Postprint of Tourism Ecological Security Assessment in the Hexi Corridor Region Based on Entropy-weighted TOPSIS Method and Fuzzy Matter-element Model

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Abstract

Ecological security assessment of tourism destinations is vital to sustainable tourism development, and the selection of optimal evaluation methods is crucial for reducing uncertainties in assessment outcomes. In this context, this study examines the tourism ecological security status of five prefecture-level cities in the Hexi Corridor region from 2011–2020, constructs a tourism ecological security evaluation index system, and evaluates the quantitative results of the entropy weight-TOPSIS method (entropy weight TOPSIS method) and the fuzzy matter-element model. Results indicate that: (1) The evaluation results of the two methods demonstrate that tourism ecological security in the Hexi Corridor region exhibits an overall upward trend. (2) The changing trends of the driving force index and pressure index in the Hexi Corridor region are relatively coordinated, the changing trends of the impact index and state index are similar, and the response index effectively reflects the outcomes of regional government initiatives. (3) The evaluation results obtained by the fuzzy matter-element model method possess higher credibility. These findings can serve as a reference for model selection in tourism ecological security assessment.

Full Text

Preamble

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Tourism Ecological Security Assessment in the Hexi Corridor Region Based on Entropy Weight TOPSIS Method and Fuzzy Matter-Element Model

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Abstract: The assessment of ecological security in tourism destinations is intricately linked to the sustainable development of tourism, and the careful selection of evaluation methods plays a critical role in mitigating uncertainties surrounding the results of such assessments. On this basis, this study focuses on the tourism ecological security conditions in five prefecture-level cities of the Hexi Corridor region from 2011 to 2020. It constructs a comprehensive index system for evaluating tourism ecological security and employs the entropy weight TOPSIS method and the fuzzy matter-element model to quantitatively assess the results. The findings indicate that: (1) Both methods reveal an overall upward trend in tourism ecological security in the Hexi Corridor region. (2) The changing trends of the driving force index and pressure index in the Hexi Corridor region are relatively coordinated, the trends of the impact index and state index are similar, and the response index effectively reflects the outcomes of regional government initiatives. (3) The evaluation results obtained using the fuzzy matter-element model demonstrate higher credibility. These findings can offer valuable insights for model selection when evaluating the ecological security of tourism systems.

Keywords: tourism ecological security; DPSIR model; fuzzy matter-element model; entropy weight TOPSIS; Hexi Corridor

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1 Introduction

1.1 Study Area Overview

The Hexi Corridor (referred to as Hexi) [37°17 ~42°48 N, 93°23 ~104°12 E] encompasses five prefecture-level cities: Wuwei, Jinchang, Zhangye, Jiuquan, and Jiayuguan. Located in western China within the northwestern part of Gansu Province, west of the Yellow River, this region forms a narrow corridor oriented in a northwest-southeast direction. Historical culture and natural landscapes represent the most valuable assets of the Hexi Corridor. The region features diverse tourism resources, including desert oases, grotto temples, grasslands, and forests. In 2020, the five cities collectively received 66.833 million domestic tourists, generating tourism revenue of ¥95.2123 billion, accounting for 36.27%

of Gansu Province's total tourism revenue. In June 2023, Gansu Province established the "Belt and Road"Hexi Corridor Tourism Promotion Alliance, dedicated to cultural dissemination and tourism development in Gansu Province and the Hexi Corridor region. However, due to its fragile ecological environment and certain anthropogenic factors, the Hexi area faces certain ecological crises, necessitating strengthened research on its tourism ecological security.

1.2 Data Sources

Data were primarily obtained from the Gansu Statistical Yearbooks (2012-2021) and corresponding annual statistical yearbooks, national economic and social development statistical bulletins, and environmental quality bulletins for the five cities of the Hexi Corridor. Some data were derived through consultation of relevant municipal government official websites and calculation based on the aforementioned sources. Missing data for individual years were supplemented using linear interpolation.

1.3.1 Index System Construction Method

DPSIR Model. The DPSIR model was developed by the European Environment Agency (EEA) by integrating the "Pressure-State-Response" (PSR) model and the "Driving Force-Pressure-State-Impact-Response"(DPSIR) model and expanding upon their advantages. Compared to other models, the DPSIR model is more comprehensive, as it can accurately describe system complexity and causal relationships while revealing the causal links between economic operations and the environment. In this study, **Driving Force (D)** refers to underlying causes of changes in the tourism ecological environment, such as urbanization development levels and tertiary industry growth conditions. **Pressure (P)** denotes direct causes of changes in the tourism ecological environment resulting from driving forces, such as employment pressure, transportation conditions, and pollutant emissions. **State (S)** represents the condition of the ecosystem after being impacted, such as tourism economic status and ecological conditions following pressure. **Impact (I)** indicates the effects of these state changes on humans and society, such as air quality. **Response (R)** refers to positive remedial strategies adopted by humans and society to mitigate negative environmental impacts, such as sewage treatment, financial support, and talent development.

Resilience Assessment. The term "resilience" originates from the Latin word "resilio," meaning elasticity. In 1973, Canadian ecologist Holling proposed the concept and theory of "ecological resilience." Resilience is widely applied in sociology, economics, geography, and other fields, and has recently been introduced into tourism research. Tourism resilience refers to the ability of tourism systems to respond, adapt, and recover when encountering sudden situations, natural disasters, and other destructive impacts. Resilience assessment is crucial for correctly understanding tourism industry resilience, with commonly applied methods including the resilience proxy method and index system method. Based on an understanding of resilience concepts and reference to previous resilience assessment index systems, this study primarily conducts tourism resilience assessment from two aspects: adaptive capacity and recovery capacity. Adaptive capacity mainly refers to the ability of tourism destination ecosystems to make rapid adjustments when impacted or encountering unexpected events, primarily reflected in regional tourism economic conditions. Recovery capacity mainly refers to the ability of the ecological environment to return to its original state and the ecosystem to return to its original or higher development level while maintaining internal structure and function, such as environmental pollution treatment (urban air quality compliance rate, etc.) and ecological environment status (per capita park green space area, etc.).

Evaluation Index System Construction. Combining existing research findings with the actual conditions of the study area and considering the scientificity, objectivity, representativeness, and data availability of index selection, this study primarily employs the DPSIR model supplemented by resilience assessment methods to construct a tourism ecological security evaluation index system, as shown in .

Tourism Ecological Safety Evaluation Index System

Index Category	Specific Indicators	Unit	Attribute
Driving Force	Population natural growth rate	%	+
	Tertiary industry growth rate	%	+
Pressure	Domestic sewage discharge	10,000 tons	-
	Solid waste generation	10,000 tons	-
	Urban unemployment rate	%	-
	Highway passenger turnover	10,000 person-km	-
State	Domestic tourism revenue	100 million yuan	+
	Per capita tourism revenue	yuan/person	+
	Per capita park green space area	m^2/person	+
	Urban built-up area green coverage rate	%	+
Impact	Days with air quality at or above Grade II	days	+
	Tourism revenue as proportion of GDP	%	+
	Tertiary industry as proportion of GDP	%	+
Response	Urban air quality compliance rate	%	+
	Sewage treatment compliance rate	%	+
	Fiscal expenditure as proportion of GDP	%	+
	Number of regular higher education students	persons	+

Note: "+" indicates positive indicators; "-" indicates negative indicators.

1.3.2 Tourism Ecological Security Evaluation Methods

This study employs two methods for comparative analysis of tourism ecological security conditions in the Hexi Corridor region: the entropy weight TOPSIS method and the fuzzy matter-element model.

Entropy Weight TOPSIS Method. This method combines the entropy weight method with the TOPSIS method. It uses the entropy weight method to determine the weights of evaluation indicators and employs the TOPSIS method to calculate the proximity of evaluation objects to positive and negative ideal solutions. By determining the distance between evaluation objects and the optimal and worst solutions and ranking them, the optimal decision scheme is identified as the one closest to the optimal solution and farthest from the worst solution. The main steps are: (1) Use the entropy method to determine indicator weights; (2) Standardize the data; (3) Establish a weighted normalized matrix; (4) Determine positive and negative ideal solutions; (5) Calculate the Euclidean distance between indicators and positive/negative ideal solutions; (6) Compute the relative closeness of indicators to ideal solutions. Larger relative closeness values indicate better tourism ecological security conditions, and vice versa. Specific formulas and procedures can be found in relevant references [22,29,32-39].

Fuzzy Matter-Element Analysis. This approach represents the organic combination of fuzzy mathematics and matter-element analysis, used to solve fuzzy and incompatible problems. It employs the fuzzy matter-element model to reflect the overall tourism ecological security status in the Hexi Corridor region and uses Euclidean closeness to scientifically measure the tourism ecological security of the five cities. The main steps include: (1) Use the entropy method to determine indicator weights; (2) Standardize the data; (3) Construct fuzzy matter-elements and compound fuzzy matter-elements; (4) Follow the principle of optimal membership degree for data processing; (5) Establish standard fuzzy matter-elements and difference square fuzzy matter-elements; (6) Calculate Euclidean closeness. Larger values indicate closer proximity, and vice versa. Specific formulas and procedures can be found in relevant references [22,36,39-41].

1.3.3 Tourism Ecological Security Levels

Currently, there is no unified standard for tourism ecological security evaluation. This study references numerous scholars [33,47-49] and combines the actual conditions of the Hexi Corridor region to divide five tourism ecological security levels based on the interval of Euclidean closeness values (Table 2).

Classification of Tourism Ecological Security Level

Ecological Security Index	Ecological Security Status
(0.0, 0.2]	Unsafe
(0.2, 0.4]	Relatively Unsafe
(0.4, 0.6]	Critically Safe
(0.6, 0.8]	Relatively Safe
(0.8, 1.0]	Safe

2 Results

2.1.1 Comprehensive Ecological Security Index

From the perspective of regional tourism ecological security index means (Table 3), the mean tourism ecological security index in the Hexi Corridor region increased from 0.312 in 2011 to 0.361 in 2020, with a small improvement magnitude but an overall upward trend. Among these, the tourism ecological security index showed a linear increase from 2011 to 2019. In 2020, due to the COVID-19 pandemic, the tourism industry was basically at a standstill, and the domestic economy suffered significant impacts, affecting all industries and causing a sudden decline in the 2020 tourism ecological security index. During the study period, the tourism ecological security status of the five cities in the Hexi Corridor was at the unsafe, relatively unsafe, and critically safe levels, with the relatively safe level only appearing in Jiuquan City. This indicates that the overall regional tourism ecological security level is continuously improving, with considerable future development potential.

From the perspective of security level changes in each city (Figure 1), Wuwei and Zhangye evolved from relatively unsafe to critically safe, Jiuquan evolved from relatively unsafe to relatively safe, while Jinchang and Jiayuguan transformed from unsafe to relatively unsafe. The overall security level of the five cities is in a state of gradual optimization.

Average Value of Tourism Ecological Safety Index in Five Cities of the Hexi Corridor from 2011 to 2020

City	Ecological Security Index Mean
Wuwei	0.345
Jinchang	0.279
Zhangye	0.354
Jiuquan	0.423
Jiayuguan	0.258

Note: This map is produced based on the standard map with review number GS(2019)3266 downloaded from the Standard Map Service website of the National Administration of Surveying, Mapping and Geoinformation, with no modifications to the base map boundaries. The same applies below.

[Figure 1: see original paper] Distribution of Tourism Ecological Security Level in Five Cities of the Hexi Corridor

2.1.2 Subsystem Ecological Security Index

Driving Force Index. The driving force index development trend can be divided into three stages: slow decline from 2011 to 2015, fluctuation from 2016 to 2019, and another decline in 2020, indicating that the contribution of driving forces to tourism ecological security is not very stable, but overall shows a fluctuating development trend. Except for a small increase in Jiayuguan City in 2020, the other four cities showed a declining trend in driving force index, with the largest decline in Jiuquan City, reaching 36.36% (Figure 2). This is mainly due to the continuous increase in population natural growth rate and population density.

Pressure Index. The pressure system overall shows an "inverted V" trend of slow rise from 2011 to 2019 and sharp decline in 2020. The average pressure index increased from 0.283 in 2011 to 0.332 in 2019, showing a steady improvement. Among them, Jiuquan, Zhangye, and Jiayuguan cities remained at the relatively unsafe level, while Wuwei and Jinchang cities were at the unsafe level. Wuwei City showed the largest fluctuation amplitude in pressure index, reaching its highest point in 2019 (0.374). The main reason is that the discharge of domestic sewage and generation of solid waste relatively decreased, alleviating environmental pressure.

State Index. The state index overall experienced a trend of first rising then falling, with 2020 as the turning point due to the COVID-19 pandemic. The average state index decreased from 0.349 in 2011 to 0.342 in 2020, with a small change magnitude but still showing an overall improvement in ecological security status. Among them, Jiuquan, Zhangye, and Jiayuguan cities showed significant improvement in 2019 compared to 2011 (Figure 2), mainly due to increased tourism economic income and significant improvement in the ecological environment.

Impact Index. The impact subsystem security index shows a significant upward trend, with the average state index increasing from 0.265 in 2011 to 0.410 in 2020. The ecological security level rose from relatively unsafe in 2011 to critically safe in 2019. Due to the pandemic causing increased population natural growth rate and reduced tourism income, the security level in 2020 transformed back to relatively unsafe. The impact indices of the five cities overall show an upward trend, reaching the highest point in 2019. Zhangye City showed the most significant increase (55.56%), mainly because the proportion of tourism revenue to regional GDP and the proportion of tertiary industry showed an upward trend, promoting the overall improvement of Zhangye' s impact index.

Response Index. The response index shows a slow upward trend, with the average index increasing from 0.358 in 2011 to 0.393 in 2020, indicating that measures and responses to tourism ecological security issues are relatively effective. Among the five cities, Wuwei and Jiuquan showed the largest response index amplitude, mainly reflected in the fluctuating rise of three indicators: sewage treatment compliance rate, fiscal expenditure as a proportion of GDP, and number of higher education students. Jiayuguan City showed the smallest amplitude, only increasing by 8.70% (Figure 2), indicating that Jiayuguan' s measures for tourism ecological security effectiveness need strengthening compared to other cities.

[Figure 2: see original paper] Tourism Ecological Security Subsystem Indices from 2011 to 2020

2.2 Fuzzy Matter-Element Analysis Results

From the perspective of mean Euclidean closeness of tourism ecological security in the Hexi Corridor region, the overall Euclidean closeness shows an upward evolution trend, increasing from 0.329 in 2011 to 0.384 in 2020, indicating that the tourism ecological security of the five cities is gradually improving. From the perspective of security level changes in each city (Figure 3), the five cities basically show a steady improvement trend. During the study period, the five cities were mainly in relatively unsafe and critically safe states, among which: the unsafe state appeared 3 times (Jiayuguan City); the relatively unsafe state appeared 21 times, in descending order: Jiayuguan (5 times), Jinchang (5 times), Jiuquan (4 times), Zhangye (4 times), Wuwei (3 times); the critically safe state appeared 21 times, in descending order: Wuwei (7 times), Zhangye (6 times), Jiuquan (4 times), Jinchang (3 times), Jiayuguan (1 time). Additionally, the relatively safe state only appeared once (Jiuquan City), indicating that the overall tourism ecological security level in the Hexi Corridor region is not high.

[Figure 3: see original paper] Distribution of Tourism Ecological Security Level in Five Cities of the Hexi Corridor

2.3 Comparison of Two Methods

Tourism ecological security evaluation is inherently complex, and different evaluation methods have varying requirements for indicator quantification. Most scholars use the entropy weight TOPSIS method to evaluate regional tourism ecological security, which objectively calculates indicator weights using the entropy method. This approach has no strict limitations on basic data and indicator quantity, offering characteristics of authenticity, intuitiveness, and reliability. However, it can only rank the superiority of each evaluation object with limited sensitivity. A few scholars have introduced the fuzzy matter-element model into regional tourism ecological security evaluation, using it to eliminate the endogenous fuzziness of the index system and transform uncertain evaluations into certain ones, thereby innovating tourism ecological security evaluation methods. Although both methods share the advantages of convenient calculation and indicator dimensionless processing, there remain certain differences in raw data processing. Additionally, the evaluation standards and calculation methods themselves differ, thus exerting certain influences on the numerical changes of research results.

As shown in Table 5, this study conducted Spearman correlation analysis on the comprehensive security index means of the five cities during 2011–2020 using the two methods. The evaluation results show a highly significant correlation, with a correlation coefficient (r) of 0.943 ($p < 0.01$), indicating statistical significance.

The ranking of mean tourism ecological security indices for the five cities calculated by the entropy weight TOPSIS method is: Jiuquan (0.423), Zhangye (0.354), Wuwei (0.345), Jinchang (0.279), and Jiayuguan (0.258). Overall, Wuwei, Zhangye, and Jiuquan transformed from "relatively unsafe" to "critically safe," while the other two cities transformed from "unsafe" to "relatively unsafe." The ranking by the fuzzy matter-element model is: Wuwei (0.384), Zhangye (0.383), Jiuquan (0.376), Jinchang (0.332), and Jiayuguan (0.306). The tourism ecological security levels of Wuwei, Zhangye, Jinchang, Jiuquan, and Jiayuguan overall transformed from "relatively unsafe" to "critically safe."

Although different evaluation models produce different research results, they do not affect the overall evolution trend of regional ecological security status, which also demonstrates the rationality of the index system construction and effectively ensures the accuracy of the study. Through comparative analysis and consideration of the actual development conditions of the five cities, the evaluation results obtained by the fuzzy matter-element model demonstrate higher credibility.

Correlation Analysis of the Results of the Two Evaluation Methods

Method	Fuzzy Matter-Element Model	TOPSIS
Fuzzy Matter-Element Model	1	0.943**
TOPSIS	0.943**	1

Note: ** indicates extremely significant correlation between the two methods' results.

3 Discussion

This study takes five prefecture-level cities in the Hexi Corridor as research objects, constructs a regional tourism ecological security evaluation index system, employs two methods to evaluate regional tourism ecological security conditions, selects an appropriate method, and provides certain supplements and improvements to tourism ecological security evaluation research. Compared with existing studies, on the one hand, there has been little research on tourism ecological security in the Hexi Corridor region. Scholars such as Mu Xueqing et al. [2], Wang Zhaofeng et al. [16], Jin Jinhe et al. [17], and Shi Dan et al. [24] have mostly concentrated their research on the Yellow River Basin, Yangtze River Economic Belt, scenic areas, and provincial regions. On the other hand, research methods in the tourism ecological security field are diverse, with the entropy weight TOPSIS method being widely used [16-17,23-24]. The fuzzy matter-element model has been applied in tourism ecological security research in recent years. By introducing the entropy weight TOPSIS method and fuzzy matter-element model to effectively evaluate the tourism ecological security status in the Hexi Corridor region, this study concludes that the fuzzy matter-element model produces better evaluation results, which also confirms the applicability of the fuzzy matter-element model in tourism ecological security research as proposed by Xu Shaogui et al. [21] and Liu Qianqian et al. [22]. The comparative analysis of the two methods can not only reduce uncertainty in tourism ecological security evaluation research but also provide methodological references for subsequent related studies when evaluating regional tourism ecological security.

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4 Conclusion

(1) From the perspective of overall tourism ecological security conditions, tourism ecological security in the Hexi Corridor region shows an overall upward trend. The entropy weight TOPSIS method results show that the tourism ecological security index increased from 0.312 in 2011 to 0.361 in 2020, with an overall improving trend. The fuzzy matter-element model results show that the comprehensive tourism ecological security index is generally on an upward trend, with the Euclidean closeness increasing year by year from 2011 to 2019 and fluctuating in the region from 2020.

(2) From the subsystem perspective, the changing trends of the driving force and pressure indices indicate that tourism economic development and ecological security in the region have long been in coordinated development. The impact and state indices of the five cities show similar trends, with basically consistent movements within the 10-year period, indicating that ecological environment governance and protection require persistent efforts. The changing trend of the response index reflects the effectiveness of ecological security protection measures within the 10-year period.

(3) From a methodological perspective, the comparative analysis of two methods to evaluate regional tourism ecological security represents an innovation of this paper. Through comparative analysis of evaluation results, the more appropriate tourism ecological security evaluation model is identified as the fuzzy matter-element model.

References (References)

[1] Yang Xiuping, Jia Yunting, Liu Lili, et al. Research trends and prospects of tourism ecological security at home and abroad[J]. Ecological Science, 2022, 41(4): 223-230.

[2] Mu Xueqing, Guo Xiangyang, Ming Qingzhong, et al. Dynamic evolution characteristics and driving factors of tourism ecological security in the Yellow River Basin[J]. Acta Geographica Sinica, 2022, 77(3): 714-735.

[3] Xiao Duning, Chen Wenbo, Guo Fuliang. On the basic concepts and contents of ecological security[J]. Chinese Journal of Applied Ecology, 2002, 13(3): 354-358.

[4] Zhang Jinhe, Zhang Jie, Wang Qun. Measuring the ecological security of tourist destination: Methodology and a case study of Jiuzhaigou[J]. Geographical Research, 2008, 27(2): 449-458.

[5] Petrosillo I, Zurlini G, Grato E, et al. Indicating fragility of socio-ecological tourism-based systems[J]. Ecological Indicators, 2006, 6(1): 104-113.

[6] Jurado E N, Tejada M T, Garcia F A, et al. Carrying capacity assessment for tourist destinations: Methodology for the creation of synthetic indicators applied in a coastal area[J]. Tourism Management, 2012, 33(6): 1337-1346.

[7] Pueyo Ros J, Garcia X, Ribas A, et al. Ecological restoration of a coastal wetland at a mass tourism destination: Will the recreational value increase or decrease?[J]. Ecological Economics, 2018, 148: 1-14.

[8] Connor C, Gyan P N. Connecting landscape scale ecological restoration and tourism: Stakeholder perspectives in the great plains of North America[J]. Journal of Sustainable Tourism, 2022, 30(11): 1-14.

[9] Brehony P, Tyrrell P, Kamanga J, et al. Incorporating social-ecological complexities into conservation policy[J]. Biological Conservation, 2020, 248(4): 108697.

[10] Salamawi A, Atkilt G, Gebremedhin N A. Potential ecotourism site suitability evaluation for sustainable natural resource management in Kafta Sheraro National Park (KSNP), north western Tigray, Ethiopia[J]. Journal of Ecotourism, 2021, 20(4): 341-370.

[11] Ambecha A B, Melka G A, Gemeda D O. Ecotourism site suitability evaluation using geospatial technologies: A case of Andiracha district, Ethiopia[J]. Spatial Information Research, 2020, 28(5): 583-595.

[12] Liu Y, Qu Y, Cang Y D, et al. Ecological security assessment for megacities in the Yangtze River Basin: Applying improved emergy ecological footprint and DEA-SBM model[J]. Ecological Indicators, 2022, 134(11): 108481.

[13] Han Y, Tang C C, Zeng R. Review of tourism ecological security from the perspective of ecological civilization construction[J]. Journal of Resources and Ecology, 2022, 13(4): 734-745.

[14] Lu Lu, Zeng Jian, Yu Tianhu. A review of studies on tourism ecological security[J]. Ecological Science, 2023, 42(2): 238-247.

[15] Xu Shaogui, Zuo Yifan, Zhang Mu. Evaluation of tourism ecological security and diagnosis of obstacle factors in China based on fuzzy object element model[J]. Scientia Geographica Sinica, 2021, 41(1): 33-43.

[16] Liu Qianqian, Zhang Xin, Wu Hanqing. Evaluation on tourism ecological security and diagnosis of its obstacle indicators based on fuzzy matter element model: Example of Anhui Province[J]. Forestry Economics, 2022, 44(8): 42-60.

[17] Yang Youbao, Guo Fuyou, Han Guosheng. Dynamic evolution and driving factors of tourism ecological security in the region of major function restricted development: A case study of Zhangjiajie[J]. Acta Ecologica Sinica, 2023, 43(20): 8404-8416.

[18] Tian Li, Yan Zihao, Wang Jie. The analysis of spatial-temporal pattern and influencing factors of border tourism ecological security[J]. Ecological Economy, 2023, 39(7): 149-156.

[19] Yang Liangjian, Cao Kaijun. Tourism ecological security early warning of Ili River Valley based on DPSIR model[J]. Ecological Economy, 2020, 36(11): 111-117.

[20] Wang Zhaofeng, Chen Qingqing. Spatio-temporal pattern evolution and trend prediction of tourism ecological security in the Yangtze River Economic Belt since 1998[J]. Acta Ecologica Sinica, 2021, 41(1): 320-332.

[21] Xu Mei, Liu Chunla, Li Dan, et al. Tourism ecological security early warning of Zhangjiajie, China based on the improved TOPSIS method and the grey GM(1,1) model[J]. Chinese Journal of Applied Ecology, 2017, 28(11): 3731-3739.

[22] Jiang Guiyan, Yun Yingxia, Ren Lijian, et al. Spatial-temporal discrimination and the related obstacle factor diagnosis for the valley cities urban eco-security in China west based on the improved TOPSIS method[J]. Journal of Safety and Environment, 2020, 20(1): 342-351.

[23] Wu Yanxia, Deng Nan. Ecological security warning for resource-based cities on RBF neural network model: Taking Yulin City as an example[J]. Ecological Economy, 2019, 35(5): 111-118.

[24] Chen Ying, Kong Zhe, Lu Zheng, et al. Land ecological security early warning based on RBF neural network: A case of Zhangye in Gansu Province[J]. Agricultural Research in the Arid Areas, 2017, 35(1): 264-270.

[25] Li Yitong, Rong Lihua, Wenlong, et al. Ecological security pattern at country level in northeast forest area of China from the perspective of ecological importance: A case of Arun Banner in Hulun Buir City[J]. Arid Land Geography, 2022, 45(5): 1615-1625.

[26] Cheng Jing, Wang Peng, Chen Hongxiang, et al. Geographical exploration of the spatial and temporal evolution of ecological risk and its influencing factors in

semi-arid regions: A case of Yanchi County in Ningxia[J]. Arid Land Geography, 2022, 45(5): 1637-1648.

[27] Jopp R, Delacy T, Mair J, et al. Using a regional tourism adaptation framework to determine climate change adaptation options for Victoria's surf coast[J]. Asia Pacific Journal of Tourism Research, 2013, 18(1-2): 144-164.

[28] Wei Xiaochen, Li Longtang. Study on early warning of tourism ecological security in northwest arid and windy sand area based on DPSIR model: Taking Zhongwei City of Ningxia Hui Autonomous Region as an example[J]. Ecological Economy, 2021, 37(6): 134-139.

[29] Zhang Jianqing, Zhang Lan, Wang Song, et al. Study on regional sustainable development efficiency measurement and influencing factors: Based on DPSIR-DEA model[J]. China Population, Resources and Environment, 2017, 27(11): 1-9.

[30] Sun Yehong, Song Yuxin. Sustainable tourism development from a resilience perspective[J]. Tourism Tribune, 2021, 36(5): 8-10.

[31] Shi Dan, Guan Jingwen. Spatial-temporal pattern measurement and obstacle diagnosis of tourism ecological security based on DPSIR-matter element in Jilin Province[J]. Chinese Journal of Ecology, 2022, 41(8): 1653-1664.

[32] Qin Xiaonan, Cheng Yu. Evaluation and type classification on Chinese tourist urban ecological security system: Based on the network DEA model with node weight[J]. Scientia Geographica Sinica, 2019, 39(1): 156-163.

[33] Wei Ye, Xiu Chunliang. Study on the concept and analytical framework of city network resilience[J]. Progress in Geography, 2020, 39(3): 488-502.

[34] Cai Chaoyue, Tang Jianxiong, He Qing. Research on the relationship between tourism economic resilience and tourism development quality in China[J/OL]. Journal of Natural Science of Hunan Normal University. [2023-08-14]. http://kns.cnki.net/kcms/detail/43.1542.n.20220803.2058.002.html.

[35] Li Ling, Ma Xing, Sun Yanhong. Dynamic evaluation of tourism ecological security in the Yellow River Basin based on DPSIR framework[J]. Ecological Economy, 2021, 37(12): 145-151.

[36] Chen Li, Song Xiaolong, Bu Xiaoyan. Dynamic evaluation and driving mechanism of tourism ecological security in Ningxia Hui Autonomous Region[J]. Research of Soil and Water Conservation, 2020, 27(6): 278-284.

[37] Li Jinhong, Zeng Xue, Cao Qingyao, et al. Evaluation and trend forecast of tourism ecological security in karst mountainous areas: Taking international mountain tourism destination of Guizhou Province as an investigation sample[J]. Ecological Economy, 2022, 38(9): 145-151.

[38] Huang Xuanhao, Liang Jiali, Huang Xin, et al. Evaluation of the health resilience of beach community system: A case study of Dapeng Peninsula, Shenzhen City[J]. Acta Ecologica Sinica, 2021, 41(22): 8794-8806.

[39] Jiang Lei, Zhang Youyin, Zhang Jingquan, et al. Evaluation and difference analysis of provincial leisure sports competitiveness based on entropy weight TOPSIS method[J]. Journal of Shaanxi Normal University (Natural Science Edition), 2022, 50(6): 113-123.

[40] Ma Junmei, Ma Jianping, Man Duoqing, et al. Distribution and regeneration characteristics of natural Populus euphratica forests in Hexi Corridor and their relationship with soil factors[J]. Arid Zone Research, 2023, 40(2): 224-234.

[41] Cai W. Extension theory and its application[J]. Chinese Science Bulletin, 1999, 44(17): 1538-1548.

[42] Xiao Fangchun. Study for fuzzy matter-element analysis and its applications[J]. Structure & Environment Engineering, 1995(2): 51-59.

[43] Xu Mei, Liu Chunla. Tourism ecological security evaluation and obstacle factors analysis of Zhangjiajie[J]. Resources and Environment in the Yangtze Basin, 2018, 27(3): 605-614.

[44] Li Y J, Chen T, Hu J, et al. Tourism ecological security in Wuhan[J]. Journal of Resources and Ecology, 2013, 4(2): 149-156.

[45] Liu D D, Yin Z Y. Spatial-temporal pattern evolution and mechanism model of tourism ecological security in China[J]. Ecological Indicators, 2022, 139: 108933.

[46] Chen M T, Zheng L, Zhang D K, et al. Spatio-temporal evolution and obstacle factors analysis of tourism ecological security in Huanggang Dabieshan UNESCO Global Geopark[J]. International Journal of Environmental Research and Public Health, 2022, 19(14): 8670.

[47] Petrosillo I, Zurlini G, Grato E, et al. Indicating fragility of socio-ecological tourism-based systems[J]. Ecological Indicators, 2006, 6(1): 104-113.

[48] Jurado E N, Tejada M T, Garcia F A, et al. Carrying capacity assessment for tourist destinations: Methodology for the creation of synthetic indicators applied in a coastal area[J]. Tourism Management, 2012, 33(6): 1337-1346.

[49] Pueyo Ros J, Garcia X, Ribas A, et al. Ecological restoration of a coastal wetland at a mass tourism destination: Will the recreational value increase or decrease?[J]. Ecological Economics, 2018, 148: 1-14.

Note: Figure translations are in progress. See original paper for figures.