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Spatial-temporal pattern and influencing factors of tourism ecological security in Huangshan City

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It is of important theoretical and practical value to scientifically evaluate tourism ecological security for the sustainable development of tourist cities. The study focuses on the "characteristics of the impact factors on tourism ecological security at different levels" of tourism ecological security that have been neglected in the previous literature. From the perspective of Compound Ecological systems theory, we built an evaluation index system for tourism ecological security in Huangshan City based on the Pressure-State-Impact-Economic-Environmental-Social (PSR-EES) model and used a combination of the entropy weight TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) method, traditional and spatial Markov chains, and panel quantile regression to analyze and characterize the spatial-temporal dynamics of security levels and driving factors. The results showed that (1) the level of tourism ecological security of the districts and counties in Huangshan City improved rapidly, but the difference was expanding. The level of tourism ecological security in the four counties was generally higher than that in the three districts. (2) In terms of the spatial-temporal dynamic evolutionary characteristics, the transfer of tourism ecological security in Huangshan City has its characteristics of stability and path dependence. Type transfers usually occur between adjacent levels. The lower the level of tourism ecological security, the higher the probability of upward transfer. A neighborhood background plays an important role in the process by which a higher neighborhood rank increases the probability of upward transfer. (3) Regarding the driving factors, environmental pollution and economic development have a negative inhibitory effect on tourism ecological security, and the negative effect decreases as the level of TES improves. The top three positive effects were government intervention and educational levels. The degree of regional greening and government intervention had greater positive marginal effects on lower-level areas. In contrast, tourism development, educational level, and labor input had greater positive marginal effects on areas with higher TES levels.

KEYWORDS

tourism ecological security (TES), dynamic evolution characteristics, spatial Markov chains, panel quantile regression, Huangshan City

1 Introduction

As a key policy objective at the global, national, and local levels (Peng et al., 2017), development of sustainable tourism has long been a focus worldwide (Ahmad et al., 2018). With its dual attributes of environmental friendliness and resource consumption, the tourism industry exhibits a binary relationship with the environment (Shi et al., 2019). Once considered a “clean” industry, tourism has become an important driver of urbanization in cities with abundant tourism resources, and many government incentives have been introduced to promote its development (Tao et al., 2017; Kapera, 2018). However, the utilization of resources in tourism development has significant negative externalities. The negative impacts of increasing tourist activities, consumption, and development are becoming increasingly evident, contradicting the need to protect the ecological environment (Williams and Ponsford, 2009). These negative effects hinder the development of the tourism industry and form a vicious cycle that impairs the integrity and services of tourism destination ecosystems, posing a threat to their ecological security (Qian et al., 2018; Xiaobin et al., 2021). It has become a consensus of all sectors of society to ensure the integrity of the structure and function of the tourist destination ecosystem, maintain the safety and stability of tourism ecology, and promote sustainable development of the tourism industry. (Ruan et al., 2019). Tourism ecological security has become a primary indicator for assessing environmental impacts and sustainable development and now it is a focal point in current research (Liu et al., 2017a). This is also in response to China’s major national strategy to promote the progress of the ecological civilization established in 2012 and the policy of developing tourism into a core industry of ecological civilization construction and becoming a strategic pillar industry of the national economy. In this context, scientifically describing the spatiotemporal evolution of tourism ecological security and its influence and driving factors in the long-term dimension of tourist cities is conducive to improving the degree of ecological security and service levels in tourist destinations and formulating targeted tourism development policies. It also has significance in promoting the coordinated and sustainable development of tourist cities.

The application of complex ecosystem and system theories provides a theoretical basis and an innovative foundation for developing an ecological security evaluation index system for tourist cities. The essence of complex ecosystem theory is that social, economic, and environmental systems differ from and restrict each other; however, they connect to form an open and complex composite ecological system with structure and function. A tourist city can be regarded as a complex ecosystem comprising economic, environmental, and social subsystems (Zhou et al., 2015). Each subsystem includes certain elements, including organisms and circumstances. Through energy flow, material circulation, and information transmission, a state of high adaptation, coordination, and unity can be achieved (Liu et al., 2007). System theory emphasizes the overall concept of the system and believes that the elements of the system are not mechanical existence and combination, but the organic relationship between the whole and parts, part and part, whole and external environment (Kenneth,

1956). However, the index system of many previous studies is only a simple list of statistical data. This not only ignores the essential issues of ecological security, that is the human-land interaction in pursuit of sustainable development and harmonious symbiosis, but also the multilevel characteristics of the economic-environmental-social subsystems of tourism cities. Additionally, it fails to evaluate the interaction between the internal elements of each system. On a theoretical basis, this study adopts the pressure-state-response-economy-environment-society model (PSR-EES) (Wang et al., 2021c), comprehensively considers the economic, environmental, and social subsystems in tourist cities, clarifies the logic between pressure-state-response (P-S-R) model (Zhou et al., 2002), innovates the ecological security evaluation index system of tourism cities, and expounds the mechanism of interaction among tourism, economy, society, and the environment in the sustainable development of tourism.

This study chose Huangshan City as the research region (Figure 1) for the following reasons: as a typical and world-famous mountainous tourist city in China, Huangshan City boasts superior cultural and tourism resources, including Mount Huangshan, which is a UNESCO-approved cultural and natural dual heritage site, and the ancient villages in Southern Anhui (Xidi and Hongcun) are listed as World Cultural Heritage sites. The city also had 5A-level scenic spots, 8 scenic areas, and 22 4A-level scenic spots. The tourism industry has experienced rapid growth, receiving a total of 71.153 million domestic and foreign tourists by 2019, with a cumulative tourism income of 59.52 billion yuan, accounting for over 70% of the city’s GDP. Therefore, the selection of this region for the case study is of significant practical importance. (2) Huangshan City is a typical mountainous tourist city with a forest coverage rate of over 82.9%, driven by the urbanization of the tourism industry (Leung, 2001; Xie et al., 2021), and faces a sharp contradiction between development and protection. With the rapid development of the tourism industry, the increasing input of resource elements and tourism waste (Wang and Chen, 2021), poses significant pressure on natural (Leung, 2001), economic, and ecological systems in scenic spots. Because the ecosystems of mountainous tourist areas are relatively fragile and easily damaged (Scott, 2006), a mountainous tourist city would lose its value as a tourist attraction without a good natural ecological environment (Lin, 1997). The districts and counties of Huangshan City have abundant cultural and tourism resources, and their tourism economies are closely linked. According to related research, tourism flows are geographically concentrated (Mou et al., 2020). The self-driving tourism flow in Huangshan City presents characteristics of agglomeration, circumnavigation, and radiation, with tourists frequently moving between districts and counties (Song et al., 2013). Therefore, high-intensity tourism activities over short distances bring about the transfer of tourism waste and pollutants, which deepens the impact on the ecological security of tourism destinations and transfers and changes between regions.

This study focuses on the following key objectives and innovations: (1) Construct an evaluation index system from the perspective of complex ecosystem theory and system theory, comprehensively considering multidimensional factors and the logical relationship between various systems and elements. In

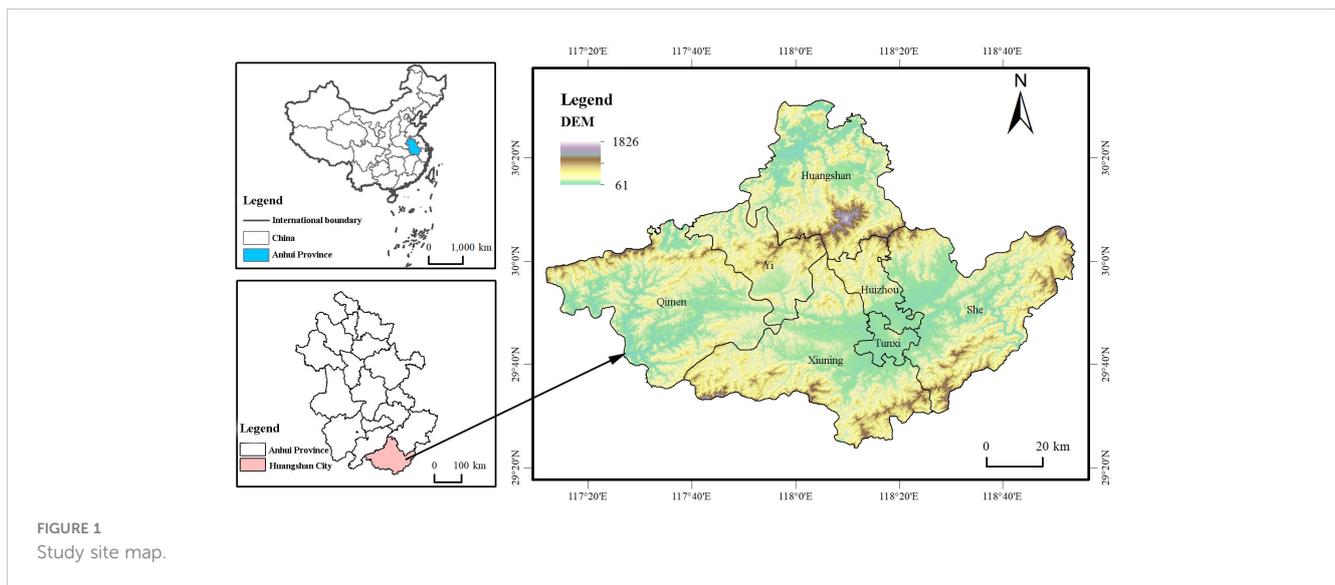


FIGURE 1
Study site map.

addition, innovating the tourism ecological security evaluation model for tourist cities. (2) Innovate research methods to investigate the transition probability, as well as the temporal and spatial evolution characteristics of security levels among districts and counties in tourist cities from a small-scale regional perspective. (3) It clarifies the key factors affecting tourism ecological security, defines the degree and characteristics of the effects of different factors at different levels, and constructs tourism ecological security driving mechanisms in different dimensions. Additionally, it enriches the content and research methods of tourism ecological security research and provides a scientific reference for promoting the sustainable development of the tourism industry in other tourist cities.

2 Literature review

2.1 Tourism ecological security

Ecological security is an important field in the study of the sustainable development of tourist destinations (Liu et al., 2009). It refers to the state in which human survival, health, well-being, basic rights, sources of life security, necessary resources, social order, and human ability to adapt to environmental changes are not threatened. Tourism ecological security refers to the ability of ecosystem of tourist destination to provide services for the sustainable development of human society and the economy within a certain time and space to maintain the long-term coordinated development of the natural-society-economic complex system (Li et al., 2019; Fan and Fang, 2020). This allowed it to become a new conceptual paradigm (Tang et al., 2018). Comparing with ecological security involves protecting an entire ecosystem, tourism ecological security focuses on protecting and managing the impact of tourism on the ecological environment. The goal is to protect and maintain the ecological environment and resources of tourist destinations during the tourism season (Zhang et al., 2008). Tourism ecological security mainly focuses on practitioners, tourists, and local communities, as well as the

ecological environment directly related to tourism activities (Qin et al., 2019). This study mainly focuses on the following aspects: From a disciplinary perspective, research on tourism ecological security is distributed across tourism (Liu and Yin, 2022), landscape ecology (Malekmohammadi and Jahanishakib, 2017; Chen et al., 2021), geography (Tang et al., 2018), management (Wolfslehner and Vacik, 2008), environmental science (Jurado et al., 2012), system dynamics (Qin et al., 2019), and energy science (Tang et al., 2015) as well as presents multidisciplinary features. The research content presents the characteristics of continuous expansion from shallow to deep and has gradually expanded from the origin of ideas (Lv, 2007), concepts and connotation (Zhang et al., 2008), evaluation (Li et al., 2017a), spatiotemporal characteristics (Ruan et al., 2019; Chen et al., 2023), influencing factors, trend forecasting (Cheng and Yue, 2011), early warning system construction (Xu et al., 2017), dynamic simulation, and other issues (Lu et al., 2019). The case studies included islands (Xiao et al., 2011; Chen et al., 2021; Wang et al., 2021a), wetlands (Li et al., 2012; Sun et al., 2021), grasslands (Lu et al., 2008), mountains (Chen et al., 2022), forests (Zheng et al., 2015), and coastal cities (Wang et al., 2016), etc. The research scale is comprehensive and covers the country (Liu and Yin, 2022), region (Ruan et al., 2019), city (Tang et al., 2018), and scenic spots (Wang et al., 2021b). Evaluation methods include the use of the environmental impact of tourism to assess (Green and Hunter, 1992) the tourism carrying capacity assessment (O'Reilly, 1986), and an acceptable change limit system for tourism development (McCool, 1994). Currently, the index evaluation model method has become the choice of most scholars for the quantitative calculation of TES because of its high applicability, strong operability, and high comparability. Scholars usually use the following models: P-S-R (Zhou et al., 2015); DPSIR (Xiaobin et al., 2021); PSR-EES (Tang et al., 2018); and the Ecological Footprint (Zhang et al., 2008; Zhou et al., 2016); the capacity-support-attraction-continuation-development capacity (CSAED) model; the threaten-quality-regulation (TQR) model (Zheng et al., 2015); and the Institutional environment-Regulatory and construction acts-Disturbing Activation-Security state (IRDS)

model. The evaluation and measurement methods chosen by scholars are different. Measurement methods for tourism ecological security include the improved Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) and linear weighting method (Li et al., 2017a), fuzzy comprehensive evaluation method (Du et al., 2021), ecological footprint method (Qian et al., 2018), grey relational projection method (He et al., 2018), system dynamics model (Qin and Cheng, 2019), and DEA data envelopment analysis (Ruan et al., 2019), etc. In previous studies, the research case, temporal and spatial evolution, and influencing factors are key issues that lay the foundation for current and future tourism research. Not only can it help us effectively understand the spatiotemporal evolution characteristics and driving factors of tourism ecological security in tourist cities, but it can also provide theoretical guidance for the sustainable development of tourism.

2.2 Methods on spatial-temporal evolution of tourism ecological security

Spatiotemporal pattern evolution is the focus of tourism geography research and has been widely applied in tourism ecological security research in recent years. (Liu et al., 2022) used a spatial autocorrelation model to analyze the spatial-temporal differentiation pattern characteristics of Chongqing's ecological security. (Zheng et al., 2023) used the standard deviation ellipse method, and the center of gravity model method was used for analysis in 31 provinces of China. (Wang and Chen, 2021) used interpolation analysis and spatial variation models to analyze the temporal and spatial dynamic evolution characteristics of the tourism ecological security level in 11 provinces of the Yangtze River Economic Belt from 1998 to 2017. (Xiaobin et al., 2021) used the spatial measurement model Spatial Durbin Model (SDM) to analyze the spatial characteristics of tourism ecological security in 41 cities in the Yangtze River Delta. Additionally, there was also the kernel density analysis (Wang et al., 2021c; Chen et al., 2023) and the dynamic degree model method (Tang et al., 2018). (Mu et al., 2022) used Markov and space Markov chains to explore the dynamic evolutionary characteristics of tourism ecological security in the Yellow River Basin. Compared with other spatial-temporal pattern analysis methods that focus on the spatial-temporal differentiation characteristics and changes in the entire study area and use cross-sectional data of the entire study area, a single year, or between years. The Markov chain and space Markov chain theory can not only be used to describe the spatial and temporal evolution of the ecological security level but also to analyze the probability of ecological security level evolution over time. Overall, considering the influence between neighborhoods, the analysis of the evolution probability and spatial-temporal evolution characteristics of the ecological security level of all research units in all years has the advantage of being meticulous and comprehensive. Used in this research, it not only explores the spatial effect of tourism but also helps to provide targeted policy formulation suggestions for units with different ecological security levels and different development levels to promote the sustainable development of tourism.

2.3 Research on influencing factors

In recent years, research on the factors influencing tourism ecological security has become a popular topic, which is also a manifestation of the expansion of the content to deeper issues and a symbol of the gradual maturity of tourism ecological security research. To scientifically and reasonably explore the effects and mechanisms of tourism's ecological security and its driving factors within a system, the choice of research methods for the influencing factors is crucial. Current research on the factors driving tourism ecological security involves research areas, including China (Qin and Cheng, 2019; Liu and Yin, 2022), the Yangtze River Delta (Ruan et al., 2019; Xiaobin et al., 2021), Shaanxi Province (Zhang et al., 2022) and other large-scale regions, Beijing (Tang et al., 2018), Dalian (Lu et al., 2019) Jiuzhaigou Scenic Area (Zhang et al., 2008), and other small-scale areas. In the research method of influencing factors, the gray correlation model was used to measure the degree of correlation between the 39 indicators in the evaluation system and the tourism ecological security index to research influencing factors (Tang et al., 2018). (Zhao and Guo, 2022) used geographic detectors to study the impact of 33 evaluation indicators on system security (Xiaobin et al., 2021) and spatial econometric models (SLM model and SEM models) to calculate the direct effects of influencing factors and indirect effects, as well as the obstacle model (Mu et al., 2022). The grey relational degree analyses the degree of influence according to the similarity degree of the geometric relationship of the data sequence curve; however, this method does not carry out the statistical testing of data; the obstacle degree calculates the influencing factors by calculating the weight of each index. This method also does not carry out the statistical testing of data, and the geographic detector method only measures the q value of the degree of influence at a single time point and cannot explore the positive and negative effects of the influence. Compared with the above methods, the panel quantile regression method must test the stationarity of each influencing factor before use, which ensures the rationality of the method. It can not only analyze the overall influencing factors of all research units at all-time points simultaneously but also explore the positive and negative effects of influencing factors, with comprehensive and holistic advantages. Moreover, compared to other methods, it has the characteristics and advantages of observing the changing trend of the independent variable regression coefficient value when the dependent variable is at different quantile points. It is convenient to draw more reliable research conclusions that have been applied and confirmed in some studies (Mu et al., 2022).

2.4 Current gaps in the literature

To clarify the necessity of this study to better explore the innovation of tourism ecological security evaluation methods and the key driving mechanisms, this paper comprehensively reviews previous related research and highlights the current research gap in tourism science. (1) In previous studies, when constructing the evaluation index system, researchers only referred to previous studies or simply listed them based on existing data, while

ignoring the importance of providing a theoretical basis for the evaluation of tourism ecological security. However, a strong theoretical background not only helps to elucidate the interactions among multiple actors in tourism ecosystems but also helps to translate complex system operating mechanisms into simple explanations. Therefore, this study introduces the ecological system as well as the system theory. (2) In terms of spatiotemporal evolution, existing studies mostly start from spatial autocorrelation and analyze the spatial evolution pattern of a large number of city-level research units based on large-scale research areas, such as provinces, river basins (Xu and Liu, 2018), and economic belts. It is significant to explore the temporal and spatial evolutionary characteristics of small-scale regional tourism ecological security especially tourist cities, and innovative research methods. (3) Scholars have previously used a variety of methods to study the influencing factors of tourism ecological security. However, these methods have limitations in terms of data inspection, reliability, and time. The panel quantile regression method has advantages and is conducive to the establishment of a comprehensive, multilevel, scientific, and accurate driving mechanism for tourism ecological security.

3 Materials and methods

The methodology used by this study for evaluating tourism ecological security of Huangshan City is composed of three parts: indicators selection and evaluation system construction, data collecting and processing, and research method including: entropy-weighted TOPSIS model, Markov chain, spatial Markov chain, panel quantile regression. The study’s method framework is shown in Figure 2.

3.1 Materials

3.1.1 Model construction

The scientific selection of indicators is key to ensuring research results and is the core of evaluating tourism ecological security (Liu and Yin, 2022). Based on the perspective of the composite ecological system theory, this study considers tourism cities as a system composed of economic-environment-social subsystems that are mutually different, mutually restrictive, and interrelated: comprehensive consideration of economy, society, tourism,

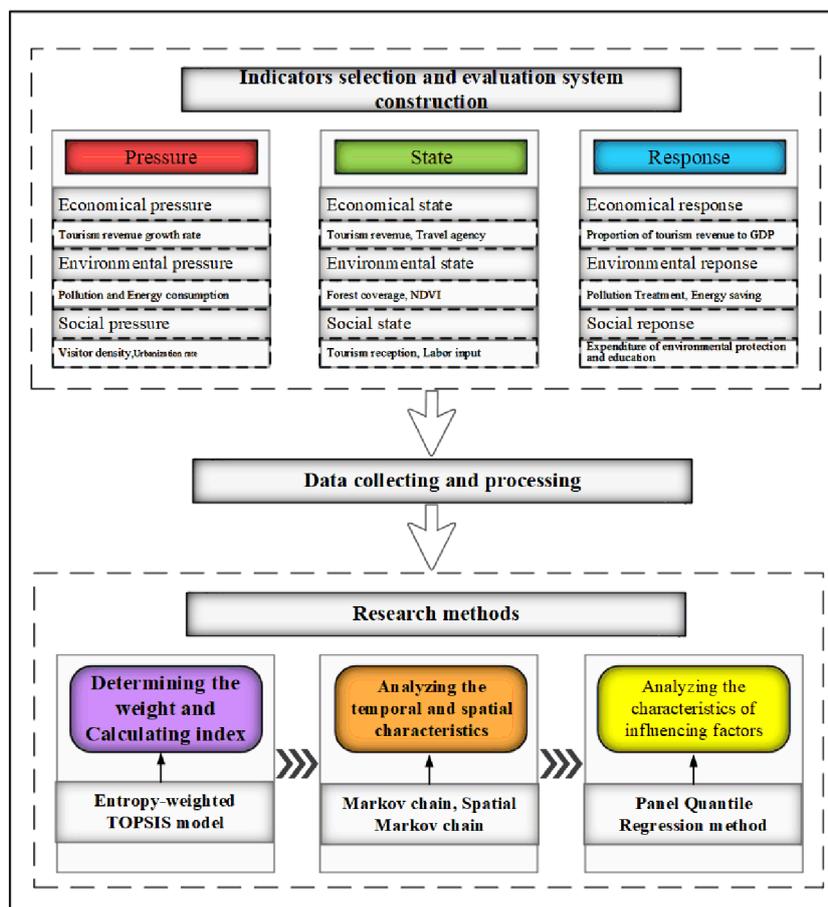


FIGURE 2 The method framework for evaluating tourism ecological security in Huangshan City.

transportation, energy consumption, ecology, environmental protection, and other factors. At the same time, based on the system theory, focusing on the integrity, relevance, hierarchical structure, and dynamic balance characteristics of the evaluation system, an evaluation index system based on the PSR-EES model was constructed, and it was applied to the research on the operation mechanism of the tourism ecological security system. Mountain-type tourism city: Huangshan City tourism ecological security issues are to be re-examined.

The operating mechanism of the PSR-EES model in tourism ecological security can be expressed as follows: human tourism activities exert economic, environmental, and social pressures on the ecosystem (P), which is the dominant cause of ecological security problems in tourist destinations; under the impact of pressure, the function and state (S) of tourism and ecological dual system change, which leads to a change in destination tourism ecological security level; to reduce risk pressure and continue the positive effect to promote and maintain the benignity of tourism and ecological environment development, tourism stakeholders are bound to exert their subjective initiative.

Taking appropriate measures to respond positively (R), this study combines the theory of tourism ecological security, following the principles of scientificity, comprehensiveness, systematization, hierarchy, and data availability, and starts from the perspective of the interaction of the three subsystems of economy, society, and the ecological environment. Using indicators with their characteristics in the tourism industry and soliciting relevant expert opinions, a tourism ecological security evaluation index system consisting of three subsystem-level first-level indicators and 38 factor-level second-level indicators was constructed, and the weight of each indicator is determined by the entropy weight method for all administrative units and 38 indicator data from 2000 to 2019. Table 1 shows the units, positive and negative attributes, weights and related references of the 38 indicators.

Currently, there is no unified standard in the academic community for evaluating tourism ecological security. This study proposes a grading standard based on existing research results (Yajuan et al., 2013; Tang et al., 2018), and the actual situation in Huangshan City (Peng et al., 2017; Hu et al., 2019; Yu et al., 2020). The proposed standard divides tourism ecological security into seven categories: deterioration, risk, sensitivity, critical security, general security, relative security, and extreme security.

3.1.2 Data sources

The statistical data used in this paper come from the Huangshan City Statistical Yearbook “Huangshan City Statistical Yearbook,” “Anhui Statistical Yearbook,” “China Tourism Statistical Yearbook,” “China County Statistical Yearbook,” “China City Statistical Yearbook,” “China Energy Statistics Yearbook” from 2001 to 2020 Yearbook”, the National Economic and Social Development Statistical Bulletin of Huangshan City and its seven districts and counties from 2000 to 2019, the Environmental Status and Environmental Protection Work Target Completion Report, and so on. NDVI data were obtained from the Resource and Environment Science and Data Center of the Chinese

Academy of Sciences (<https://www.resdc.cn/>) from 2000 to 2019, and the Chinese 30 m land cover fine classification product (CLCD30) of Yang Jie’s team at Wuhan University (<https://zenodo.org/record/5210928>) from 1999 to 2019. Linear interpolation was used for the missing data to complement and complete the dataset.

3.2 Methods

3.2.1 Entropy-weighted TOPSIS model

TOPSIS was first proposed by Hwang and Yoon (1981). This method constructs the optimal and worst-case scenarios for each indicator and then calculates the relative closeness to the optimal and worst-case scenarios. It evaluates the advantages and disadvantages of each scenario based on the distance between positive and negative ideal solutions. This method has the advantages of being true, intuitive, and reliable, with no strict restrictions on data distribution, sample size, or the number of indicators, and has been used successfully by many scholars (Zhou et al., 2015). In this study, we use this method to evaluate the level of tourism ecological security in Huangshan City. The steps are as follows: (1) standardize the evaluation indicators using the range method; (2) calculate the indicator weights using the entropy weight method, which has strong objectivity; (3) establish a weighted normalization matrix; (4) determine the positive and negative ideal solutions; (5) calculate the distance from the target value to the positive and negative ideal solutions; and (6) calculate the proximity index of each evaluation object to the optimal solution in each year, with a value range of [0,1]. The larger the value, the safer the tourism ecological system of the research unit, and vice versa. The specific calculation formula can be found in the reference (Huang, 2008; Behzadian et al., 2012).

3.2.2 Markov chain

A Markov chain is a type of Markov process in which both the time and state are discrete (Hastings, 1970). This method discretizes the continuous tourism ecological security index into k categories and calculates the probability distribution and interannual transition changes of the corresponding categories to approximate the entire regional evolution process. It can be used to analyze the probability of the evolution of tourism ecological security levels over time and extreme security, and the specific level classification is shown in Table 2. The probability distribution of tourism ecological security levels in year t can be represented as a $1 \times k$ state probability vector $P_t = [P_{1,t}, P_{2,t}, \dots, P_{k,t}]$. The transition between different tourism security levels in different years is represented by the Markov transition probability matrix M .

$$M = \begin{bmatrix} m_{11} & m_{12} & \dots & m_{1j} \\ m_{21} & m_{22} & \dots & m_{2j} \\ \vdots & \vdots & \vdots & \vdots \\ m_{i1} & m_{i2} & \dots & m_{ij} \end{bmatrix} \quad (1)$$

TABLE 1 Evaluation index system of tourism ecological security in Huangshan City.

Standard level	Factor level	Index level	Unit	Attribute	Weight	References	
Pressure	Economic pressure	D1 Tourism economic density	10,000 yuan/km ²	-	0.0163	Qian et al., 2018	
		D2 Domestic tourism revenue growth rate	%	-	0.0263	Williams and Ponsford, 2009	
		D3 International tourism revenue growth rate	%	-	0.0250	Liu et al., 2017a	
		D4 Tertiary industry growth rate	%	-	0.0310	Tang et al., 2018	
	Environmental pressure	D5 Industrial wastewater discharge	tons	-	0.0130	Liu and Yin, 2022	
		D6 So ₂ emissions	tons	-	0.0143	Zhou et al., 2015	
		D7 Solid waste discharge	tons	-	0.0424	Li et al., 2019	
		D8 Daily water consumption per capita	liters	-	0.0269	Williams and Ponsford, 2009	
		D9 Soot emission	tons	-	0.0292	Kapera, 2018	
		D10 Ecological footprint per capita	hm ² /person	-	0.0162	Zhang et al., 2008	
	Social pressure	D11 Tourist Density	person times/hm ²	-	0.0131	Li et al., 2017b; Tang et al., 2018	
		D12 Domestic tourist growth rate	%	-	0.0253	Liu et al., 2017b	
		D13 International tourist growth rate	%	-	0.0276	Malekmohammadi and Jahanishakib, 2017	
		D14 Urbanization rate	%	-	0.0150	Jurado et al., 2012	
State	Economic state	D15 Domestic tourism revenue	Billion yuan	-	0.0163	Liu et al., 2017b; Liu and Yin, 2022	
		D16 Number of star hotels		-	0.0207	Shi et al., 2019	
		D17 International tourism revenue	10,000 dollars	-	0.0318	Xiaobin et al., 2021	
		D18 Tourism revenue per capita	yuan/person	-	0.0137	Ruan et al., 2019	
		D19 Number of travel agencies			0.0135	Tang et al., 2018	
	Environmental state	D20 Forest coverage	%	+	0.0134	Fan and Fang, 2020	
		D21 Forest area per capita	hm ² /person	+	0.0217	Fan and Fang, 2020	
		D22 Proportion of nature reserves to urban areas	%	+	0.0234	Xiao et al., 2011	
		D23 Per capita park green area	m ² /person	+	0.0527	Li et al., 2017a	
		D24 NDVI		+	0.0140	Yang and Cao, 2021	
	Social state	D25 Ratio of tourist arrivals to local population	%	-	0.0183	Qian et al., 2018	
		D26 Number of employees in tertiary industry	person	+	0.0455	Xiaobin et al., 2021	
	Response	Economic response	D27 Proportion of total tourism revenue to GDP	%	+	0.0741	Tang et al., 2018
			D28 Proportion of Tertiary industry revenue to GDP	%	+	0.0253	Tang et al., 2018
D29 Proportion of fiscal expenditure to GDP			%	+	0.0527	Liu et al., 2017a	
Environmental response		D30 Industrial wastewater treatment rate	%	+	0.0266	Liu and Yin, 2022	
		D31 Harmless disposal rate of domestic waste	%	+	0.0192	Williams and Ponsford, 2009	
		D32 Industrial solid waste disposal rate	%	+	0.0298	Lu et al., 2019	
		D33 Reforestation area in the year	hm ²	+	0.0395		
			tons	-	0.0166	Cheng and Yue, 2011	

(Continued)

TABLE 1 Continued

Standard level	Factor level	Index level	Unit	Attribute	Weight	References
		D34 Energy consumption per 10,000 Yuan GDP				
		D35 Number of industrial waste gas treatment facilities		+	0.0476	
		D36 Decreasing rate of ecological land	%	-	0.0130	
	Social response	D37 Proportion of environmental protection expenditure to GDP	%	+	0.0217	Tang et al., 2018
		D38 Proportion of education expenditure to GDP	%	+	0.0276	Xiaobin et al., 2021

TABLE 2 Tourism ecological security level standard in Huangshan City.

Close-Degree	[0,0.3]	(0.3,0.4]	(0.4,0.5]	(0.5,0.6]	(0.6,0.7]	(0.7,0.8]	(0.8,1]
Security grade	I	II	III	IV	V	VI	VII
Security Situation	Deterioration	Risk	Sensitive	Critical Security	General Security	Relative Security	Extreme Security

The element m_{ab} represents the probability of a region belonging to category a in year t transitioning to category b in the following year, where $m_{ab} = n_{ab}/n_a$. Here, n_{ab} represents the sum of the number of regions belonging to category a in year t , that transitioned to category b in year $t + 1$, and n_a represents the sum of the number of regions belonging to category a during the study period. If the tourism ecological security of a region remains the same in the following year as it was in the initial year, it indicates that its transition is in a steady state. If the tourism ecological security level improves, it is defined as an upward transition; otherwise, it is defined as a downward transition.

3.2.3 Spatial Markov chain

A spatial Markov chain is a combination of the traditional Markov chain method and spatial lag (Roberts and Rosenthal, 2004). By introducing spatial lag factors, the spatial Markov chain accounts for the states of neighboring regions, thereby compensating for the shortcomings of traditional Markov chains in terms of spatiality. This method can be used to analyze the possibility of upward or downward transitions of tourism ecological security in a unit affected by neighboring units and reveal the spatial interaction relationship in the process of tourism ecological security change and the relationship between the probability of tourism ecological security type transition and neighboring counties.

The spatial Markov transition probability matrix decomposes the traditional $N \times N$ Markov matrix into k $N \times N$ transition probability matrices, based on the spatial lag type of region i in the initial year. For the k th conditional matrix, the element $m_{ab}(k)$ represents the one-step spatial transition probability that the region belongs to type i in the current year and transitions to type b in the following year, given that the spatial lag type is k . The spatial lag value Lag_e of unit e is the weighted average

of the observation values of its neighboring units, as shown in the following formula:

$$Lag_e = \sum_{f=1}^n (Y_e W_{ef}) \tag{2}$$

Y_e represents the observation value of unit e ; W_{ef} is the spatial weight matrix. Because of the significant spatial adjacency and continuity among the districts and counties of Huangshan City, this study used the adjacency weight matrix, where adjacent units have a weight of 1 and otherwise a weight of 0, representing the spatial relationship between units e and unit f .

3.2.4 Panel quantile regression

The quantile regression method was first proposed by (Koenker and Bassett, 1978), and has been widely used in panel data research in recent years (Huang et al., 2017). The quantile regression method has the characteristic of observing the regression coefficient values at different quantile points and can comprehensively and systematically study the influence of the independent variable X on the dependent variable Y (Koenker and Hallock, 2001). Compared with ordinary linear OLS regression, the quantile regression algorithm is more robust, and the conclusion is more testable when there are outliers in the data when the dependent variable Y is not normally distributed, or when heteroscedasticity problems occur. In short, panel quantile regression does not need to consider that the data obey a normal distribution and can also better eliminate the interference of outliers. Controlling for differences in the explanatory variables effectively describes the differences between the explained variables at different quantile points influences relationships (Koenker, 1994). Its expression is:

$$Q_{Y_i}(\tau | X_{it}) = a_i + X_{it}^T \beta(\tau), \quad (i = 1, 2, \dots, n; t = 1, 2, \dots, T) \tag{3}$$

In the formula: $Q_{Y_{it}}$ is the conditional quantile function of tourism ecological security; Y_{it} is the value of tourism ecological security; a_i is a constant item; X_{it} is the explanatory variable matrix; n is the research sample size; T is the research period; $\beta(\tau)$ Indicates the influence coefficient under the τ quantile; the quantile points set in this paper are 0.1, 0.25, 0.5, 0.75, 0.9

$$\beta(\theta) = \min_{(\alpha, \beta)} \sum_{k=1}^q \sum_{i=1}^n \sum_{t=1}^T w_k \rho_{\tau_k} [Y_{it} - a_i - X_{it}^T \beta(\tau_k)] \quad (4)$$

In the formula: $\beta(\theta)$ is the influence coefficient; q is the number of quantile arrays; k is the k th group of quantiles; ρ_{τ_k} is the quantile loss function; w_k is the weight coefficient of the k th quantile; $\beta(\tau_k)$ is the influence coefficient of the k th quantile.

Considering the real situation in Huangshan City and the calculated results of tourism ecological security in this study, a representative index was selected to construct a model system of driving factors for the comprehensive effect of multiple factors on tourism ecological security in Huangshan City. From the aspects of tourism development level, economic development level, labor input, environmental pollution, tourism load level, regional greening degree, government intervention, and education level, the spatiotemporal evolution process of tourism ecological security under the influence of multiple factors was systematically quantified. Table 3 shows types, interpretations, and statistical descriptions of the variables.

4 Result

4.1 Temporal evolutionary characteristics of tourism ecological safety

To ensure the reliability and comprehensiveness of the data as much as possible, the time before COVID-19 was analyzed for as long as possible to better explore the cyclical characteristics of tourism ecological security. This paper analyzed and calculated the 2000–2019 Huangshan and comprehensive index of tourism ecological security in each district. The average index of tourism ecological security in

Huangshan City and its districts steadily increased from 0.288 in 2000 to 0.432 in 2019, with an average annual growth rate of 2.16%, as shown by the line graph (Figure 3A) and box plot (Figure 3B). The development of tourism and protection of the ecological environment has been priorities for governments at all levels. Policies such as the State Council’s “Opinions on Accelerating the Development of Tourism” (No. 41, 2009), the Joint National Ecotourism Development Outline (2008–2015) issued by the former National Tourism Administration and the Ministry of Environmental Protection, and the “Huangshan Ecological Strong City Construction Implementation Plan” (No. 20, 2013) issued by the Huangshan City Government aim to strengthen the relationship between ecological protection and tourism development. These policies have led to a decrease in the number of counties and districts that are deteriorating or at risk, whereas the number of sensitive and critically safe areas has continued to increase, showing an overall positive trend (Figure 4). However, during the study period, different districts showed varying degrees of improvement in the ecological security of tourism. The difference in the tourism ecological security index among districts also showed a widening trend. Therefore, there remains great potential for improvement in the tourism ecological security level in Huangshan City.

The comprehensive tourism ecological safety index for Huangshan City and its districts and counties from 2000 to 2019 was analyzed and calculated, showing a steady upward trend in the overall index, with some fluctuations in certain years. However, the gap between the ecological safety indices of various districts and counties is continuously widening, and there are differences in the ecological safety status of each district and county. Specifically, She County, Xiuning County, and Yi County showed steady upward trends, reaching their highest values in 2019. Tunxi District experienced significant declines in 2003–2004 and 2012–2013 but has otherwise steadily increased. Qimen County and Huangshan District steadily increased before 2013–2014 but have since slowly decreased each year. Huizhou District steadily increased before 2011 and has remained stable since then. Sorting the average tourism ecological safety index of each district and county during the study period from the highest to lowest results in the following order: “Yi County (0.413) > She County (0.380) > Tunxi District

TABLE 3 The main variables of the panel quantile regression equation and their descriptive statistics.

Type	Variable	Interpretation	Mean	Std. Dev.	Min	Max
Explained Variable	Tourism Ecological Security	Tourism Ecological Security Index	0.359	0.060	0.271	0.511
	Tourism Development	Tourism revenue (100 million yuan)	30.752	35.473	0.638	173.701
Explanatory Variable	Economic Development	GDP (100 million yuan)	47.170	42.056	3.950	198.540
	Labor Input	Number of employees in tertiary industry (10,000 people)	4.240	2.509	1.154	10.777
	Environmental Pollution	Solid waste discharge (t)	214.691	411.112	2.000	2211.000
	Tourism Load Level	Ratio of tourist arrivals to local population (%)	24.512	25.627	1.417	141.985
	Regional Greening Degree	Per capita park green area (m ² /person)	5.996	5.040	1.299	20.731
	Government Intervention	Proportion of fiscal expenditure to GDP (%)	19.351	7.534	8.528	42.856
	Educational Level	Proportion of education expenditure to GDP (%)	2.683	0.599	1.630	5.734

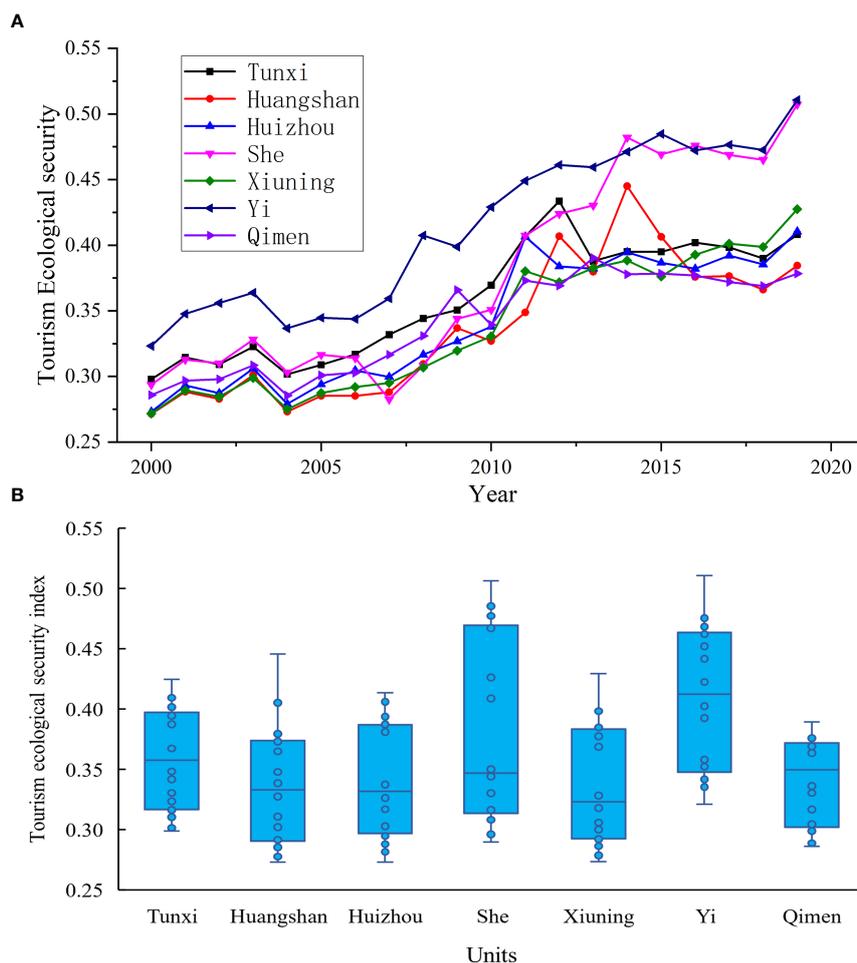


FIGURE 3 Changes and characteristics of tourism ecological safety index by districts and counties in Huangshan City from 2000 to 2019. (A) Folding line chart; (B) Box line chart.

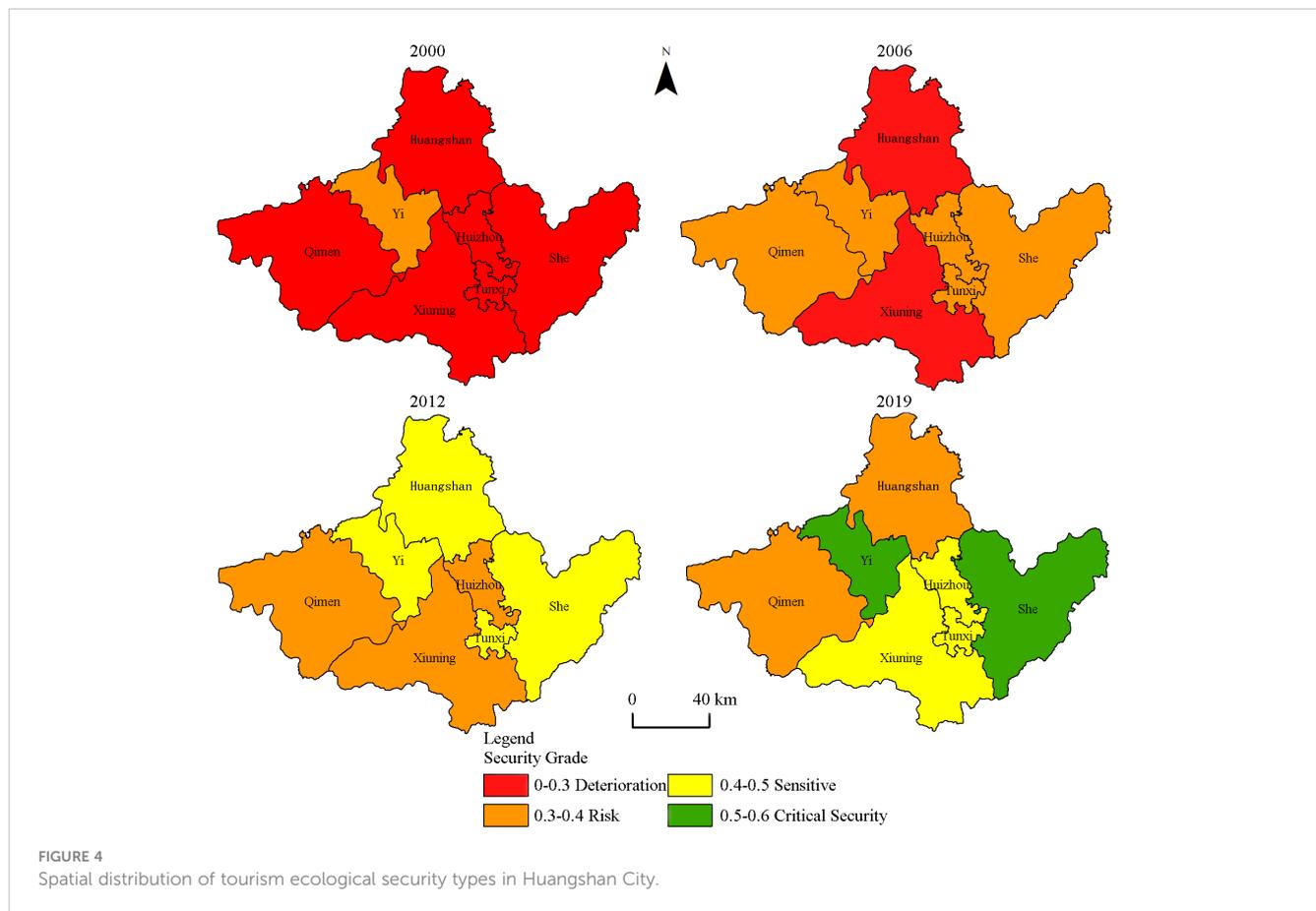
(0.359) > Huizhou District (0.342) > Qimen County (0.341) > Huangshan District (0.338) > Xiuning County (0.337)”, with Yi County having the highest level of tourism ecological safety. From the perspective of the degree of improvement, the order of each district and county’s tourism ecological safety index increase value and proportion is: “She County (0.214, 72.76%) > Yi County (0.187, 57.98%) > Xiuning County (0.156, 57.37%) > Huizhou district (0.137, 50.23%) > Huangshan district (0.113, 41.63%) > Tunxi district (0.110, 37.02%) > Qimen county (0.093, 32.38%)”. The county had the highest increase in tourism ecological safety level during the study period, with an increase of 0.214 and an average annual growth rate of 2.92%, indicating that the degree and speed of tourism ecological safety optimization were better than those of other districts and counties.

4.2 Spatial evolutionary characteristics of tourism eco-safety types

This study examined the dynamic transfer characteristics of tourism ecological security levels among different districts and

counties in Huangshan City by constructing traditional and spatial Markov transition matrices. According to the classification criteria of tourism ecological security levels, the ecological security of Huangshan City is divided into four types: deterioration level I (0, 0.3], risk level II (0.3, 0.4], sensitivity level III (0.4, 0.5], and critical safety level IV (0.5, 0.6].

In the Markov transition probability matrix, the diagonal elements represent the probability of a single unit’s tourism ecological security level remaining unchanged, while the off-diagonal elements represent the probability of transition between different tourism ecological security levels. Table 4 illustrates the dynamics of tourism ecological security transfer in Huangshan City from 2000 to 2019, disregarding the geographical spatial pattern. The results indicated that all level types showed convergence and stability, with values on the diagonal being higher than those off the diagonal. The probability of an area belonging to a particular level remaining in that level in subsequent years is at least 60.71%, 78.48%, and 69.23% for levels I, II, and III, respectively, and level-type transfers have a “path-dependent” effect. Additionally, off-diagonal elements indicate that transfers usually occur between adjacent levels, with few cross-level transfers. Finally, the



probability of counties in level I remaining unchanged was 60.71%, while the probability of transferring to a higher level was 39.29%. The probability of counties in level II transferring to a higher level was 15.19%, while the probability of transferring to a lower level was 6.33%. Based on Table 4, the research findings suggest that the probability of upgrading Levels I and II tourism ecological security is relatively high, indicating the need for urgent promotion of the upgrading of low-level tourism ecological security regions. However, the probability of level III transferring to a higher level was only 7.69%, whereas the probability of transferring to a lower level was 23.08%. Thus, regions with tourism ecological security level III require attention to prevent them from falling to lower levels, expand their safety level, and guide them toward transforming into a higher safety level.

The level of tourism ecological safety is not isolated and is often influenced by changes in the safety level of the surrounding areas, exhibiting certain spatial agglomeration and spatial interaction effects.

Compared with traditional Markov models, the traditional spatial Markov probability transition matrix not only reflects changes between different types but also considers the influence of changes in the safety level of neighboring counties on the tourism ecological safety type in the study area (Figure 5). By adding spatial lag terms to the traditional Markov transition probability matrix, we construct a spatial Markov transition probability matrix for tourism ecological safety in Huangshan City. Table 5 shows that compared with the traditional Markov transition matrix, the transition probabilities of tourism ecological safety types in Huangshan City have undergone significant changes under different neighborhood conditions. The neighborhood background plays a significant role in the dynamic changes in ecological safety levels in various districts and counties in Huangshan City, and the types of tourism ecological safety levels under different neighborhood backgrounds exhibit significant differences.

Generally, if a region has high ecological safety level areas as neighbors, the probability of upward transition will increase and its

TABLE 4 Markov transition probability matrix of tourism ecological security types in Huangshan City from 2000 to 2019.

t/(t+1)	n	I	II	III	IV
I	28	0.6071	0.3929		
II	79	0.0633	0.7848	0.1519	
III	26		0.2308	0.6923	0.0769
IV	0				

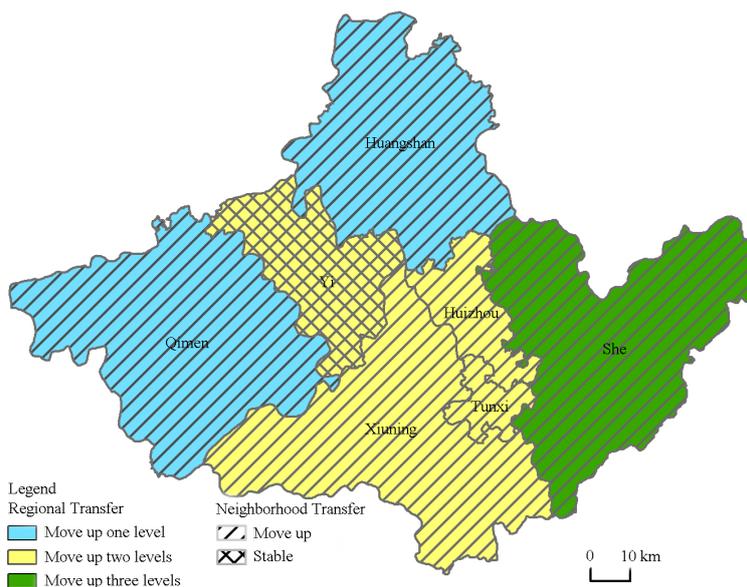


FIGURE 5 The spatial pattern of the types of tourism ecological security transfer and neighbor transfer types in Huangshan City.

probability of downward transition will decrease. Conversely, if it has low-level areas as neighbors, the probability of an upward transition decreases, and the probability of a downward transition increases. For example, in the traditional Markov transition probability matrix, the probability of level II transitioning to level III is 15.19%, whereas considering the spatial neighborhood background adjacent to level III, the transition probabilities are 24.12% and 0 when adjacent to levels II and III, respectively. The probability of level III transitioning

to level IV was 7.69%. However, when adjacent to level II, the transition probability was 0, whereas it was 22.22% when adjacent to level III. There is a certain degree of “club convergence” phenomenon, and there is a certain spatial inertia in the spatial and temporal changes of each type’s transition probability. For Level II, the probabilities of maintaining itself unchanged when its neighborhood background is Level I, Level II, and Level III are 0.8824, 0.7576, and 0.7586, respectively. For level III, the probabilities

TABLE 5 Markov transition probability matrix of tourism ecological security type space in Huangshan City from 2000 to 2019.

Neighbor Type	t/(t+1)	n	I	II	III	IV
I	I	11	0.5455	0.4545		
	II	16	0.0588	0.8824	0.0588	
	III					
	IV					
II	I	17	0.6471	0.3529		
	II	33	0.1212	0.7576	0.1212	
	III	17		0.1765	0.8235	
	IV					
III	I					
	II	29		0.7586	0.2412	
	III	7		0.4444	0.3333	0.2222
	IV					
IV	I					
	II					
	III					
	IV					

of maintaining itself unchanged when its neighborhood background was level II and level III were 0.8235 and 0.3333, respectively.

4.3 Influencing factors

To explore the influencing factors and driving mechanism of tourism ecological security in Huangshan City, this study chooses the panel quantile regression method for estimation and selects five representative quantile points: 0.1, 0.25, 0.5, 0.75, and 0.9 in the model, these five representative quantile points At the same time, the calculated ordinary OLS regression results are compared with the panel quantile regression results to explore the changes in the elastic coefficients of all influencing factors. To avoid the phenomenon of spurious regression, between panel quantile regression, this paper chooses Levin, Lin, and Chu's t-test (LLC test), ADF-Fisher Chi-square (ADF test), and PP-Fisher Chi-square (PP test). Three commonly used unit root test methods are used to test the stationarity of panel data. As shown in Table 6, all the variables passed the test at a significance level of 1%.

From the estimation of the panel quantile regression results (Table 6) and its visualization results (Figure 6), environmental pollution factors and economic development levels have a negative inhibitory effect on tourism ecological security in general, while other factors have a significant promotion effect. However, there were significant differences in the sizes of the influence coefficients of each variable at different quantile points.

(1) In terms of the change in the impact coefficient of the tourism development level variable, the level of tourism development has a significant effect on the tourism ecological security of Huangshan City at each quantile point and continues to rise as the quantile point, from 0.064 at the 10th percentile point to 0.074 at the 90th percentile point. Owing to low resource consumption, low pollution, and recyclable green characteristics of tourism in the process of promoting economic development, tourism development is an important way to improve the level of tourism ecological security in various regions. (2) The overall economic development level negatively affected the change in the influence coefficient of the economic development level variable. The negative effect increased in the low quantile, decreased in the

middle quantile, and gradually approached a positive effect above the 90% quantile. Overall, the higher the level of development, the smaller the negative effect. This shows that we must actively promote high-level and high-quality economic development, develop tourism, optimize and promote the evolution of the industrial structure toward rationalization and advanced development. (3) In terms of the change of the influence coefficient of the labor input variable, the labor input has a significant positive effect on the tourism ecological security, and the influence coefficient at each quantile point presents an inverted "N" trend. The impact coefficient was greater than that of the low quantiles. Tourism is a typical labor-intensive industry that can absorb large amounts of labor. This shows that vigorously developing the tourism industry, promoting the optimization of the labor force structure, increasing the number of people engaged in the tertiary industry, and increasing the proportion of the entire labor force in the station has a positive effect on improving the level of tourism ecological security. (4) In terms of the impact coefficient of environmental pollution variables, environmental pollution has a significantly negative inhibitory effect on the ecological security of tourism. Industrial solid waste, the largest and most important pollutant in Huangshan City, significantly impacts the ecological security of tourism. The estimated coefficient of the upper environmental pollution quantile decreased with an increase in the quantile, indicating that environmental pollution is the main obstacle in low-level tourism ecological security areas, and that strengthening environmental governance is an important measure to improve the safety of regional ecological systems. The negative effect of pollution at higher levels is weaker. This is attributed to the implementation of relevant policies on environmental governance, optimization of the energy structure, and the development of green emission reduction technologies. (5) The change in the impact coefficient of the tourism load level variable has a positive impact effect, and the effect increases from the low quantile point to the high quantile point, indicating that the tourism reception and tourism load of Huangshan City have not yet exceeded the reasonable carrying capacity of the regional tourism environment; however, there is still room to receive more tourists and promote the development of tourism. (6) In terms of the changes in the influence coefficient of the regional greening degree variable, the influence

TABLE 6 Unit root test of panel data.

Variable	LLC test value t	ADF test value t	PP test value t	Result
lnTES	18.9182***	-13.0109***	-18.29196***	Stable
lnTD	-18.8974***	-14.1578***	-38.91605***	Stable
lnED	-10.2261***	-13.8479***	-17.32828***	Stable
lnLI	-26.9125***	-6.88846***	-31.63923***	Stable
lnEP	-15.138***	-14.043***	-66.34316***	Stable
lnTLL	-11.9612***	-15.27***	-43.97197***	Stable
lnRGD	-35.3869***	-13.124***	-48.63407***	Stable
lnGI	-12.1274***	-8.73391***	-20.88389***	Stable
lnEL	-13.0853***	-16.4579***	-36.48225***	Stable

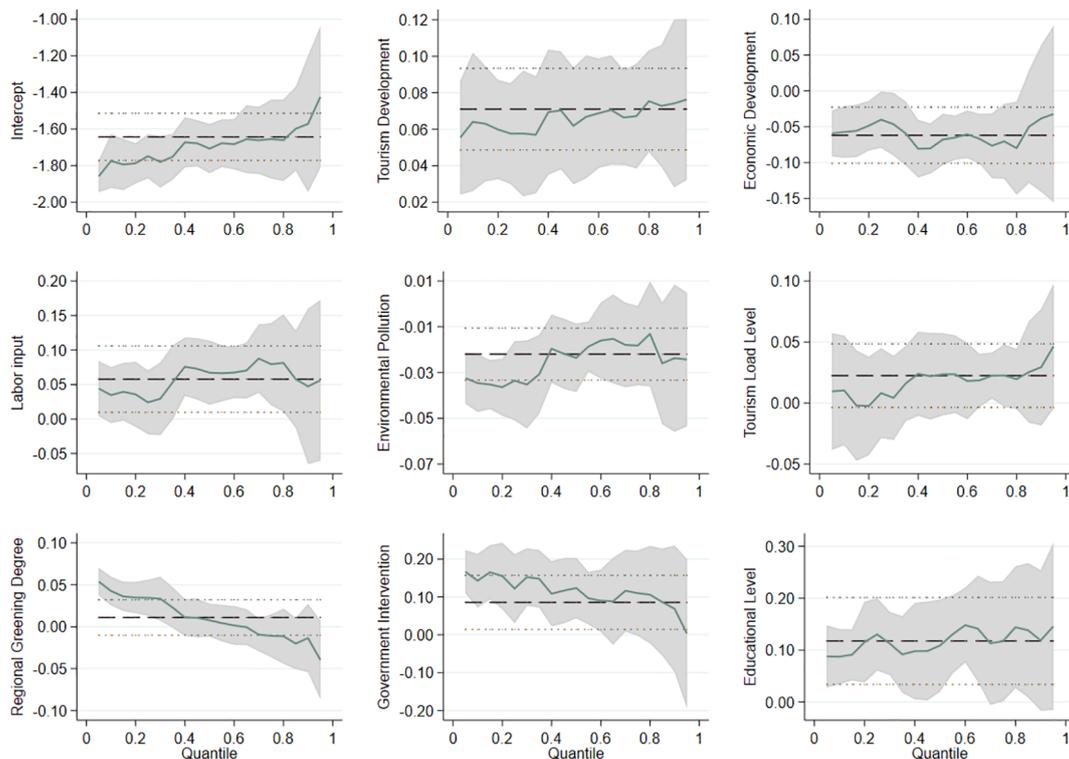


FIGURE 6
Quantile regression results of tourism ecological security in Huangshan City.

coefficient of the regional greening degree decreases from the low quantile point to the high quantile point, indicating that the greening level of lower-level tourism ecological security units is low, and the resource background is not good. Moreover, the carrying capacity of the tourism industry is limited, and the degree of greening of such units has a greater marginal effect on the improvement of tourism ecological security. At the same time, with improvements in the level of tourism ecological security, all regions must strengthen urban greening construction, and the degree of greening cannot keep pace with the development of tourism which has a negative effect. (7) In terms of changes in the influence coefficient of the government intervention variables, overall government intervention has a positive effect with a large influence coefficient, and the influence coefficient decreases from the low quantile point to the high quantile point. The relatively large influence coefficient of government intervention on the low quantile points indicates that government departments should pay more attention to and strengthen the maintenance and governance of tourism ecological security in low-level areas. At the same time, with the improvement in the level of tourism ecological security, change the government intervention model, increase investment, and be wary that government intervention will not keep pace with the development of tourism. Governments should increase investments in environmental protection funds, strengthen environmental protection publicity, integrate tourism resources, and improve management efficiency which would affect the tourism’s ecological security. (8) In terms of the change in the influence coefficient of the educational level variable, the overall effect was positive and

fluctuated upward, and the influence coefficient was relatively large. Residents in areas with high educational levels have a strong awareness of environmental protection, and travel modes tend to be green and low. Carbon can improve the ecological security of tourism. Education levels should be improved, which is important for promoting tourism ecological security in various regions.

5 Discussion

5.1 Theoretical implications

This study has important theoretical value for tourism ecological security, including the following points: First, from the perspective of composite ecological system theory and system theory, the interaction between the economy and environment-society subsystems in the tourism ecosystem is clarified. Moreover, the integrity, relevance, hierarchical structure, and dynamic balance of the evaluation system are emphasized. The PSR-EES evaluation index system was used to explore the temporal change and spatial evolution characteristics of tourism ecological security in Huangshan City. This is a follow-up research on ecotourism in tourism cities and has reference value for the evaluation of urban resilience and land security (Wang et al., 2021a).

Second, it explored the spatiotemporal evolution patterns and characteristics of tourism ecological security of tourism cities represented by Huangshan City and the small-scale regional perspectives at the district and county levels. This study not only

provides a theoretical basis for the sustainable development of tourism ecology in the future but also makes great contributions to the implementation of policies and the coordinated development of regional tourism. This study not only reveals the characteristics of each grade transfer but also proves that the grade change process is affected by neighborhood grades. This study has theoretical contributions and practical value for the government to formulate policies that focus on the improvement of low-level areas, guard against the decline of high-level areas, promote the coordinated development and system of regional tourism, and improve the ecological security level of the entire tourist city.

Third, it clarifies the key factors of tourism ecological security and the direction and degree of different quantiles, which enriches the research methods for the factors affecting tourism ecological security. This solves the shortcomings of the lack of data verification and reliability in previous studies; only a single time point is calculated, and the direction of the influencing factors is lacking. This method not only measures the influencing factors of the whole period and the entire unit as a whole but also emphasizes the dynamic heterogeneity characteristics and changing trends of the driving factors under the background of different levels of tourism ecological security to better reflect the impact of various factors on tourism ecology. The reality of security impacts will help make policies more scientific and reasonable.

5.2 Practical implications

The results of this study will help maintain and improve the level of tourism ecological security and provide targeted improvement policies and suggestions. First, it is necessary to consider the systemic issues of the economy, environment, and society involved in the ecological security of tourism. Government managers should formulate policies to comprehensively promote tourism ecological security (Cernat and Gourdon, 2012), starting from the three levels of economy, environment, and society. It should strengthen restrictions on pressure factors, actively promote the improvement of tourists' civilized quality and ecological awareness, reduce energy and resource consumption, and at the same time levy taxes on high-polluting industries to reduce pollutant emissions (Liu et al., 2017a); actively improve tourism ecology, strengthen regional greening, improve tourism service level and service quality, and actively promote the development of ecotourism; take active response measures; strictly implement environmental protection-related policies; vigorously develop low-carbon industries and green industries; and strengthen pollution control (Ahmad et al., 2018), while strengthening spending on environmental protection and education, raising tourists' awareness of ecotourism, and improving the cultural and professional levels of practitioners (Watson, 2008).

Second, the research results show that although the level of tourism ecological security in the districts and counties of Huangshan City has improved, there is an imbalance in the development of tourism ecological security between districts and counties. Simultaneously, the changes in the ecological security level of each district and county are affected by the neighborhood

background. Therefore, the government must treat this phenomenon correctly, strengthen its guiding role, formulate targeted policies for the different development stages of each district and county, and promote the coordination and balance of development in each district and county (Liu, 2003). At the same time, it promotes inter-regional cooperation, giving full play to the leading role of regions with high levels of tourism ecological security such as She County and Huizhou District, each is the highest levels in counties and districts, promoting their governance experience, and providing experience and material support to regions with low levels. Promoting the coordinated development of tourism ecological security in Huangshan City and sustainable tourism development.

Third, the results show that government intervention, education level, and tourism development level have significant positive effects, whereas environmental pollution and economic development level have negative inhibitory effects on tourism ecological security. To promote sustainable development of the tourism industry, the government should actively promote the upgrading of the industrial structure, actively develop the tourism industry, and promote the development of the tourism industry from traditional to sustainable, green, and low-carbon to drive economic development (Ahmad et al., 2018). Large financial, environmental protection, and educational expenditures. Simultaneously, we formulated different strategies for different stages of ecological security levels, increased the degree of regional greening (Nepal et al., 2019), and fiscal expenditures in lower-level areas such as Qimen County and Huangshan District, and focused more on units with higher levels of tourism ecological security transformation and upgrading of the tourism industry, investment in education, and improvement in the overall quality of tourism practitioners.

5.3 Limitations and future research

Although this study draws some conclusions in the analysis of tourism ecological security in Huangshan City, there are still some deficiencies, such as the difficulty in obtaining statistical data on environmental pollution and energy consumption directly caused by tourism. Owing to the difficulty in collecting data from districts and counties, the absence of older data has led to certain limitations in the research results. At the same time, at the data level, data types can be enriched in future research (e.g., satellite remote sensing image data (Sun et al., 2021), especially hyperspectral (HS) data and high spatial resolution (HR) (Sun et al., 2022), tourism flow big data, pollution monitoring site data, tourists' and residents' ecological security perception questionnaire data) to further enrich the evaluation of the tourism ecological security index system.

6 Conclusions

Based on the PSR-SEE model, this study scientifically measures the tourism ecological security index of Huangshan City from 2000 to 2019 and uses the entropy weight method, the improved TOPSIS

method, Markov chain, space Markov chain, gray correlation analysis, and other methods to analyze Huangshan. The characteristics and influencing factors of the dynamic evolution of the city's tourism ecological security were deeply analyzed. The main conclusions are as follows.

During the study period, the average level of tourism ecological security in all districts and counties of Huangshan City was 0.359, and the average index increased from 0.288 in 2000 to 0.432 in 2019, showing a steady upward trend. The ecological security of tourism in Huangshan City lies between deterioration and risk levels. The number of districts and counties gradually decreased. In contrast, the number of sensitive levels and critical safety levels continued to increase. The overall development has been positive; however, there is still great potential for improvement. The ecological security indices of the four counties were generally higher than those of the three districts, and the tourism ecological security index of Yi County ranked first.

In terms of dynamic evolutionary characteristics, the type of transfer of tourism ecological security in Huangshan City has the characteristics of self-stability and path dependence. The transfer of regional tourism ecological security usually occurs sequentially between adjacent levels, and there is a risk of downward transfer. The transfer of tourism ecological security types in Huangshan City does not occur in isolation in geographical space. The neighborhood background plays a very important role in the dynamic change process of ecological security levels in various districts and counties of Huangshan City. There were significant differences in the types of tourism ecological security levels among different neighborhood backgrounds, which played different roles in the transfer of regional ecological security levels. The higher the neighborhood level, the higher the probability of upward transition.

In terms of influencing factors, tourism ecological security in Huangshan City is positively promoted by tourism development level, labor input, tourism load level, regional greening degree, government intervention, and education level. It is negatively affected by environmental pollution and economic development level inhibition. Among them, the negative inhibitory effect of environmental pollution and economic development level on low-level tourism ecological security units was more obvious, and the negative effect decreased with an increase in the tourism ecological security level. The overall positive impact coefficients of government intervention, educational level, and tourism development rank among the top three. The positive coefficients of the degree of regional greening and government intervention on low-level tourism ecological security units are larger, whereas the other indicators have larger impact coefficients on higher-level regions. The research results indicate that optimizing the structure of the above variables and improving the quality of comprehensive

development is key to optimizing tourism ecological security in Huangshan City.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

Conceptualization, JZ and JM; methodology, JM and FS; software, JM, CZ, and TM; writing and original draft preparation, JM; writing—review and editing, JM and JZ; funding acquisition, JZ. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fevo.2023.1214741/full#supplementary-material>

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