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Research article

Research on tourism ecological safety evaluation of Huizhou Cultural and ecological reserve based on entropy -TOPSIS

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ABSTRACT

Tourism ecological security is the basic guarantee for the sustainable development of tourist sites, Huizhou Cultural and Ecological Reserve is an important area for the im-plementation of ecological protection in China, and it is of great significance to carry out research on tourism ecological security. The study adopted the DPSIR model to construct a comprehensive evaluation index system for tourism ecological security and used entropy value-TOPSIS and ArcGIS software to analyze the inter-annual changes and spatial change characteristics of tourism ecological se-curity in the study area. The results show that: firstly, the comprehensive index of tourism ecological safety in the study area from 2010 to 2021 shows a trend of “decreasing-increasing" and an overall increasing trend; secondly, all the sub-systems show an increasing or stabilizing state in recent years during 2010–2021; the state and response sub-systems show an increas-ing or stabilizing state in recent years; and the state and response sub-systems show an increasing trend in recent years. Secondly, all the subsystems showed an increase or stabilization in recent years between 2010 and 2021, and the state and response sub-systems are the main systems to improve the ecological safety of tourism in the study area; thirdly, the difference in the level of ecological safety of tourism in each county of the study area increased and then narrowed from 2010 to 2021, and the change of safety level usually shifted between neighboring levels, and the proba-bility of transfer-ring across the levels was relatively small. , Shexian County, Yixian County, Qimen County, Tunxi District, and the tourism eco-safety level of Huangshan District, Hui-zhou District, Jixi County, and Xiuning County increased at a faster rate than other counties. The study further extends the scale to the district and county level, tries to explore the relevant factors affecting the ecological security of tourism, and proposes countermeasures for the sustainable development of the study area based on the re-sults, which will bring some reference value to the ecological governance and policy formulation of this kind of research.

1. Introduction

Ecological problems gradually threaten the sustainable development of society along with population growth and economic development [1,2], and achieving sus-tainable ecological and socioeconomic development has become a global issue. To bal-ance

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social, economic, and environmental sustainability, governments around the world are actively promoting ecological and environmental protection measures [3], and ecological security is considered as important as military, political, economic, and national security [4]. Ecological security has become an urgent and popular research topic in the twenty-first century and is gradually rising as a key to sustainable devel-opment strategies and a significant component of national security and social stability [5]. To this end, China established a major national strategy for promoting ecological progress in 2012, developed a national ecological environment system, established cultural and ecological reserves, and made tourism a key focus of the Eco-Civilization construction, and tourism industry has gradually become a major issue and core sup-port industries for the development of eco-civilization in various parts of China [6]. Development of tourist industry has intensified the conflict among tourist and ecology, affecting the function of ecological safety barrier of tourism places, the risk coefficient of ecosystem safety has increased, and the sustainability of tourism sites is endangered, and the resolution of the conflict among ecological security of tourism sites and tourist industry needs urgent consideration and attention.

Foreign scholars began to study ecological security in 1940, and the ecologist Aldo Leopold first established a system of evaluation to determine the health of land func-tions in 1941 [7], thus launching the study of ecological safety. Ecological security has been conceived for the first time since 1989at the IIASA, stating that ecological secu-rity is the fundamental right to ensure human life, health, and well-being [8]. Domes-tic and foreign scholars have different understandings of the concept of eco-safety, which is classified as two categories: eco-safety in a special meaning indicates the se-curity of the safety of the natural and seminatural ecosystem, reflecting overall and healthy ecosystems [9]; broadly speaking, ecological security means that human life, labor, heath, basic rights, and social order are guaranteed [10]. In addition, the re-search focuses on sustainable development [11], risk early warning and regulation [12], ecological environment carrying capacity and barrier degree [13–15], etc., and the re-search objects mainly focus on cities and urban clusters [16–19], land [20,21], waters [22,23], forests [24,25], tourism [26–28], etc.

Tourism eco-safety is a significant aspect of eco-safety study. The tourism eco-safety refers to the eco-environment and natural sources upon which the tourist area depends are in good balance, and it is a crucial basis for measuring the tourism industry's sustainable development [29,30]. Research content on ecological safety in tourism mainly concentrates on tourist sustainability assessment [31], the implemen-tation effect of ecological protection policies [32], tourism environmental carrying ca-pacity [33,34], tourism environmental impact [35,36], and ecological vulnerability of tourism sites [26,37]. When conducting assessment of tourism ecological safety, the in-dicator assessment mode method became the approach chosen by most researchers, mainly including EES model [9], PSR model presented by UNEC [35,36], and DPSIR model presented by the EEA [28,38–41] and others to build an ecological safety evalu-ating indicator system. Among them, the DPSIR model provides a better idea to com-prehensively and scientifically evaluate the eco-safety status of tourism sites, and rel-evant research results show the model has strong applicability in tourism eco-safety, can accurately identify the specific links that threaten the eco-safety of tourism sites, and effectively characterize the comprehensive and structural nature of its spatial in-ternal state, which has been extensively applied in eco-safety assessment [42]. In terms of research methods, TOPSIS method (Technique for Order Preference by Similarity to an Ideal Solution) [43–45], hierarchical analysis method [46], and structural equation modeling [47] are mainly used to carry out research. Among them, TOPSIS method is also known as the distance between superior and inferior solutions method, which is effective in evaluating multidimensional and multi-indicator research objects, has the advantages of being realistic, intuitive, and reliable, and is conducive to reflecting the systematic process of tourism ecological safety evaluation.

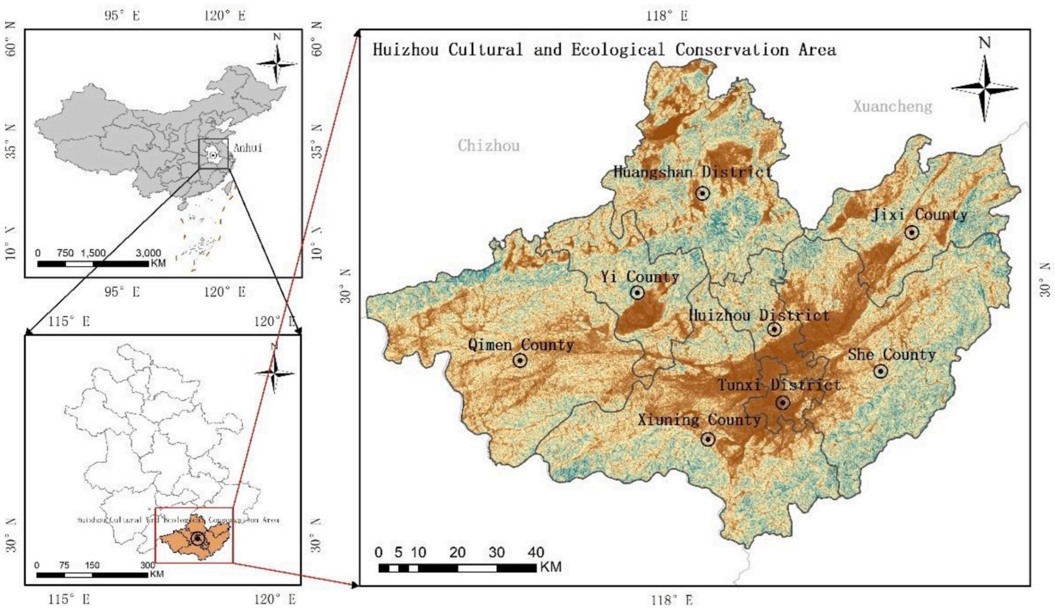

Fig. 1. Research area map.

Therefore, it is of great significance to carry out tourism ecosystem safety evalua-tion for the sustainable and high-quality development of ecological environmental protection and tourism. Existing research on tourism ecosystem safety evaluation has not yet formed a complete system, and there is still a large space in the theoretical basis, research methodology, selection of evaluation indicators and selection of research are-as, among which, in the selection of research areas, there is a lack of attention to the “cultural and ecological reserves". Cultural ecological reserves contain rich cultural and ecological values and are a concrete practice of holistic protection of NRLs in China, carrying an important development strategy, which is of great significance to study and protect them to ensure their sustainable development. In this study, the Huizhou Cultural Ecological Reserve was selected among the cultural ecological re-serves that have been established in China, which is in the southern mountainous area of Anhui Province, including eight districts and counties (Fig. 1). The intangible cultural heritage of Huizhou Cultural Ecological Reserve is rich in content, with a total of 15 national lists, 48 provincial lists, and 106 municipal lists, which have high aca-demic and socio-cultural values. However, under the multiple influences of climate change, anthropogenic activities, and the development of tourism industry, ecological problems have emerged in Huizhou Cultural and Ecological Reserve and affected the function of its ecological security barrier. The relationship between the ecological secu-rity of Huizhou Cultural and Ecological Reserve and the interactive response of the tourism industry urgently arouses thoughts and concerns. In order to better promote the future ecological governance of the Huizhou Cultural and Ecological Reserve, we aim to address the following questions in this study.

(1) Characteristics of spatial and temporal changes in tourism ecological security in Huizhou Cultural and Ecological Reserve, 2010–2021.
(2) What are the main factors affecting tourism ecological security in Huizhou Cultural and Ecological Reserve?
(3) The dynamic evolution characteristics and regularity of tourism ecological se-curity at county and district scales within the Huizhou Cultural and Ecological Re-serve.

The study constructs tourism ecological security evaluation index system based on DPSIR research framework, uses entropy weight-TOPSIS and gray correlation method to evaluate tourism ecological security of Huizhou cultural ecological reserve, and diagnoses obstacles to tourism ecological security, so as to put forward relevant suggestions to solve the problem of tourism ecological security of Huizhou cultural ecological reserve, so as to gain a deeper understanding of the ecological status of Huizhou cultural ecological reserve and realize the virtuous cycle and sustainable development of all links of tourism ecosystem, and promote the deep integration be-tween ecological protection and cultural tourism development and construction. status, realize the benign cycle and sustainable development of tourism ecosystem, promote the deep integration between ecological protection and cultural tourism development and construction, and promote the win-win situation of ecological environment and economic development in the protected area. Spe-cifically, the structure of this paper is as follows: Section 1 introduces the relevant contents of this research area; Section 2 introduces

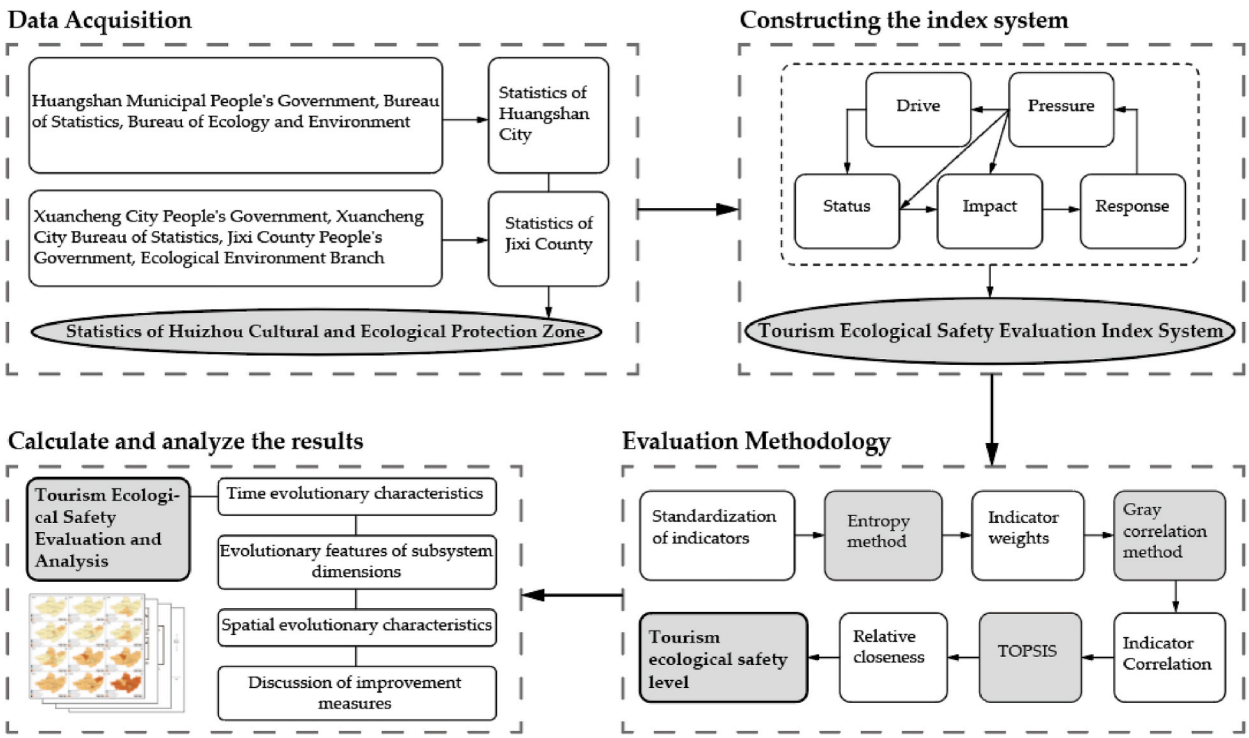

Fig. 2. Method flow chart.

the data sources, methods and empirical methods used in this study. Section 3 discusses the empirical results derived from the data analysis. Section 4 the results of this study are discussed. Section 5 presents relevant recommendations for decision making based on the results of the study. Section 6 concludes this study.

2. Methods and data

2.1. Methodology

This research evaluates tourism ecological safety of Huizhou cultural and ecolog-ical reserve from the perspective of sustainable development and adopts entropy weight TOPSIS and gray correlation method for empirical research. Firstly, we stand-ardized the official statistics from Huangshan Municipal People's Government, Bureau of Statistics, Bureau of Ecological Environment and Xuancheng Municipal People's Government, Xuancheng Bureau of Statistics, Jixi County People's Government and Branch of Ecological Environment. Secondly, the DPSIR model was used to construct a comprehensive assessment index system of tourism ecological security, including five aspects of drive, pressure, state, impact, and response. Again, the relative proximity of each index was calculated using entropy weighted TOPSIS, and the correlation degree of each index was calculated using the gray correlation method to classify the tourism eco-safety level of each place in the research area each year. Finally, tourism ecological safety in the research area was analyzed from three dimensions: temporal, subsystem and spatial, and ways to improve tourism ecological safety in the research area were discussed (Fig. 2).

2.2. Data source

Research data were primarily taken from the official websites of Huangshan Mu-nicipal People's Government, Bureau of Statistics, and Branch of Ecology and Envi-ronment of Anhui Statistics Yearbook (2010–2021); Huangshan Municipal Statistics Yearbook (2010–2021); Huangshan Municipal Bulletin of Ecological and Environmen-tal Conditions (2010–2021); Xuancheng Municipal People's Government, Xuancheng Municipal Bureau of Statistics, Jixi County People's Government, and Branch of Ecol-ogy and Environment of 2021); Xuancheng City People's Government, Xuancheng City Bureau of Statistics, Jixi County People's Government, and Ecological Environment Branch official websites of the Propaganda City Statistical Yearbook (2010–2021); Na-tional Economic and Social Development Statistical Bulletin (2010–2021), and the very few missing data by linear interpolation method to make up for it.

2.3. Research hypothesis

According to the actual situation of tourism ecological safety construction work in Huizhou Cultural and Ecological Reserve, reviewing the conclusions of previous studies, the ecological safety status of Anhui Province in 2019 improved significantly and reached a safe state [48], and there are regional differences in the coupling coordination of regions within the Yangtze River Economic Belt in China [49], etc., the hypotheses were established.

H1. The overall development change of tourism ecological security status in Huizhou Cultural and Ecological Reserve is rising and tends to be stable.

H2. There are differences in the level of tourism ecological security in the counties and districts within the Huizhou Cultural and Ecological Protection Zone.

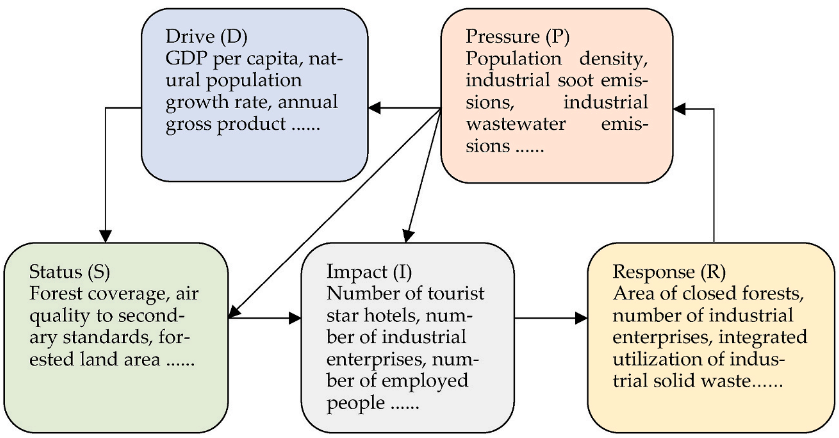

Fig. 3. DPSTR operation model diagram.

2.4. Model index system construction

To scientifically evaluate the tourism ecological safety in Huizhou Cultural and Ecological Reserve, this paper chooses to construct a total assessment indicators sys-tem for tourism eco-safety of Huizhou cultural and ecological reserve. (Fig. 3). The DPSIR model can organically integrate tourism with economic development and eco-logical protection according to a certain systemic coupling relationship, and better evaluate the overall ecological safety of the region as well as the influence relationship between each subsystem [50]. In 1993, the European Environment Agency established the DPSIR model, which explains relationships between the environment and human activities in a systemic perspective and includes five areas: driver, pressure, state, im-pact, and response, which are widely applied in various areas related with environ-ment recently. This model reflects the rapid economic and social growth as the driving force acting on the ecosystem, which in turn causes some level of pressure to the eco-system, thus causing changes in the state of the ecosystem and various impacts on the ecosystem, and the impacts prompt humans to make a series of responses to the eco-system state changes, which respond to the composite system composed of human so-cial, economic and ecological environment or act directly upon the Ecosystem pres-sures, states and impacts.

In tourism ecological safety evaluation, the DPSIR model indicators are specifi-cally related to social, economic, environmental, energy and resource aspects closely associated with the tourism. Among them, the “driving force" (D) refers to the intrinsic factors of tourism ecosystem change, reflecting the trend of demographic change, the trend of socio-economic activities and the direction of industrial and economic devel-opment. These factors are the invisible factors of environmental changes and the most original and important indicators of changes in the security system. The study selected five aspects of tourism industry development and socio-economic development to con-struct driving force indicators, namely GDP per capita, natural population growth rate, tertiary industry value added, annual gross product, and tertiary industry growth rate [6,28,41,51,52]. Among them, GDP per capita, natural rate of population, added ter-tiary sector value, and annual gross product reflect the economic growth of the study area; the growth rate of visitors reflects the tourism development.

"Pressure" (P) is a progression of driving factors, reflecting the access of tourists to the surrounding resources and the direct impact on the surrounding environment during tourism. The study responds the regional pressure of economic and social growth on the ecological security in tourist areas from five indicators: population den-sity, emission of industrial fumes, emission of industrial wastewater, emission of in-dustrial waste gas, and generation of industrial solid waste, and thus constructs pres-sure indicators [41,50,52,53]. Among them, population density reflects the density condition of population activities and ecological safety bearing, and the bigger the population density index, the bigger the reflection that the population is disrupting urban life, representing the social pressure in the study area. Industrial smoke emission, industrial wastewater emission, the generation of industrial emissions and industrial solid waste reflects the pressure on the atmospheric and water environment of the tourist area., which is the negative impact on tourism ecology.

Table 1
Evaluation index system of tourism eco-safety.

Target layer	Project Level	Program level	Unit	Characteristic
A: Evaluation index system of tourism ecological safety in Huizhou cultural and ecological reserve	D: Drive	D1: GDP per capita	Yuan	+
		D2: Natural population growth rate	%	–
		D3: Annual gross product	million yuan	+
		D4: Value added of tertiary industry	million yuan	+
		D5: Share of tertiary sector in GDP	%	+
	P: Pressure	P1: Population density	People/km2	–
		P2: Industrial fume emissions	ton	–
		P3: Industrial wastewater discharge	million tons	–
		P4: Industrial waste gas emissions	Billion standard cubic meters	–
		P5: Industrial solid waste production	million tons	–
	S: Status	S1: Forest cover	%	+
		S2: Air quality up to secondary standard	Heaven	+
		S3: Area with forest land	million hectares	+
		S4: Visitor growth rate	%	–
		S5: Visitor capacity	million people	–
	I: Impact	I1: Number of tourist-starred hotels	individual	–
		I2: Number of industrial enterprises	individual	–
		I3: Number of employed persons	million people	+
		I4: Number of people employed in the public environment	People	+
		I5: Tourism production value	billion	+
	R: Response	R1: Closed Forest area	hectares	+
		R2: Industrial waste gas treatment facilities for the number of	Set	+
		R3: Integrated utilization of industrial solid waste	ton	+
		R4: Environmental protection capital investment	million yuan	+

The “state" (S) is the various conditions presented by the ecological environment, mainly reflecting the environmental carrying capacity level of the ecosystem. The study selected forest cover, air quality up to secondary standards, forested land area, tourist growth rate, and tourist reception to construct state indicators from both eco-logical environment and tourism economic development [6,10,28,53]. Among them, the forest coverage rate, air quality up to secondary standard, and forested land area, reflect the level of ecological health and sustainable development, forests cover per-centage reflects the richness in forest assets, with higher values being more beneficial to the eco-security at tourist sites.; number of air quality days at or above secondary standard is a direct measure of the air safety status of a tourist destination. reflecting the condition of atmospheric quality and ecological environment of the tourist place. The larger the area of forested land is, the more difficult it is to be disturbed by the out-side world. Visitor growth rate, visitor arrivals reflect tourism development in the study area.

"Impact" (I) refers as a reflection of the various states of the tourism ecosystem in terms of economic, social, resource and environment impacts, as well as the extent of the impacts. The study constructs impact indicators in five aspects: the number of tourism star hotels, volume of industrial enterprises, number of people employed, number of people employed in the public environment, and value of tourism [28,52,53]. These five indicators reflect the income from tourism, the economic influence of de-veloping tourism and the support of local government for it and represent the tourism growth and infrastructure level of the research area.

"Response" (R) represents a set of human measures to enhance the natural envi-ronments of tourist areas. The “response" index is constructed from four aspects: the area of closed forests, industrial waste gas treatment facilities, industrial solid waste comprehensive utilization, environmental protection capital investment [28,52,54]. Among them, the area of closed forests, amount of industrial emissions treatment equipment, as well as the amount of industrial solid wastes comprehensive utilization are important ways to solve pollution problems through environmental management measures to restore ecological safety and stability, reflecting the local efforts to main-tain the ecological safety status of tourism; environmental protection funds reflect the positive response of the local efforts to protect ecology and ecosystem sustainability.

In summary, the evaluation system of this study was constructed with 24 indica-tors in combination with data availability (Table 1).

2.5. Entropy weight TOPSIS

In order to more accurately and objectively evaluate and analyze the tourism ecological security of Huizhou Cultural and Ecological Reserve, this paper adopts the entropy value-TOPSIS method, which is one of the commonly used multi-objective decision-making analysis methods in system engineering, and it evaluates the evaluation object by defining a measure in target space and measuring how close the target is to the positive ideal solution and how far it is from the negative ideal solution. TOPSIS method is one of the commonly used multi-objective decision analysis methods in system engineering, by defining a measure in the objective space, and measuring the degree of the target close to the positive ideal solution and far from the negative ideal solution to evaluate the evaluation object, without strict restrictions on data distribution, sample content, the number of indicators, etc., which has the advantages of truthfulness, intuition, reliability, and is conducive to reflecting the systematic process of the assessment of ecological safety of tourism. The “entropy value-TOPSIS" method is a comprehensive evaluation method that integrates the entropy value method and the TOPSIS method. Compared with the hierarchical analysis method, entropy value method, principal component analysis method and other methods, it has the advantage that the entropy value method can avoid the bias of subjective assignment, and it also has the advantage that the TOPSIS method can provide a good and bad grade for each sample. The advantages and disadvantages of each sample can be evaluated one by one. Therefore, this paper adopts this comprehensive evaluation method for the assignment and synthesis of the basic indexes in the comprehensive evaluation index system of tourism ecological security of Huizhou Cultural and Ecological Reserve.The specific measurement steps are as follows.

(1) Standardization of indicators

The indexes are divided in positive and negative directions, and the positive (negative) direction indicates the positive (negative) impact of the indicators on the ecological carrying capacity. The higher the positive indicator value indicates the higher the ecological safety of tourism in the protected area and lower the value of negative indicator means the higher the ecological safety of tourism in protected areas. The positive and negative indicators were normalized in a dimensionless way to make them comparable to each other, and the values of the processed indicators were between [0,1], and the normalization was calculated as shown in equations (1) and (2):

Positive indicators.

$$Y_{ij} = \frac{X_{ij} - X_{min}}{X_{max} - X_{min}} \tag{1}$$

Negative indicators.

$$Y_{ij} = \frac{X_{max} - X_{ij}}{X_{max} - X_{min}} \tag{2}$$

(2) Determining indicator weights

According to equations (3) and (4), the entropy value method, which is more ob-jective, is utilized to determine the weights of each evaluation index.

$$E_j = -\ln(n)^{-1}\sum_{j=1}^{n}\frac{Y_{ij}}{\sum_{j=1}^{n}Y_{ij}}\ln\frac{Y_{ij}}{\sum_{j=1}^{n}Y_{ij}} \tag{3}$$

$$W_j = \frac{(1-E_j)}{\sum_{j=1}^{n}(1-E_j)} \tag{4}$$

Where, E_j denotes the information entropy; W_j shows the power level of the jth index; n is an evaluation year.

(3) Calculate the correlation degree based on gray correlation analysis

Sorting based on the magnitude of the correlation, summing the correlation coef-ficients and finding the average value, which represents the degree of correlation be-tween the comparison series and the reference series, as shown in equation (5).

$$r_i = \frac{1}{n}\sum_{j=1}^{n}\frac{\Delta min + \rho\Delta max}{\Delta_i + \rho\Delta max} \tag{5}$$

Where, ρ denotes the resolution coefficient; Δmin is the minimum difference of two levels; Δmax is the maximum difference of two levels.

(4) The following equation (6) is used to build the weighted normalization matrix.

$$Q_{\text{Drive}} = \sum_{j=1}^{5}Y_{ij}\omega_j;\ Q_{\text{Pressure}} = \sum_{j=6}^{10}Y_{ij}\omega_j;\ Q_{\text{Status}} = \sum_{j=11}^{16}Y_{ij}\omega_j;$$

$$Q_{\text{Impact}} = \sum_{j=16}^{21}Y_{ij}\omega_j;\ Q_{\text{Response}} = \sum_{j=21}^{26}Y_{ij}\omega_j \tag{6}$$

Construct the weighted normalization matrix according to equation (7).

$$Q_{cm} = Q_{r\times 5} = \begin{bmatrix} Q_{11} & Q_{12} & Q_{13} & Q_{14} & Q_{15} \\ Q_{21} & Q_{22} & Q_{23} & Q_{24} & Q_{25} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ Q_{r1} & Q_{r2} & Q_{r3} & Q_{r4} & Q_{r5} \end{bmatrix} \tag{7}$$

Where: Q_{cm} is the weighted normalization matrix; c refers to the quantity of study units, c = 1, 2 …, r; m is the index number, m = 5 in this paper, which are the drive index, stress index, condition index, influence index and response index, respectively.

(5) Determine the positive and negative ideal solutions through Eq. (8)

$$Q_m^+ = \{max\ Q_{cm}|c = 1, 2, \cdots, r\};\ Q_n^- = \{min\ Q_{cm}|c = 1, 2, \cdots, r\} \tag{8}$$

Where: Q_m^+ is the indicator positively desired solution; Q_m^- is the negative desired solution.

(6) Calculate the distance from the target value to the positive and negative ideal solu-tions by using equation (9)

$$D_c^+ = \sqrt{\sum_{m=1}^{5}(Q_{cm} - Q_m^+)^2};\ D_c^- = \sqrt{\sum_{m=1}^{5}(Q_{cm} - Q_m^-)^2};\ c = 1, 2, \cdots, r \tag{9}$$

(7) Calculate the approximation between the evaluation subject and the desired solution for each year Z_c , , as shown in equation (10)

$$Z_c = \frac{D_c^-}{D_c^+ + D_c^-} \tag{10}$$

Where: Z_c takes values in the scope of [0, 1], the higher its worth, then the safer the tourism ecosystem in the study unit, and vice versa, the more deteriorated it is.

(8) With reference to the relevant literature, the evaluation results are divided into seven tourism ecological safety levels with equal spacing (Table 2) [53].

3. Results and analysis

To evaluate and analyze the tourism ecological security of Huizhou Cultural and Ecological Reserve more objectively, the entropy value method and gray correlation method are used to calculate the indicators, to obtain the characteristics of the in-ter-annual changes of the tourism ecological security of the study area from 2010 to 2021, and to make the related using Microsoft Excel 2010, Microsoft Word 2010 and ArcGIS software. The charts and tables are illustrated, in which the calculated data come from government statistical yearbooks, bulletins and official websites.

The entropy method was used to calculate the weight and gray correlation of each indicator (Table 3), which measures the degree of association between the data by the size of the correlation, and facilitates further discussion on the influencing factors af-fecting the tourism ecological security in the study area.

The entropy method was used to calculate the inter-annual changes in tourism ecological security in the study area for each year from 2010 to 2021 (Table 4), and by combining the ideal solutions (positive and negative ideal solutions), the final degree of proximity was computed Z_c. The relative closeness for each year was ranked to facilitate further discussion about the overall inter-annual changes in the state of tourism ecological security in the study area.

Similarly, using equation (10), the tourism ecological safety indices of the eight counties in the research area from 2010 to 2021 were calculated, and the relative proximity of tourism ecological safety of each county in the study area was obtained (Table 5).

3.1. Temporal evolutionary characteristics of tourism eco-safety

From 2010 to 2021, the comprehensive tourism ecological safety index for Huizhou Cultural and Ecological Reserve ranges from 0.33 to 0.62, and the comprehensive tourism ecological safety index shows an “decreasing increasing “trend, with a general increase (Fig. 4).

From 2010 to 2013, the level of tourism eco-safety in Huizhou Cultural and Ecological Reserve showed an overall slow decline, and the ecosystem safety index reached a 12-year low of 0.338 in 2013, and the tourism eco-safety level was at a less safe level. In addition to the fast growth of tourism construction of tourism construction in Huizhou Cultural ecological Protection Area from 2010 to 2011, which provided sufficient driving force for ecological safety of tourism, and the stress index in tourism eco-safety was small as well as the tourism ecological security index increased slightly. From 2011 to 2013, the environmental pollution in the study area has become more serious with the development of tourism, and the tourism eco-safety index has been decreasing year by year.

From 2013 to 2021, the tourism ecological safety level of Huizhou Cultural and Ecological Reserve shows an overall rising trend, with tourism Eco-safety Index increasing from 0.338 to 0.612, and the ecosystem safety index reaching a 12-year maximum of 0.612 in 2021. In 2013, Huangshan City around the construction of a modern international tourism city strategic objectives, Qimen County, Yixian County, She County officially named the provincial eco-county, the phase of sustainable development concept into concrete action, the implementation of a series of environmental initiatives to enhance a series of tourism development quality and efficiency, making a steady rise in the level of ecological safety of tourism.

3.2. Evolutionary characteristics of the dimensions of the tourism ecosystem safety subsystem

From the driving force dimension, tourist eco-safety index in the research area from 2010 to 2021, except for 2012, the driving force dimension tourism ecological safety index has been steadily increasing year by year with a significant increase, and the tourism ecological safety index has increased significantly, and the ecological safety level has risen from " critical security level " to “very security level" (Fig. 5). With the further socio-economic development of the reserve, the economic structure is becoming more and more perfect, providing an increasingly strong driving force and economic guarantee for the eco-logical safety of protected area tourism, prompting potential changes to the ecological environment of the reserve to begin to occur.

In terms of the pressure dimension, tourist eco-safety index in 2010–2021 has been fluctuating in the first 6 years, and has stabilized in the last 6 years, with tourist eco-safety indices ranging from 0.6 to 0.8 (Fig. 5). The statistical data show that, taking 2016 as the

Table 2
Tourism ecological safety grading standard for Huizhou cultural and ecological protection zone.

Security Level	Deterioration level	Risk level	Sensitivity level	Critical security level	General security level	Compare security level	Very security level
Ecological security value	[0–0.05]	(0.05–0.10]	(0.1–0.2]	(0.2–0.4]	(0.4–0.6]	(0.6–0.8]	(0.8–1]

Table 3
Summary of results of entropy method to calculate weights.

Scheme layer	Information entropy value e	Information utility value d	Weighting factor w	Gray correlation degree	Gray correlation ranking
D1	0.894	0.107	0.463	0.501	23
D2	0.927	0.073	0.316	0.559	14
D3	0.910	0.090	0.391	0.583	11
D4	0.892	0.108	0.468	0.548	16
D5	0.879	0.121	0.527	0.504	22
P1	0.967	0.033	0.143	0.907	1
P2	0.953	0.047	0.203	0.602	8
P3	0.963	0.037	0.159	0.800	3
P4	0.922	0.078	0.339	0.513	20
P5	0.858	0.142	0.618	0.671	5
S1	0.923	0.077	0.333	0.726	4
S2	0.887	0.113	0.491	0.587	10
S3	0.963	0.037	0.160	0.848	2
S4	0.896	0.104	0.452	0.661	6
S5	0.900	0.100	0.436	0.534	18
I1	0.866	0.134	0.584	0.574	13
I2	0.835	0.165	0.718	0.557	15
I3	0.928	0.073	0.315	0.601	9
I4	0.787	0.213	0.925	0.429	25
I5	0.911	0.089	0.385	0.520	19
R1	0.926	0.074	0.322	0.435	24
R2	0.920	0.080	0.347	0.509	21
R3	0.851	0.149	0.645	0.542	17
R4	0.940	0.060	0.261	0.576	12

Table 4
Interannual variation of tourism ecological safety index in Huizhou cultural and ecological reserve.

Year	D+	D-	Z_c	Sorting results
2010	0.182	0.113	0.383	8
2011	0.171	0.107	0.385	7
2012	0.172	0.094	0.353	10
2013	0.164	0.084	0.338	12
2014	0.164	0.087	0.346	11
2015	0.158	0.096	0.377	9
2016	0.140	0.105	0.429	6
2017	0.139	0.121	0.467	4
2018	0.147	0.127	0.464	5
2019	0.126	0.145	0.536	3
2020	0.109	0.170	0.609	2
2021	0.112	0.177	0.612	1

Table 5
Interannual variation of tourism ecological safety index in each county of Huizhou Cultural and Ecological Protection Zone.

Region	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Tunxi District	0.286	0.267	0.269	0.227	0.186	0.224	0.278	0.365	0.404	0.519	0.723	0.593
Huangshan District	0.367	0.366	0.357	0.294	0.308	0.310	0.444	0.476	0.503	0.542	0.561	0.614
Huizhou District	0.385	0.377	0.382	0.408	0.472	0.464	0.433	0.446	0.55	0.557	0.571	0.621
She County	0.332	0.336	0.324	0.323	0.327	0.248	0.354	0.466	0.461	0.523	0.556	0.609
Xiuning County	0.391	0.399	0.416	0.400	0.417	0.428	0.507	0.584	0.593	0.597	0.591	0.601
Yi County	0.296	0.289	0.275	0.267	0.255	0.254	0.382	0.607	0.618	0.579	0.495	0.495
Qimen County	0.25	0.236	0.228	0.213	0.212	0.214	0.451	0.46	0.505	0.595	0.561	0.713
Jixi County	0.318	0.392	0.367	0.412	0.403	0.371	0.469	0.493	0.547	0.598	0.651	0.648

dividing line, the tourism ecological safety index of pressure dimension tends to be stable after 2016, and the industrial soot emissions and “three wastes" emissions of Huizhou Cultural and Ecological Reserve before 2016 are high and unstable, while the industrial soot emissions and “three wastes" emissions after 2016 are generally high and stable. After 2016, the industrial smoke emissions and “three wastes" emissions decreased in general, and the annual emissions were steadily controlled within a reasonable range. These productions put pressure on tourism ecology as well as damage to the environmental of protected areas, so improving the “three waste" treatment technology is helpful in relieving ecological pressure.

Regarding the state dimension, the tourism ecological safety index of Huizhou Cultural and Ecological Reserve decreases and then increases from 2010 to 2021 (Fig. 5). With the strong support from the national and local governments, the travel industry of the study

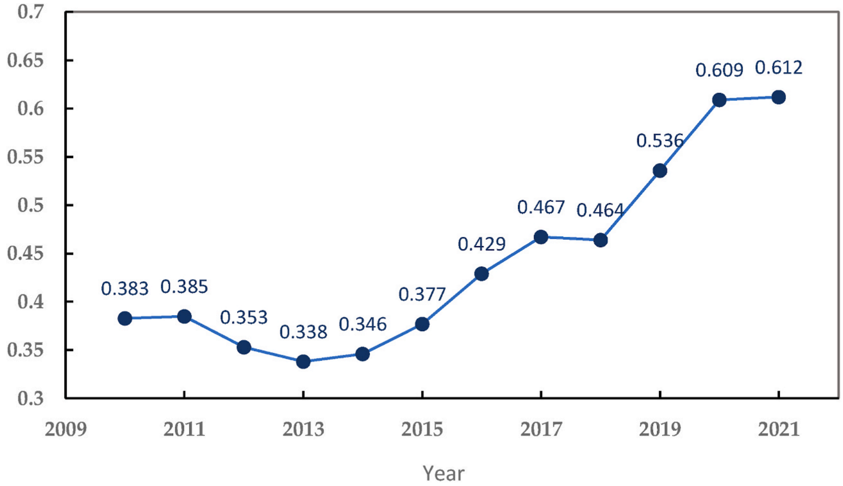

Fig. 4. Interannual variation of the composite index of tourism ecological safety in Huizhou Cultural and Ecological Reserve.

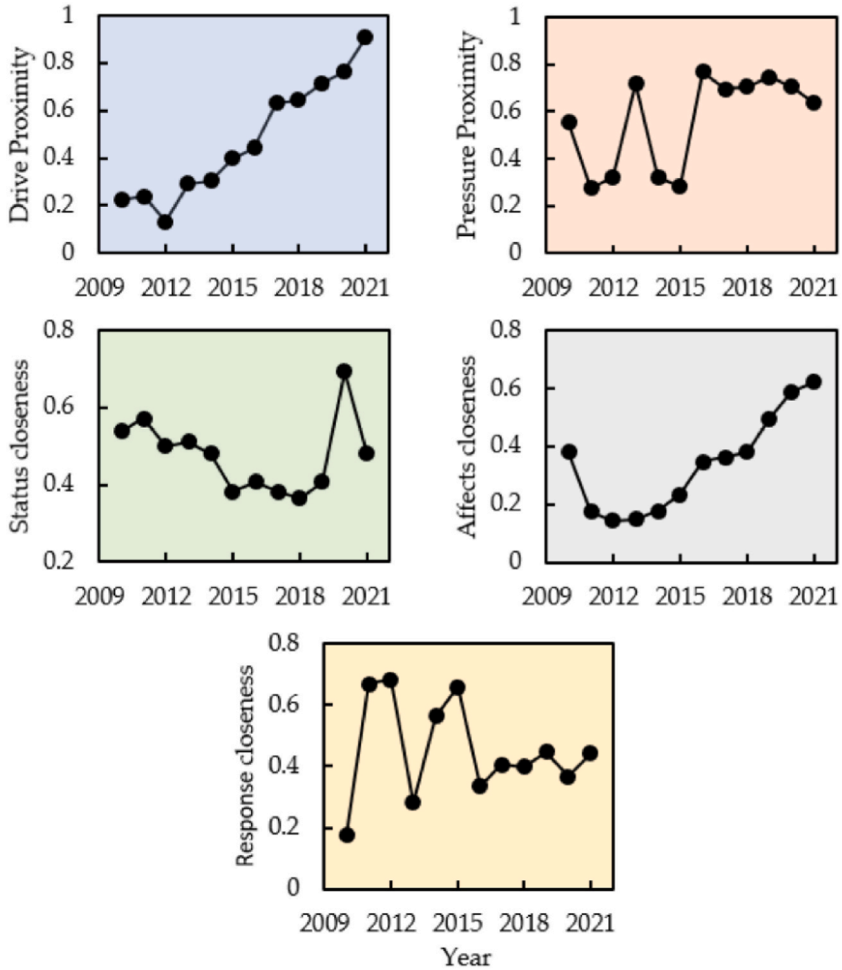

Fig. 5. Interannual variation in drivers, pressures, states, impacts, and response closeness of tourism ecological security.

area flourished, the tourist reception and growth rate increased rapidly, the tourism market scale has continuously expanded, so that the environmental status of the reserve has been affected, and the state dimension tourism ecological safety index is difficult to be improved. 2020 was affected by the epidemic, and the tourist reception and growth rate of the study area decreased significantly, and the environmental status of the reserve The state rebounded significantly, and the tourism ecological safety index increased significantly.

In terms of the impact dimension, from 2010 to 2021, the tourism ecological safety index of the study area first decreases and then increases, and after 2012 the tourism ecological safety index increases year by year with a significant increase, and the ecological safety level rises from “critical security level" to “compare security level " (Fig. 5). The data show that since 2012, the reserve has increased environmental protection, decrease in the number of star-rated hotels, and increase in employment in the public environment, and the whole tourism ecological environment has been gradually optimized.

In terms of response dimension, the tourism eco-safety index has fluctuated from 2010 to 2015 in the research area, and after 2015, the fluctuation of tourism eco-safety index tended to be stable, stabilizing between 0.33 and 0.45 (Fig. 5). The improvement of response measures and protection system has stabilized the tourism ecological safety index of the reserve in recent years. During this period, although the research area vigorously developed ecological tourism and followed a healthy development path, the number for the industrial exhaust gases handling facilities and solid waste from industry comprehensive utilization, and the investment in environmental protection funds were constantly increased, the area of closed mountains and forests could not grow steadily, which made it difficult for the ecological safety index to rise continuously.

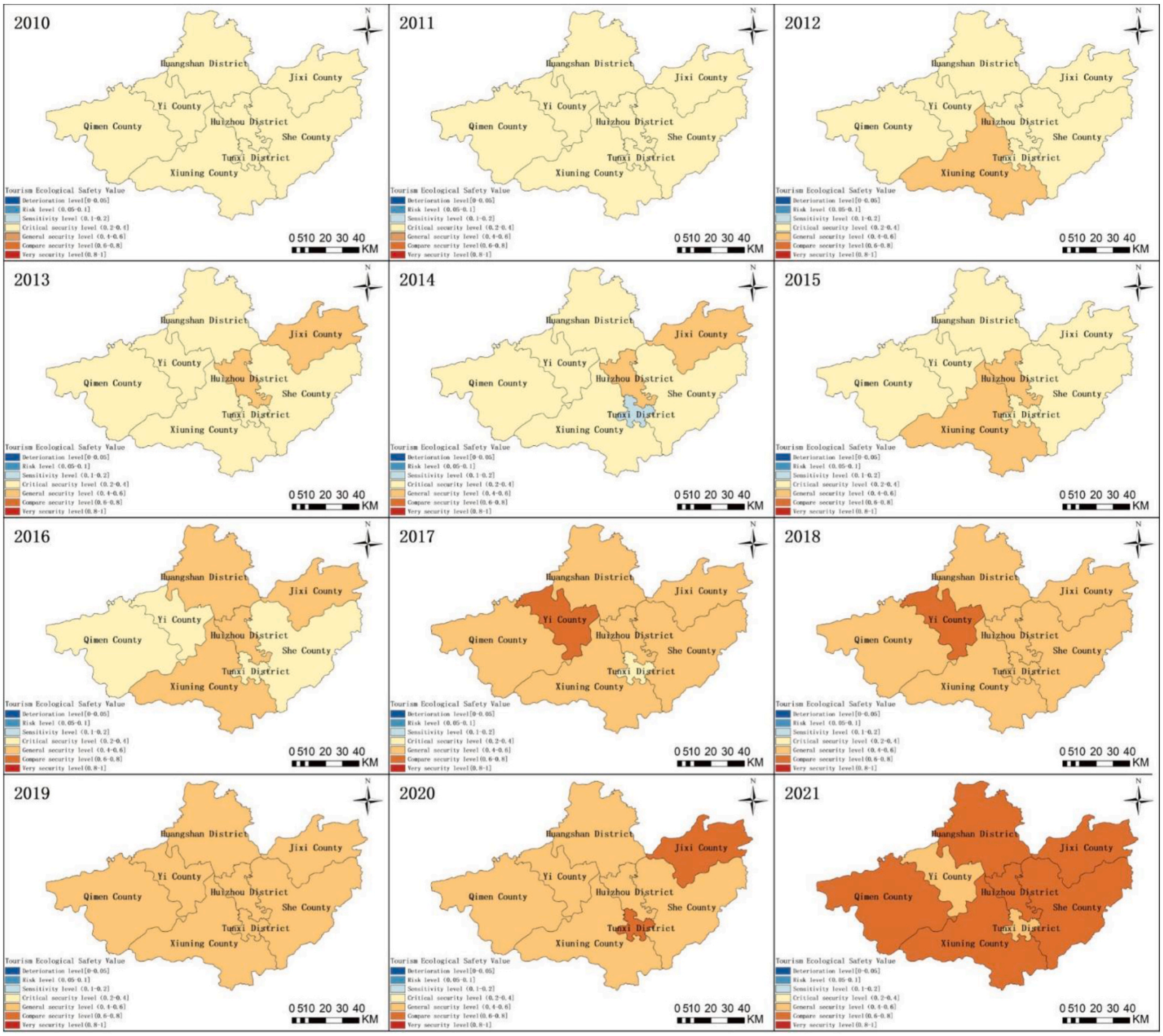

Fig. 6. Spatial distribution patterns of tourism ecological security in Huizhou cultural and ecological reserve counties and districts during 2010–2021.

3.3. Spatial evolutionary characteristics of tourism eco-safety

To show the local spatial features of tourist eco-safety in the research area more clearly, a spatial visualization analysis of the tourist eco-safety levels and indices of each county in the research area was conducted using ArcGIS software (Fig. 6). The tourist eco-safety level of each county and city in the study area from 2010 to 2021 is located between sensitivity level, critical safety level, general safety level and comparative safety level, and there is no risk level, deterioration level or very safe level status, and the overall trend tends to be good.

In 2010–2015, the tourism eco-safety level of the research area is mainly based on the key safety level; in 2016–2020, the tourism ecological safety level is mainly based on the general safety level, and the number of general safety level in 2016 is increased from 2 to 4 in 2015; in 2021, the tourism ecological safety level is mainly based on the more safety, and the number of more safety level in 2021 is increased from In 2020, the number of safer levels increased from 2 to 6. The average value of tourism ecological safety of the eight counties and districts in the study area over the past 12 years, the rankings from highest to lowest as Xiuning County (0.4937), Jixi County (0.4724), Huizhou District (0.4722), Huangshan District (0.4285), She County (0.4049), Yixian County (0.4010), Qimen County (0.3865), Tunxi District (0.3618). In addition, the speed of improving tourism ecological safety level in each county differs slightly, with the speed of improvement transitioning from the middle to both sides. Huizhou District, Huangshan District, Jixi County, and Xiuning County are elevated faster, while Tunxi District, Yixian County, Qimen County, and She County are elevated more slowly. 2012, Xiuning County was the first to reach the general safety level, and the tourism eco-safety level of all four counties has been stabilized at the general safety level and above since 2016.

And, by the box plot of tourism ecological safety (Fig. 7), the mean value of tourism ecological safety in the study area from 2010 to 2021 fluctuates slowly and then rises, and the difference of tourism ecological safety index of each county and district in the reserve first increases and then decreases, with a convergence trend in recent years.

4. Discussions

Cultural ecological reserve is the first regional cultural practice proposed in China for the holistic protection of cultural forms centered on non-heritage, and its construction is also conducive to maintaining the balance and stability of the cultural ecosystem in the region and promoting the overall coordination and sustainable development of the local active society. The study focuses on the systematic research on the characteristics of the evolution of tourism ecological security in the Huizhou Cultural Ecological Reserve, which is of great significance in promoting the sustainable development of ecological protection in the Cultural Ecological Reserve and the continuous improvement of tourism quality.

4.1. The overall development of tourism ecological security status of Huizhou cultural and ecological reserve is up and stabilizing

From 2010 to 2021, the tourism ecological security index of Huizhou Cultural and Ecological Reserve is between 0.33 and 0.62, the lowest value of tourism ecological security index is 0.338 in 2013, and the highest value of tourism ecological security index is 0.612 in 2021, and the tourism ecological security index shows a trend of “decreasing first and increasing later". The comprehensive index of tourism ecological safety shows the trend of “first decline and then rise", and the overall trend is upward. Therefore, this result confirms H_1.

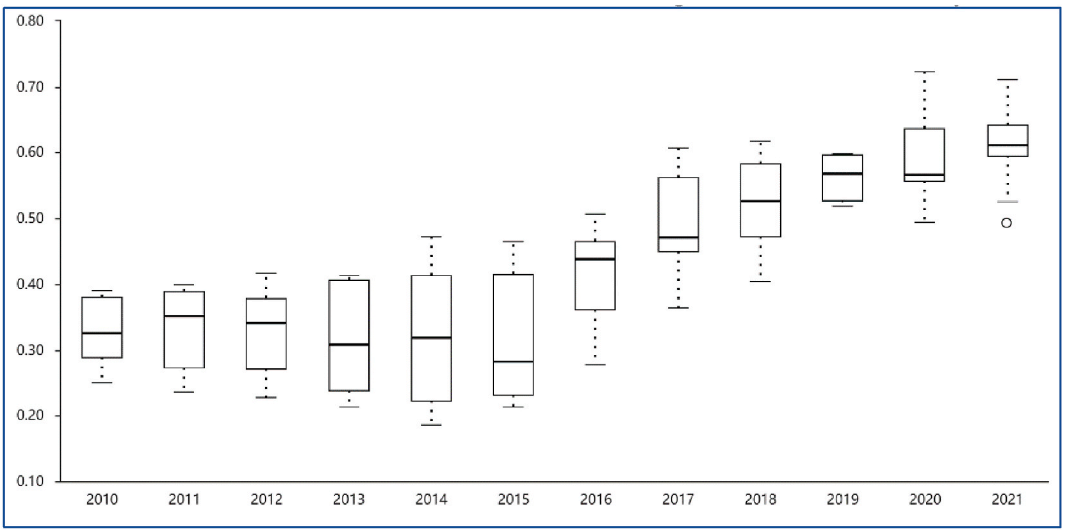

Fig. 7. Tourism eco-safety box plot.

4.2. Differences in the level of tourism ecological security among counties and districts within the Huizhou Cultural and Ecological Protection Zone

By calculating the tourism eco-safety index of each county and district in Huizhou Cultural and Ecological Protection Zone, it can be concluded that the 12-year tourism eco-safety average value of the eight counties and districts in the protection zone is ranked from high to low as Xiuning County, Jixi County, Huizhou District, Huangshan District, Shexian County, Yixian County, Qimen County and Tunxi District. There is a slight difference in the speed of improving the level of tourism ecological safety in each county and district, and the speed of improvement transitions from the middle to the sides, with Huangshan District, Huizhou District, Jixi County, and Xiuning County leading other counties and districts in the development of tourism ecological safety excellence. By comparing with previous studies, it was found [49] that regional differences are common, so differentiated countermeasures are needed to improve the tourism ecological security of the protected area and make the protected area sustainable. Therefore, this result confirms H_2.

In addition, compared with similar studies [28,38–41], the study expanded the research field of tourism ecological security by focusing on the tourism ecological security of national cultural and ecological reserves by taking the regional Huizhou cultural and ecological reserve under holistic protection as the research object. Secondly, TOPSIS can be used to compare relative differences in similar studies [43–45,55]. In addition to using entropy weight-TOPSIS to analyze the relative differences in tourism ecological security of Huizhou cultural and ecological reserve, this study introduces the gray correlation method into the evaluation study, with the help of which we comprehensively explore the correlation of related factors affecting tourism ecological security, and provide theoretical support for the construction of cultural and ecological reserve In addition, the gray correlation method is introduced into the evaluation study to comprehensively explore the correlation of related factors affecting tourism ecological security, so as to provide theoretical support for the construction of cultural and ecological reserve, and to propose specific initiatives to improve tourism ecological security.

5. Policy making suggestions

The study helps to make more targeted suggestions to improve tourism ecological security in Huizhou Cultural and Ecological Reserve. First, the indicator model of this study also proves that tourism ecological security is characterized by systemic nature, so the government should fully consider the systemic nature of tourism ecological security in the formulation of relevant policies. Policies should be formulated from a systemic perspective and in a comprehensive manner to promote the improvement of tourism ecological security, strengthen the restrictive measures on stressors, promote the healthy development of drivers, responses, and other factors, and strictly implement environmental protection policies.

Second, the results of the study show that there is some inter-regional imbalance in the level of tourism ecological security in the Huizhou Cultural and Ecological Reserve. Therefore, the Anhui provincial government and the regional and county governments need to develop initiatives to balance the spatial pattern of tourism ecological security, and fully coordinate and balance the developmental differences in the level of tourism ecological security between regions. While giving full play to the guiding role and demonstration effect of regions with leading tourism ecological security levels, it is necessary to optimize the tourism market structure of regions with low values of tourism ecological security, guide the flow of factors between regions, strengthen exchanges and cooperation between counties and districts, and jointly improve the level of tourism ecological security in pursuit of the sustainable development of the Huizhou Cultural and Ecological Reserve.

In addition, indicators such as the growth rate of tourists and the number of tourists received in the state subsystem are the main factors affecting the ecological security of tourism. The ecological pressure brought by tourists should not be ignored, and tourists, as the most active factor in tourism activities, are of great significance in maintaining the healthy state of tourism ecological security in Huizhou Cultural and Ecological Reserve. Tourist attractions should rationally plan tourists' tourism activities, call on tourists to choose a more low-carbon and natural way of tourism, and pay more attention to eco-tourism and green tourism, and tourists should also take the initiative to actively choose green tourism. The four indicators in the response subsystem, namely, the area of closed forests, the number of industrial exhaust gas treatment facilities, the amount of comprehensive utilization of industrial solid waste, and the investment of environmental protection funds, have a large room for improvement and are important factors affecting the level of tourism ecological security. In order to further improve the level of tourism ecological safety in the study area, in the future, the person in charge of the Huizhou Cultural and Ecological Reserve and tourist attractions should strengthen the enhancement of the state subsystem and the response subsystem, strengthen the protection of forests, and accelerate the development of the forest recreation and ecotourism industry so as to further improve the air quality; and increase the financial guarantee for tourism ecological safety and support the construction of eco-tourism facilities, which will in turn improve the level of tourism ecological safety.

6. Conclusion

This paper takes Huizhou Cultural and Ecological Reserve as the study area, constructs the theoretical framework and evaluation index system of tourism ecological security based on the DPSIR model, and analyzes the tourism ecological security of the study area in the time dimension, the theoretical framework subsystem, and the spatial dimension for the period of 2010–2021, and the results of the study can objectively reflect the tourism ecological security of the Huizhou Cultural and Ecological Reserve status and evolution trend. The main findings of the study are as follows.

(1) In the time dimension, the comprehensive index of tourism ecological security of Huizhou Cultural Ecological Reserve showed a "decreasing increasing" and generally increasing trend from 2010 to 2021. From 2010 to 2013, the tourism ecological security level of the protected area showed an overall slow decline, and from 2013 to 2021, the tourism ecological security level of the protected area showed an overall increasing trend.
(2) In the sub-systems, the driving force, state, impact, and response sub-systems all showed an increase in recent years or stabilized in recent years during 2010–2021, and the state and response sub-systems are the main systems to enhance the tourism ecological security of Huizhou Cultural and Ecological Reserve. In the subsystem, the driving force index shows a stable upward trend, with a significant increase; the pressure index tends to be stable in the past 6 years, and the tourism ecological security index is between 0.6 and 0.8; the state index decreases first and then rises, and the index rebounded significantly in 2020; the impact index decreases first and then rises, and it rises year by year since 2012, with a significant increase; the response index fluctuates greatly, and it tends to be stable in the past 7 years, and it stabilizes at the level of 0.33–0.45. 0.45.
(3) In the spatial dimension, from 2010 to 2021, the tourism eco-safety level of each county and district of Huizhou Cultural and Ecological Reserve has developed from unsafe and less safe to critical safe and relatively safe, without the state of very safe level, and the overall trend of increasing level. The change of safety level usually occurs in the recurrence of transfer between adjacent levels, and the probability of cross-level transfer is small. The difference of tourism ecological safety index of each county and district from 2010 to 2021 increases and then narrows, and the trend of convergence is shown in recent years.

The 12-year tourism ecological safety mean values of the eight counties and districts in the protected area are ranked from high to low as Xiuning County, Jixi County, Huizhou District, Huangshan District, Shexian County, Yixian County, Qimen County and Tunxi District. The level of tourism ecological safety in each county and district to improve the speed of slight differences in the rate of improvement from the middle to both sides of the transition, Huangshan District, Huizhou District, Jixi County, Xiuning County tourism ecological safety excellent development speed ahead of the other counties and districts.

The research innovations are as follows.

(1) The study further extends the scale to the district and county level, which can better explain the heterogeneity and regularity of tourism ecological security at the county and district scale in the study area. And the spatial visualization analysis of tourism ecological security index during the study period was carried out by using ArcGIS software, which can intuitively and effectively analyze the dynamic transfer process and law of tourism ecological security of the counties in the study area, intuitively reveal the influence of the neighboring background of the dynamic evolution of tourism ecological security, and clarify the direction of the improvement of the tourism ecological security in the future of the Huizhou Cultural and Ecological Protection Zone, so as to provide data support and scientific basis for the formulation of corresponding tourism ecological security strategies in the Huizhou Cultural and Ecological Protection Zone. It provides data support and scientific basis for the development of tourism ecological security strategies in Huizhou Cultural Ecological Reserve.
(2) The study takes the Huizhou Cultural Ecological Reserve under holistic protection as the research object, which expands the research field of tourism ecological security. Secondly, the study introduces the gray correlation method into the evaluation research, with the help of which the correlation of related factors affecting tourism ecological security is comprehensively explored, which brings certain reference value to this kind of research.

Study limitations and future recommendations are listed below:

This study still has deficiencies that need to be further optimized. The selection of tourism ecological security evaluation indexes of Huizhou Cultural and Ecological Reserve in this study is not long enough in time span, and due to the difficulty in obtaining some of the key data in the early years, it is difficult to obtain them, and only the years of 2010–2021 are selected to conduct tourism ecological security research in the study area. In addition, this study lacks the comparison of tourism ecological security research between different protected areas, and in the exploration of tourism ecological security of protected areas, only the evaluation of Huizhou Cultural and Ecological Reserve, which is worth studying and comparing in the future. At the same time, this study lacks the prediction of the ecological security carrying capacity of the study area, and future research is to be further supplemented in this aspect.

Data availability statement

The experimental data used to support the findings of this study are included in the article.

CRediT authorship contribution statement

Yanlong Guo: Data curation, Conceptualization. **Jiaying Yu:** Writing – original draft, Data curation. **Yelin Zhu:** Writing – review & editing, Data curation. **Han Zhang:** Writing – original draft, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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