to forest systems, for example, forest decline, such as canopy thinning and abnormal defoliation, natural disasters, forest pests and rodents, and forest fires. Scholars hope to restore degraded forest ecosystems through effective management practices [18–20]. On the other hand, evaluation studies focused on spatial and temporal changes in forests [21] and tourists' perceptions [22]. In addition to evaluation studies, hierarchical analysis (AHP) [23,24], the entropy weight method [25], principal component analysis (PCA) [26], and the subjective evaluation method are more commonly used in evaluation methods. According to the above methods, most of the existing studies focus on the Yangtze River Basin region, the Yangtze River Basin region [27], and other regions with more prominent ecological and economic statuses. This shows that there is a lack of evaluation of the YRB. This may be since the YRB is very complex in terms of spatial span, ecosystems, and socioeconomic systems. The key question, then, that needs to be urgently addressed is how to enhance the usefulness of forest ecosystems in complex environments and to propose applicable evaluation methods.

We conducted research on the construction of the FES index system. Experts have used different models to build indicator systems [28,29], and then combined these with different disciplinary backgrounds [30,31]. Some models are, for example, the framework and methodology for constructing a forest resource carrying capacity index (FRCCI) and forest ecological security index (FESI), etc. However, the above indicators focus on forest hazards and forest resources [32]. For aspects such as response (R) and management (M), further improvements are needed. The current research on the definition, connotation, theoretical basis, and scientific selection of the indicators of the FES is relatively insufficient. The PSR (pressure-state-response) model [33–36] and DPSIR (driver-pressure-state-impact-response) model [37] are mainly used in the selection of FES evaluation models, and the DPSIRM model is less often applied.

Along with the quick development of the economy, this speeds up the processes of municipalization and commercialization. A huge quantity of forest habitat in the YRB has been occupied. The deteriorating regional forest ecology has resulted in the creation of worsening atmospheric poverty, frequent acid rain, and declining biological resources. Therefore, this study takes 11 provinces (cities) in the YRB as a research region with the evaluation model of the DPSIRM, aiming to dissect the forest ecosystem impact factors and their evolutionary trend characteristics from 2012 to 2021. Forest ecosystem mainly refers to the interaction between trees as the building block species and the ecological environment to form a relatively stable ecosystem. Among them, factors such as atmospheric heat and moisture conditions have a profound influence on forests. The research team put forward a proposed viewpoint for the conservation of forest ecology in the YRB. The findings contribute to the scientific basis of China's Yangtze River Forest conservation strategy and the high-level growth of the economic belt of the Yangtze River, and provide cases and references for watershed ecosystem management.

2. Methods

2.1. Method Flow

This research proposes a framework for a consolidated FES indicator framework based on the DPSIRM Model, and entropy-TOPSIS and GRA were selected to test the degree to which forest quality has evolved in the YRB. The main purpose was to first determine the indicator weights using the objective evaluation method entropy method, and then measure and evaluate the forest development level using TOPSIS method. Most of the previous studies have used methods such as principal component analysis, AHP, and entropy method. However, the explanatory significance of the principal component analysis method is not only ambiguous, but also requires a high cumulative contribution rate of the extracted principal components, which often cannot fully reflect the differences among the evaluation objects when the sample size is small, and the degree of differentiation is not high. With AHP, it is difficult to avoid the influence of subjective factors when determining the weights. Although the entropy method can better determine the differences between indicator states, it cannot reflect the gap between the actual and ideal levels of forest development when targeting the same evaluation object. For this reason, this study adopts the entropy-TOPSIS method to improve the evaluation object and the formula of positive and negative ideal solution values, on the one hand, so that the evaluation results can further match with the actual situation. On the other hand, it overcomes the shortcomings of AHP and traditional TOPSIS method, which mainly rely on experts' subjective opinions to determine the weights.

The specific methodological flow (Figure 1) was as follows: firstly, the six-dimensional indicator system was constructed based on the DPSIRM framework, drawing on existing studies. Secondly, there was data collection and processing. The study materials of the YRB, from China Statistical Yearbook, Water Resources Bulletin (2012–2021), the Soil and Hydrological Maintenance Bulletin (2012–2021), and the Ecological and Environmental Quality Status Bulletin (2012–2021), were collected and processed. Thirdly, we conducted a synthesis evaluation of the YRB by entropy weight-TOPSIS. The research team analyzed the horizontal level of development and vertical changes in 11 provinces (municipalities) within the YRB. Fourthly, the degree of impact of different indicators in the same region was compared in conjunction with GRA, since GRA can characterize the correlation between complex factors and does not require a high sample size. Therefore, this paper uses GRA to determine the association between forest condition and FES indicators of YRB to find the subjective association of FES indicators in each region [38].

2.2. Research Area

The field of research was the YRB (Figure 2). The geographical location was between 24°27′ N–35°54′ N and 90°33′ E–122°19′ E [39]. The basin is rich in landform types and has large elevation differences. The space–time distribution of rainfall in the basin is extremely heterogeneous. The yearly precipitation in the source area is less than 400 mm. Most of the remaining areas receive 800–1600 mm. The economic development of YRB is very uneven, and the effects of man's activism vary widely. Although the richness of landscape types offers a favorable habitat setting for the evolution of forest diversity, with the increasing human activities, forest diversity has, however, significantly decreased.

2.3. Research Methodology

The entropy-TOPSIS method combines the two methods to construct the entropy TOPSIS model, which reflects both the importance of each indicator and the dynamic evolution trend of the forest in a comprehensive way. The entropy method uses entropy to calculate the weight value based on the information provided by each evaluation index value in order to overcome some shortcomings. The TOPSIS method is used to determine the optimal and inferior solutions and to determine the distance between each comparison object and the optimal and inferior solutions.

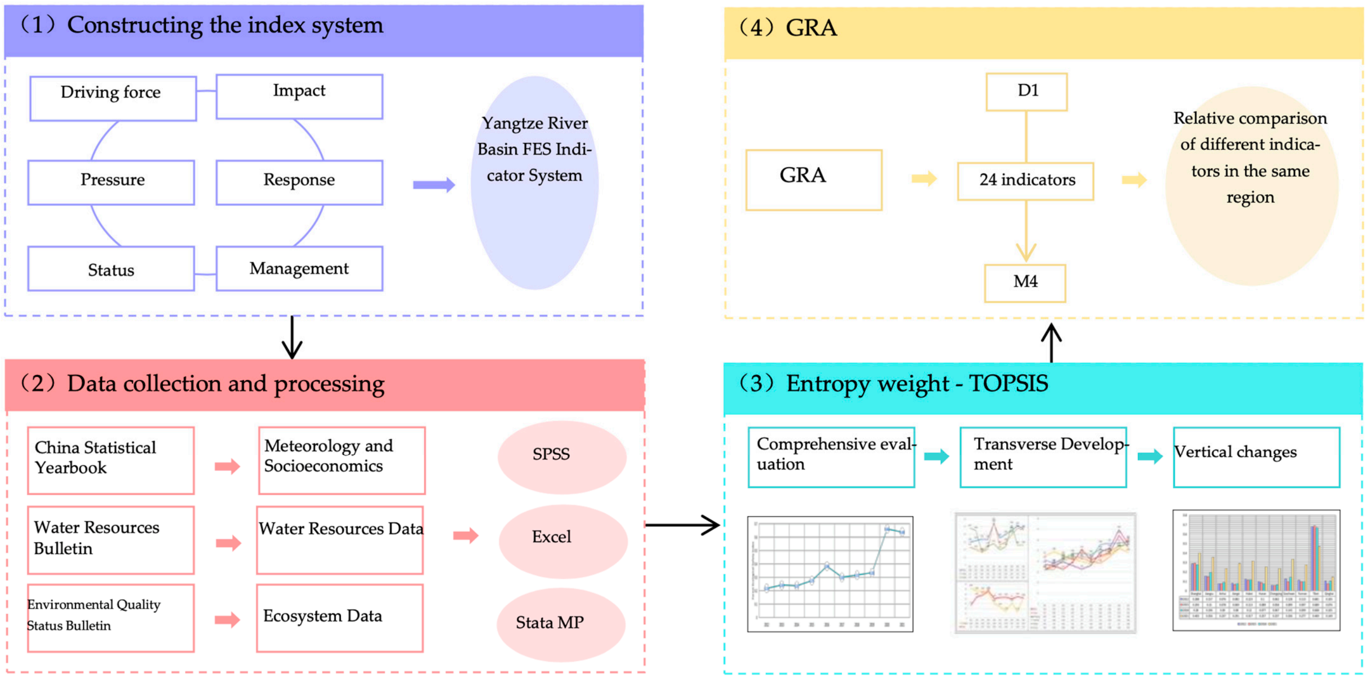


Figure 1. YRB FES Methodology Process.

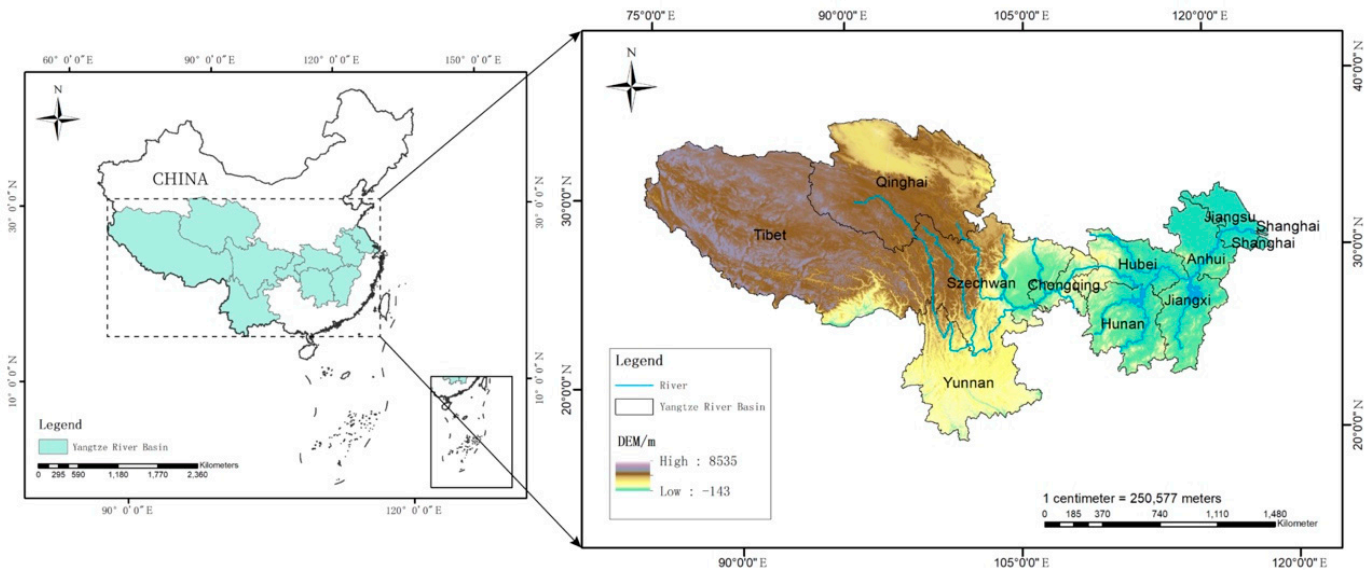


Figure 2. Study area of 11 provinces (cities) in the YRB, China.

The gray correlation method effectively measures the similarity and correlation between evaluation objects. The method measures the degree of relationship between indicators mainly based on the dependence of development dynamics among them. The gray correlation degree between each indicator and the research target is calculated separately by the correlation degree formula, which has certain accuracy and scientificity. The above two methods have different decision-making principles and bases and have good complementarity.

In addition, this study used ArcGIS for some of the data analysis, which is represented using maps. ArcGIS allows the use of built-in mapping tools and data analysis tools, for example, charting tools, spatio-temporal analysis tools, etc. The software helps users visualize and analyze geographic data.

The model decision-making process is as follows. Determine the evaluation object, collect the raw data, and obtain the initial decision matrix $X = (x_{ij})_{n\times m}$. Among them, $n = 25$. x_{ij} is the attribute value of the ith evaluation unit under the jth indicator.

In the first step, the indicators are normalized to obtain the normalized decision matrix $V = (v)_{n\times m}$. Equations (1) and (2) are the calculation steps.

$$V_{ij} = \frac{x_{ij} - \min\limits_{i}(x_{ij})}{\max\limits_{i}(x_{ij}) - \min\limits_{i}(x_{ij})} \tag{1}$$

$$V_{ij} = \frac{\max\limits_{i}(x_{ij}) - x_{ij}}{\max\limits_{i}(x_{ij}) - \min\limits_{i}(x_{ij})} \tag{2}$$

In the second step, the index weights are determined. In Equations (3)–(5), $w_j = (w_1, w_2, \cdots, w_n)$.

$$p_{ij} = v_{ij} / \sum_{i=1}^{m} v_{ij} \tag{3}$$

$$e_j = -1/\ln(m) \sum_{j=1}^{m} p_{ij} \cdot \ln p_{ij} \tag{4}$$

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

In the third step, in Equation (6), the matrix Y is obtained:

$$Y = (y_{ij})_{m\times n} = (w_j v_{ij})_{m\times n} \tag{6}$$

In the fourth step, calculate f_j^+ and f_j^- for Equations (7) and (8), respectively:

$$f_j^+ = \max_i(y_{ij}) \tag{7}$$

$$f_j^- = \min_i(y_{ij}) \tag{8}$$

In the fifth step, the gray correlation is calculated. Equations (9)–(12) calculate the correlation degree r_i^+ and r_i^-:

$$\gamma_{0ij}{}^{+} = \frac{\min\limits_{i}\min\limits_{j}\left|f_j{}^{+} - y_{ij}\right| + \rho \max\limits_{i}\max\limits_{j}\left|f_j{}^{+} - y_{ij}\right|}{\left|f_j{}^{+} - y_{ij}\right| + \rho \max\limits_{i}\max\limits_{j}\left|f_j{}^{+} - y_{ij}\right|} \tag{9}$$

$$\gamma_{0ij}{}^{-} = \frac{\min\limits_{i}\min\limits_{j}\left|f_j{}^{-} - y_{ij}\right| + \rho \max\limits_{i}\max\limits_{j}\left|f_j{}^{-} - y_{ij}\right|}{\left|f_j{}^{-} - y_{ij}\right| + \rho \max\limits_{i}\max\limits_{j}\left|f_j{}^{-} - y_{ij}\right|} \tag{10}$$

$$r_i{}^{+} = \frac{1}{n}\sum_{j=1}^{n} \gamma_{0ij}{}^{+} \tag{11}$$

$$r_i{}^{-} = \frac{1}{n}\sum_{j=1}^{n} \gamma_{0ij}{}^{-} \tag{12}$$

In the sixth step, the Euclidean distances d_j^+ and d_j^- are calculated. Equations (13) and (14) are calculated as:

$$d_j^+ = \sqrt{\sum_{j=1}^{n}\left(f_j^+ - y_{ij}\right)^2} \quad (13)$$

$$d_j^- = \sqrt{\sum_{j=1}^{n}\left(f_j^- - y_{ij}\right)^2} \quad (14)$$

It is worth mentioning that the FES score of YRB is [0, 1]. When the score is closer to 0, it means that the comprehensive level of forest ecological security is lower; when the score is higher than 1.0, the comprehensive level of forest ecological security is higher. Equation (15) is as follows:

$$T_j = \frac{D_j^-}{D_j^+ - D_j^-} \quad (15)$$

3. Index Creation and Database Origin

3.1. Index Establishment

Forest ecosystems are complex systems that contain multiple natural environmental factors and socioeconomic factors [40]. Human activities have intensified harmful disturbances to forest ecosystems. The traditional dynamical model cannot fully reflect the role of human social factors or realize the conceptual kernel of the forest concept which is highly concerned with human society. Compared with the pre-improvement model, the DPSIRM model contains more complete factors, broader coverage, and richer evaluation criteria. In this study, the DPSIRM model was used to establish the indicator system in evaluating the ecological security of YRB forests, and the DPSIRM model consists of six categories of factors: driving force, pressure, state, impact, response, and management. The proposed model introduces the management of waste (M) subsystem module in addition to the DPSIR Model. The management (M) subsystem represents the proactive human response to changes in environmental state [41], and the cost of inputs. In addition, the entropy-TOPSIS principle is to determine the weight values of evaluation indicators using the entropy weighting method, and then evaluate the YRB forest resource management performance by weighted TOPSIS measurement. The GRA determines the degree of correlation between two quantities based on the similarity of development trends between the reference series and the comparison series. Based on the above analysis, the research team developed the DPSIRM framework (Figure 3). The model can represent the implication of the factors and help to explain the factors affecting the forest.

Combined with the practical conditions of the research zone, the present research establishes the metrics according to the DPSIRM structure. Based on the DPSIRM Model, social, economic, environmental, resource, ecological, and other influencing factors were considered. Twenty-four evaluation indicators were selected from six aspects to build an indicator system containing three layers: a goal layer, guideline layer, and index layer (Table 1). In particular, the driving force (D) refers to the impact on the forest caused by the interaction between human activities and physical factors. Pressure (P) is the direct result of the driving factors, which is usually measured by the impact factors generated by human activities. State (S) refers to the state of forest wood quality, wood volume, and green cover changes produced by driving forces and pressures. Impact (I) refers to the result of changes in the forest under the influence of the above factors. Response (R) is a series of human responses forced by threats to the forest. Management of waste (M) is the proactive intervention and restoration measures used by government departments to reduce the destruction of forests due to anthropogenic practices.

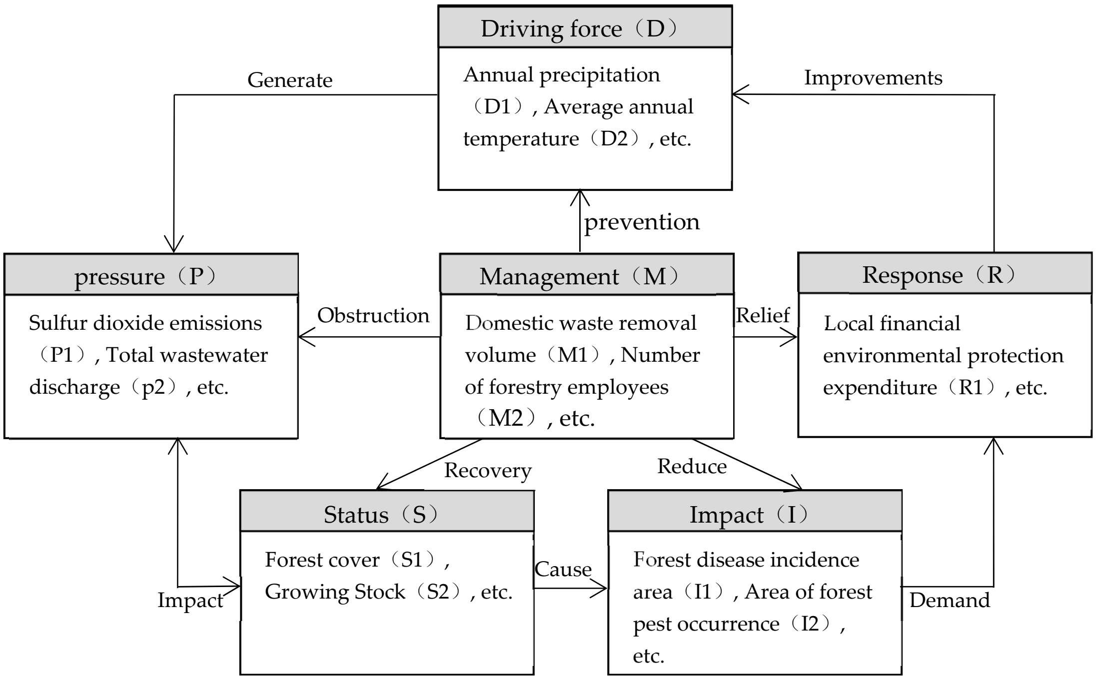


Figure 3. DPSIRM Framework.

Driving force indicators (D): four indicators were established to reflect the driving force of forest development. Drawing on existing studies, three positive indicators reflecting the drivers of forest in each region were set: annual precipitation (D1), average annual temperature (D2), and GDP per capita (D3). Usually, the higher the annual equivalents of regional precipitation, the greater the average temperature and longer the average duration of sunshine. The higher the soil productivity, the richer the biodiversity, and the higher the ecological quality of the forests. GDP per capita can measure the level of economic growth of each region in the YRB. The degree of industrial progress affects people's awareness of forest ecology protection. In the meantime, the level of industrial growth restricts the government's financial support for forest ecological construction. The value added of the secondary sector (D4) is set an inverse indicator. The value added of the secondary industry (D4) reflects the development scale of regional industrial industry; the larger the added value, the greater the intensity of mineral extraction and environmental damage.

Pressure indicators (P): drawing on existing studies, the pressure on the forest is expressed through four inverse indicators. Sulfur dioxide emissions (P1) refer to the overall intensity of emissions from regional industrial enterprises during production in a certain period. The greater the intensity in emissions, the more harmful this is to the natural ecosystem of the forest. Total wastewater emissions (P2) indicate that sewage not only harms forest security directly, but also harms forest quality indirectly by changing soil properties. The higher the population density (P3), the more human activity behavior interferes with the ecological stability of the forest. The higher the urbanization rate (P4) index, the more people depend on forest resources and their by-products, and the more destruction is caused to resources and the environment.

Status indicators (S): based on existing studies, four positive indicators are established to reflect the carrying capacity of regional forests at the current stage. Forest cover (S1) is the percent of forest cover over the surface of the region. S1 reflects the extent of coverage and actual occupancy of forest resources. Growing stock (S2) refers to the total stock of all trees on a certain range of land and is an important indicator of forest ecosystem health and productivity [42]. The amount of water resources per capita (S3) refers to the amount of water resources held by each person in the region, on average, according to the population, reflecting the abundance of forest water resources in each region. The severe per capita water resource situation has implications for the future sustainable development of China's forests and is worth exploring. The rate of good air quality (S4) refers to the proportion of monitoring days with good or better air quality within the YRB to the total monitoring days of the year. It indicates that forests have a very positive effect on air quality.

Impact indicators (I): drawing on existing studies, three inverse indicators were established to reflect the impact of forest ecological changes. The areas of forest disease occurrence (I1) and forest insect pest occurrence (I2) reflect the impact of forest ecology on the stability of its own ecological structure. Diseases, insects, and rodents are the main natural disasters in forests and are important factors leading to forestry losses. The decrease in the metric means that the forest ecology is more favorable, and the ecological structure is more stable. Direct economic damage from the natural hazard (I4) reflects the impact of the forest on the climatic environment. A lower metric indicates a higher forest ecology and significant climate regulation. Meanwhile, this study sets a positive indicator. Greening coverage of built-up areas (I3) refers to the percentage of greening coverage of built-up areas in urban built-up areas. Greening coverage area is the vertical projection area of all vegetation, such as trees, shrubs, and lawns, in the city. Urban planning focuses on greening, increasing green coverage in building design and layout, allowing more vegetation into the city, and improving urban air quality and comfort.

Response indicators (R): drawing on existing studies, four positive indicators are set to reflect the remedial measures taken passively by human society after the forest ecosystem is threatened or destroyed. Local financial expenditure on environmental protection (R1) and completed investment in industrial pollution control (R3) both reflect the government's attention to ecological environment construction and protection. The proportion of total afforestation area (R2) refers to the area of the region on 'forest-able' barren hills and wastelands or fallow land. The proportion of the artificially created forest area to the area of the regional national territory reflects the artificial afforestation efforts and green development status. As a biological disaster, forest diseases, bugs, and plagues are a serious threat to the integrity of forest ecosystems. Although there are various reasons for the occurrence of pests, diseases, and rodents, certain protection and control measures can suppress the occurrence of these disasters. Forest disease, insect, and rodent control rate (R4) is the rate of control taken passively by humans after the formation of diseases, insects, and rodents in the forest.

Management of waste (M): this is the manifestations of more proactive human implementation of positive interventions and restoration of forest ecological order. Drawing on existing studies [43], four positive indicators were established to reflect the proactive management measures taken by human society in response to ecological changes. Domestic waste disposal capacity (M1) is the amount of domestic waste collected and delivered to each domestic waste treatment site and the domestic waste final disposal point during the reporting period. Daily wastewater treatment capacity (M3) is the design capacity of wastewater treatment plants and wastewater treatment units to treat the amount of wastewater per day and night. M1 and M3 reflect the cost of pollution treatment invested by regional industrial growth. Meanwhile, M1 and M3 are important indicators reflecting the intensity of local pollution treatment, the higher the value, the stronger the intensity of pollution treatment. The number of personnel employed in forestry (M2) can reflect the scale of regional manpower for forestry construction and management. As forest resources reach maturity, the volume of business in the forestry sector is expected to continue to grow in the future. To consolidate ecological achievements, expand the scale of governance, accelerate industrial development, and improve management, the forestry industry will inevitably need to be supported by a larger and better-qualified team of forestry professionals. Harmless treatment factory (M4) refers to a variety of household waste treatment facilities designed, constructed, operated, maintained, and managed in accordance with relevant technical, environmental and health standards and specifications, mainly including sanitary landfills, composting plants, and incineration plants, etc. Improper disposal of waste in landfills and less than strict on-site engineering treatment can easily contaminate the soil environment. Soil is the main factor for the growth and development of forest trees in the forest. Soil structure, soil type, and soil texture directly affect the growth and development of forest trees, moreover, they affect the continuous annual growth of forest trees, and affect the wood production and wood quality of forest trees. Therefore, having enough plants is an important basis for strengthening forestry and ensuring forest quality.

Firstly, the awareness of environmental protection of enterprises is an important manifestation of social responsibility. Participating in social environmental protection activities is not only an obligation, but also an important path to sustainable development. Secondly, the government is always concerned with the smooth implementation of ecological environmental protection. The government should raise the construction of regional ecological civilization to the same level of importance as economic development. Thirdly, the root of environmental protection is to raise people's awareness of environmental protection. Low-carbon environmental protection should not only attract the attention of the government and enterprises, but also be a popular concept for the public and draw the attention of the whole society.

Table 1. YRB FES Indicator System.

Target Layer	Guideline Layer	Indicator Layer (Nature)	Unit	References	Weights
A: Comprehensive Evaluation of Forest Ecological Security in the YRB	Driving force (D)	D1: Annual precipitation (+)	mm	Tyrväinen, L., et al. (2014) [44]	0.0301
		D2: Annual average temperature (+)	Degrees Celsius		0.0220
		D3: GDP per capita (+)	Million yuan		0.0342
		D4: Secondary industry value added (+)	Billion		0.0332
	Pressure (P)	P1: Sulfur dioxide emissions (−)	Million tons	Lu, S., et al. (2019) [45]	0.0494
		P2: Total wastewater discharge (−)	Million tons		0.0424
		P3: Population density (−)	People/square kilometer		0.1705
		P4: Urbanization rate (−)	%		0.0814
	Status (S)	S1: Forest cover (+)	%	Gaoue, O. G., et al. (2011) [46]	0.0318
		S2: Growing Stock (+)	Billion cubic meters		0.0266
		S3: Water resources per capita (+)	Cubic meter/person		0.0217
		S4: Excellent air quality rate (+)	%		0.0266
	Impact (I)	I1: Area of forest disease incidence (−)	Million hectares	Alig, R. J., et al. (2006) [47]	0.0730
		I2: Area of forest pest incidence (−)	Million hectares		0.0528
		I3: Greening coverage of built-up areas (+)	%		0.0191
		I4: Direct economic losses from natural disasters (−)	Billion		0.0413
	Response (R)	R1: Local financial expenditure on environmental protection (+)	Billion	Raumann, C. G., et al. (2008) [48]	0.0343
		R2: Total afforestation area (+)	Thousands of hectares		0.0201
		R3: Industrial pollution control completed investment (+)	Million yuan		0.0191
		R4: Forest pest and rodent control rate (+)	%		0.0340
	Management of waste (M)	M1: Domestic waste removal volume (+)	Million tons	Martell, D. L., et al. (1998) [43]	0.0406
		M2: Number of forestry employees (+)	Million people		0.0294
		M3: Daily sewage treatment capacity (+)	Million cubic meters		0.0361
		M4: Harmless treatment factory (+)	pcs		0.0305

3.2. Data Source

The evaluation index system constructed in this paper involves a total of 24 indicators, and the time range is 2012–2021. The main sources of datum used for this review were: firstly, the meteorological figures and socio-economic statistics are obtained from the National Bureau of Meteorology, the China Statistical Yearbook, provincial statistical annals, and statistical bulletins on civil administration and public development. Secondly, water resources data were obtained from the Water Resources Bulletin (2012–2021) and Soil and Water Conservation Bulletin (2012–2021) for each region of the YRB. Thirdly, the ecological environment data were derived from the ecological condition bulletin of the YRB regions (2012–2021). All data operations were performed in SPSS, Excel, and Stata MP software. In addition, considering the growth cycle of the forest, in order to enhance the precision of this data, in this research, 2012, 2015, 2018, and 2021 were selected as representative years at 3-year intervals to evaluate the changes and differences in forest dynamics in the YRB.

4. Results

4.1. Comprehensive Evaluation of the YRB

The combined FES score for the YRB improved from 0.218 to 0.638 between 2012 and 2021. The FESI estimates for the YRB for 2012–2021 were 0.218, 0.243, 0.237, 0.276, 0.384, 0.301, 0.317, 0.335, 0.662, and 0.638, respectively (Table 2). Overall, the forest status of the YRB showed an upward trend under small fluctuations (Figure 4), which can be divided into three stages.

Table 2. Relative proximity of the YRB, 2012–2021.

Year	d_j^+	d_j^-	Total Relative Proximity Value	Ranking
2012	0.236	0.066	0.218	10
2013	0.232	0.075	0.243	8
2014	0.227	0.070	0.237	9
2015	0.220	0.084	0.276	7
2016	0.198	0.123	0.384	3
2017	0.215	0.093	0.301	6
2018	0.206	0.095	0.317	5
2019	0.203	0.102	0.335	4
2020	0.110	0.214	0.662	1
2021	0.120	0.211	0.638	2

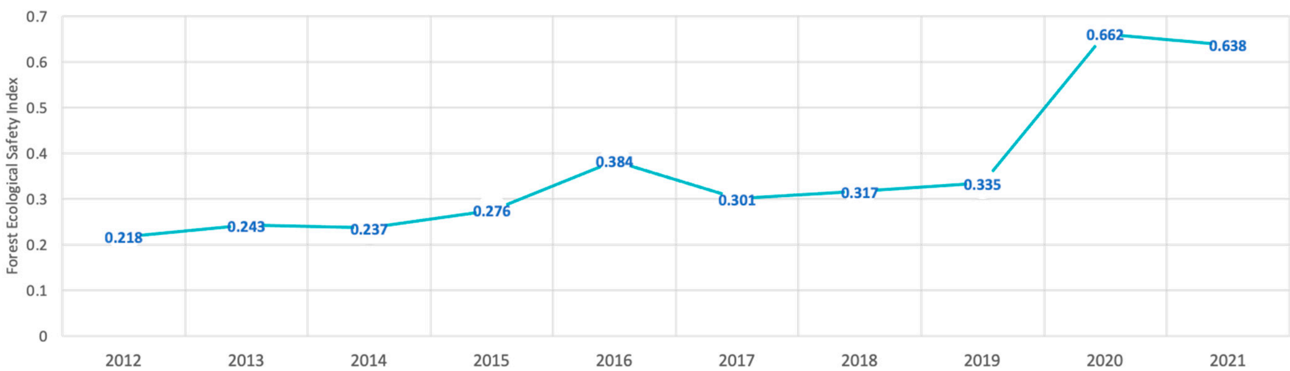


Figure 4. YRB Folding Map 2012–2021.

Stage 1 involves a small climbing phase from 2012 to 2016. Indicator-wise, the forest cover (S1) increased from 31.05% to 33.37%. Growing Stock (S2) rose from 13.157 billion cubic meters to 13.845 billion cubic meters. Sulfur dioxide emissions (P1) decreased from 5,834,400 tons to 2,848,700 tons. Positive factors, such as forest cover (S1), total standing tree accumulation (S2) and sulfur dioxide emissions (P1), drove the forest ecological index up. Meanwhile, total wastewater emissions (P2) rose from 245,883,665,700 tons to

26,332,885,400 tons. The urbanization rate (P4) increased from 51.64% to 54.81%. The negative effects of total wastewater discharge (P2) and urbanization rate (P4) caused a decrease in the forest ecological index. Overall, the positive push slightly outweighs the negative constraint, pushing the index to climb slightly. The underlying reasons are since 2012, the country has implemented several key ecological projects in the forestry sector. Furthermore, the YRB Comprehensive Plan (2012–2030), the YRB Protection Forest System Construction Phase III Project Plan (2011–2020), the Forestry Development "12th Five-Year Plan", and other major ecological forestry construction measures were introduced one after another.

Stage 2 entails the basic flat phase from 2016 to 2019. In terms of positive contributors, the air quality excellence rate (S4) increased from 81.99% to 86.12%. GDP per capita (D3) increased significantly from 55,400 to 72,600. Forest coverage (S1) increased from 33.37% to 35.41%. In terms of negative contributors, population density (P3) increased from 283.16 to 285.79 persons/km^2. The area of forest disease incidence (I1) increased from 819,900 to 861,200 hectares. The positive contributing factors and negative contributing factors offset each other. The self-contained characteristics of the forest ecosystem allowed for the continuation of the financial and institutional effects following the deepening of the forest rights system reform in 2016.

Stage 3 has a significant increase phase from 2019 to 2021. Indicators show that GDP per capita (D3) increased from 72,600 to 80,400. Forest coverage (S1) increased from 35.42% to 36.67%. The rate of good air quality (S4) increased from 86.12% to 91.40%. The area of forest pest (I2) decreased from 2,559,300 hectares to 2,435,900 hectares.

4.2. Cross-Sectional Comparison of YRB Provinces

We compared the relative proximity values according to the entropy weighted-TOPSIS method (Figure 5). The proximity values indicate the proximity of the evaluated object to the optimal solution, and the larger the value, the closer it is to the optimal solution. In descending order, they are Tibet (0.483), Shanghai (0.404), Jiangsu (0.373), Hubei (0.314), Szechwan (0.295), Yunnan (0.259), Jiangxi (0.258), Hunan (0.254), Anhui (0.230), Chongqing (0.207), and Qinghai (0.103). The findings indicate that the changes in forests in the YRB from 2012 to 2021 are grouped into three types (Figure 6).

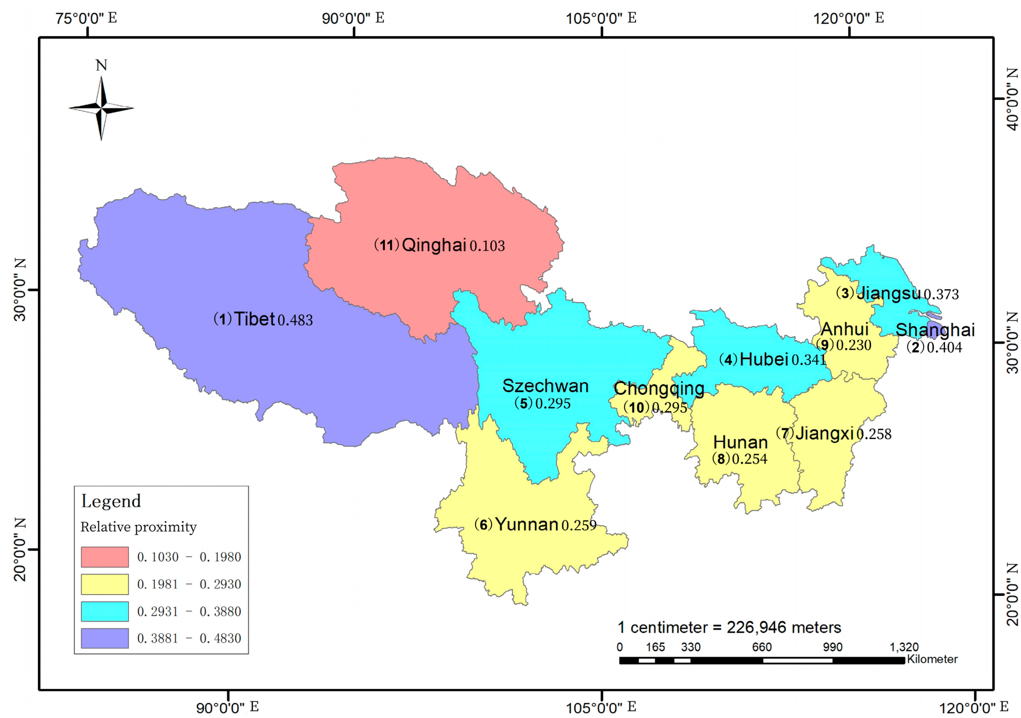


Figure 5. Relative Proximity of YRB Regions.

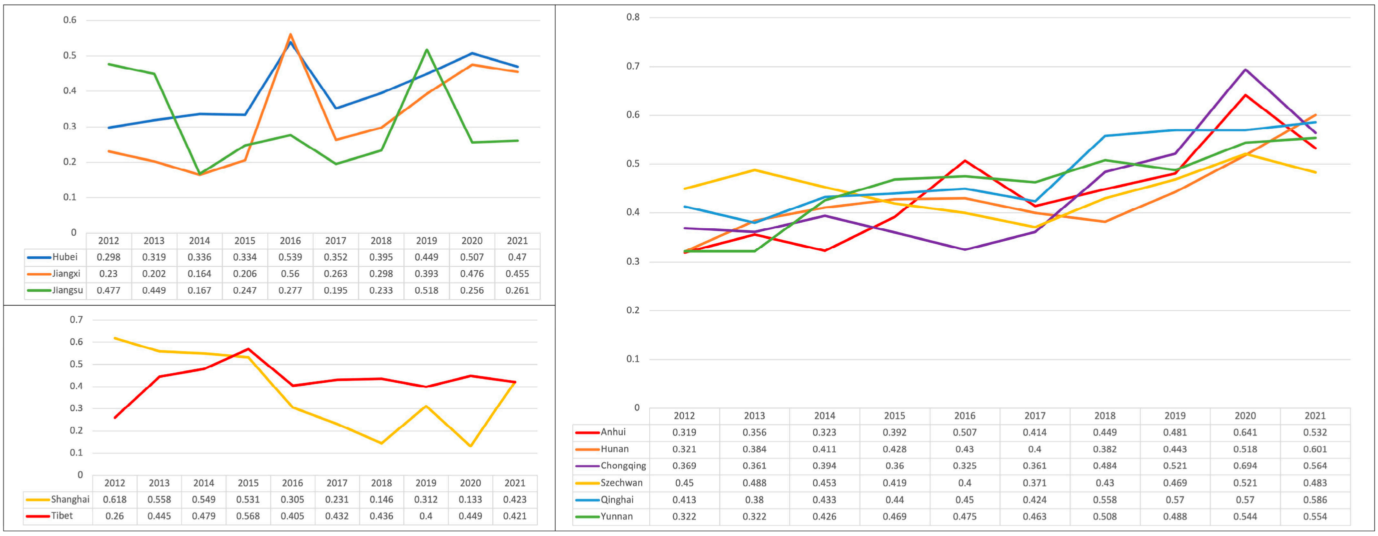


Figure 6. Forest Change Folding Line Chart for 11 Provinces (Cities), 2012–2021.

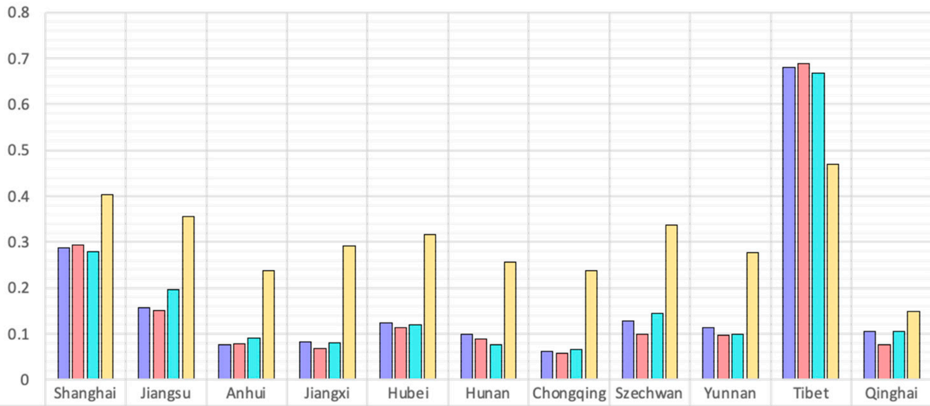
Firstly, the forest status of Hubei, Jiangxi, and Jiangsu suddenly increased in individual years during the study period. Hubei and Jiangxi had higher forest statuses in 2016 than other years. This is since 2016 was the first year in which Hubei completely stopped commercial logging of natural forests.

Secondly, the development of forest conditions in Tibet and Shanghai was unstable during the study period. However, Shanghai is well deserving of being in second place because of its strong policy, financial, and human resources to maintain the ecological status of the forest. It is worth noting that the artificial forest system built in Shanghai is imperfect and unstable. In addition, Tibet has a higher overall index than Shanghai and ranks first in the overall index. This is since Tibet is one of the provinces (regions) with the richest forest resources in China and, compared to Shanghai, Tibet is extremely rich in forest vegetation. Moreover, the low annual temperature difference in Tibet can prolong the growth period of forest trees, which is beneficial to the growth of forest trees.

Thirdly, the forest status of Szechwan, Yunnan, Anhui, Hunan, Chongqing, and Qinghai gradually increased during the study period. The above six provinces (cities) show a relatively stable trend of forest status. Compared with the other four provinces (cities), Szechwan (0.295) and Yunnan (0.259) have a higher composite index. The main reason is that, since 2012, Szechwan and Yunnan have distributed the policy of the "Pilot Program for Sustainable Management and Management of Forest Resources in Sichuan Province" and the "Forest Land Protection and Utilization Plan for Yunnan Province (2010–2020)". These two provinces attach great importance to the conservation and utilization of forest land and the harmonious development of economy and society. In addition, Chongqing (0.207) and Qinghai (0.103) are under greater threat due to the relative scarcity of forest resources. The measures taken to maintain the forest status in these two provinces are insufficient and can only be placed at the bottom of the overall ranking.

4.3. Longitudinal Comparison from 2012 to 2021

Combined with the entropy weighting results, the relative proximity of each region in the YRB was calculated in 2012, 2015, 2018, and 2021 (Figure 7). Using ArcGIS software, the forest relative proximity index was divided into four classes, and the distribution of evaluation classes in each region of the YRB for the research duration was mapped (Figure 8). The comprehensive forest index of the YRB improved by 192.66% during 2012–2021. The state of forest habitat in the YRB region is improving smoothly. Most of the provinces (cities) have improved, and Tibet has the best forest status. The Shanghai, Szechwan, Hubei, and Jiangsu regions have gradually improved their forest status in recent years. However, the remaining six provinces (cities) have been in low grade, facing the outstanding problems of insufficient total forest resources, low quality, and increasing management pressure. Therefore, the six provinces (cities) should strengthen forest land resource management, improve forest management level, and effectively replenish forest land resources.



	Shanghai	Jiangsu	Anhui	Jiangxi	Hubei	Hunan	Chongqing	Szechwan	Yunnan	Tibet	Qinghai
2012	0.288	0.157	0.076	0.082	0.123	0.1	0.062	0.128	0.113	0.681	0.105
2015	0.293	0.15	0.078	0.069	0.113	0.089	0.058	0.099	0.097	0.689	0.076
2018	0.28	0.196	0.09	0.08	0.12	0.077	0.067	0.145	0.099	0.668	0.105
2021	0.403	0.356	0.237	0.291	0.317	0.257	0.237	0.336	0.277	0.469	0.149

2012 2015 2018 2021

Figure 7. Trends in YRB by region in 2012, 2015, 2018, and 2021.

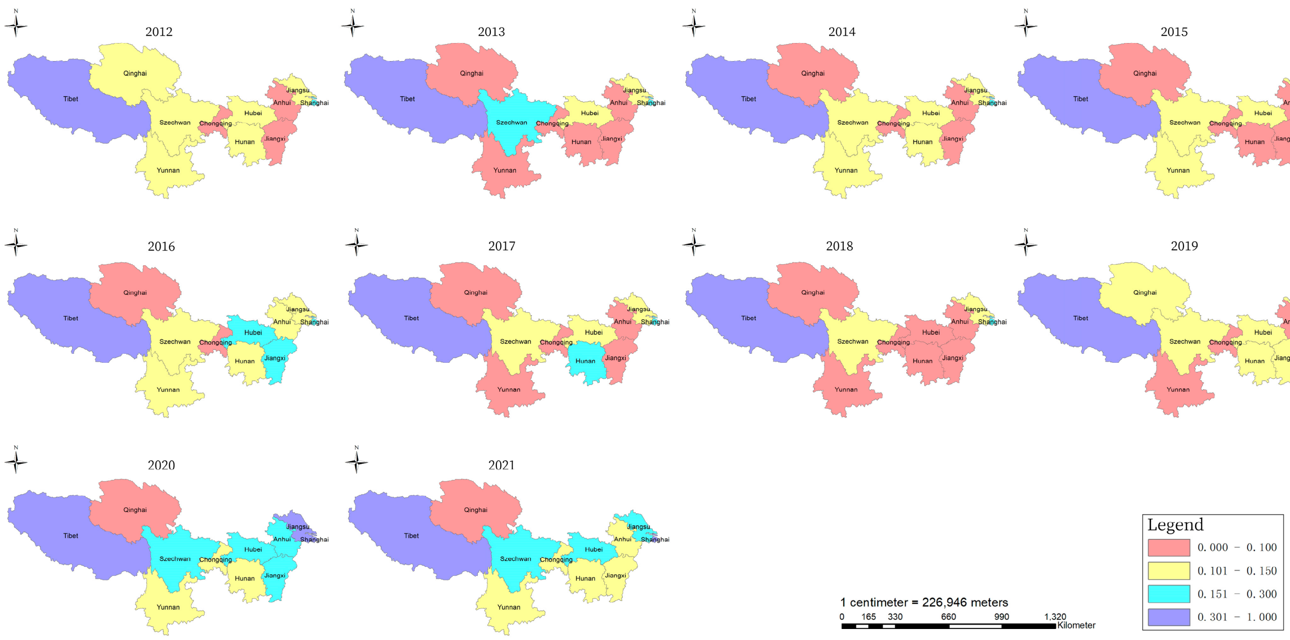


Figure 8. Distribution of evaluation levels by region in the YRB from 2012 to 2021.

4.4. *Relative Comparison of Different Indicators in the Same Provinces*

Due to the large number of correlation factors, this study ranked the correlation values between the indicators and the forest status of the YRB (Figure 9) and compiled the top and bottom ranking indicators of each province (city) as the influencing factors of the region. Also, due to the large amount of data, the comprehensive data from 2012 to 2021 were selected for evaluation. To analyze the correlation indicators of forests in 11 provinces (municipalities) in the YRB, this study was divided according to the downstream, midstream, and upstream of the YRB, and the situation of each province (municipality) was evaluated separately.

Figure 9. The YRB provinces (cities) indicators' correlation value ranking.

In the downstream of the Yangtze River, the land spans the provinces (cities) of Jiangxi (divided by the city of Hukou), Shanghai, Jiangsu, and Anhui. Shanghai, as the busiest city in the YRB at the mouth of the sea, the volume of domestic waste removed (0.852) is the main indicator of the forest status in the area. The decrease in total afforestation area (R2) has a strong negative impact on the forests in Jiangsu and Anhui. Among them, the more developed economic level of Jiangsu makes the total afforestation area of Jiangsu (0.938) have a higher impact on the forest than the total afforestation area of Anhui (0.798). Sulfur dioxide emissions (0.488), total standing tree accumulation (0.746), and direct economic loss from natural disasters (0.618) are the key indicators that hinder the enhancement of forest levels in the lower YRB. Even though they are constrained by environmental and economic conditions, reducing domestic emissions, and improving the high-quality level of forestry can promote sustainable forest development.

In the midstream region, the land spans three provinces (cities) in China, including Hubei (divided by Yichang City in Hubei Province), Hunan, and Jiangxi. The data show that indicators such as the number of forestry employees (M2), the amount of water resources per capita (S3), and the average annual temperature (D2) are the primary elements influencing the forest status in the Central Rivers of the Yangtze River. The middle reaches of the Yangtze River are rich in forest resources, but there is a shortage of forestry-related talent and a lack of attention to the natural weather of forests. The correlation indicators relate to forestry talents and the natural state of forests. This indicates the need to cultivate forestry-related talents in the midstream region, protect forest water resources, and improve the quality of local forests. In this way, the contradiction between scientific and technological development and natural ecology in the midstream region can be alleviated.

In the upstream area, it passes through the Tibet, Qinghai, Yunnan, Szechwan, and Chongqing provinces (cities). The main indicator affecting Qinghai is the annual mean temperature of the region (0.755). Qinghai is deeply inland, far from the sea, and located on the Tibetan plateau. This causes the annual average temperature of Qinghai to be influenced by the topography, which tends to adversely affect the forest state. The low level of green cover in the constructed area (0.901) is the primary indicator that hinders the improvement in Tibet's forests. It indicates that, although Tibet pays attention to the maintenance of forest resources, the level of urban construction still lags, resulting in insufficient green areas in the region. An important indicator for Szechwan is the rate of forest pest and disease control (0.892). In 2021, Szechwan ranked sixth in the country in terms of GDP and dominated in terms of economic development rate but had deficiencies in forest pest control technology. In the Chongqing region, the main influencing factor was the rate of good air quality (0.863). This indicates that the decrease in atmospheric conditions was not conducive to the maintenance of forest ecology. In contrast, forests have special ecological functions that have an irreplaceable role in the ecological environment and can effectively alleviate air pollution in the region. The main indicator of forest level in Yunnan was total wastewater discharge (0.839), indicating that the increase in wastewater constrained the increase in local forest level. In the process of vigorous industrial development, Yunnan tried to reduce the emission of pollutants as much as possible, striving to achieve green and sustainable development. The pollution of Yunnan's Forest resources was reduced at the source.

According to the above analysis, the main indicators associated with the forest status of the YRB provinces (cities) were the forest response indicators. The YRB should focus on the local financial expenditure on environmental protection (R1), the total area of afforestation (R2), the industrial pollution control completed investment (R3), and forest pest and rodent control rate (R4).

5. Discussion

This research shows that, along with the concept of green development, China has adopted some ways to protect the ecological environment. For example, some specific environmental and ecological protection strategies were proposed to improve the quality of forest cultivation. The improvement in forest quality needs the attention of Chinese ecological protection organizations. At the same time, the actual growth of the YRB will be considered in order to achieve the expected ecological and environmental protection goals. On the basis of the above data analyses, this research presents the following views on regions with various levels of resource status and industrial growth.

Firstly, the forest status in the Yunnan (0.259), Jiangxi (0.258), Hunan (0.254), and Anhui (0.230) areas is relatively stable. The above areas need to maintain the stewardship of forest assets, especially the conservation of natural forests. These four provinces (cities) should conscientiously implement governmental forest land protection and utilization plans and take measures to strengthen the comprehensive management of degraded forest ecosystems.

Secondly, the state of the forests in most of the YRB is influenced by the level of economic development. Shanghai, Szechwan, Hubei, and Jiangsu were in the top ten of the total GDP ranking of Chinese provinces in 2021. Based on the advantages of economic resources, these regions create a harmonious and stable relationship between the regional economy and external environmental protection, which is mutually beneficial. Constrained by economic conditions, and except for Tibet, the remaining six provinces (cities) still suffer from the uneven distribution of forest resources, unreasonable industrial structure, and the slow development of forestry technology. Therefore, governments at all levels, forestry departments, and related personnel should analyze the root causes of forest resource problems in depth and adopt targeted strategies to improve and refine them. Although Tibet ranks low in the overall GDP ranking of Chinese provinces, it takes advantage of its vast area and low population density to enact the "Regulations on Forest Protection in Tibet Autonomous Region" to protect the richness of forest vegetation. In conclusion, the degree of forest ecology in the YRB increased significantly between 2012 and 2021 but remained differentiated across regions.

This document requires all regions to effectively strengthen the protection of natural forests, as well as to effectively carry out the important responsibility of protecting and developing forest resources. In the same year, Jiangxi issued the Opinions on the Implementation of Sustainable Management and Management of Forest Resources in Jiangxi

Province. Jiangxi has made afforestation and the protection of forest resources a priority for ecological civilization. And Jiangsu's Forest status in 2019 was greater than the rest of the years. The major cause is that the Provincial Forestry Bureau took the 2019 China Forest Tourism Festival, held in Nantong, Jiangsu, as an opportunity. The provincial forestry bureau organized the preparation of medium and long-term development planning of forest tourism in Jiangsu Province and strengthened the construction of forest tourism infrastructure. Notably, although the comprehensive income from forest tourism in Jiangsu is growing rapidly year by year, the production method of ecological products, however, cannot be a means of industrialization and cannot go against the laws of nature.

Thirdly, for regions with backward forest conditions, such as Chongqing (0.207) and Qinghai (0.103), the regions should strengthen their forest land and forest protection efforts and strictly implement the ecological red line management mechanism. These two provinces (cities) should reduce the pressure exerted by humans on forests and guide construction projects not to occupy tree forests, special shrub forests or public welfare forest land, or to occupy them less, and they should increase the cultivation of sustainable forest management to effectively enhance the carrying capacity of forest ecosystems themselves.

Fourthly, for areas with sufficient forest resources and stable forest status, such as Tibet (0.483), Tibet should take advantage of its superior natural conditions, good resource endowment, and government policies at all levels to improve the forest status. Also note that Tibet is highly susceptible to the reversal of the sensitive and fragile forest resource health once it suffers from deteriorating natural conditions and increased human behavior disturbances. In addition, indicators such as mean annual temperature (D2) and total afforestation area (R2) are the main factors affecting the forest status in the YRB.

Fifthly, in management subsystem (M), management refers to the enhancement of the FES's macro-regulatory capacity through policies. During the study period, Hubei, Hunan, and Jiangxi showed a fluctuating upward trend. In 2012, the YRB proposed to actively innovate environmental economic policies and increase investment in environmental protection. The number of forestry employees (M2) indicators in the management subsystem has a large impact. This indicates the effectiveness of the implemented forest management policies.

The underlying reason is that, with economic development, the government financial support for ecological forestry construction has increased. Meanwhile, at this stage, the Yangtze River Basin began to implement comprehensive institutional reforms, precise forestry quality improvement projects, and increased investment in forestry management. The YRB focuses on forestry management and the conservation dynamics of forest inventory. Damage to forest resources by people's actions has been significantly reduced, while the stock improvement in forest quality is obvious.

There are some shortcomings in the process of this study, although the index system is the result of combing through the relevant literature and continuous derivation. However, there is inevitably a degree of subjectivity. Due to the difficulty in obtaining relevant data on the population and enterprises in the study area, the management (M) indicators of the study area are not further explored in this paper. In future studies, data from enterprise surveys, government surveys, and population change surveys need to be analyzed, on the one hand, and other evaluation methods, such as AHP and ecological footprint, should be explored to assess the forest status of YRB. In addition, potential sources of error in the results presented in this study need to be considered. Therefore, how to make the construction of the evaluation index system more scientific and reasonable, and what evaluation methods to choose, need further research.

6. Conclusions

The YRB accounts for about half of China's population size and economic output. The YRB is abundant in terms of plant and animal species and is an area where rare and endangered wildlife is concentrated in China. It is vital to protect natural forest resources and bring into full effect the basic support function of natural forests in the conservation and restoration of the ecology of the YRB. This not only has a very important role in maintaining the watershed, but also is the key to promoting local development and achieving the strategic goal of Yangtze River protection. This study proposes the following feasible suggestions to further improve forest status, based on the problems existing in the YRB forests and the analysis results of the data.

6.1. Alleviate the Negative Impact of Social Pressure and Effectively Establish a Forest Ecotourism Business Model

For areas with high economic levels, social pressure indicators, such as urbanization rate, population density, population growth rate, energy consumption, and total exhaust emissions, negatively affect forests. The above negative pressures have resulted in long-term overcutting of wild forests in the Yangtze River, increasing soil erosion and frequent ecological disasters. Studies by some researchers have shown that anthropogenic factors do influence ecological changes. However, the impact of anthropogenic activities on forest degradation varies among tributaries. High-economic-level regions should now enhance the implementation and control of initiatives to effectively suppress and control the amount and rate of energy consumption. Some regions are using their economic advantages to develop local forest tourism. Tourism development will certainly increase the number of people in the area. With a certain total amount of resources, an increase in population will not only bring about a strain on resource allocation but will also increase the emission of household pollutants. The development of forest tourism requires additional infrastructure, such as the construction of roads. This will inevitably cut down trees and damage the ecology.

6.2. The Government Formulates Policies and Strengthens Supervision for the Rational Use of Forest Ecological Resources

For low-economic-level areas, the government should play a leading role in strengthening the construction of their forest ecological protection. Firstly, practical ecological security protection policies should be formulated. For example, the provincial (municipal) governments of Szechwan, Yunnan, and Chongqing have issued timely logging bans. The logging apparatus of forest industry enterprises were sealed and timber processing plants and timber trading places in forest areas were closed. For the 11 provinces of the Yangtze River Economic Belt, researchers likewise showed that Sichuan, Yunnan, and Chongqing are the provinces with higher forest maintenance. Secondly, localities have strengthened the supervision of natural forest resources and promoted ecological infrastructure projects. For example, the Tianbao Project has become a project to promote ecological and environmental management in the YRB and strengthen the ecological foundation for development. The implementation of the project has achieved great ecological, financial, and cultural advantages. From the implementation of the Tianbao Project to the ninth inventory, all provinces and cities in the YRB have experienced growth in forest cover, forest area, and forest accumulation.

6.3. Upgrade the Caliber of Forestry Practitioners and Strengthen Public Awareness of Environmental Protection

Looking at the current state of forests in most regions, improving the quality and professionalism of forestry practitioners is now one of the top priorities. Their overall quality is improved through regular training as well as through the assessment of professionalism. This is mainly carried out in two ways. On the one hand, there are numerous forestry colleges and universities in the YRB, transforming the scientific research findings of the institutions into technical achievements and enhance forestry science and technology. On the other hand, it is important to increase the importance of introducing forestry science and technology-oriented talents, develop the professional capacity of forestry personnel to further improve the state of forests in the YRB, promote the fact that the FES is not only driven by the skills and work of professionals, but also by the participation of the public. Lastly, it is important to mobilize the public to participate in the construction and management of ecological environment.

6.4. Comparative Analysis

A forest ecosystem is a complex system that contains many natural environmental factors and socio-economic factors. As human activities intensify, harmful interference with forest ecosystems increases, and traditional dynamical models such as the DPSIR model cannot fully reflect the role of human and social factors, nor can they realize the core of the concept of forest ecosystem security, which is highly concerned with human society. To achieve the goal of forest ecosystem security, the interaction and contribution of various factors to forest ecosystem security should be reflected as comprehensively as possible. In this study, the DPSIRM model was introduced to construct the indicator system. The model is based on the original DPSIR model, and the management (M) subsystem module is introduced. Management represents the cost of human initiative in response to the change in environmental conditions. Based on this model framework, the DPSIRM-based forest ecological safety evaluation index was established. The model can reflect the various factors that affect FES, reflecting the interlocking effects of each factor, and helping to analyze the influence mechanism of forest ecological security in China.

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