

Study on the Spatial Network Structural Characteristics and Influencing Factors of Tourism Economic Resilience in Cities of the Middle and Lower Reaches of the Yellow River Basin

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Study on the Spatial Network Structural Characteristics and Influencing Factors of Tourism Economic Resilience in Cities of the Middle and Lower Reaches of the Yellow River Basin

Abstract: Ecological protection and high-quality development of the Yellow River Basin has risen to the level of a major national strategy. As a key pillar industry within the basin, the stability and sustainable development of tourism are vital to the regional economy and society. Enhancing the resilience of the tourism economy has become a critical issue for achieving high-quality regional development. This paper takes 39 prefecture-level cities in the middle and lower reaches of the Yellow River Basin as research units. Using methods such as the Entropy Weight-TOPSIS model, VAR model, social network analysis, and QAP regression model, it comprehensively measures and conducts time-series analysis of the tourism economic resilience levels of each city from 2010 to 2024, determines the intercity resilience relationships, and constructs a spatial correlation network based on these findings to further explore the structural characteristics and influencing factors of the spatial network. The results show: (1) During the study period, the overall comprehensive scores of tourism economic resilience in the middle and lower reaches of the basin showed an upward trend, but there is significant internal regional imbalance. (2) The spatial network structure of regional resilience is distinct, with 269 correlation relationships identified; the overall network density needs improvement and presents a typical "core-periphery" hierarchical structure. (3) Block model analysis reveals that cities play four differentiated roles and functions in the network: "net spillover," "bidirectional spillover," "broker," and "net beneficiary." (4) QAP regression analysis confirms that population mobility, geographical proximity, differences in economic development, and differences in tourism resource endowments are all significant positive influencing factors driving network formation. They constitute the network's "circulatory system," "spatial framework," "hierarchical order," and "internal gravity," respectively. Finally, based on the empirical analysis, this paper proposes policy recommendations for optimizing the spatial layout of the tourism economy in the Yellow River Basin and formulating differentiated strategies to enhance resilience.

Keywords: Yellow River Basin; Tourism economic resilience; Spatial network; Structural characteristics; Influencing factors

1. Introduction

In recent years, the Yellow River Basin has confronted unprecedented challenges—

and concurrently, emerging opportunities—driven by global climate change and structural transformations in China’s domestic economy. Ecological fragility, chronic water scarcity, and recurrent flooding have intensified, posing systemic risks to the basin’s long-term socioeconomic sustainability. Conversely, the national strategic initiative “Ecological Protection and High-Quality Development of the Yellow River Basin” has catalyzed a paradigm shift in regional development priorities. Within this context, tourism—widely acknowledged as a green, low-carbon, and inherently sustainable economic sector—has assumed a pivotal role in advancing high-quality development across the basin.

As a cornerstone of the regional economy, tourism generates direct multiplier effects across ancillary sectors—including hospitality, food services, and transportation—while simultaneously fostering cultural heritage preservation, stimulating innovation in intangible cultural practices, and enhancing urban branding and international visibility. Critically, it serves as a strategic lever for structural transformation and upgrading toward high-quality growth. Yet tourism economies are inherently exposed to multifaceted uncertainties: market volatility, extreme climatic events, regulatory shifts, and geopolitical contingencies. Their capacity to absorb shocks, adapt dynamically, and sustain developmental trajectories—i.e., their *resilience*—has thus become a central metric of regional economic robustness. Notably, cities in the middle and lower reaches of the Yellow River exhibit increasingly interdependent tourism economies, coalescing into a complex spatial network. This network governs not only the efficiency of tourism resource allocation but also the propagation, buffering, and recovery dynamics of resilience across jurisdictions. Consequently, elucidating the topological properties and determinants of this spatial resilience network—and identifying actionable pathways to strengthen its systemic coherence and adaptive capacity—is both theoretically imperative and policy-relevant.

Contemporary scholarship on tourism economic resilience falls broadly into four thematic strands: (1) *Determinants and mechanisms*: Studies in this domain quantify regional tourism resilience levels and subsequently identify socioeconomic, institutional, and environmental drivers using regression-based or structural equation modeling approaches [1] – [4]. (2) *Spatiotemporal evolution*: Leveraging geospatial visualization and longitudinal analysis, these works map resilience trajectories across time and space, often linking observed patterns to underlying drivers such as infrastructure investment or ecological governance [5] – [14]. (3) *Resilience – high-quality development nexus*: Emerging literature posits a bidirectional relationship: input-side resilience (e.g., diversified funding sources, adaptive governance) enables high-quality development outcomes (e.g., innovation intensity, service sophistication), while output-side achievements reinforce system-level resilience through feedback loops [15][16]. (4) *Resilience and urban sustainability*: Conceptual ambiguity persists between “urban tourism economic resilience” and “urban sustainability.” While some scholars treat them as overlapping constructs—

both encompassing ecological integrity, economic viability, and social equity across multiple scales (enterprise, city, region) [19]—others emphasize their ontological distinction: sustainability denotes a normative end-state, whereas resilience refers to processual capacity under uncertainty [17][18]. Empirical studies further suggest that policy implementation frequently conflates the two, despite scholarly calls for conceptual differentiation.

A growing body of research specifically addresses the Yellow River Basin. Most adopt entropy-weighted composite indices to assess tourism economic resilience. Spatially, Wang et al. [13] report persistently low—but gradually improving—resilience levels from 2005 to 2018, with marked heterogeneity: downstream > midstream > upstream. To probe causal mechanisms, scholars have integrated threshold effect models, Moran's I spatial autocorrelation, and vector autoregression (VAR) frameworks, identifying the digital economy [3], urban ecological resilience [20], informatization level [13], and tourism specialization [13] as statistically significant determinants.

Notwithstanding these advances, three critical theoretical and methodological gaps remain. First, prevailing assessments predominantly adopt a reductionist, jurisdictional lens—evaluating cities in isolation—thereby overlooking how intercity synergies, competitive spillovers, and functional interdependencies collectively shape *networked* resilience. Second, although spatial network methodologies have matured in measuring connection strength (e.g., via gravity models or flow data), they remain underdeveloped in capturing *dynamic transmission pathways*: specifically, how structural features—such as core-periphery hierarchies, structural holes, and brokerage positions—mediate resilience diffusion, absorption, and amplification across the network. Third, basin-specific studies continue to frame ecological protection and economic growth as binary trade-offs, rarely integrating resilience cultivation, spatial network reconfiguration, and multilevel factor analysis into a unified analytical architecture—thus limiting the scalability and policy translatability of findings.

To address these gaps, this study advances three interrelated contributions. First, we develop an integrated three-dimensional analytical framework—comprising dynamic resilience measurement, network topology analysis, and multidimensional mechanism decomposition—to systematically uncover the formation logic and evolutionary trajectory of the spatial tourism economic resilience network among cities in the middle and lower reaches of the Yellow River. Second, moving beyond geographic adjacency, we propose an enhanced resilience association model grounded in functional interdependence (e.g., tourist flows, supply-chain linkages, digital platform integration), enabling precise reconstruction of cross-regional resilience networks and identification of critical nodes and transmission corridors. Third, we innovatively apply Quadratic Assignment Procedure (QAP) regression—a non-parametric permutation-based technique—to rigorously test network-level hypotheses while

mitigating multicollinearity and preserving spatial dependence structure. Through this approach, we disentangle the differential impacts of population mobility patterns, interregional economic disparities, and heterogeneous tourism resource endowments on network configuration. Collectively, these methodological innovations yield a holistic intervention framework: “structural diagnosis → mechanism analysis → pathway design” —offering both theoretical refinement and actionable insights for basin-scale resilience governance.

2 Research Design

2.1 Research Area

The specific reasons for focusing the study of the spatial network structure of tourism economic resilience in the Yellow River Basin on the urban agglomerations in the middle and lower reaches of the Yellow River are summarized as follows: (1) Tourism Economic Activity and Influence: On one hand, in terms of tourism economic activity, the middle and lower reaches of the Yellow River have a greater endowment of tourism resources and more active tourism economic activities compared to the upper reaches. This means that the tourism industry in the middle and lower reaches is larger in scale and more diversified, and the process of withstanding external shocks and recovery is more complex and typical. Therefore, studying the tourism economic resilience of the middle and lower reaches is more targeted and has greater practical significance. On the other hand, in terms of tourism economic influence, the middle and lower reaches are home to many nationally renowned tourist destinations such as Xi'an, Luoyang, Zhengzhou, and Jinan. The health of their tourism economies plays an important role in the overall tourism pattern of the Yellow River Basin, as well as the national cultural tourism landscape. Thus, researching the tourism economic resilience of the middle and lower reaches can more directly have a positive impact on regional economic stability and development, and has greater practical value. (2) Concentration of Resilience Resources: The middle and lower reaches have more abundant resources that support tourism economic resilience, including transportation hubs, tourism infrastructure, emergency management capabilities, capital, and talent. The concentration of these resilience resources gives the middle and lower reaches a stronger foundation to prevent and respond to crises and achieve tourism economic recovery. Therefore, studying this area can better reveal the key elements of resilience formation and more easily identify practical ways to enhance resilience. (3) Environmental Complexity of Resilience: The environment for shaping resilience in the middle and lower reaches is more typical and complex, including strict ecological protection policies, the overlay of significant national strategies, and more frequent interactions of people, goods, and information flows. (4) Diversity of Resilience Actors: The middle and lower reaches bring together numerous tourism enterprises, industry associations, government departments, research institutions, and a large number of tourism market players, forming a more complex and closely knit tourism economic spatial network and governance structure. Therefore, studying the tourism economic resilience of urban agglomerations in the middle and lower reaches can

more comprehensively reflect the transmission and interaction mechanisms of resilience in a network composed of diverse actors, and better reflect the overall level and structural characteristics of tourism economic resilience in the Yellow River Basin.

On this basis, this paper selects the urban agglomerations in the middle and lower reaches of the Yellow River as the research object, analyzes the current development status of urban tourism economic resilience in this region and its spatial network structure characteristics, and further explores the influencing factors and improvement strategies of the spatial network structure of tourism economic resilience in the cities of the middle and lower reaches of the Yellow River, thereby promoting the high-quality development of the entire Yellow River Basin.

This paper follows the spatial delineation framework of the "Comprehensive Plan for the Yellow River Basin (2012–2030)" and takes the geographical course of the main stream of the Yellow River as the basis, combined with the official demarcation standards of the Yellow River Conservancy Commission of the Ministry of Water Resources, to determine the research spatial scope. Considering data availability during the study period, the final research object selected in this paper is 39 prefecture-level cities in the four provinces (regions) of the middle and lower reaches of the Yellow River Basin (see Figure 1), with the specific city affiliations strictly following the authoritative classification standards of the "Comprehensive Plan for the Yellow River Basin." The specific division of cities is shown in Table 1.

Table 1 Prefecture-level administrative regions in the middle and lower reaches of the Yellow River Basin

Distribution in the Yellow River Basin	Provinces Passed Through	Prefecture-level Cities
Middle reaches	Shaanxi Province	Xi'an City, Tongchuan City, Baoji City, Yan'an City, Weinan City, Yan'an City, Yulin City, Shangluo City
	Henan Province	Zhengzhou City, Luoyang City, Jiaozuo City, Sanmenxia City
	Shanxi Province	Taiyuan City, Datong City, Yangquan City, Changzhi City, Jincheng City, Shuozhou City, Jinzhong City, Yuncheng City, Xinzheng City, Linfen City, Lüliang City
Downstream	Henan Province	Xinxiang City, Kaifeng City, Anyang City, Hebi City, Puyang City, Shangqiu City
	Shandong Province	Jinan City, Zibo City, Dongying City, Jining City, Tai'an City, Linyi City, Dezhou City, Liaocheng City, Binzhou City, Heze City

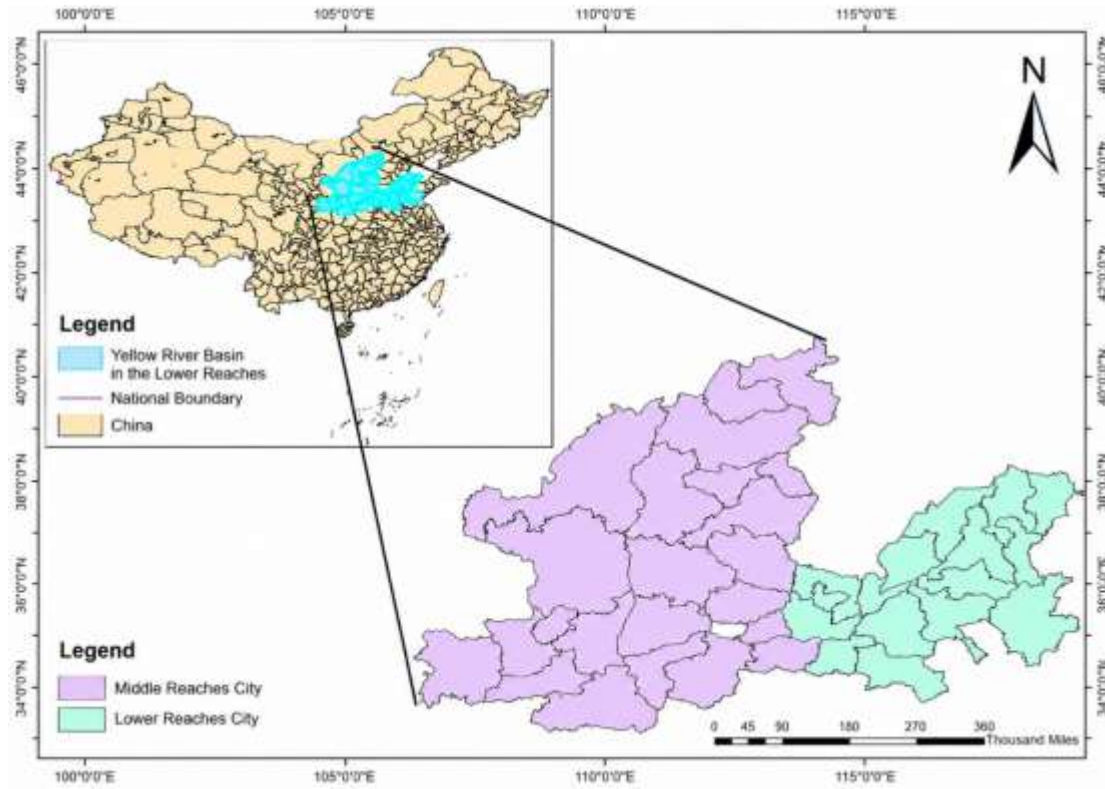


Fig.1 Study area plot

2.2 Research Methods

2.2.1 Spatial Statistical Analysis Method

This study integrates resilience theory with the tourism economic system and conducts an in-depth analysis of urban tourism economic resilience through rigorous logical reasoning. Based on existing research on urban resilience and regional economic resilience, an objective and comprehensive evaluation indicator system tailored to the characteristics of urban tourism economic resilience is constructed.

The entropy weight method and the TOPSIS method are employed to determine the weights of each evaluation indicator, and accordingly, the tourism economic resilience scores of cities in the middle and lower reaches of the Yellow River Basin are calculated.

2.2.2 Measurement Model of Tourism Economic Resilience Linkage Strength

To analyze the dynamic relationship of economic resilience between two cities, this study first constructs a Vector Autoregression (VAR) model for the resilience variables of each pair of cities, and then applies the VAR-based Granger causality test. If the time series of tourism economic resilience between cities A and B passes the Granger causality test, it indicates a statistically significant interdependence between

their resilience levels. By applying this method to every pair of cities, a directed network of spatial linkages can be constructed.

Assume that the tourism economic resilience time series of city 1 (y_{1t}) and city 2 (y_{2t}) are interrelated. The following VAR models are established as shown in Equations (2-1) and (2-2):

$$y_{1t} = f(y_{1, t-1}, y_{1, t-2}, y_{1, t-3}, \dots) \quad (2-1)$$

$$y_{2t} = f(y_{2, t-1}, y_{2, t-2}, y_{2, t-3}, \dots) \quad (2-2)$$

where t represents the time period of the study.

A bivariate VAR model is further constructed, where the lag order is 1, as shown in Equation (2-3):

$$\begin{cases} y_{1t} = \mu_1 + \pi_{11}y_{1, t-1} + \pi_{12}y_{2, t-1} + \mu_{1t} \\ y_{2t} = \mu_2 + \pi_{21}y_{1, t-1} + \pi_{22}y_{2, t-1} + \mu_{2t} \end{cases} \quad (2-3)$$

where μ_{1t} , μ_{2t} are independently and identically distributed with mean $(0, \sigma^2)$, $\text{cov}(\mu_{1t}, \mu_{2t})=0$.

The matrix form is expressed as Equation (2-4):

$$\begin{bmatrix} y_{1t} \\ y_{2t} \end{bmatrix} = \begin{bmatrix} \mu_1 \\ \mu_2 \end{bmatrix} + \begin{bmatrix} \pi_{11} & \pi_{12} \\ \pi_{21} & \pi_{22} \end{bmatrix} + \begin{bmatrix} y_{1, t-1} \\ y_{2, t-1} \end{bmatrix} + \begin{bmatrix} \mu_{1t} \\ \mu_{2t} \end{bmatrix} \quad (2-4)$$

Let: $Y_t = \begin{bmatrix} y_{1t} \\ y_{2t} \end{bmatrix}$, $\mu = \begin{bmatrix} \mu_1 \\ \mu_2 \end{bmatrix}$, $\Pi_1 = \begin{bmatrix} \pi_{11} & \pi_{12} \\ \pi_{21} & \pi_{22} \end{bmatrix}$, $\mu_1 = \begin{bmatrix} \mu_{1t} \\ \mu_{2t} \end{bmatrix}$, then the VAR representation can be written as:

$$Y_t = \mu + \Pi_1 Y_{t-1} + \mu_t \quad (2-5)$$

Subsequently, it is necessary to examine whether the explanatory power of the Y_t model improves significantly after adding X_t , and whether the lagged variables become statistically significant, in order to verify the existence of a Granger causal relationship. Therefore, the following two regression models are constructed:

$$Y_t = \beta_0 + \sum_{i=1}^m \beta_i Y_{t-i} + \sum_{i=1}^m \alpha_i X_{t-i} + \mu_t \quad (2-6)$$

$$X_t = \delta_0 + \sum_{i=1}^m \delta_i Y_{t-i} + \sum_{i=1}^m \delta_i Y_{t-i} + V_t \quad (2-7)$$

where, μ_t , V_t are assumed to be uncorrelated.

In this study, the Granger causality test is used to determine whether: (1) the inclusion of city A's tourism economic resilience variable X_t improves the explanatory power of city B's Y_t model; and (2) the inclusion of city B's variable Y_t improves the explanatory power of city A's X_t model. Based on these results, four types of causal relationships can be identified, as shown in Table 2. The directionality of the VAR Granger causality test results is then used to construct the spatial correlation network of urban tourism economic resilience.

Table 2 Distribution of Granger causality test results

Test Content	Direction Characteristics	Interpretation
Adding A to predict B significantly improves model fit; Adding B to predict A is not significant; Adding A to predict B is not significant;	Unidirectional	A is the Granger cause of B
Adding B to predict A significantly improves model fit; Adding A to predict B is not significant;	Unidirectional	B is the Granger cause of A
Adding B to predict A is not significant; Adding A to predict B is not significant;	No relationship	No Granger causality exists
Adding A to predict B significantly improves model fit; Adding B to predict A significantly improves model fit;	Bidirectional	A and B are mutual Granger causes

2.2.2 Social Network Analysis Method

The social network analysis (SNA) method is employed to examine the structural characteristics of the urban tourism economic resilience network. This approach enables the identification of multiple network attributes, including overall, individual, and clustering characteristics. Using UCINET software, the network structure is systematically analyzed from two perspectives: overall network characteristics (network density, network efficiency, and core-periphery structure) and individual network characteristics (degree centrality, betweenness centrality, closeness centrality, and block model analysis).

Based on this framework, the roles and positions of different cities within the tourism economic resilience network are identified. Furthermore, the Quadratic Assignment Procedure (QAP) regression model is applied to examine the influencing factors of the spatial network structure of urban tourism economic resilience.

2.3 Construction of the Tourism Economic Resilience Evaluation Indicator System

Guided by regional economic resilience theory, the construction of the tourism economic resilience indicator system emphasizes systemic thinking, spatial heterogeneity, and nonlinear evolutionary processes to better reflect the dynamic economic environment and potential external shocks.

This study adopts the regional resilience assessment framework proposed by Martin [21], which highlights four interrelated dimensions: resistance, recovery, renewal, and reconfiguration. Based on prior studies by Wang Qian [22], Chen Xuejun [23], and Pang Dongyan [24], the first-level indicators of tourism economic resilience are classified into four dimensions: resistance capacity, recovery capacity, reconfiguration capacity, and renewal capacity.

The second- and third-level indicators are optimized and refined based on existing literature. The final indicator system consists of 8 second-level indicators (e.g., tourism economic index, tourism industry development index, etc.) and 16 third-level indicators, including tourism revenue, total number of tourists, and per capita regional GDP.

All indicators are positive indicators. Based on prior research, the tourism economic resilience indicator system adopted in this study is presented in Table 3.

Table 3 Tourism economic resilience index system

First-level indicator	Second-level indicator	Third-level indicator	Indicator meaning & unit	weight
Resistance capacity	Tourism economic development index [24]	Tourism revenue [24]	Reflects the scale of tourism economy / 10,000 yuan	0.077
		Total number of tourists [24]	Reflects tourist volume / 10,000 person-times	0.117
	Regional economic development index [24]	GDP per capita [24]	Reflects regional economic level / yuan per capita	0.032
		Urbanization rate [25]	Reflects regional urbanization level / %	0.012

Recovery capacity	Tourism environment index [26]	Per capita park green space area [26]	Reflects greening level and recreational space / m ²	0.013
		Green coverage rate of built-up area [26]	Reflects ecological greening level of tourism destinations / %	0.002
	Tourism industry index [13]	Wholesale, retail, accommodation and catering output value [13]	Reflects tourism-related industry scale / billion yuan	0.083
		Number of star-rated hotels [13]	Reflects tourism reception capacity / units	0.042
Reconfiguration capacity	Social consumption index [27]	Total retail sales of consumer goods [28]	Reflects overall consumption scale / 10 billion yuan	0.076
		Per capita disposable income of urban residents [27]	Reflects purchasing power of residents / yuan	0.019
	Tourism economic reconfiguration index [28]	Share of tourism fixed asset investment in total fixed asset investment [28]	Reflects tourism investment intensity / %	0.060
		Share of total tourism revenue in value added of tertiary industry [28]	Reflects tourism contribution to tertiary industry / %	0.081
Renewal capacity	Tourism innovation potential index [29]	Number of tourism-related patent grants [29]	Reflects technological support for tourism innovation / cases	0.153
		Number of higher education institutions [30]	Reflects talent supply for tourism innovation / units	0.119
		Road mileage [31]	Reflects transport accessibility for tourism / km	0.021
	Tourism transport index [31]	Number of public buses and electric buses in operation at year-end [32]	Reflects public transport capacity for tourism / vehicles	0.085

2.4 Data Sources and Processing

First, the relevant indicator data of tourism economic resilience for prefecture-level cities from 2010 to 2024 were collected from the China City Statistical Yearbook and the Statistical Bulletins on National Economic and Social Development issued by each city.

Second, the entropy weight method and the TOPSIS method were employed to calculate the tourism economic resilience scores of each city.

Third, using Stata software, the Granger causality test based on the time series of tourism economic resilience between every pair of cities (calculated via the entropy weight and TOPSIS methods) was conducted to measure the linkage strength of tourism economic resilience among cities.

Fourth, based on the calculated intercity linkage strength, a spatial correlation matrix of tourism economic resilience for cities in the middle and lower reaches of the Yellow River Basin was constructed.

Fifth, based on the constructed correlation matrix, the NetDraw software was used to visualize the spatial correlation network of tourism economic resilience, while UCINET was applied to analyze the structural characteristics of the network, including both overall and individual-level network properties.

Sixth, population flow data for the National Day holiday period in 2024 (September 28 to October 4) were obtained from the Baidu Migration Big Data platform. The data include inflow and outflow proportions as well as migration scale for each city. A population flow index was constructed by multiplying inflow/outflow proportions by migration scale. If the population flow index between two cities is above the mean value, a significant population flow relationship is identified, based on which a population flow matrix is constructed.

Seventh, spatial distances between cities were measured using the distance measurement tool in Baidu Maps, and a geographic distance matrix was constructed accordingly.

Eighth, GeoDa software was used to generate a spatial adjacency matrix, and per capita GDP differences between cities were calculated to construct an economic development disparity matrix.

Ninth, a tourism resource endowment difference matrix was constructed based on the number of A-level scenic spots in each city.

Tenth, taking the spatial correlation matrix of tourism economic resilience as the dependent variable, and the population flow matrix, geographic proximity matrix, per capita GDP difference matrix, and tourism resource endowment difference matrix as independent variables, a QAP regression analysis was conducted using UCINET software to explore the influencing factors of the spatial network structure of tourism economic resilience in the middle and lower reaches of the Yellow River Basin.

3 Results and Analysis

3.1 Measurement Results of Tourism Economic Resilience

3.1.1 Measurement Results for Middle-Reach Cities in the Yellow River Basin

The middle reaches of the Yellow River Basin consist of 23 cities. After processing the tourism economic resilience-related indicators of each prefecture-level city from 2010 to 2024, a total of 345 samples were obtained using the TOPSIS method. As shown in Figure 2, higher values indicate stronger tourism economic resilience.

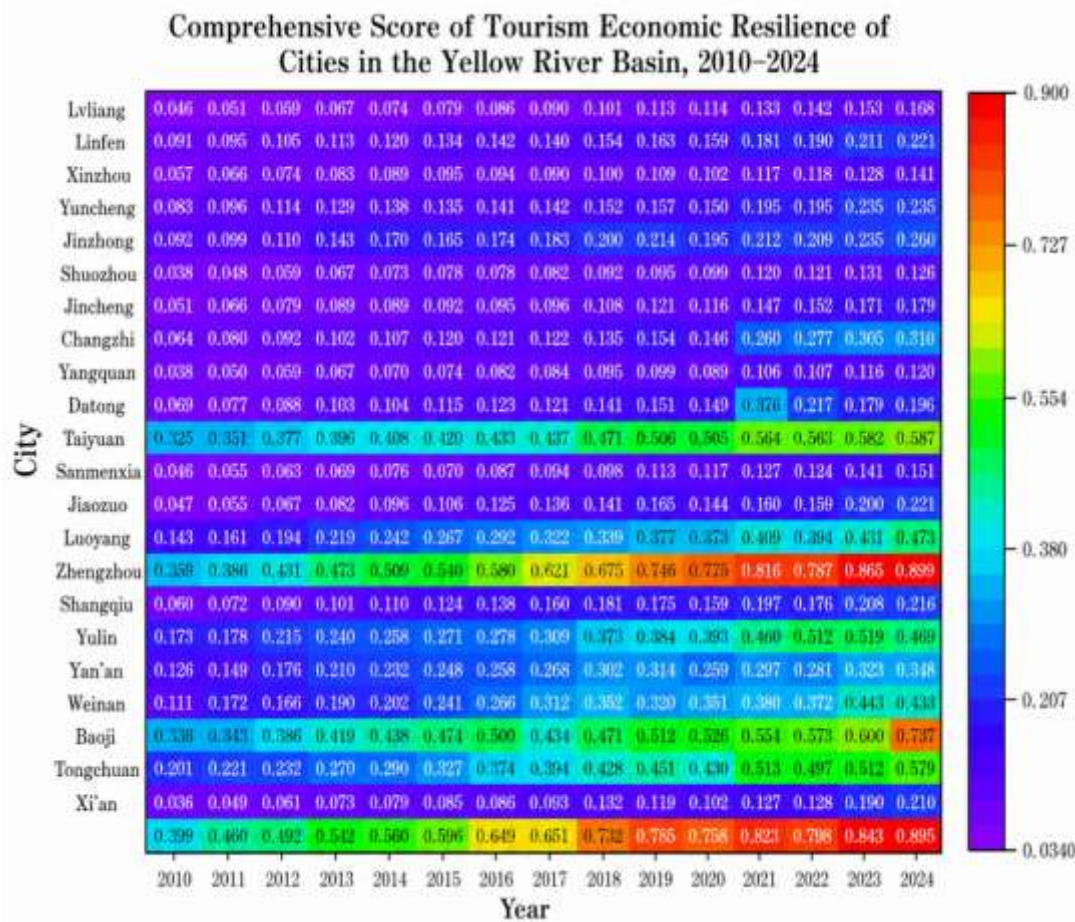


Figure 2 Comprehensive score of tourism economic resilience in cities in the middle reaches of the Yellow River Basin from 2010 to 2024

3.1.2 Measurement Results of Tourism Economic Resilience in Cities of the Lower Reaches of the Yellow River Basin

The lower reaches of the Yellow River Basin comprise 16 prefecture-level cities. After processing the tourism economic resilience indicators for each city from 2010 to 2024, the TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) method was employed to evaluate tourism economic resilience. A total of 240 sample observations were obtained. As shown in Figure 3, a higher score indicates a greater level of tourism economic resilience for a given city.

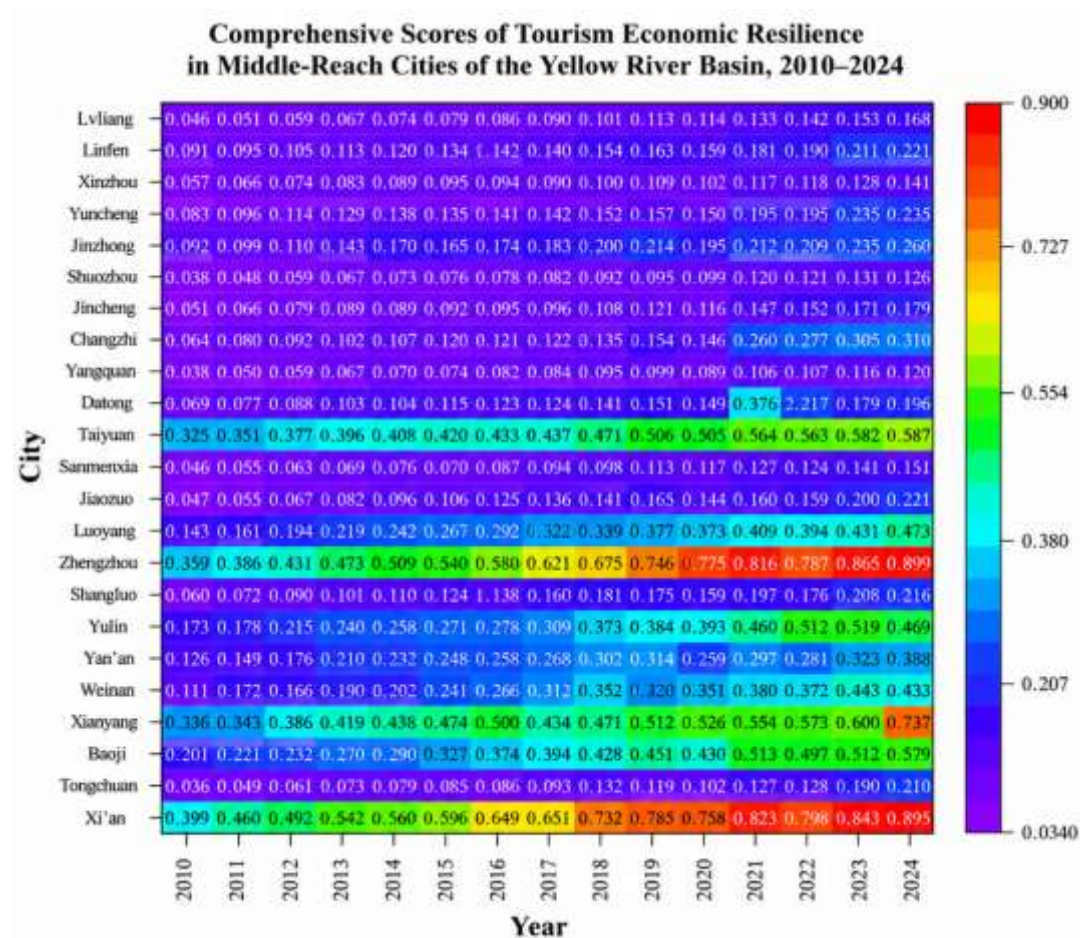


Figure 3 Comprehensive score of tourism economic resilience in cities in the lower reaches of the Yellow River Basin from 2010 to 2024

3.2 Analysis of the Measurement Results of Tourism Economic Resilience of Provincial Capital Cities

Provincial capital cities have certain representativeness in terms of economic development. This paper first selects Xi'an, Zhengzhou, Taiyuan, and Jinan as the representative cities to conduct a comparative analysis of their urban economic resilience from 2010 to 2024, as shown in Figure 4. It can be seen that the overall tourism economic resilience of the typical cities from 2010 to 2024 shows an upward trend, and the main fluctuations occurred during the period from 2019 to 2022.

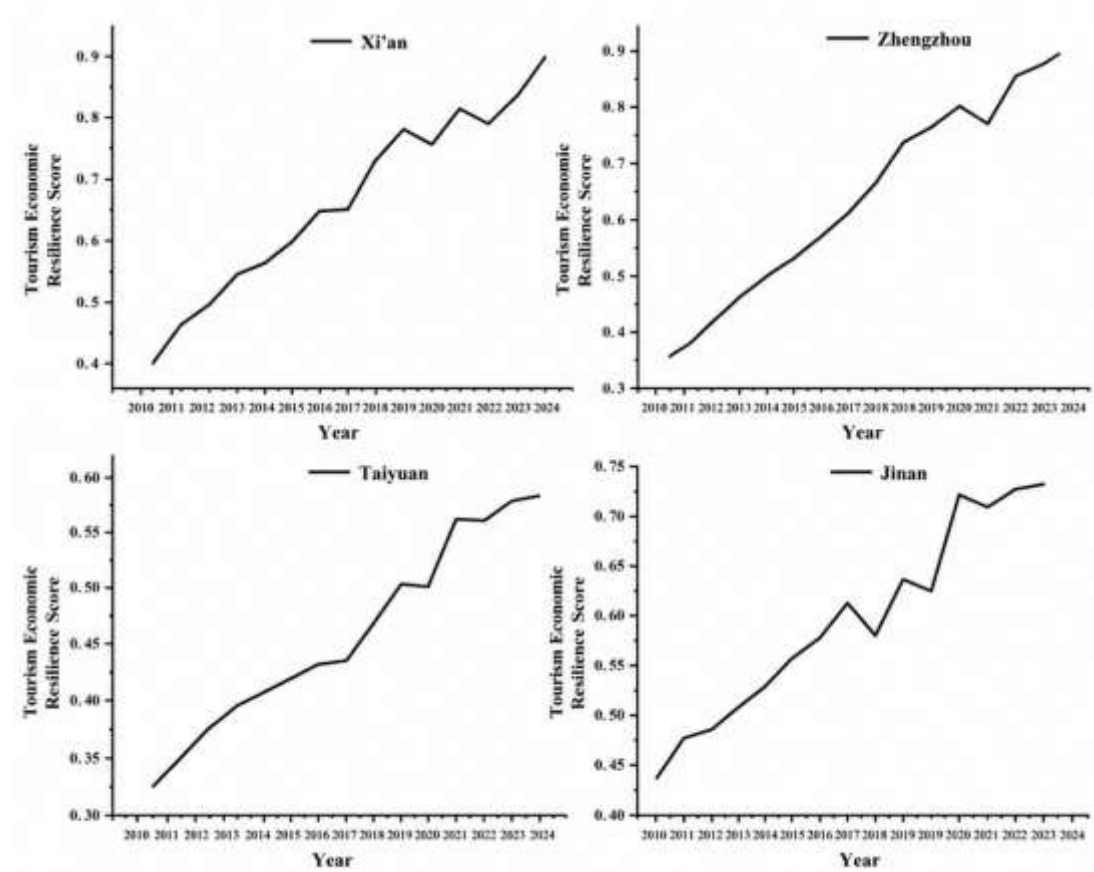


Figure 4 Comparison of tourism economic resilience in typical cities

Overall, the comprehensive tourism economic resilience scores of Xi' an, Zhengzhou, Jinan, and Taiyuan all exhibit a continuous upward trend. The evolution of resilience in the four cities can be divided into three distinct stages.

The first stage (2010 – 2012) is characterized by a slow but steady increase in resilience, with relatively limited growth momentum. The second stage (2013 – 2019) shows a rapid growth phase, during which tourism economic resilience increases significantly, indicating strong development momentum. The third stage (2019 – 2024) is characterized by a fluctuating upward trend.

This pattern reflects the increasing emphasis placed by both national and local governments on the tourism industry, as well as the sustained growth of domestic tourism demand. These factors jointly strengthen the foundational “base” of tourism economic resilience. Over time, tourism infrastructure in the four cities—such as scenic areas, transportation systems, and accommodation facilities—has been continuously improved, while tourism product supply, including cultural experiences and leisure tourism, has become increasingly diversified, laying a solid material foundation for resilience enhancement.

From a more detailed perspective during the fluctuating phase (2019 – 2024), resilience shows a decline from 2019 to 2020, a rebound in 2020 – 2021, and another noticeable decline in 2021 – 2022. This pattern is highly likely associated with the shocks of the COVID-19 pandemic in 2019 and 2021.

This stage can be interpreted as a “reconfiguration” phase within the adaptive cycle framework. The pandemic severely disrupted tourism economic systems, leading to shortages in key production factors such as labor and productive capacity. Subsequently, with the gradual accumulation and reallocation of human capital and financial resources, tourism economic resilience recovered to some extent.

Among the four cities, Zhengzhou maintained a relatively stable upward trend during the pandemic period (2019 – 2021), demonstrating comparatively stronger resilience performance. This may be attributed to its role as a major transportation hub, where tourism demand is more dependent on diversified structures such as transit tourism and business tourism. In addition, strong industrial linkages—particularly the integration of tourism with convention, logistics, and service industries—helped mitigate the negative impacts of the pandemic. Timely government policy responses, such as corporate relief measures and digital tourism promotion strategies, also contributed to resilience stability.

In terms of cross-city comparison, Xi’ an exhibited relatively high and stable tourism economic resilience before 2019. Overall, Xi’ an, Zhengzhou, and Jinan showed relatively similar levels of resilience during the pre-pandemic period. Xi’ an’s leading position can be attributed to its strong cultural tourism brand and advantages in digital transformation, such as online cultural tourism promotion.

After the outbreak of COVID-19, Zhengzhou surpassed Xi’ an, demonstrating a stronger capacity to “find opportunities within crises.” In contrast, Taiyuan’s tourism economic resilience remained relatively lower compared to the other three cities, likely constrained by geographical conditions and resource endowment limitations.

3.3 Spatial Correlation Analysis of Inter-City Tourism Economic Resilience

Using the calculated tourism economic resilience values of cities in the middle and lower reaches of the Yellow River Basin, pairwise VAR-based Granger causality tests were conducted.

First, ADF (Augmented Dickey-Fuller) unit root tests were performed. The results indicate that some cities such as Weinan, Taiyuan, and Kaifeng are stationary time series, while Zhengzhou, Yan’ an, Datong, Jinan, and Tai’ an are integrated of order I(1), and other cities are integrated of order I(2). After differencing transformation, pairwise VAR models were constructed. The optimal lag length was determined using a comprehensive selection approach, followed by Granger causality tests with a significance level of 5%.

A total of 741 pairwise tests were conducted, yielding 269 significant relationships. Tables 4 – 6 present selected representative results.

In Table 4, D.y denotes the first-difference series of Zhengzhou’s tourism economic resilience, while D2.x denotes the second-difference series of Luoyang’s tourism economic resilience. The results show that all p-values are below 0.05, indicating a bidirectional causal relationship between tourism economic resilience in Zhengzhou and Luoyang.

Table 4 Zhengzhou-Luoyang Granger test results

variable being explained	explained variable	P-value
D.y	D2.x	0.001
D2.x	D.y	0.008

In Table 5, D2.y denotes the second-differenced time series of Xi'an's tourism economic resilience, while D.x represents the first-differenced time series of Yan'an's tourism economic resilience. The results indicate that Xi'an's tourism economic resilience is the Granger cause of Yan'an's tourism economic resilience, demonstrating a unidirectional causal relationship.

Table 5 Xian-Yanan Granger test results

variable being explained	explained variable	P-value
D2.y	D.x	0.037
D.x	D2.y	0.277

In Table 6, D2.y represents the second-differenced time series of Heze's tourism economic resilience, while D.x denotes the first-differenced time series of Sanmenxia's tourism economic resilience. The results show that all p-values are greater than 5%, indicating that there is no statistically significant causal relationship between tourism economic resilience in Sanmenxia and Heze, and no Granger causality exists between the two cities.

Table 6 Sanmenxia-Heze Granger test results

variable being explained	explained variable	P-value
D2.y	D.x	0.628
D.x	D2.y	0.222

3.4 Overall Spatial Network Structure Characteristics

3.4.1 Network Density and Network Efficiency

Based on the test results, the spatial correlation network of urban tourism economic resilience was visualized using NetDraw, as shown in Figure 5. The results indicate that the tourism economic resilience network of cities in the middle and lower reaches of the Yellow River Basin exhibits a significant “core – periphery” structure.

Cities with a higher number of spatial connections are primarily concentrated in Xi'an, Binzhou, Zhengzhou, Shouzhou, Linfen, Jinan, Changzhi, Luoyang, and Datong. This suggests that the tourism economic resilience of these cities is more likely to be influenced by surrounding cities, and simultaneously exerts a stronger influence on other cities within the network.

The network consists of 269 connections in total, through which tourism economic resilience in the middle and lower reaches of the Yellow River Basin diffuses via these 269 “channels.” No city is isolated in the network, and each city maintains more than two dynamic linkages, indicating that tourism economic resilience in the study area is generally interconnected in space.

The network density of the spatial correlation network is 0.182, which is below 0.5. This indicates that the overall level of connectivity among cities remains relatively low, and there is still considerable room for improvement in the coordinated enhancement of tourism economic resilience.

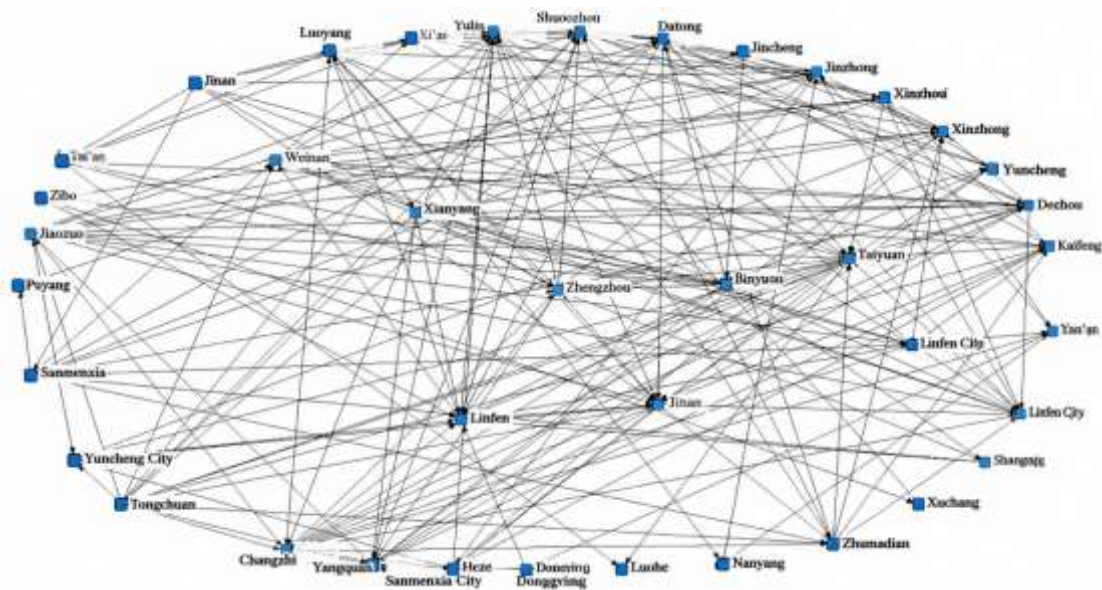


Fig.5 Spatial correlation network of tourism economic resilience in the middle and lower reaches of the Yellow River Basin

Using the “Core/Periphery – Categorical” approach in UCINET, this study further explores the core – periphery structure and node composition of the spatial network of tourism economic resilience in the middle and lower reaches of the Yellow River Basin. The classification results of the 39 cities into core and periphery groups are shown in Figure 6.

The core region consists of 15 cities, including Xi'an, Zhengzhou, Jinan, and Luoyang. These cities occupy dominant positions within the network, featuring higher centrality and stronger capacities for resource control and spillover diffusion. They are densely interconnected and form multiple resilience subgroups, such as the

Guanzhong urban agglomeration centered on Xi'an, parts of the Central Plains urban agglomeration centered on Zhengzhou, and parts of Shandong Province led by Jinan. Together, these core cities constitute strategic nodes supporting the entire tourism economic resilience network of the basin. These cities typically share several characteristics: they serve as major transportation hubs, possess high-level tourism resources (e.g., World Heritage Sites and AAAAA scenic areas), or function as regional economic and policy centers. As a result, they demonstrate stronger capabilities in resisting shocks, adapting to disturbances, and recovering from crises, while also exerting significant spillover effects on peripheral cities through network linkages.

In contrast, the peripheral region includes 24 cities such as Xianyang, Taiyuan, Yuncheng, Zibo, and Jinzhong. These cities occupy relatively passive positions in the network and are characterized by weaker connectivity with other nodes. Their capacity to receive resource spillovers and policy diffusion is limited, making them more vulnerable to external shocks.

Their peripheral status may be attributed to relatively lower levels of tourism resource development, insufficient transportation accessibility, underdeveloped tourism industry support systems, or weak interaction intensity with major economic centers.

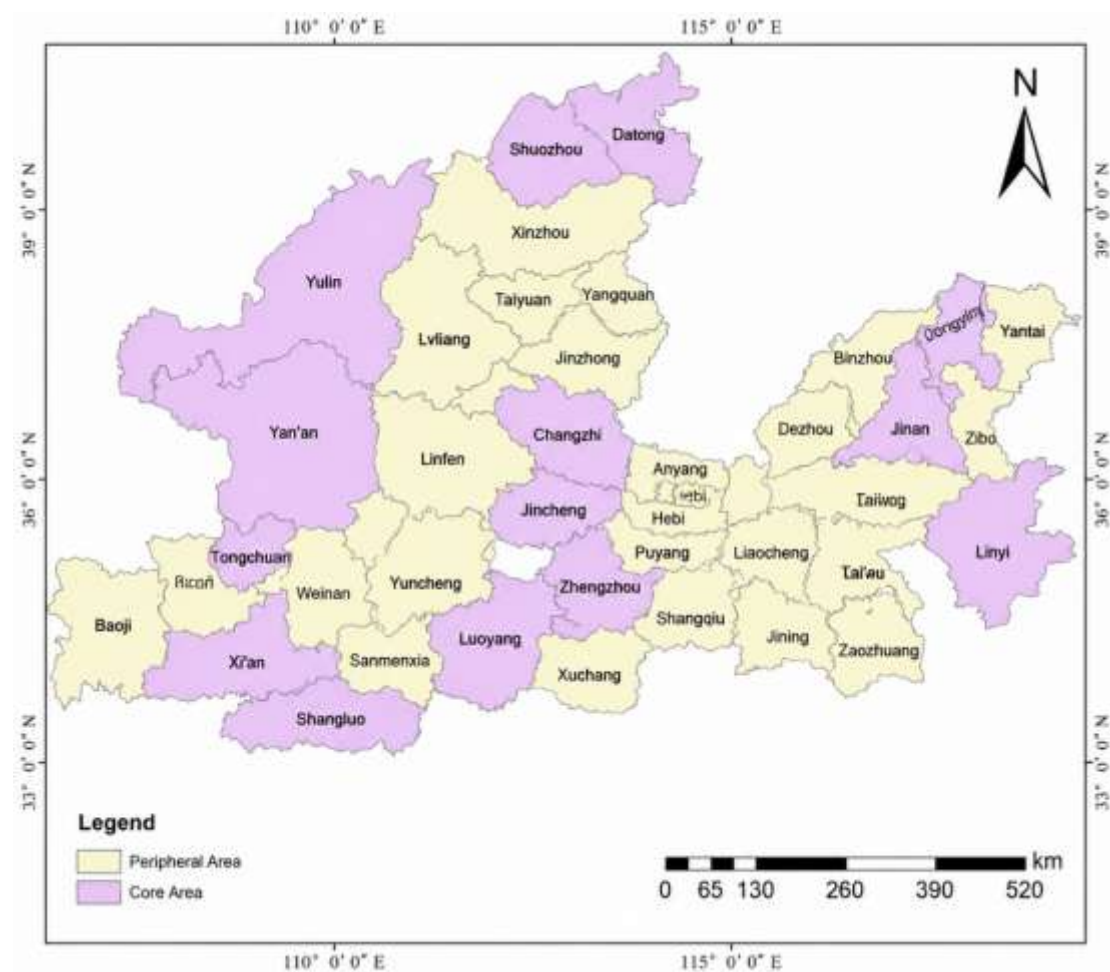


Figure.6 Core-Edge Distribution of Tourism Economic Resilience in Cities of the Middle and Lower Reaches of the Yellow River

This structural pattern reveals that the tourism economic resilience network in the middle and lower reaches of the Yellow River Basin is not a homogeneous system, but rather exhibits a pronounced hierarchical differentiation. Core cities play a key role in maintaining network stability and resilience; however, the presence of a large number of peripheral cities also highlights the structural vulnerability of the network.

3.5 Individual Spatial Network Structural Characteristics

To further capture the influence and positional roles of cities within the tourism economic resilience network, this study employs three centrality measures and block model analysis to examine individual-level network structural characteristics.

3.5.1 Relative Degree Centrality

As shown in Figure 7, 23 cities exceed the average level of relative degree centrality (0.31) in the middle and lower reaches of the Yellow River Basin. This indicates that these cities maintain relatively strong connectivity with other cities in terms of tourism economic resilience linkages.

Among them, 7 cities are located in Shaanxi Province, 7 in Shanxi Province, 4 in Henan Province, and 4 in Shandong Province. This suggests that cities located in the middle reaches of the basin exhibit higher levels of external connectivity and interaction intensity within the tourism economic resilience network.

Furthermore, among these 23 cities, 13 cities—including Binzhou, Datong, Changzhi, Linfen, Yan'an, Yulin, Shangluo, Shouzhou, Xinxian, Weinan, Dezhou, Heze, and Baoji—exhibit higher in-degree than out-degree centrality (as shown in Figure 8). This indicates that these cities receive more resilience linkages than they transmit, demonstrating a “siphon effect,” where they are more strongly influenced by other cities than they influence others.

The top five cities in terms of relative degree centrality are Binzhou, Datong, Zhengzhou, Changzhi, and Linfen. These cities have the highest influence within the tourism economic resilience network of the study area. Notably, Binzhou, Datong, Changzhi, and Linfen all exhibit stronger in-degree than out-degree relationships, indicating that their tourism economic resilience is more susceptible to external influence. In contrast, Zhengzhou, Xi'an, Luoyang, Jinan, Jiaozuo, and Taiyuan exhibit stronger out-degree than in-degree relationships, suggesting that these cities exert greater influence on the resilience of other cities.

The five cities with the lowest relative degree centrality are Dongying, Sanmenxia, Xianyang, Liaocheng, and Linyi. These cities are less influenced by others and also exert limited influence on other cities' tourism economic resilience, indicating that they occupy peripheral positions within the spatial correlation network.

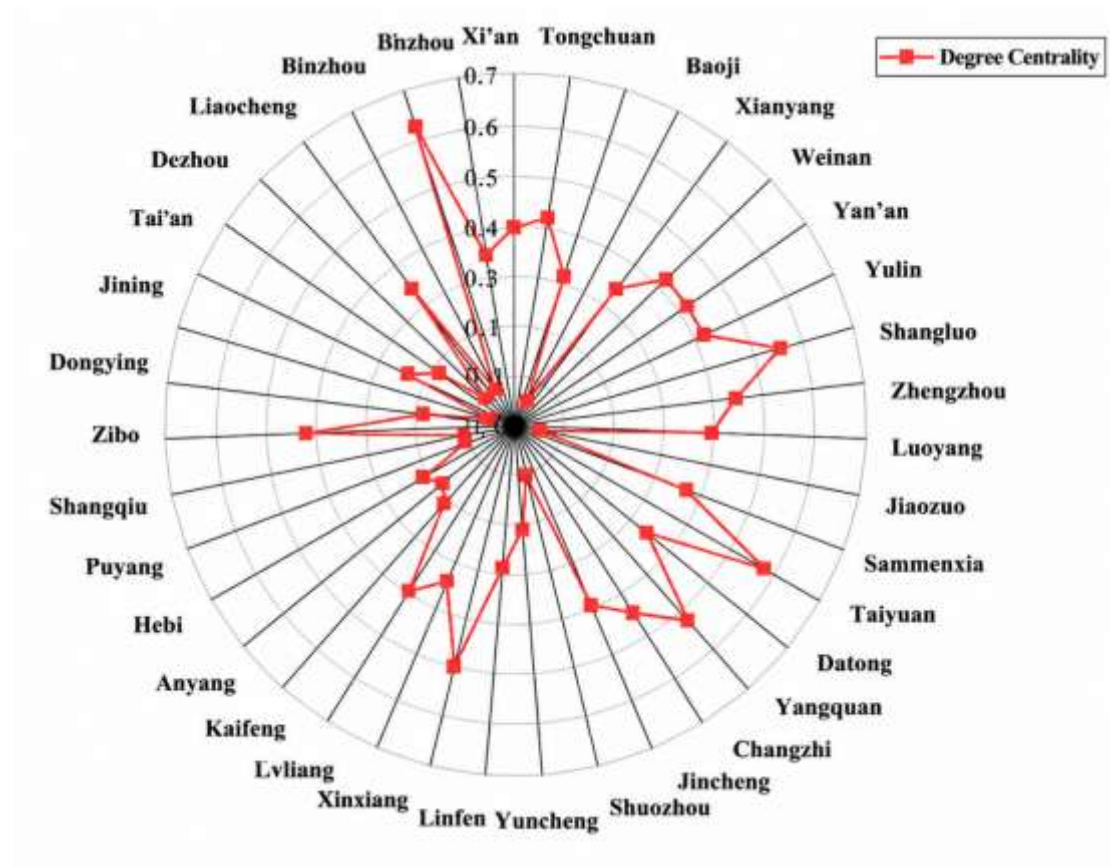


Figure 7 Relative Degree Centrality Analysis of the Spatial Network of Tourism Economy Resilience in Cities of the Middle and Lower Reaches of the Yellow River

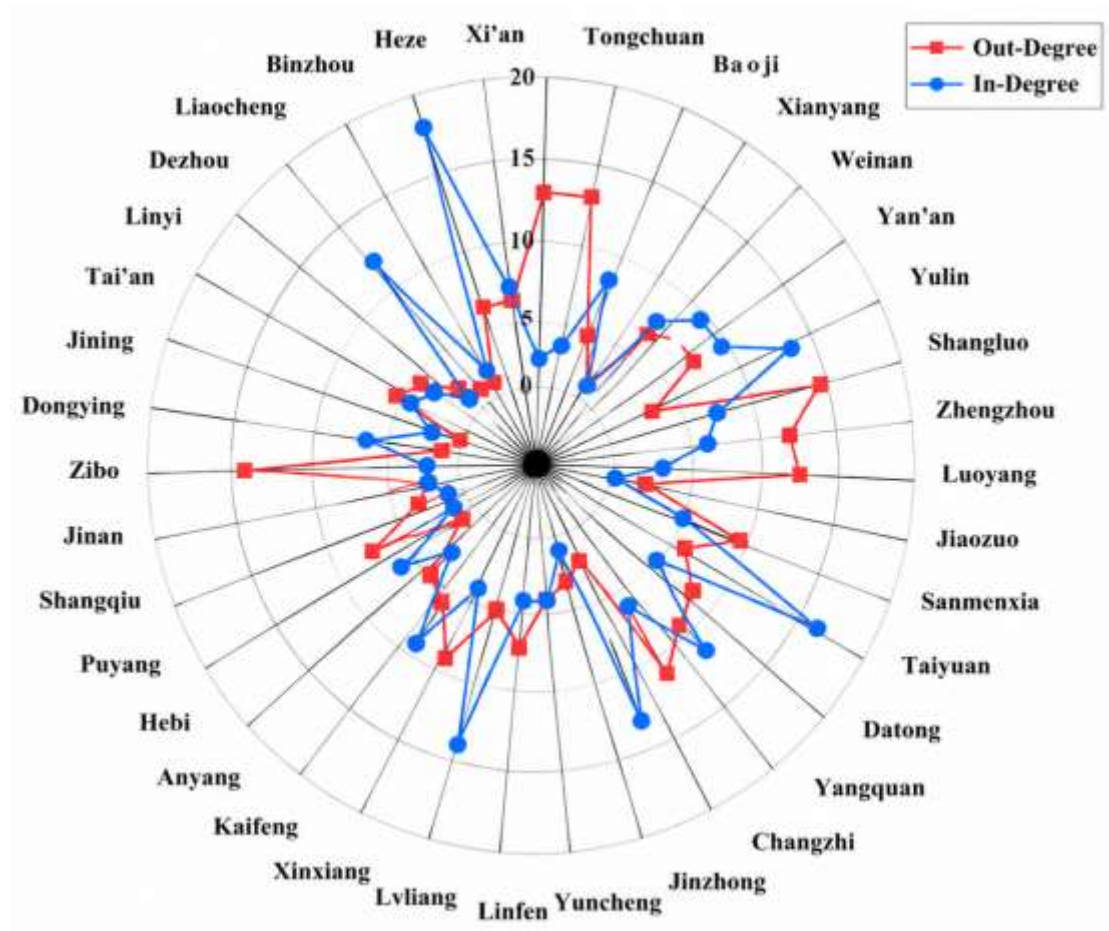


Figure 8 Analysis of In-Degree and Out-Degree in the Spatial Network of Tourism Economic Resilience in Cities of the Middle and Lower Reaches of the Yellow River

3.5.2 Relative Betweenness Centrality

Relative betweenness centrality is used to measure the extent to which a node lies on the shortest paths between other nodes, reflecting its ability to control the flow of information or resource diffusion within the network [33]. It captures the “intermediary” position of a node in facilitating or constraining network interactions. The results (Figure 9) show that the mean value of relative betweenness centrality for the 39 cities in the middle and lower reaches of the Yellow River Basin is 56.384. A total of 13 cities—Zhengzhou, Xinxiang, Binzhou, Heze, Jinan, Linfen, Datong, Yulin, Luoyang, Changzhi, Xi'an, Jincheng, and Weinan—exhibit values above the average level.

This indicates that these cities occupy key structural hole positions within the network and function as important “bridges” or intermediaries. They can effectively regulate or even dominate the transmission paths of tourism economic resilience among cities, exerting significant control over overall information flows and resource allocation within the network.

In contrast, five cities—Shangqiu, Xianyang, Linyi, Dongying, and Sanmenxia—show the lowest levels of relative betweenness centrality. A low betweenness centrality suggests that these cities rarely appear on the shortest paths between other nodes. Their spatial linkages with other cities are more dependent on intermediary roles played by external nodes rather than their own active control. In other words, these cities exhibit a relatively “malleable” network position and are more likely to be influenced and regulated by core nodes within the network.

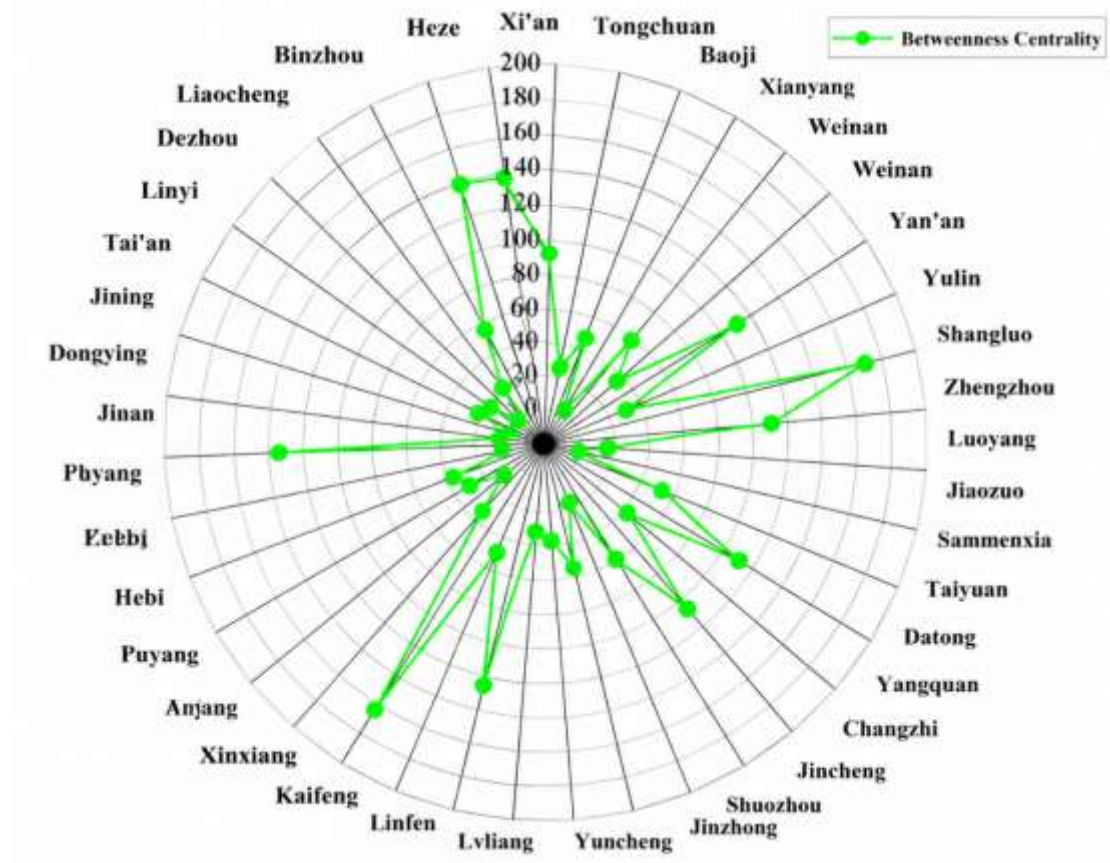


Figure 9 Relative Betweenness Analysis of the Spatial Network of Tourism Economy Resilience in Cities of the Middle and Lower Reaches of the Yellow River

3.5.3 Relative Closeness Centrality

Closeness centrality measures the average distance between a given node and all other nodes in the network, reflecting its efficiency in information transmission and overall accessibility within the network.

The results (Figure 10) show that the mean value of relative closeness centrality for the 39 cities in the middle and lower reaches of the Yellow River Basin is 0.362. A total of 24 cities exceed this average level, including Xi'an, Jinan, Zhengzhou, Luoyang, Tongchuan, Jiaozuo, Jincheng, Changzhi, Lüliang, Yulin, Taiyuan, Datong, Yangquan, Xinzhou, Binzhou, Heze, Jinzhong, Xinxiang, Hebi, Baoji, Weinan, Kaifeng, Jining, and Linfen.

These cities benefit from advantageous network positions, enabling them to establish connections with other nodes through relatively shorter paths. As a result, they hold a comparative advantage in information acquisition and resource allocation, and function as “central actors” in the resilience diffusion network.

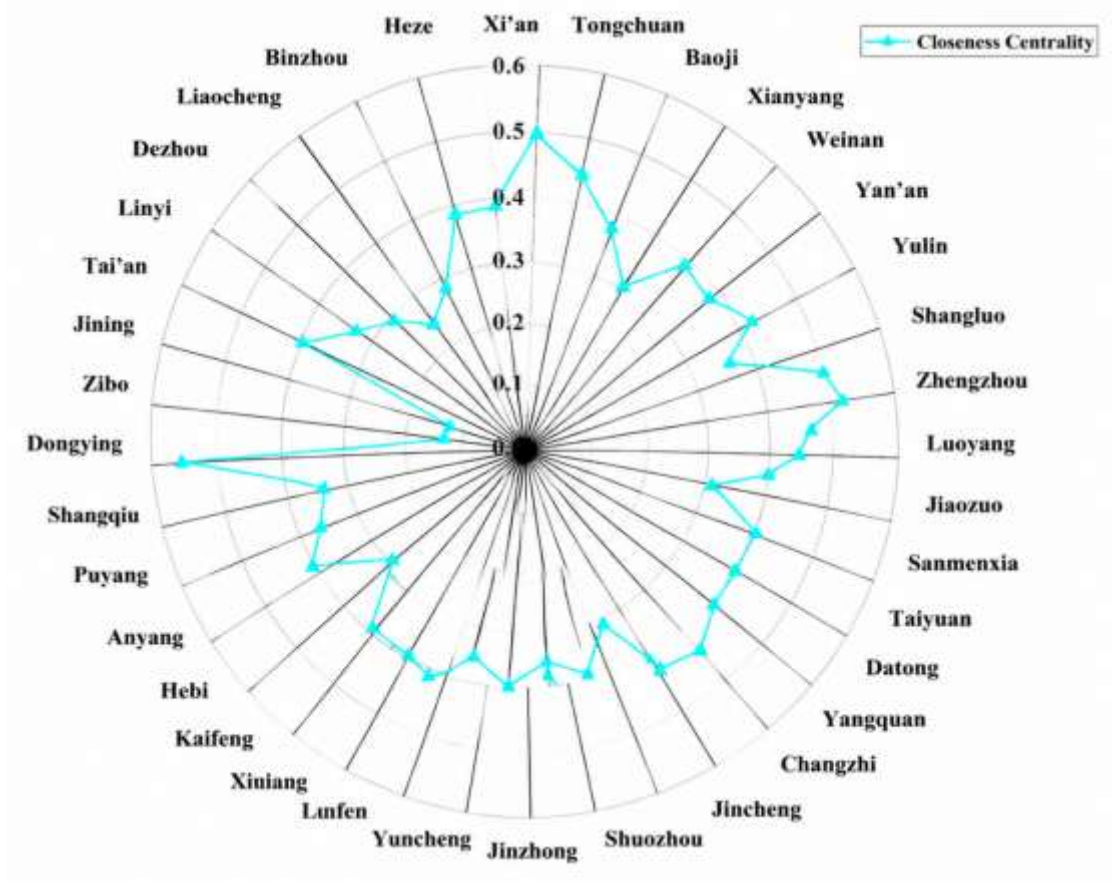


Figure 10 Relative Closeness Centrality Analysis of the Tourism Economy Resilience Spatial Network in Cities of the Middle and Lower Reaches of the Yellow River

3.5.4 Block Model Analysis

Using a maximum partition depth of 2, a convergence criterion of 0.2, and a maximum of 25 iterations, the 39 cities are classified into four blocks, as shown in Table 7.

Among the 269 total relational ties, 85 are internal block relationships, while 184 are inter-block relationships, indicating a strong spillover effect between blocks. The classification is primarily based on the comparison between expected internal relationship (ER) proportions and observed relationship (PR) proportions.

Block 1 of the tourism economic resilience network includes cities such as Xi'an and Xinzhou. Cities in this block exhibit significantly more outgoing ties to other blocks than incoming ties, while internal outgoing ties are relatively limited. Therefore, this block is identified as a net spillover block. Cities in this block generate strong net spillover effects on both intra-block and inter-block tourism economic resilience.

Block 2 includes cities such as Zhengzhou and Jinan. These cities simultaneously exhibit substantial outgoing and incoming ties, with relatively balanced interaction intensity. They also maintain a considerable number of internal connections. Therefore, this block is defined as a bidirectional spillover block, indicating that cities within this block exert mutual spillover effects on both internal and external cities.

Block 3 includes cities such as Dezhou and Heze. These cities receive significantly more incoming ties from other blocks than they send outward, and their PR values are higher than ER values. Therefore, Block 3 is identified as a net benefit block, indicating that cities in this group primarily benefit from external spillover effects rather than generating them.

Block 4 includes cities such as Shangqiu and Binzhou. These cities both send and receive external ties, with incoming ties (48) and outgoing ties (45) being relatively balanced. However, internal block ties are relatively few (17), indicating weak internal cohesion. These cities play an important brokerage (intermediary) role in the spatial spillover of tourism economic resilience, functioning as bridges connecting different blocks.

Table 7 Block model analysis of the spatial correlation network of tourism economic resilience in the middle and lower reaches of the Yellow River Basin

Block	Number of Incoming Relations		Number of Outgoing Relations		Number of Cities in Block	Expected Internal Relation Ratio	Actual Internal Relation Ratio	Block Type
	Internal	External	Internal	External				
1	16	23	16	51	8	18.42%	23.88%	Net Outflow Section
2	41	21	41	74	13	31.58%	35.65%	Bidirectional Outflow Section
3	11	66	11	18	8	18.42%	37.93%	Net Profit Section
4	17	48	17	45	10	23.68%	32.69%	Broker Section

By changing the density matrix, an image matrix is obtained, revealing the relationships between the plates. It is plotted as in Table 8 and Figure 11. The bidirectional spill-over plates send out correlations to the net-extraverted plates, and after the economic resilience of the net-extraverted plates is enhanced, they send out correlations to the net-benefited plates, promoting the enhancement of the economic resilience of the net-benefited plates. Then, through plate 4, plate 3 sends feedback to plate 2.

Table 8 Density matrix and image matrix of tourism economic resilience correlation

network in the middle and lower reaches of the Yellow River Basin

Block Name	Density Matrix				Image Matrix			
	Block1	Block2	Block3	Block4	Block1	Block2	Block3	Block4
Block 1	0.243	0.144	0.453	0.087	1	0	1	0
Block 2	0.215	0.192	0.173	0.154	1	1	0	0
Block 3	0.125	0.029	0.254	0.218	0	0	1	1
Block 4	0.038	0.302	0.237	0.278	0	1	1	1

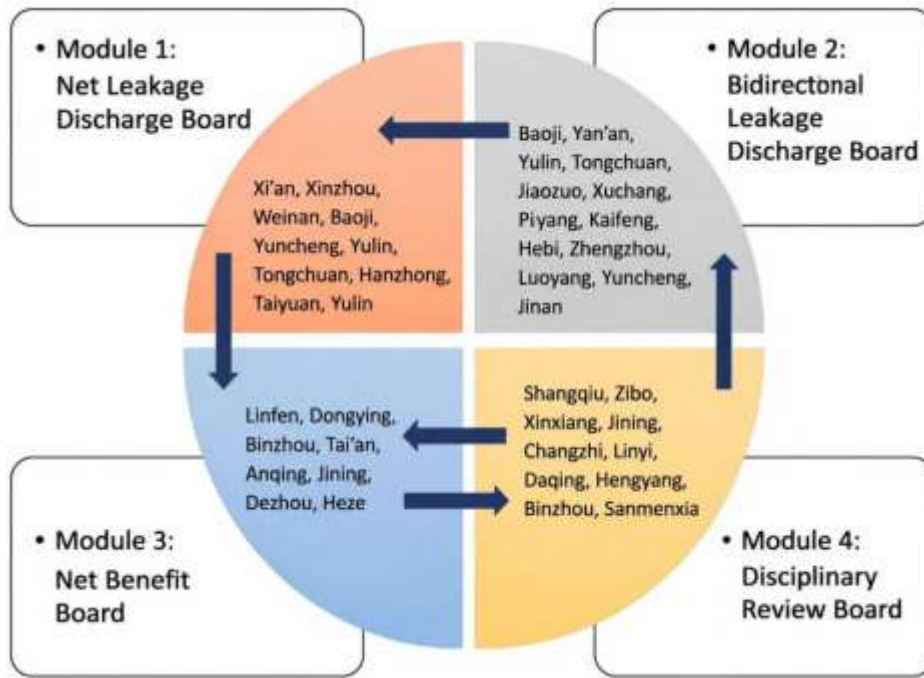


Figure 11 The relationship between the economic resilience plates of the middle and lower reaches of the Yellow River Basin

3.6 Analysis of Influencing Factors of Spatial Network Structure

Based on the constructed QAP (Quadratic Assignment Procedure) regression model, this study uses the tourism economic resilience relational matrix as the dependent variable, and the economic development disparity matrix, population mobility matrix, geographical proximity matrix, and tourism resource endowment disparity matrix as independent variables to conduct the QAP regression analysis. A total of 10,000 random permutations are selected.

This method effectively addresses the autocorrelation problem inherent in relational data and, while controlling for other factors, evaluates the net effect of each independent variable on the dependent variable.

The results of the QAP regression analysis of the influencing factors of the tourism economic resilience spatial network structure are presented in Table 9. All independent variables pass the significance tests, jointly explaining the formation mechanism of the spatial network structure of tourism economic resilience.

Table 9 Results of QAP regression analysis

Independent Variable		Standardized Coefficient	Regression P-value
Economic Development	Disparity Matrix	0.105**	0.045
Population Mobility Matrix		0.173***	0.000
Geographic Proximity Matrix		0.165***	0.000
Tourism Resource Endowment	Disparity Matrix	0.129**	0.046

Note: *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

3.7 Analysis of Influencing Factors of Spatial Network Structure

As shown in Table 9, the standardized regression coefficient of the population mobility matrix is the highest ($\beta = 0.173$, $p < 0.01$). This indicates that, after controlling for the effects of economic development, geographical distance, and resource endowment, population mobility remains the most powerful driving force.

This finding reveals that the essence of tourism economic resilience lies in the vitality and adaptability generated by “flows.” Frequent population mobility is not only a direct manifestation of tourism consumption, but also a key channel for knowledge spillover, information diffusion, managerial experience transfer, and the learning of crisis response strategies.

Secondly, the geographical proximity matrix also shows a strong and significant positive effect, with a standardized coefficient of 0.165 (significant at the 1% level). This suggests that even though modern transportation and information technologies have weakened the constraints of physical distance, geographical proximity still serves as a fundamental structural force shaping the resilience network.

Thirdly, the tourism resource endowment difference matrix has a significantly positive coefficient ($\beta = 0.134$, $p < 0.05$), indicating that resource complementarity is an intrinsic driver of network connectivity. This result supports the classical tourism geography proposition that “differences generate attractiveness.” In the context of

resilience, such heterogeneity implies functional redundancy and substitution capacity, enhancing system robustness.

In addition, the economic development disparity matrix also shows a significant positive effect ($\beta = 0.105$, $p < 0.05$). This suggests that differences in economic development levels do not hinder network formation; instead, they act as a facilitating factor. This may reflect a gradient transfer and functional complementarity mechanism within the regional tourism economy, where core-periphery interactions strengthen resilience linkages and enhance the system's ability to absorb asymmetric shocks.

Overall, the QAP regression results indicate that the spatial network of tourism economic resilience in the middle and lower reaches of the Yellow River Basin is driven by multiple mechanisms simultaneously. Population mobility forms the most dynamic “circulatory system” of the network; geographical proximity provides the fundamental spatial skeleton; resource heterogeneity acts as the intrinsic attraction force; and economic disparity shapes a hierarchical structure of functional complementarity.

These four factors jointly drive the evolution of the regional tourism economic resilience network from isolated “point-based resistance” to interconnected “networked response,” providing a solid theoretical basis for coordinated regional policy design aimed at enhancing overall tourism economic resilience.

4 Conclusions and Implications

4.1 Conclusions

This study examines the spatial network characteristics and associated influencing factors of tourism economic resilience among 39 prefecture-level cities in the middle and lower reaches of the Yellow River Basin during 2010–2024. By integrating the entropy weight-TOPSIS method, VAR-based Granger causality analysis, social network analysis, and QAP regression, this study provides a network perspective for understanding the spatial interactions of urban tourism economic resilience. The main findings are summarized as follows.

(1) The overall level of tourism economic resilience in the study area exhibited an increasing trend from 2010 to 2024, although substantial spatial heterogeneity remained among cities. The improvement in resilience scores suggests that tourism economic systems in the middle and lower reaches of the Yellow River Basin generally experienced enhanced development capacity and adaptive potential. However, differences among cities persisted, indicating an uneven distribution of resilience resources and development foundations.

(2) The tourism economic resilience network demonstrated a certain degree of spatial connectivity, with 269 significant inter-city relationships identified among the 39 cities. Nevertheless, the relatively low network density (0.182) indicates that the degree of interaction among cities remains limited and that the spatial linkage system has not yet achieved a highly integrated structure. The network presents a clear core–periphery pattern, where cities such as Xi'an, Zhengzhou, Jinan, and Luoyang occupy relatively central positions, while some peripheral cities show weaker network embeddedness.

(3) The analysis of individual network positions and block structures reveals differentiated roles among cities. Some cities function as important intermediaries or sources of network spillovers, while others mainly receive external linkages. The existence of net spillover, bidirectional spillover, brokerage, and net beneficiary blocks indicates that tourism economic resilience does not evolve independently within each city but is associated with differentiated patterns of inter-city interaction.

(4) QAP regression results indicate that population mobility, geographical proximity, differences in economic development levels, and differences in tourism resource endowments are significantly associated with the formation of the spatial network of tourism economic resilience. Among these factors, population mobility shows the strongest statistical association, suggesting that inter-city flows of people may provide important channels for tourism-related interaction and knowledge exchange. Meanwhile, geographical proximity and resource heterogeneity also contribute to shaping network connections. These findings highlight the importance of considering spatial interactions when analyzing tourism economic resilience.

Overall, this study demonstrates that tourism economic resilience in the middle and lower reaches of the Yellow River Basin has evolved from a city-centered development pattern toward a more interconnected spatial network. However, the current network remains characterized by uneven connectivity and hierarchical differentiation. Strengthening inter-city cooperation and improving the participation of peripheral cities may contribute to a more balanced regional resilience network.

4.2 Policy Implications

(1) Strengthening core hub functions to build a multi-polar coordinated development pattern of tourism economic resilience. Core cities such as Xi'an, Zhengzhou, Jinan, and Luoyang should further enhance their roles as regional hubs by establishing emergency response and information-sharing platforms, and promoting resilience spillovers through knowledge and capability diffusion.

(2) Cultivating peripheral cities and encouraging proactive embedding into the regional network through partnership programs and differentiated development strategies.

(3) Implementing differentiated policies based on block types (net spillover, bidirectional spillover, net benefit, brokerage) to improve targeted coordination.

(4) Optimizing key driving channels by facilitating population mobility, leveraging geographical proximity advantages, and promoting resource- and economy-based complementarity through cross-regional tourism circuits.

4.3 Limitations and Future Research

Despite providing empirical evidence on the spatial network characteristics of tourism economic resilience, this study has several limitations that should be acknowledged.

First, the measurement of tourism economic resilience relies on a composite indicator system constructed from socioeconomic and tourism-related variables. Although the entropy weight-TOPSIS approach provides an objective evaluation framework, the selected indicators may not fully capture all dimensions of resilience, particularly institutional adaptability, governance capacity, enterprise-level responses, and tourists' behavioral changes during external shocks.

Second, the construction of the spatial correlation network is based on VAR-Granger causality relationships among cities' resilience indicators. Although this approach helps identify potential temporal linkages, Granger causality does not necessarily represent direct causal mechanisms. Therefore, the identified network relationships should be interpreted as statistical associations rather than definitive causal effects.

Third, the QAP regression model identifies factors associated with network formation but does not fully reveal the complex nonlinear mechanisms through which these factors influence tourism economic resilience. Future research could integrate spatial econometric models, configurational approaches, or multi-level analytical frameworks to further explore causal pathways.

Fourth, this study focuses on 39 prefecture-level cities in the middle and lower reaches of the Yellow River Basin. Although this regional focus allows a detailed investigation of spatial interactions, the findings may not be directly generalizable to other regions with different institutional, economic, or tourism development contexts. Comparative studies across different river basins or urban agglomerations would provide further validation.

Future research could incorporate more dynamic data sources, such as tourism flow data, online platform data, and enterprise-level information, to improve the

measurement of resilience evolution and better understand the mechanisms underlying regional tourism resilience networks.

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Ethical approval

This article does not encompass studies involving human participants conducted by any of the authors.

Informed consent

This article does not include any studies involving human participants conducted by the authors.