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Posted Date: August 21st, 2023

DOI: https://doi.org/10.21203/rs.3.rs-3180961/v1

Additional Declarations: No competing interests reported.

Article

Evaluation of tourism ecological security and its Obstacles in Semi-Arid River Valley Urban: A Case Study of Lanzhou, China

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Abstract: Tourism ecological security is an integral component of sustainable tourism development. In this study, we utilized the DPSIR model to establish an evaluation index system for assessing the ecological security of tourism in Lanzhou. The study investigates the evolutionary characteristics of the tourism ecological security level in Lanzhou, a semi-arid river valley city, from 2009 to 2021. The research employs the TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method, coupled with the coordination degree model and obstacle degree model, to examine the influencing factors on the tourism ecology of Lanzhou. The research results indicate that:(1) The overall evaluation value of tourism ecological security in Lanzhou exhibits an upward trend. Specifically, the evaluation values of various subsystems were higher in 2019 compared to 2009, while the evaluation values in 2009 were relatively lower. Furthermore, the evolution patterns of the evaluation values for the driver subsystems and the influencing subsystems were similar. The evaluation value curves for the state subsystem and the response subsystem evolved in a generally consistent manner. (2)The coupling coordination between the driver subsystem and the pressure subsystem (DP), the driver subsystem and the response subsystem (DR), the pressure subsystem and the response subsystem (PR), as well as the state subsystem and the response subsystem (SR) continuously increases. However, the coupling coordination between the pressure subsystem and the state subsystem (PS), the state subsystem and the impact subsystem (SI), and the impact subsystem and the response subsystem (SR) is unstable. (3)During the analysis of criterion layer obstacle degree, it was found that the state subsystem exhibited the most significant increase in obstacle degree, followed by the impact and pressure subsystems. The obstacle degree of the response subsystem fluctuated, while the driver subsystem experienced a significant decrease in obstacle degree. (4)The natural population growth rate has consistently been a primary obstacle factor in the tourism ecological security system of Lanzhou, and it has increased over time. On the other hand, the obstacle degrees of per capita disposable income and the growth rate of the tertiary industry have decreased over time. Indicators such as per capita park green area, forest coverage rate, proportion of natural protected areas to land area, green area, afforestation area of barren hills and wastelands, as well as general industrial solid emissions, have been major obstacle factors in most years. Among these indicators, the obstacle degrees for forest coverage rate, proportion of natural protected areas to land area, and green coverage rate are relatively high. The aim of this study is to enhance the tourism ecological security level of Lanzhou, a semi-arid river valley city, and provide valuable insights for the high-quality development of the tourism industry in the Yellow River Basin.

Keywords: Lanzhou; tourism ecological security; DPSIR model; obstacle degree model

1. Introduction

The tourism industry was once regarded as a natural "green industry." However, the industry's dependence on the environment and its resource consumption characteristics inevitably lead to conflicts with the ecological environment. With the rapid development of the global tourism industry, many regions are facing increasing pressure on their ecological environment. This poses a significant threat to tourism ecological security and hinders the sustainable development of the tourism industry [1].Currently, the tourism industry is relatively less regulated compared to other industries. It is imperative to take certain measures to enhance the synergistic development of the tourism industry with the local society, economy, and ecological environment [2-3].Ecological security refers to the provision of necessary service support for sustainable development of human society and economy within a certain spatial and temporal range, while maintaining the health, stability, and functional integrity of the ecosystem with minimal or no threats. It ensures the biodiversity and survival development of both humans and other organisms. The primary objective is to enhance the level of ecological security through targeted measures, promoting long-term coordinated development among nature, society, and economy, and maintaining the stability and integrity of ecosystems [4-6].Tourism ecological security originates from ecological security. It refers to ensuring the stability and diversity functions of ecosystems within a specific spatial and temporal range through rational development of tourism resources and effective management of the ecological environment at tourism destinations. It aims to maintain the healthy and stable operational state of ecosystems while providing sufficient material resources and a harmonious environmental space for tourism development. Tourism ecological security promotes the coordination between tourism development, ecological environment protection, and economic development, thereby achieving sustainable development of the tourism industry [7]. Tourism ecological security is an important research field in the context of sustainable tourism development. It serves as a significant topic in ecological security assessment and represents a novel management objective for sustainable tourism destinations. Additionally, it holds a prominent position in ecological security research [8-10].

Through the review and synthesis of relevant literature on tourism ecological security, research in this field has gradually shifted from the conceptual definition of tourism ecological security, the construction of evaluation indicator systems, and methodological models, to more profound issues such as impacts, predictions, spatial patterns, driver mechanisms, and early warning studies. Furthermore, the research has evolved from a single-disciplinary domain to a multidisciplinary field, encompassing various disciplines including tourism, economics, management, ecology, and geography. Firstly, in the construction of evaluation indicator systems, commonly used models such as the PSR [11], DPSIR [12-13], CSAED [14], and TQR [15] models are primarily employed for evaluating ecological security in different urban contexts, including urban tourism, mining areas, and resource-based cities. Other models are hybrid models that have been developed by improving or combining the PSR and DPSIR models with other analytical techniques, such as the DPSEEA [16], PSR-ANP-GRAY [17], DPSIR-EDA [18], and DPSWR [19-20] models. These models provide a research framework for addressing the complex interactions between tourism activities and the ecological environment, and they can assist in formulating relevant strategies. Secondly, in terms of methodological approaches, previous studies have provided a range of quantitative research methods for evaluating the ecological security of different tourist destinations. These methods include the ecological footprint method [21-28], structural equation modeling [29], entropy-based material-element model [30-31], remote sensing and geographic information technology [32], fuzzy-entropy method [33], ANP and fuzzy TOPSIS method [34-35], Grey-TOPSIS method [36], and Entropy-TOPSIS method [37].These methods enable comprehensive evaluation of the ecological security of tourist destinations, including assessing the carrying capacity of tourist destinations [38], analyzing the spatiotemporal patterns and impacts of ecological security, and determining optimal tourism locations. Lastly, in terms of research scale, previous studies have been conducted at various scales, ranging from micro-scale, such as lakes [39], rivers [40], mountains [41], and islands [42], to meso-scale, such as urban clusters [43] and provinces [44], and macro-scale, such as countries [1].

Regarding the research on tourism ecological security, it started relatively late. However, scholars have made significant achievements. Both the construction of evaluation systems and the methods and models used have been diversified. However, there are still certain shortcomings in the research on tourism ecological security. Firstly, there is a lack of unified standards for selecting indicators of tourism ecological security, which introduces subjectivity. Secondly, these studies primarily focus on analyzing the ecological security status of nature-based tourism destinations, while overlooking cultural tourism destinations and tourism destinations with specific topography, geomorphology, and climate environments. Lastly, the majority of studies primarily utilize the ecological footprint model for evaluation. However, there is a lack of emphasis on identifying the barriers and providing recommendations to address the factors affecting tourism ecological security.

This study constructs a tourism ecological security indicator system for Lanzhou, a semi-arid river valley city, based on the DPSIR model. The entropy-weighted TOPSIS method was used to measure the weights and proximity values of tourism ecological security indicators in Lanzhou from 2009 to 2021. Then, a coupling coordination degree model was employed to analyze the coupling and coordination degree among the subsystems of tourism ecological security in Lanzhou. Furthermore, an obstacle degree model was used to analyze the factors hindering Lanzhou's tourism ecological security and propose corresponding countermeasures. This study aims to enhance the level of tourism ecological security in Lanzhou, a semi-arid river valley city, and provide valuable insights for the high-quality development of tourism in the Yellow River Basin.

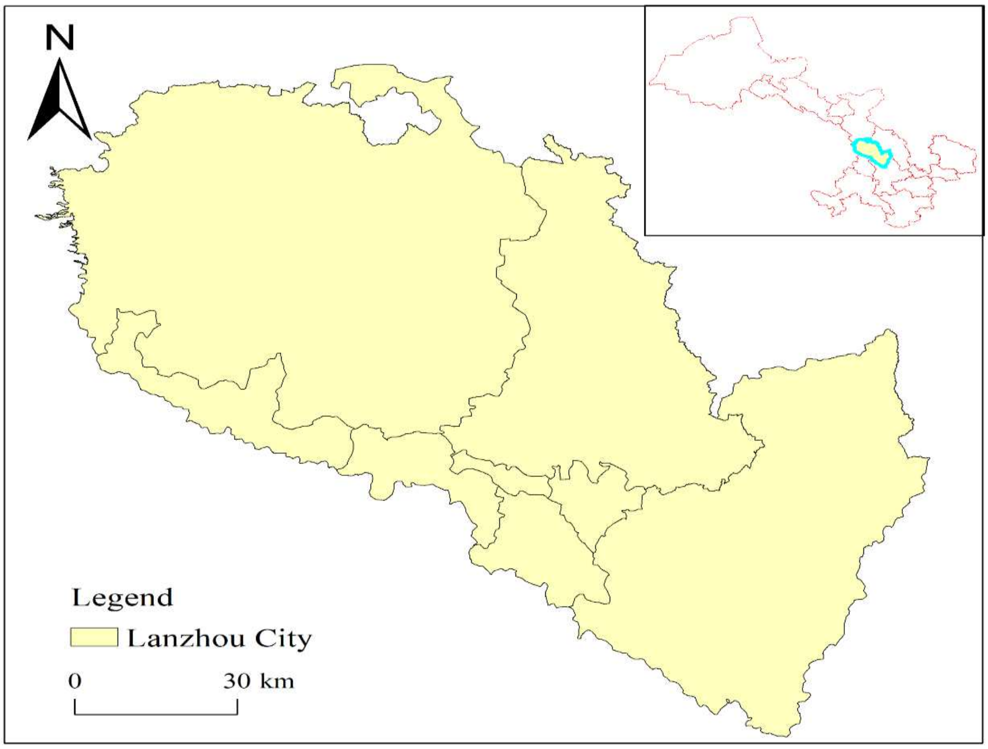

Fig 1. Study area.

2. Materials and methods

2.1. Materials

2.1.1. Research areas and data sources

This study focuses on Lanzhou, a typical semi-arid river valley city in northwest China, as depicted in Figure 1. Located in the northwest region of China, Lanzhou is a typical semi-arid river valley city. It is situated in a string-of-pearls-shaped valley between basins and canyons, and its abundant sunshine and scarce rainfall contribute to its semi-arid characteristics. In recent years, the tourism industry in Lanzhou has experienced rapid development with continuous improvement in infrastructure, expansion of industry scale, and optimization of industry structure. According to statistics, in 2019, Lanzhou received a total of 82.108 million domestic and international tourists, generating a tourism revenue of 76.65 billion yuan. The per capita tourist expenditure reached 933 yuan, marking the highest level during the study period. Despite the impact of the COVID-19 pandemic, the tourism industry in Lanzhou has maintained a positive development trend, demonstrating the resilience and potential of the city's tourism sector. As of 2021, Lanzhou has 27 Class A scenic spots, with tourism revenue reaching 59.4 billion yuan, marking a year-on-year growth of 40.8%. The number of tourists has increased by 43.9%, reaching 69.36 million person-times. Lanzhou plays a crucial role as a component of the western ecological barrier. However, being situated in a fragile ecological environment, there exists a certain conflict between its tourism development and environmental conservation. This conflict may even affect the tourism ecological security of the Yellow River Basin and the entire northwest region. Therefore, the development of tourism in Lanzhou should be integrated with ecological security. This integration aims to achieve a new tourism model centered around the Yellow River National Cultural Park and the Silk Road Tourism Belt. Efforts should be made to strengthen the ecological protection of the Yellow River Basin and promote the high-quality development of tourism. The ultimate goal is to achieve harmonious coexistence between tourists and the natural ecological environment.

The primary data used in this study mainly consisted of the "China Statistical Yearbook," "China Environmental Statistical Yearbook," "China Cultural Tourism Yearbook," "Gansu Statistical Yearbook," "Lanzhou Statistical Yearbook," "Lanzhou Environmental

Bulletin," and official data from the Lanzhou Cultural Tourism Bureau. To ensure the integrity, accuracy, and scientific rigor of the data, this study analyzed data from a span of 13 years, from 2009 to 2021, and used mean values to supplement the limited missing data.

2.1.2. Index selection

The accurate selection of indicators is crucial and fundamental in constructing the evaluation index system for tourism ecological security, which ensures the reliability of research results. The tourism ecological system is a complex system composed of various factors such as tourism resources, ecological environment, economy, population, and society, where various elements are interconnected and interact with each other. The evaluation indicators for tourism destination ecological security involve multiple disciplines, and the selection of evaluation indicators must be professional and scientific. Therefore, this study adopts the DPSIR model to construct the evaluation system for tourism ecological security in Lanzhou. The system consists of five sub-systems: drivers (D), pressures (P), state (S), impacts (I), and responses (R) [45-48]. The DPSIR model, originally developed by the Organisation for Economic Co-operation and Development (OECD, 1993) and the European Environment Agency (EEA, 1995) for adaptive management of SESs, is one of the primary tools. It has evolved into a commonly used model in interdisciplinary research. This model links the causal relationships among the five sub-systems and is used to analyze and evaluate the ecological and social issues influenced by human factors [49-50]. Among them, the driver subsystem includes social and economic factors, tourism resources, population, and the ecological environment. Under the drivers of tourism and economic development, tourism destinations face pressure on factors such as the ecological environment and tourist density, leading to changes in their original state. These changes, in turn, have positive or negative impacts on tourism development and the ecological environment. Finally, to maintain or enhance the level of tourism ecological security in the destination, certain response measures will be implemented to promote positive impacts, mitigate negative impacts, alleviate pressure, improve the state, and strengthen the drivers. The five subsystems of this framework occupy distinct positions and are interconnected to create a feedback loop system. The interconnection and mutual influence among the five subsystems form the engineering system of tourism ecological security, as shown in Figure 2.

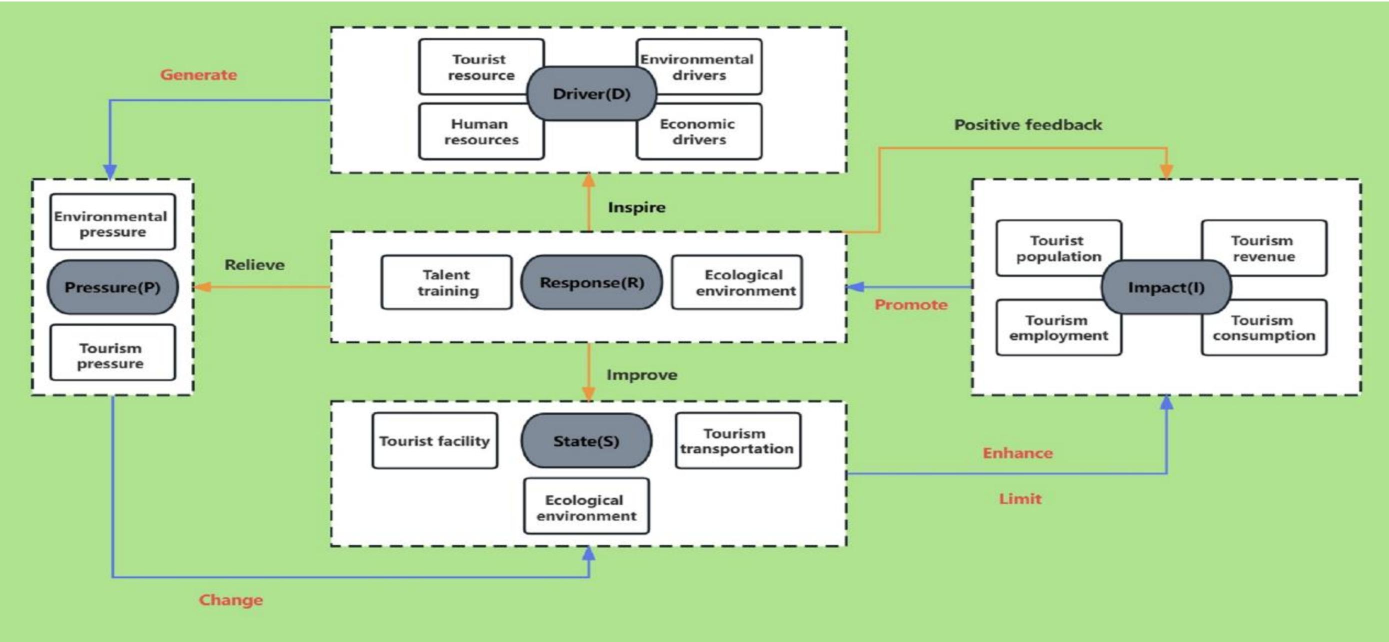

Fig 2. DPSIR conceptual model for the evaluation of tourism ecological security

This study is based on the DPSIR model and considers various factors such as economic conditions, ecological environment, tourism resources, energy transportation, energy conservation, and environmental protection. It constructed a tourism ecological security index system for Lanzhou, as shown in Table 1. The system consists of four levels, each level providing a refinement or supplementary explanation of the previous layer. Specifically, it is divided into: (1) the criterion layer, which is further divided into drivers, pressures, states, impacts, and responses; (2) the element layer, primarily addressing concepts related to economic conditions, ecological environment, tourism resources, energy transportation, energy conservation, and environmental protection, which are generally non-quantifiable; (3) the index layer, which further refines the element level and focuses on various measurable data aspects that can be quantified; and (4) the weight layer, which measures the weight of each indicator in the tourism ecological security evaluation system.

Table 1. Evaluation index system of tourism ecological security for Lanzhou.

Criterion layer	Element layer	Index layer	Weight layer
Driver	Economic drivers	D1 GDP per capita (ten thousand yuan)	0.028
		D2 Disposable income per capita (yuan)	0.036
		D3 Growth rate of tertiary industry (%)	0.043
	Human resources	D4 Natural population growth rate (‰)	0.033
	Environmental drivers	D5 Urbanization rate (%)	0.019
		D6 Number of days with air quality reaching Level II (days)	0.035
	Tourist resource	D7 Tourism revenue growth rate (%)	0.018
		D8 Number of A-grade scenic spots	0.021
Pressure	Environmental pressure	P1 Wastewater discharge (10000 tons)	0.021
		P2 Sulfur dioxide emissions (10,000 tons)	0.036
		P3 Smoke emission (10000 tons)	0.034
		P4 Solid waste discharge (10,000 tons)	0.029
		P5 Domestic waste removal volume (10,000 tons)	0.031
	Tourism pressure	P6 Tourism spatial index (person/km2)	0.032
		P7 Tourist density index	0.034
State	Tourist facility	S1 Number of museums	0.027
		S2 Number of starrated hotels	0.020
	Ecological environment	S3 Park greenspace per capita (km2)	0.036
		S4 Green coverage rate (%)	0.039
		S5 Forest coverage rate (%)	0.049
		S6 Nature reserves account for the proportion of the city's land area (%)	0.039
	Tourism transportation	S7 Passenger turnover (100 million passengerkm)	0.032
Impact	Tourist population	I1 Domestic tourists (10000/person)	0.035
	Tourism revenue	I2 Proportion of total tourism revenue in GDP (%)	0.030
		I3 Per capita tourism income (yuan)	0.020
	Tourism employment	I4 Proportion of tourism employees in the tertiary industry (%)	0.025
	Tourism consumption	I5 Tourism Consumer Price Index	0.029
Response	Ecological environment	R1 Sewage treatment rate (%)	0.024
		R2 Comprehensive utilization rate of solid waste (%)	0.023
		R3 Harmless treatment rate of household garbage (%)	0.019
		R4 Afforestation area of barren mountains and wasteland (10,000 mu)	0.041
		R5 Proportion of environmental pollution control investment in GDP (%)	0.037
	Talent training	R6 Number of university students per 10,000 population (person)	0.025

2.2. Methods

2.2.1. The mean square deviation method and entropy method

In this study, the mean square deviation method and entropy method were employed to determine the weights of each indicator in the tourism ecological security index system of Lanzhou. These two weight calculation methods were combined. Firstly, each method was separately applied to calculate the weights. Then, the results were weighted averaged to obtain the comprehensive weights. It should be noted that a higher value of a positive indicator indicates a better evaluation, while a larger negative value indicates a poorer evaluation. The specific calculation steps are as follows.

Firstly, normalize the raw data.

$$\boldsymbol{r_{ij}} = \frac{z_{ij} - \min z_j}{\max z_j - \min z_j} \tag{1}$$

$$\boldsymbol{r_{ij}} = \frac{\max z_j - z_{ij}}{\max z_j - \min z_j} \tag{2}$$

where r_{ij} represents the value after normalization of the original data, z_{ij} represents the value of the *j*th indicator in the *i*th year of the original indicator data, while $minz_j$ and $maxz_j$ represent the minimum and maximum values of the *j*th indicator over the years.

Next, calculate the weights using the mean squared deviation method.

$$\boldsymbol{S_i} = \sqrt{\frac{\sum_{i=1}^{n}(r_{ij} - \bar{r}_j)^2}{n}} \tag{3}$$

$$\boldsymbol{\omega_1} = \frac{S_i}{\sum_{i=1}^{n} S_i} \tag{4}$$

where S_i represents the mean square deviation value, $\bar{r}_j$ is the average value of the standardized *j*th indicator, *n* is the number of indicators, and ω_1 is the weight obtained by the mean square deviation method.

Thirdly, the entropy method is used to calculate the weights ω_2.

$$\boldsymbol{P_{ij}} = \frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}} \tag{5}$$

When $P_{ij} = 0$, a correction is needed, which is defined as follows:

$$\boldsymbol{P_{ij}} = \frac{1 + r_{ij}}{\Sigma_{j=1}^{n}(1 + r_{ij})} \tag{6}$$

$$\boldsymbol{E_j} = -\frac{1}{\ln m}\sum_{i=1}^{m} p_{ij} \ln p_{ij} \tag{7}$$

$$\boldsymbol{\omega_2} = (1 - E_j)/\Sigma_{j=1}^{n}(1 - E_j) \tag{8}$$

where P_{ij} represents the proportion of the *i*th sample in the *j*th indicator, E_j represents the information entropy of the *j*th indicator, ω_2 is the weight obtained through the entropy method, *n* is the number of indicators, and *m* is the number of evaluation years.

Finally, the comprehensive weight is calculated ω.

$$\boldsymbol{\omega} = \frac{\omega_1 + \omega_2}{2} \tag{9}$$

where ω represents the arithmetic mean of the weights obtained from the mean square deviation method and entropy method.

2.2.2. TOPSIS method

Tourism ecological security evaluation is a complex systemic process. The TOPSIS method, widely applied in systems engineering, is a multi-objective decision analysis technique commonly used for comprehensive evaluation within a group. The method utilizes the information provided by the raw data to accurately reflect the differences between various evaluation indicators [51-52]. This study employs the TOPSIS method to evaluate the tourism ecological security of Lanzhou. By calculating the evaluation values of each system and indicator and ranking them, the overall level of tourism ecological security in Lanzhou is reflected. The specific calculation steps are as follows.

Firstly, a normalized weighting matrix is established.

$$\boldsymbol{r} = \begin{pmatrix} \boldsymbol{r_{11}} & \cdots & \boldsymbol{r_{1n}} \\ \vdots & \ddots & \vdots \\ \boldsymbol{r_{m1}} & \cdots & \boldsymbol{r_{mn}} \end{pmatrix} \quad (10)$$

$$\boldsymbol{r_{ij} = z_{ij}\omega_j(i = 1, 2, \dots m; j = 1, 2, \cdots n)} \quad (11)$$

where r_{ij} is the standardized index matrix; z_{ij} is the standardized value of the original data; w_i is the jth integrated index weight.

Then, calculate the optimal and worst solutions.

$$\boldsymbol{r^+ = \left\{ max \textstyle\sum_{1 \le i \le m} r_{ij} \middle| i = 1, 2, \dots, m \right\}} = \{\boldsymbol{r_1^+, r_2^+, \dots, r_m^+}\} \quad (12)$$

$$\boldsymbol{r^- = \left\{ min \textstyle\sum_{1 \le i \le m} r_{ij} \middle| i = 1, 2, \dots, m \right\}} = \{\boldsymbol{r_1^-, r_2^-, \dots, r_m^-}\} \quad (13)$$

where r^+ and r^- are the optimal and inferior solutions, respectively.

Then, the distance between each alternative and the superior and inferior solutions is calculated.

$$\boldsymbol{D_j^+ = \sqrt{\textstyle\sum_{i=1}^{m}\left(r_{ij} - r_i^+\right)^2}} \quad (14)$$

$$\boldsymbol{D_j^- = \sqrt{\textstyle\sum_{i=1}^{m}\left(r_{ij} - r_i^-\right)^2}} \quad (15)$$

where D_j^+ and D_j^- represent the optimal and the worst vector solutions, respectively.

Finally, obtain the evaluation score index.

$$\boldsymbol{C_i = \frac{D^-}{D^- + D^+}(0 \le C_i \le 1)} \quad (16)$$

where *D*+ and *D*- represent the distance (Euclidean distance) between the evaluation object and the optimal or inferior solution (*A*+ or *A*-), respectively. The larger these values, the farther the distance. The larger the *D*+ value of the research object, the farther the distance from the optimal solution; the larger the *D*- value, the farther the distance from the inferior solution. The most understood research object is the one with the smaller *D*+ value and the larger *D*- value simultaneously. The evaluation score index *C* is calculated as *C* = (*D*-) / (*D*+ + *D*-), in which the numerator is the *D*- value and the denominator is the sum of *D*+ and *D*-. The larger the *D*- value, the farther the evaluation object is from the worst solution, and the better the evaluation object is; the larger the *C* value is, the better the research object is.

2.2.3. The Coupling Coordination Degree (CCD) model

The Coupled Coordination Degree (CCD) model is a systemic approach utilized for analyzing the level of coordinated development. This model employs coupling degree and coordination degree as key indicators to reflect the extent of interaction, interdependence, mutual constraint, and overall coordination among different systems. Coupling degree measures the level of interaction between systems or components and is employed to determine the strength of interaction and coupling among systems. However, depending solely on the coupling degree fails to sufficiently capture the overall effects of "efficiency" and "synergy". Thus, it is necessary to introduce an indicator for coordination degree in order to comprehensively evaluate the level of coordination in the interactions between systems [53].The Coupled Coordination Degree Model is important tool for enhancing the coordination and sustainable development of systems [54]. It assists in analyzing the degree of coordination and coupling among diverse systems, as well as evaluating the interactions and interdependencies between the system of development intensity and the systems of resources, environment, and carrying capacity. This enables formulating more rational and effective development strategies to achieve long-term sustainable development of the system. In this study, the CCD model was used to analyze the coupling and coordination relationships among drivers, pressures, states, impacts, and responses. Furthermore, the study aimed to explore the level of tourism ecological security in Lanzhou, following the specific steps outlined below.

$$\boldsymbol{V} = -\left[\frac{\boldsymbol{U_a U_b}}{(\boldsymbol{U_a}+\boldsymbol{U_b})^2}\right]^{\frac{1}{2}} \quad (17)$$

where V represents the degree of coupling, and U_a and U_b are the ecological security assessment values of the subsystems analyzed for coupling coordination.

Secondly, calculate the coordination degree index *T*.

$$\boldsymbol{T} = \boldsymbol{\beta_a U_a} + \boldsymbol{\beta_b U_b} \quad (18)$$

where T represents the coordination index and $\boldsymbol{\beta_i}$ represents the weight.

Finally, the coupling coordination degree D value is obtained.

$$\boldsymbol{D} = \sqrt{\boldsymbol{V} * \boldsymbol{T}} \quad (19)$$

where D represents the degree of coupling coordination, V is the degree of coupling, and *T* is the coordination index.

2.2.4. The Obstruction Degree (OD) model

The Obstruction Degree (OD) model is an analytical tool used to evaluate the potential and limiting factors in regional development. This model is based on diverse economic, social, and ecological indicators within the region, facilitating the calculation of the obstruction degree for each indicator. The objective is to evaluate the influence of these indicators on regional development and establish a foundation for formulating scientifically sound regional development plans [55-57]. In this study, the OD model was employed to analyze the key factors impeding tourism ecological security in Lanzhou. The specific steps undertaken are described below. These findings aim to provide valuable support in formulating targeted countermeasures and recommendations.

Firstly, calculate the contribution of factors.

$$\boldsymbol{F_j} = \boldsymbol{w_j} * \boldsymbol{p} \quad (20)$$

where F_j represents the contribution of the index, w_j is the comprehensive weight of the *jth* index, and p is the weight value of each subsystem.

Secondly, calculate the deviation of indicators.

$$\boldsymbol{I_{ij} = 1 - r_{ij}} \tag{21}$$

where I_{ij} represents the deviation degree of the index, where r_{ij} is the normalized value of the *jth* index in the *ith* year.

Thirdly, calculate the obstacle degree *O* value and standard layer obstacle degree *U* value for the indicators.

$$\boldsymbol{O_j = \frac{F_j I_{ij}}{\sum_{j=1}^{n}(F_j I_{ij})}} \tag{22}$$

$$\boldsymbol{U = \Sigma O_j} \tag{23}$$

where O_j represents the degree of obstruction of each indicator to tourism ecological security, *U* represents the standard layer's obstruction to tourism ecological security, and n represents the number of indicator items.

2.3. Tourism ecological security level classification standards

Based on a review of previous literature, it was found that there is currently no unified classification standard for tourism ecological security levels. In this study, we considered classification systems proposed by different scholars and integrated them with the specific interactions between tourism development and the ecological environment in Lanzhou. Consequently, five level intervals were defined, with each interval representing distinct safety statuses and levels [1,18,55], as illustrated in Table 2.

Table 2. Evaluation criteria for tourism ecological security

security level interval	security status	security level	security level characteristics
[0~0.2]	insecure	I	Tourism development at the cost of ecological damage
(0.2~0.4]	less secure	II	Tourism development and protection of the ecological environment are in conflict, ecological problems are more obvious
(0.4~0.6]	criticality security	III	Tourism development and protection of the ecological environment are largely compatible, but still have a significant impact
(0.6~0.8]	more secure	IV	Tourism development and protection of the ecological environment are in good harmony, but some constraints still exist
(0.8~1]	security	V	Tourism development and ecological environment protection go hand in hand to achieve win-win and sustainable development

2.4. The division of coupling coordination levels

The division of coupling coordination levels is based on the numerical range of coupling degree and coordination degree, which allows for the characterization of the degree of coupling and coordination among subsystems within a regional system. Different scholars have variations in the classification of coupling coordination levels. Determining the specific classification criteria relies on the research objectives and data conditions [58-59]. In this study, considering the actual situation in Lanzhou and referring to previous standards for classifying coupling coordination levels, the coupling coordination degree was divided into ten hierarchical levels, as illustrated in Table 3.

Table 3. Criteria for division of coupling coordination levels

Coordination level	Coupling coordination D	Degree of coordination
1	(0-0.1]	Extreme dysregulation
2	(0.1-0.2]	Severe dysregulation
3	(0.2-0.3]	Moderate dysregulation
4	(0.3-0.4]	Mild dysregulation
5	(0.4-0.5]	On the verge of dysregulation
6	(0.5-0.6]	Barely coordination
7	(0.6-0.7]	Junior coordination
8	(0.7-0.8]	Intermediate coordination
9	(0.8-0.9]	Well coordination
10	(0.9-1.0]	High-quality coordination

3. Results and analysis

3.1. Overall Evolution of tourism ecological security in Lanzhou

The evaluation and analysis of tourism ecological security in Lanzhou from 2009 to 2021 were conducted using the TOPSIS method. The overall trend of tourism ecological security in Lanzhou demonstrates a positive trajectory, as observed in Table 4 and Figure 3. In 2019, the evaluation value of tourism ecological security in Lanzhou peaked at 0.565, signifying a significant increase of 0.231 compared to the lowest value of 0.334 in 2009. On average, there was an annual growth rate of 0.021. Nevertheless, the evaluation value of tourism ecological security in Lanzhou experienced minor fluctuations during the period from 2013 to 2018.Moreover, the evaluation value of tourism ecological security in Lanzhou declined in 2020 and 2021 due to the adverse effects of the COVID-19 pandemic on tourism activities.

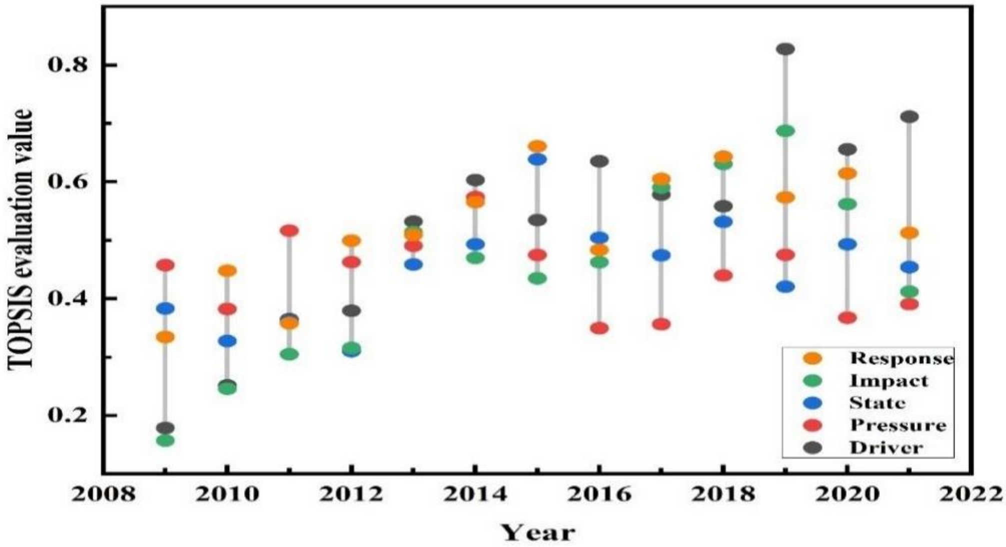

Figure 3. TOPSIS Evaluation Values of the Five Subsystems

Table4. TOPSIS evaluation value of tourism ecological security 2009-2021 for Lanzhou

Year	Positive ideal solution distance (D+)	Negative ideal solution distance (D-)	Composite score index （C）	Sort
2009	0.800	0.402	0.334	13
2010	0.809	0.414	0.338	12
2011	0.732	0.483	0.398	11
2012	0.680	0.453	0.400	10
2013	0.557	0.553	0.499	8
2014	0.513	0.615	0.545	4
2015	0.492	0.617	0.556	2
2016	0.585	0.565	0.491	9
2017	0.557	0.569	0.506	6
2018	0.526	0.633	0.546	3
2019	0.539	0.700	0.565	1
2020	0.567	0.657	0.537	5
2021	0.590	0.598	0.503	7

Table 5 illustrates the evolution of the levels of the criteria layers within the tourism ecological security indicator system in Lanzhou during the study period. The evaluation levels of the subsystems for tourism ecological security exhibit an overall upward trend. In particular, the evaluation levels of the subsystems were comparatively high in 2019, contrasting with the situation in 2009.The driver subsystem witnessed the most significant improvement in evaluation levels, advancing from level II in 2009 to level V in 2019.Subsequently, the impact subsystem experienced progress, moving from level II in 2009 to level IV in 2019.In contrast, the evaluation levels of the status and response subsystems demonstrated comparatively slower improvement, with a slight decline observed in the evaluation level of the pressure subsystem. The evaluation level evolution of the subsystems during 2020-2021 has limited reference value and may not accurately reflect the overall trend due to the influence of the COVID-19 pandemic.

Table5. Evaluation Levels of Lanzhou Tourism Ecological Security Subsystems from 2009 to 2021

Year	Driver	Pressure	State	Impact	Response
2009	II	III	II	II	II

2011	II	III	II	II	II
2012	II	III	II	II	III
2013	III	III	III	III	III
2014	IV	III	III	III	III
2015	III	III	IV	III	IV
2016	IV	II	III	III	III
2017	III	II	III	III	IV
2018	III	III	III	IV	IV
2019	V	III	III	IV	III
2020	IV	II	III	III	IV
2021	IV	II	III	III	III

3.2. Evolution of tourism ecological security Subsystems in Lanzhou

The evaluation value curves of the driver and impact subsystems within the tourism ecological security indicator system in Lanzhou demonstrate a notable similarity during the period of 2009-2014, as observed in Figure 4. This observation suggests a strong correlation between the driver factors, including economy, population, tourism resources, and ecological environment, as well as the influencing factors, in the evolutionary process of Lanzhou's tourism ecological security. Moreover, it highlights the direct impact of the driver factors on the status of Lanzhou's tourism ecological security. The curves illustrating the evolutionary trends of the state and response subsystems exhibit a fundamental consistency, signifying the interplay between the variations in Lanzhou's ecological environment and tourism resources and the implemented measures for environmental protection and response. Implementing response measures effectively generates a positive feedback effect on the state subsystem, promoting the recovery or improvement of various state factors. The evaluation value curve of the pressure subsystem displays instability, manifesting fluctuating trends. This indicates the uncertain nature of the pressures exerted on Lanzhou's tourism ecological security by factors such as waste, wastewater, air emissions, and tourist density. The corresponding response measures can induce short-term changes in the ecological environment of tourist destinations. Nevertheless, mitigating the pressures necessitates long-term environmental investments and a more comprehensive and effective strategic framework.

The evaluation value curve of the driver subsystem exhibits an ascending trend, attributable to two primary factors. Firstly, both destination residents and tourists aspire to a higher quality of life and greater sense of happiness when their economic level improves, and tourism serves as one of the effective pathways to achieve happiness. Secondly, rapid economic development can enhance the infrastructure of tourist destinations and increase investment in the ecological environment, thereby stimulating the growth of the tourism industry. Based on these two factors, the level of driver factors for tourism ecological security in Lanzhou will continue to increase.

The evaluation curve of the pressure subsystem shows a spiral downward trend, which is attributed to the characteristics of Lanzhou as a tourist city and the high-density tourist population as a provincial capital. The increase in the number of tourists, on one hand, promotes the development of various tourism-related industries such as dining, accommodation, transportation, sightseeing, shopping, and entertainment. On the other hand, it leads to an increase in the emission of solid waste, wastewater, and harmful substances such as sulfur dioxide, intensifying the pressure on the entire tourism ecosystem.

The evaluation curve of the state subsystem shows an overall upward trend, reaching its peak in 2015.This trend indicates an overall improvement in the various state factors within the tourism ecological security system in Lanzhou. The implementation of ecological conservation response measures contributes to the enhancement of the evaluation values of these state factors. The year 2015 represents the optimal level of state factors during the study period. However, Lanzhou's traditional developmental advantages are facing significant challenges, leading to changes in the quality and quantity of various energy and tourism resources, resulting in a downward trend in the evaluation values of the state subsystem.

The evaluation values of the impact subsystem show an overall upward trend, reaching the highest point in 2019, followed by a downward trend due to the impact of the COVID-19 pandemic. This indicates that the tourism industry in Lanzhou is thriving, and its significance in the national economy is increasingly growing, reaching its highest level in 2019.The evaluation value of the impact subsystem showed a small peak in 2013, reached a low point in 2015, and then continued to rise. In 2013, the Financial Office of the Lanzhou Municipal Government initiated an investment promotion program that attracted domestic and international financial enterprises as well as state-owned companies. This program facilitated rapid economic development and resulted in the sustained growth of the tourism industry. However, during the period from 2013 to 2015, Lanzhou faced evident transportation constraints and insufficient investment in urban infrastructure construction, which significantly hindered the development of the tourism industry. Additionally, a shortage of service industry professionals and lagging enterprise management made it challenging to sustain the development of the tertiary sector. The publication of "Vision and Actions on Jointly Building the Silk Road Economic Belt and 21st-Century Maritime Silk Road" by Lanzhou in 2015 presented strategic opportunities for the development of the modern service industry and provided policy guidance for tourism development.

The evaluation curve of the response subsystem shows an overall upward trend, reaching its peak in 2015.In 2015, Lanzhou accelerated the environmental governance of key enterprises, completing 13 in-depth pollution control projects for 7 major industrial companies. This effectively regulated and transformed various sources of environmental pollution, leading to a rapid increase in the evaluation value of the response subsystem in the short term. However, over time, routine enforcement faced several challenges primarily due to the specialized and complex nature of environmental administrative penalties, insufficient enforcement personnel, and inadequate enforcement capacity. These factors have hindered the sustainability of Lanzhou's initial achievements in environmental governance, resulting in a decline in the evaluation value of the response factors. Lanzhou developed and released the "2018 Lanzhou Air Pollution Control Implementation Plan" and the "Three-Year Action Plan to Win the Battle for Blue Skies in Lanzhou (2018-2020)." Additionally, a strategic cooperation agreement on air pollution control was signed with Lanzhou University in 2018. As a result, the evaluation value of the response factors reached a high level in 2018. However, these policy measures did not adequately address Lanzhou's long-term ecological environmental issues. Subsequently, the outbreak of the COVID-19 pandemic affected various response measures, leading to fluctuations in the evaluation value curve.

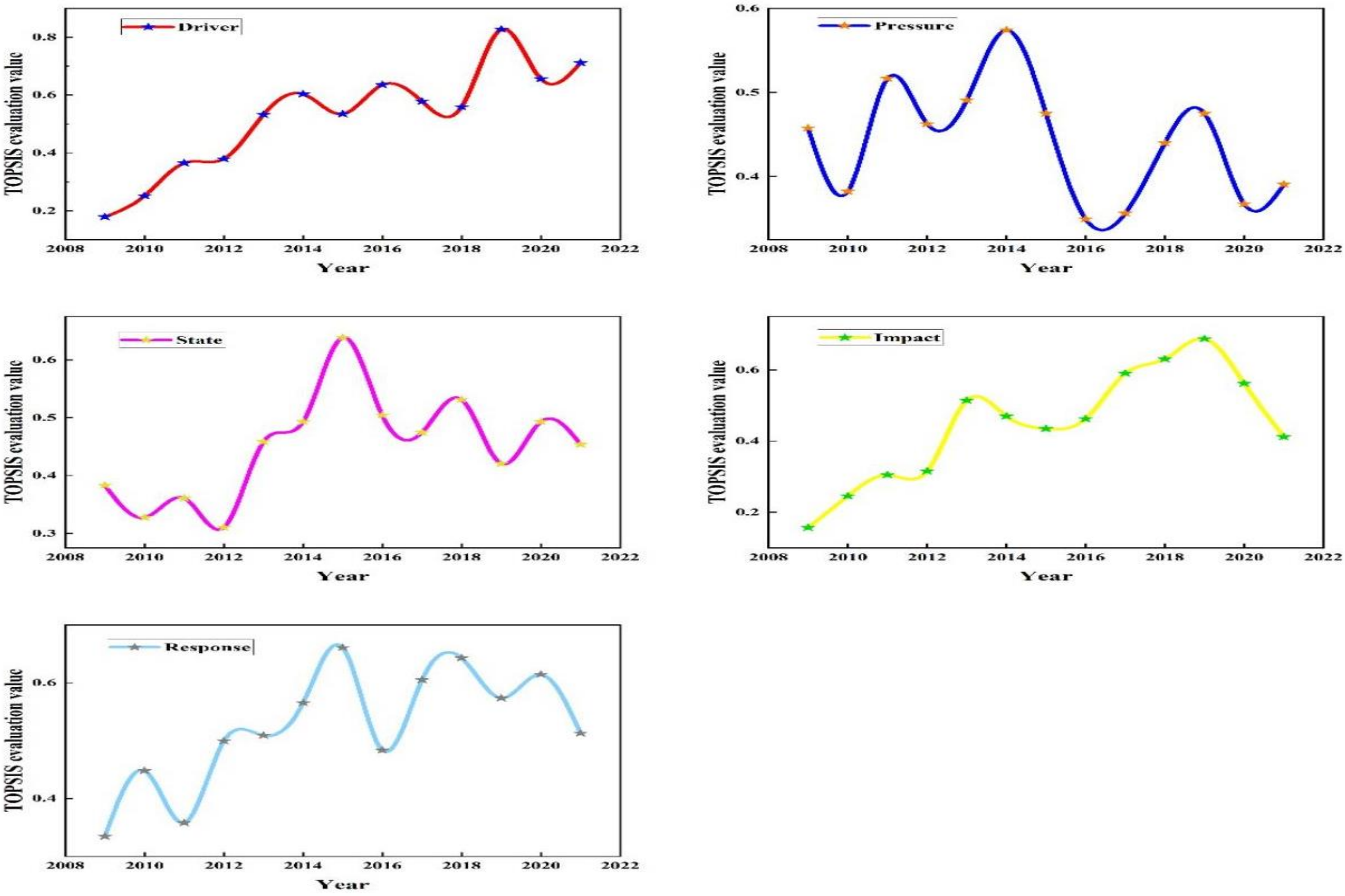

Figure 4. Evolution of TOPSIS evaluation values of tourism ecological security subsystems in Lanzhou

3.3. Analysis of Coupling and Coordination Degree of tourism ecological security Subsystems in Lanzhou

Table 6 presents an analysis of the coupling coordination among the subsystems within the tourism ecological security system in Lanzhou. Overall, there is an increasing trend in the coupling coordination among the subsystems. However, the outbreak of the COVID-19 pandemic at the end of 2019 may have caused fluctuations in the data for 2020 and 2021, thereby exerting a limited impact on the overall evolutionary trend throughout the study period.

The coupling and coordination value between the driver subsystem and the pressure subsystem increased from 0.268 in 2009 to 0.813 in 2019, with an increment of 0.545. The level of coupling coordination shifted from moderate imbalance to excellent coordination. This indicates that during the study period, the coupling and coordination relationship between the driver subsystem and the pressure subsystem became increasingly tight, and the changes in the driver subsystem exerted growing pressure on the tourism ecological security in Lanzhou. The improvement in driver factors such as economic development, tourism resources, and population in Lanzhou has placed enormous pressure on the ecological environment, leading to increased discharge of wastewater, waste gases, garbage, and higher tourist density.

In 2019, the coupling and coordination value between the driver subsystem and the response subsystem was 0.921, which increased by 0.821 compared to 0.100 in 2009. The level of coupling coordination shifted from extreme imbalance to high-quality coordination. This indicates that in the tourism ecological security system of Lanzhou, the coupling and coordination relationship between the driver and response subsystems was extremely limited in 2009. However, over time, the coupling and coordination relationship between the two subsystems continuously improved. The implementation of response measures can have a positive feedback effect on driver factors such as economic and tourism development, while economic growth, in turn, ensures the better implementation of response measures.

In the research period, the coordination value between the pressure subsystem and the state subsystem reached its maximum in 2016, while it reached its minimum in 2012. These results indicate that the coupling and coordination relationship between the pressure subsystem and the state subsystem in the tourism ecological security system of Lanzhou is unstable. The pressure factors in 2016 led to significant changes in the state factors, while in 2012, the pressure factors only resulted in limited changes in the state factors.

The coupling and coordination value between the pressure and response subsystems increased from 0.268 in 2009 to 0.753 in 2019, with an increase of 0.485. The coordination level also shifted from moderate imbalance to moderate coordination. This indicates that the implementation of response measures contributes to alleviating the pressure on the tourism ecological security system of Lanzhou. Measures such as investment in environmental protection, waste recycling, and improving the level of education can greatly reduce the pollution caused by waste emissions to the ecological environment.

The coupling and coordination value between the state subsystem and the influence subsystem reached its highest level in 2015, with a value of 0.829, indicating excellent coordination. However, in 2019, the coupling and coordination value dropped to 0.241, indicating moderate imbalance. This suggests that the coupling and coordination relationship between the two subsystems is highly unstable. Moreover, in 2019, the changes in the state factors of the tourism ecological security system in Lanzhou primarily resulted in negative impacts, which is the opposite of what occurred in 2015.

The coupling and coordination value between the state subsystem and the response subsystem increased from 0.218 in 2009 to 0.705 in 2019, showing an increase of 0.487. The coordination level also improved from moderate imbalance to moderate coordination, and even reached a high-quality coordination level at some point. This indicates that the implementation of response measures plays a restorative or promotional role in the state factors of tourism ecological security in Lanzhou. Environmental investment measures contribute to the restoration and even improvement of tourism facilities and resources.

The coupling and coordination value between the influence and response subsystems reached its minimum value of 0.292 in 2019, indicating a moderate imbalance. The maximum value was recorded in 2015, reaching 0.829 and indicating excellent coordination. This suggests that Lanzhou needs to strengthen environmental protection measures to attract tourists with a healthy ecological environment, increase tourism revenue, and subsequently invest more in ecological environmental measures, forming a virtuous cycle.

Table 6. Coupling and coordination relationship of tourism ecological security subsystems in Lanzhou

Year	DP	DR	PS	PR	SI	SR	IR
2009	0.268	0.100	0.586	0.268	0.689	0.218	0.315
	Moderate dysregulation	Extreme dysregulation	Barely coordination	Moderate dysregulation	Junior coordination	Moderate dysregulation	Mild dysregulation
2010	0.565	0.453	0.478	0.738	0.475	0.383	0.734
	Barely coordination	On the verge of dysregulation	On the verge of dysregulation	Intermediate coordination	On the verge of dysregulation	Mild dysregulation	Intermediate coordination
2011	0.525	0.391	0.453	0.381	0.583	0.337	0.490
	Barely coordination	Mild dysregulation	On the verge of dysregulation	Mild dysregulation	Barely coordination	Mild dysregulation	On the verge of dysregulation
2012	0.628	0.631	0.265	0.708	0.289	0.267	0.770

	Junior coordination	Intermediate coordination	Moderate dysregulation	Intermediate coordination	Moderate dysregulation	Moderate dysregulation	Intermediate coordination
2013	0.672	0.734	0.641	0.669	0.622	0.701	0.648
	Junior coordination	Intermediate coordination	Junior coordination	Junior coordination	Junior coordination	Intermediate coordination	Junior coordination
2014	0.284	0.823	0.273	0.290	0.692	0.791	0.734
	Moderate dysregulation	Well coordination	Moderate dysregulation	Moderate dysregulation	Junior coordination	Intermediate coordination	Intermediate coordination
2015	0.702	0.858	0.814	0.814	0.829	0.995	0.829
	Intermediate coordination	Well coordination	Well coordination	Well coordination	Well coordination	High-quality coordination	Well coordination
2016	0.912	0.752	0.874	0.820	0.708	0.720	0.664
	High-quality coordination	Intermediate coordination	Well coordination	Well coordination	Intermediate coordination	Intermediate coordination	Junior coordination
2017	0.876	0.843	0.832	0.943	0.555	0.801	0.628
	Well coordination	Well coordination	Well coordination	High-quality coordination	Barely coordination	Well coordination	Junior coordination
2018	0.768	0.860	0.795	0.864	0.526	0.890	0.572
	Intermediate coordination	Well coordination	Intermediate coordination	Well coordination	Barely coordination	Well coordination	Junior coordination
2019	0.813	0.921	0.622	0.753	0.241	0.705	0.292
	Well coordination	High-quality coordination	Junior coordination	Intermediate coordination	Moderate dysregulation	Intermediate coordination	Moderate dysregulation
2020	0.903	0.888	0.844	0.939	0.605	0.829	0.674
	High-quality coordination	Well coordination	Well coordination	High-quality coordination	Intermediate coordination	Well coordination	Junior coordination
2021	0.901	0.817	0.772	0.815	0.691	0.699	0.729
	High-quality coordination	Well coordination	Intermediate coordination	Well coordination	Junior coordination	Junior coordination	Intermediate coordination

3.4. Analysis of the obstacle factors of Lanzhou tourism ecological security

(1) Analysis of criterion layer of obstacle degree. As shown in Figure 5, the obstacle degrees of the pressure, state, and impact subsystems in Lanzhou's tourism ecological security system exhibit an increasing trend, while the obstacle degree of the driver subsystem shows a decreasing trend, and the obstacle degree of the response subsystem fluctuates. Among these, the obstacle degree of the state subsystem shows the most significant increase, with an approximate increase of 10%, which is the primary obstacle factor. Furthermore, the obstacle degree value of the impact subsystem increased by approximately 8%, while the obstacle degree value of the pressure subsystem had the smallest increase, approximately 5%. The obstacle degree value of the driver subsystem decreased significantly by approximately 24%. From 2009 to 2016, the obstacle degree of the response subsystem exhibited minimal changes but experienced a significant decrease in 2017. Moreover, from 2015 to 2021, the obstacle degree of the response subsystem remained at the lowest level among the five subsystems.

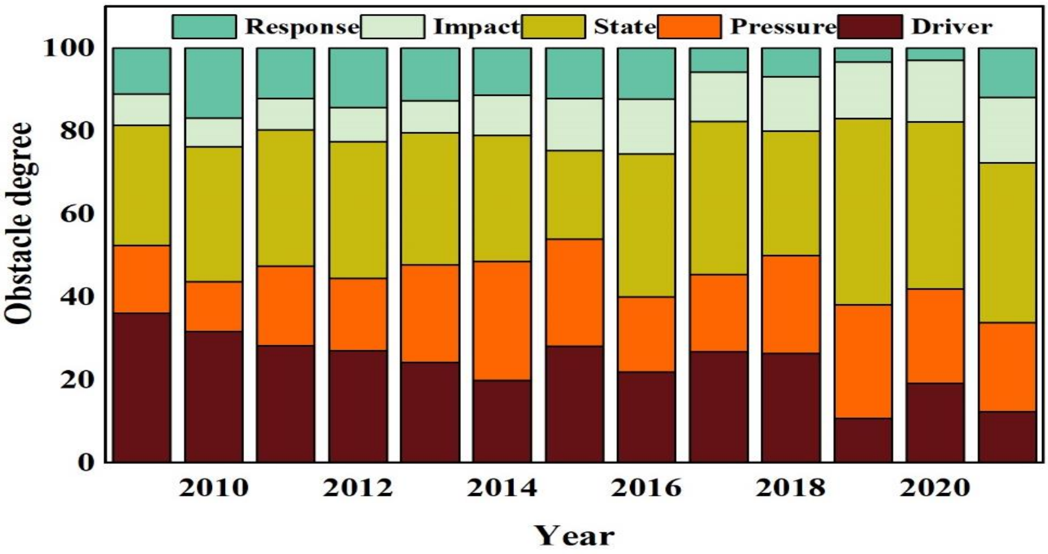

Figure 5. Tourism ecological security Standard-level obstacle degree in Lanzhou

(2) Analysis of obstacle degree at the indicator layer. Considering the relatively large number of evaluation indicators for Lanzhou's tourism ecological security, this study selected representative years, namely 2009, 2012, 2015, 2018, and 2021. Thirteen indicators with obstacle degrees below 3% were chosen for analysis, as shown in Table 7. The results indicate that the main obstacle factors of Lanzhou's tourism ecological security are indicators within the driver, pressure, and state subsystems. The primary obstacle factors of Lanzhou's tourism ecological security have undergone changes in terms of their types, quantities, and obstacle degrees.

Among them, the natural population growth rate has consistently been a primary obstacle factor, and its obstacle degree increases over time. This indicates the need for greater attention to the inhibitory role of population factors on Lanzhou's tourism ecological security. In contrast, the obstacle degree of per capita disposable income and the growth rate of the tertiary industry decrease over time, indicating a continuous reduction in the inhibitory effect of Lanzhou's social and tourism economy on Lanzhou's tourism ecological security. Indicators such as per capita park and green space area, forest coverage rate, proportion of natural protected areas to total land area, green area, and afforestation area of barren hills and wastelands have been the main obstacle factors for most years, significantly impeding the improvement of Lanzhou's tourism ecological security level. Therefore, it is necessary to increase investment in ecological environment protection to reduce the inhibitory effect of these indicators. During the research period, indicators such as forest coverage rate, proportion of natural protected areas to total land area, and green coverage rate have relatively high obstacle degree values, indicating the need for strengthening these indicators. The current ecological environment status is insufficient to sustain the continuous improvement of Lanzhou's tourism ecological security. The obstacle degree value of the number of days with air quality reaching Level II in 2018 is the highest, indicating the instability of this indicator and its significant hindrance to Lanzhou's tourism ecological security in certain years, warranting attention. The obstacle degree values of indicators in the pressure subsystem such as sulfur dioxide emissions and tourist population density fluctuate, suggesting that the proper handling of these indicators can have a significant impact on the improvement of Lanzhou's tourism ecological security level. The obstacle degree of general industrial solid emissions is relatively high compared to other indicators, indicating its significant impact on ecological environment pollution and the need for timely responsive measures to reduce its inhibitory effect. The obstacle degree of other indicators in the pressure subsystem is relatively low, suggesting that these indicators have limited inhibitory effects on Lanzhou's tourism ecological security.

Table 7. Obstacle degree of tourism ecological security index layer in Lanzhou

Year	2009	2012	2015	2018	2021
Natural population growth rate (‰)	4.369	4.745	4.322	6.070	7.847
Disposable income per capita (yuan)	6.422	5.571	5.166		
Growth rate of tertiary industry (%)	7.133	7.436	4.965		
Number of days with air quality reaching Level II (days)	4.779		5.747	9.728	
Sulfur dioxide emissions (10,000 tons)	3.707	3.904	4.144		
Solid waste discharge (10,000 tons)		4.918	6.582		5.092
Tourism spatial index (person/km2)	4.416			6.479	3.780
Tourist density index			3.595	7.136	3.648
Park greenspace per capita (km2)	6.511	5.905	5.256		4.320
Green coverage rate (%)	6.450	4.175		6.426	5.995
Nature reserves account for the proportion of the city's land area (%)		5.352	7.617	7.865	9.822
Forest coverage rate (%)	8.827	9.412		8.704	8.810
Afforestation area of barren mountains and waste-land (10,000 mu)	5.258	5.393	4.429		7.047

4.Discussion and conclusions

4.1. Discussion

Firstly, this study constructed a tourism ecological security evaluation index system for Lanzhou based on the DPSIR model. Compared to the PSR model, the DPSIR model incorporates the driver and impact subsystems, allowing for a more comprehensive construction of the evaluation index system and addressing the shortcomings of the PSR model. In the study of tourism ecological security in Wuhan, the PSR model was applied. The results revealed a lack of correlation between the pressure and response subsystems, indicating their independent existence and significantly reducing the effectiveness of the entire tourism ecological security evaluation system. This highlights the notable shortcomings of tourism ecological security [9]. The DPSIR model used in this study has distinct advantages. The results of this research demonstrate that within the tourism ecological security evaluation index system of Lanzhou, there exist interconnected and interactive relationships among the subsystems. Furthermore, these five subsystems form a cyclical system, wherein any changes in one subsystem can trigger changes in the other subsystems. Simultaneously, within the tourism ecological security index system, our research employed a combination of the variance method and entropy method to determine weights. This approach helps to overcome the limitations of a single method. By utilizing both the variance method and entropy method, which are derived from mathematical statistics and information theory respectively, we can calculate determinism in mathematical statistics while assessing uncertainty in information theory.

Furthermore, in terms of research methodology, this study employed the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method to evaluate the level of tourism ecological security in Lanzhou City. Additionally, the coupling coordination degree model was used to analyze the coupling and coordination relationships among the subsystems. Finally, the obstacle degree model was applied to investigate the main obstacles affecting tourism ecological security in Lanzhou City. The analysis was conducted from two dimensions: the criterion level and the index level. Based on these findings, targeted strategies and recommendations were proposed to address the identified issues. In previous studies, the evaluation of ecological risks in the Wei River Basin in China was conducted using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method [35]. Additionally, the tourism ecological security of Zhangjiajie has been subjected to early warning analysis [36], and the tourism competitiveness of destinations in the Yangtze River Delta in China has been evaluated using TOPSIS [37]. Based on the success of these studies, it is considered both feasible and reliable to employ the TOPSIS method in evaluating the tourism ecological security of Lanzhou. Regarding the degree of coupling coordination, previous scholars have applied it less frequently in the study of tourism ecological security and more commonly in the context of innovation and industrial transformation, new urbanization, economic growth, or the coordinated development between industries [61-64].This study utilizes the coupling coordination model to analyze the coupling and coordination relationships among various subsystems. On one hand, this provides further supplementation to previous research on tourism ecological security. On the other hand, it enables the identification of factors influencing the coupling and coordination relationships among the subsystems, thus facilitating the formulation of corresponding strategies and recommendations. In terms of the obstacle model, previous studies on tourism ecological security have mostly focused on measuring and diagnosing at the national and provincial scales [55-57]. However, the identified obstacle factors vary across different regions. For instance, the analysis of obstacle factors affecting tourism ecological security in Wuhan revealed that the main obstacles include the proportion of environmental protection investment to GDP, tourism building density, and the rate of increase in tourism land demand [9]. In contrast, the results of the obstacle diagnosis in this study indicate that factors such as forest coverage are the primary obstacles. One reason for this disparity is the significant geographical differences between Lanzhou and Wuhan, resulting in substantial gaps in economic development, ecological environment, and tourism development between the two locations. Therefore, the primary obstacle factors for tourism ecological security in Wuhan primarily focus on the economic and land aspects, while Lanzhou, as a semi-arid valley city, faces obstacles primarily related to natural resources and environmental conditions.

4.2. Main findings

This study examines the level of tourism ecological security in Lanzhou, the coupling and coordination relationships among its subsystems, and the primary obstacle factors over a period of 13 years. Currently, research on tourism ecological security in the Northwest region and the Yellow River basin mainly focuses on individual provinces and multiple cities, covering large areas. However, there is a lack of detailed studies on specific areas [13,56]. This study aims to address this gap by focusing on Lanzhou, a semi-arid river valley city, in order to provide a more comprehensive analysis of its tourism ecological security level and the factors influencing it. The evaluation method used in this study is feasible, and the results obtained are reliable, providing valuable references for future research on tourism ecological security in the Yellow River Basin and even the Northwestern region of China. Additionally, our study has generated some novel findings.

Firstly, during the study period, the overall evaluation value of tourism ecological security in Lanzhou showed an upward trend. Specifically, in 2019, the evaluation values of various subsystems were higher, while in 2009, the evaluation values were lower. The outbreak of the COVID-19 pandemic led to significant changes in the evaluation values in 2020 and 2021, which do not accurately reflect the normal state of tourism ecological security. Furthermore, the evaluation value of the driver subsystem increased from level II to level IV, showing the most significant upward trend within the entire tourism ecological security system, while the evaluation value of the pressure subsystem exhibited a declining trend. Moreover, the evaluation value curves of the driver subsystem and the influencing subsystem exhibit similar trends, while the evaluation value curves of the state subsystem and the response subsystem for tourism ecological security evolve in a largely consistent manner.

Secondly, the overall coupling coordination of the subsystems within the tourism ecological security system in Lanzhou shows an upward trend, indicating a gradual strengthening of the coupling coordination among the subsystems. The coupling coordination between the driver subsystems and the pressure subsystems continuously increases, indicating a growing pressure exerted by the driver subsystems on the tourism ecological security system in Lanzhou. The coupling coordination between the driver subsystems and the response subsystems is also gradually increasing, indicating a positive feedback effect of the response measures on the driver factors. The coupling coordination between the pressure subsystem and the state subsystem is unstable, and pressure factors may cause significant or limited changes in the state factors. The coupling coordination between the pressure subsystem and the response subsystem has increased, indicating that response measures contribute to alleviating system pressure. The coupling coordination between the state subsystem and the influence subsystem is also unstable, and in 2019, changes in the state factors had a significant negative impact on the system. The coupling coordination between the state subsystem and the response subsystem has increased, indicating that response measures play a role in the recovery or promotion of state factors. The coupling coordination between the influence subsystem and the response subsystem is also unstable, and the implementation of response measures can have both positive and negative impacts on the tourism ecological security level in Lanzhou.

Thirdly, in the analysis of standard-level obstacle degrees, the state subsystem exhibited the most significant increase in obstacle severity, with an approximate 10% increase, posing a significant hindrance to system operation. This may be attributed to factors such as environmental conditions and resource utilization. The obstacle severity of the influence subsystem increased by approximately 8%, exerting a certain impact on the system operation. This may be attributed to factors such as economic development and tourism resources. Meanwhile, the obstacle severity of the pressure subsystem showed a growth rate of around 5%, indicating a slow increase in the hindering effect of the pressure subsystem on the tourism ecological security system in Lanzhou. The obstacle severity of the driver subsystem decreased by approximately 24%, indicating a significant decline. This suggests that driver factors have positively influenced the system operation, possibly due to factors such as economic development and policy support. The obstacle level of the response subsystem fluctuated, indicating an unstable hindering effect on the tourism ecological security of Lanzhou. It varies between good and bad.

Fourth, according to the analysis of obstacle severity at the indicator level, the population natural growth rate has consistently been the main obstacle factor in the tourism ecological security system of Lanzhou, and its severity has increased over time. The obstacle severity of per capita disposable income and the growth rate of the tertiary industry has decreased over time, indicating a reduction in the hindering effect of the social and tourism economy on the system. In most years, indicators such as per capita park green space area, forest coverage rate, proportion of natural protected areas to land area, green area, and afforestation area of barren mountains and wasteland pose significant obstacles. The obstacles posed by indicators such as forest coverage rate, proportion of natural protected areas to land area, and green coverage rate are relatively high, necessitating the enhancement of these ecological environment indicators to support the continuous improvement of Lanzhou's tourism ecological security system. The number of days in 2018 that reached the second-level air quality standard posed the most significant obstacles and requires special attention. Among the pressure subsystem indicators, the obstacles posed by sulfur dioxide emissions and tourist population density fluctuate, and correctly managing these indicators can have a significant positive impact on the system level. General industrial solid emissions pose significant obstacles and require responsive measures to mitigate their hindering effect. Other pressure subsystem indicators have a lower level of obstacles, and their hindering effect on the system is limited.

4.3. countermeasures and recommendations

Firstly, at the government level: (1) The government should strengthen the formulation of laws, regulations, and policies concerning tourism ecological security, clearly define responsibilities and standards, and enhance management and regulatory efforts. Simultaneously, there should be increased emphasis on promoting environmental protection through educational campaigns to raise public awareness of the importance of the ecological environment and foster a stronger sense of ecological conservation.(2) To generate collective efforts in promoting tourism ecological security, the government should establish interdepartmental collaboration mechanisms, strengthen communication and coordination among government departments, and establish good cooperative relationships with scenic area management entities, communities, and tourism enterprises.(3) The government should also formulate appropriate policies for support and incentives to encourage the tourism industry to prioritize ecological protection and sustainable development, and to encourage enterprises and scenic areas to implement corresponding environmental protection measures.(4) For a city like Lanzhou, situated in a semi-arid river valley region, water resources are a crucial environmental element. Therefore, the government should strengthen the management and protection of water resources to ensure that tourism activities do not exert excessive pressure on local water sources. Through scientific water resource allocation and conservation measures, the ecological sustainability of tourism in Lanzhou can be guaranteed. (5) Lanzhou has a rich historical heritage and abundant cultural treasures. The government and tourism destinations should strengthen their awareness of cultural heritage preservation, formulate appropriate management measures, and provide targeted cultural education and experiential activities to enable tourists to gain in-depth knowledge of and respect for the local culture.(6) Considering the geographical characteristics and distribution of tourist resources in Lanzhou, the government should actively promote green transportation modes, such as developing rail transportation and encouraging walking and cycling, to reduce car usage and exhaust emissions, mitigate the negative environmental impact of tourism, and enhance the ecological sustainability of tourism.

Secondly, at the level of tourism destinations (scenic areas): (1) Strengthening ecological conservation management is crucial. Tourism destinations (scenic areas) should establish comprehensive environmental monitoring and protection mechanisms, effectively control tourist influx, and minimize human-induced damage. (2) Tourism destinations (scenic areas) should also develop detailed plans for the development and protection of tourism resources, including the rational planning of tour routes and tourist capacity. It is important to strengthen the management of scenic areas, protect the ecological environment and cultural heritage, as well as enhance the construction and maintenance of tourism facilities to improve the overall experience and ensure the safety of tourists.(3) Tourism destinations (scenic areas) should enhance employee training to improve the quality and level of service and provide tourists with a superior travel experience.(4) Tourism destinations (scenic areas) should strengthen their educational and promotional efforts aimed at tourists. They can establish environmental education centers to communicate important information on environmental and ecological conservation. Furthermore, they should conduct environmental education activities, organize events with an environmental protection theme, produce promotional materials, and enhance tourists' awareness and appreciation of ecological conservation. These measures aim to guide tourists in developing environmental consciousness and adopting sustainable behaviors. (5) To promote sustainable tourism behavior, tourism destinations (scenic areas) can effectively communicate essential information about environmental and ecological conservation to tourists through the use of tour guides, informational signs, labels, and environmental campaigns. These efforts aim to guide tourists in adhering to ethical tourism practices, emphasizing the importance of ecological conservation, and encouraging low-carbon, environmentally friendly travel behaviors.

Thirdly, at the level of society :(1) Society should strengthen its attention to and participation in tourism ecological security, enhance public awareness and participation in tourism ecological security, and promote environmental protection actions through publicity and educational activities. This can be achieved by encouraging various sectors of society to participate in environmental protection activities, such as volunteering and waste sorting.(2) Promote local cultural education to enhance public respect and awareness of local culture and ecology, and advocate for sustainable tourism development principles.(3) Establish a collaborative mechanism among the government, businesses, and social organizations to collectively promote sustainable development and ecological conservation in the tourism industry, fostering a multi-stakeholder approach. Advocate for responsible and environmentally-friendly behavior among tourists to cultivate a sense of responsibility and engagement in various sectors of society towards tourism ecological security. (4) Encourage community residents to participate in the operation and management of the tourism industry, increasing their income and decision-making rights. Additionally, strengthen the collaboration between communities, scenic areas, the government, and tourism enterprises to collectively promote the protection and development of tourism ecological security.

Fourth, at the level of tourists :(1) Tourists should consciously abide by the rules and regulations of the tourist area, respect local culture and customs, adhere to the requirements of ecological conservation, and refrain from causing arbitrary damage or pollution to the environment.(2) Tourists should actively engage in environmental conservation awareness campaigns, practice resource conservation, minimize waste generation, prioritize ecological conservation in their travel behaviors, and choose sustainable tourism products.(3) Tourists should opt for sustainable travel modes such as walking or cycling to minimize their environmental impact. They should also support tourism operators with strong environmental awareness and choose tourism products and services that are environmentally certified. These measures will contribute to the sustainable development of tourism in Lanzhou, as well as the preservation and enhancement of the ecological environment and rich cultural heritage of the tourist destinations. The collaborative efforts of the government, tourist destinations, society, and tourists can establish a mechanism of synergistic cooperation to improve the ecological security level of tourism in Lanzhou.

4.4. Limitations and future research

Considering the potential impact of the COVID-19 pandemic over the past two years on the assessment of tourism ecological security in Lanzhou, further research and monitoring should be conducted to determine the stability of the assessment trends. Continuous data collection and analysis will facilitate improvements to the assessment system and the effectiveness of intervention measures. The evaluation system for tourism ecological security is complex, encompassing a wide range of factors. However, there are currently no established criteria for selecting indicators. The indicator system constructed in this study may have subjectivity and flaws, and further research is needed for improvement. In addition, this study utilized both mean square deviation method and entropy method to determine the weights of the indicators, instead of using subjective weighting. In future research, the determination of weights can be further improved by combining expert rating methods and adopting a mixed objective-subjective approach. Finally, this study employed TOPSIS method, coupled coordination scheduling model, and obstacle degree model to assess and diagnose the temporal status level and evolutionary trend of tourism ecological security in Lanzhou. Future research can consider incorporating spatial analysis from a geographical perspective to investigate the spatiotemporal distribution differences in the study area.

Author Contributions: An Z.H: Formal analysis, Investigation, Methodology, Software, Validation, Writing - original draft. Wu M.T: Investigation; Methodology, Software; Writing - original draft. Wu K.J: Investigation; Conceptualization, Resources; Writing - original draft. Jiao H: Investigation; Data curation, Validation.

Funding: This research was funded by the Gansu Provincial Higher Education Innovation Fund Project (No. 2022B-088), and the Lanzhou Philosophy and Social Science Planning Project (No.22-B87).

Data Availability Statement: Not applicable.

Acknowledgments: We would like to thank all the authors of this article for their important contributions, and I would like to express my sincere gratitude to the developers and institutions where the auxiliary tools used in this study are located.

Conflicts of Interest: The authors declare no conflict of interest.

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