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Research on the Resilience of Typical Rural Landscape Heritage in North China: An Analysis Framework Based on "Buffering Capacity-Adaptive Capacity-Transformative Capacity"

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Abstract

Enhancing the resilience of rural landscape heritage to internal and external disturbances contributes to the authentic preservation and innovative development of cultural heritage. Based on clarifying the conceptual connotation of resilience, this article constructs a resilience evaluation framework for rural landscape heritage comprising three sub-dimensions: buffering capacity, adaptive capacity, and transformative capacity. Taking traditional villages in Jiaozuo City, China as an example, the entropy-weighted TOPSIS method is employed to measure the resilience of traditional village landscape heritage, and the geographic detector method is used to reveal its key influencing factors. The findings demonstrate that abundant landscape resources form the solid foundation for rural landscape heritage resilience, while systemic weaknesses in innovation transformation capabilities and significant inter-village disparities constitute critical bottlenecks requiring urgent breakthroughs. Factor analysis reveals that rural landscape heritage resilience is not determined by a single element, but rather shaped by four interconnected dimensions: talent, innovation, environment, and funding. Among these, high-quality talent and traditional skill innovation in the talent and innovation dimensions exert the strongest influence, serving as key determinants.

1 Introduction

Rural landscape heritage refers to the social-ecological system located in the countryside with heritage value. It is the product of long-term interaction between human and nature, covering local natural ecological environment, farming methods, culture, folk customs, and other ecological, social, and economic factors (ICOMOS-IFLA ISCCL, 2017). As a living carrier of agricultural civilization, rural landscape heritage not only contains rich ecological wisdom and cultural genes, but also is the key to the inheritance and innovation of agricultural civilization. Its protection and sustainable development are of great value to promote the sustainable development of rural areas and highlight the characteristics of rural diversification and modernization (Gomez-Baggethun et al. 2012; Rossler, 2006).. However, with the acceleration of globalization and rural tourism, rural landscape heritage faces unprecedented pressures, such as ecological fragmentation caused by urban expansion and the erosion of local distinctiveness due to cultural homogenization—exemplified by the endangerment of European traditional crafts under the impact of mainstream culture (Antrop, 2005; Council of Europe, 2017) and the disintegration of Asian vernacular landscapes in the wave of urbanization (Dahiya, 2012; Liu et al., 2010). As a country with rich rural heritage, China attaches great importance to the protection of rural landscape heritage. Policies such as the "China Rural Revitalization Strategy Plan (2018–2022)" and the "National Rural Revitalization Strategy (2023)" have been successively issued, emphasizing the need to demarcate historical and cultural protection lines for rural construction, and to protect cultural relics, traditional villages, ethnic villages, and traditional architecture. Although certain achievements have been made under policy guidance, enhancing public recognition of rural culture, improving the appeal of rural tourism, and promoting rural economic development.. In this context, enhancing the resilience of rural landscape heritage and achieving both authentic preservation and innovative development has become particularly important and urgent.

Resilience theory originated in the field of engineering before being introduced into ecology by Professor Holling (Holling, 1973). It has since expanded into diverse research domains such as disaster prevention and mitigation (Aktürk and Hauser, 2024), tourism management (Zhao et al., 2023), and social-ecological systems (Folke, 2016). Within the study of social-ecological systems, early research was primarily concentrated in urban areas (Ruan et al., 2021). In recent years, it has gradually extended to rural contexts, covering topics such as governance models (Robertson et al., 2021), settlement systems (Zhang et al., 2023), and overall resilience (Wilson et al., 2018). This expansion has given rise to specialized branches, including resilience assessment of rural landscape heritage (Rescia, 2023) and pathways for sustainable development (Chen and Qin, 2023). Current research on the resilience of rural landscape heritage can be categorized into three main aspects: Exploration of Resilience Concepts. The transition from equilibrium resilience to evolutionary resilience (Scolt, 2013) reflects a shift in understanding. Early equilibrium

resilience frameworks emphasized systems' capacity to maintain or restore stability under external disturbances, primarily focusing on passive responses to shocks like disasters. For instance, enhancing resilience to protect cultural heritage from natural disasters (Rohit et al., 2022). In contrast, evolutionary resilience emphasizes the developmental process of resilient systems in rural landscapes, highlighting systemic interactions and the flow of elements within rural systems (Li, 2023). It is generally summarized as encompassing three capacities: resilience, adaptation, and transformation. Construction of theoretical frameworks. Common existing frameworks include the "Exposure-Vulnerability-Response Capacity" model (Gerlitz et al., 2017), the five-dimensional "Natural-Economic-Social-Cultural-Institutional" framework (Kelly et al., 2015), and the "Pressure-State-Response" framework (Cui et al., 2025), among others. Measurement and evaluation of resilience. This includes both qualitative and quantitative approaches. Qualitative assessments primarily employ methods such as questionnaire surveys (Ingerpuu, 2023), interviews, and other similar tools. Quantitative analyses involve constructing indicator systems (Speranza, 2013) and applying models such as entropy weighting, AHP, TOPSIS, and composite index methods for quantitative measurement. The research subjects are predominantly World Heritage sites (Chen and Qin, 2023; Szepesi et al., 2017), indicating a distinct preference in research focus.

Through reviewing existing research, it is found that there are still two aspects of deficiency in the study of rural landscape heritage resilience: In terms of research framework, the existing studies often focus on static frameworks, lacking research on the differentiated response characteristics of rural landscape heritage systems before, during, and after disturbances, and insufficient attention to the dynamic process of rural landscape heritage systems in response to external disturbances. Under the dual pressures of rapid urbanization and rural tourism development, rigid static conservation measures and top-down, inflexible management approaches are inadequate to meet the demands of sustainable development. There is an urgent need to shift towards a dynamic resilience enhancement pathway centered on living transmission and innovative transformation. Concerning the research subjects, existing studies show a strong bias towards internationally recognized heritage sites, such as the Honghe Hani Rice Terraces in Yunnan (Gu, 2012), volcanic heritage sites (Szepesi et al., 2017), and the Cultural Landscape of Old Tea Forests of the Jingmai Mountain (Chen and Qin, 2023). While these sites hold significant value in terms of systematic integrity, representativeness, and international recognition, their geographical coverage and typological diversity remain relatively limited, failing to fully reflect the rich and varied heritage realities across broader rural regions. As living rural heritage that evolves continuously, traditional villages have accumulated rich historical information, cultural landscapes, and nostalgic memories throughout the long history of agrarian civilization. Their development is far more uncertain and conflict-prone than that of specific landscape heritage sites. Therefore, conducting resilience research on traditional villages can better reflect the resilient evolution of rural landscapes under external disturbances, which holds broader and more significant practical implications for advancing resilience theory studies.

To address the aforementioned research gaps, this study examines the dynamic response of rural landscape heritage systems to external disturbances. Following the three-phase evolutionary logic of "buffering-adaptation-transformation," we develop a resilience evaluation framework comprising three subsystems: buffering capacity, adaptive capacity, and transformative capacity. Using traditional villages in Jiaozuo City, North China as a case study, we quantify village resilience through the entropy-weighted TOPSIS model and employ the geospatial detector method to uncover underlying driving mechanisms. This research aims to broaden the research perspective on rural landscape heritage resilience and provide scientific evidence for enhancing global rural landscape heritage resilience.

2 Data and methods

2.1 Study area

This study takes Jiaozuo City in Henan Province, China as the research area. Located at the junction of the North China Plain and the Taihang Mountains, the city boasts diverse landforms, profound historical accumulation, and rich cultural resources, providing an excellent natural and humanistic foundation for nurturing rural landscapes with diverse types, distinct characteristics, and outstanding heritage value (He et al., 2024). The traditional village architecture in the region exhibits varied styles, with abundant intangible cultural heritage, and shows significant gradient differences in socio-economic development levels, forming an ideal and diversified sample group for comparative studies on the resilience of rural landscape heritage. Particularly since Jiaozuo City was included in the list of China's All-for-One Tourism Demonstration Zones in 2016, the development and utilization of its traditional villages have seen a surge, driven by government initiatives and market collaboration. Against the backdrop of rapid urbanization and the rise of rural tourism, the traditional villages of Jiaozuo City collectively demonstrate the universal tension between protection and development faced by rural landscapes with outstanding cultural heritage value in the process of modernization, making them a key research subject for exploring how such heritage can enhance resilience and achieve sustainable development. Their experiences and challenges hold significant reference value for understanding rural landscape heritage facing similar circumstances globally (Fig. 1)

The main sources of data are as follows: (1) From March to June 2024, textual information related to traditional villages in Jiaozuo City was collected and organized, including policy documents, local histories and records, planning achievements, news reports, and network information. (2) From June 20 to 30 in 2024, stratified sampling method was adopted to draw sample villages based on factors such as geographic location, economic level, and type of development, and 11 traditional villages in Jiaozuo City were finally identified as the sample villages for the study (Table 1). (3) From July 4 to 5 in 2024, a pre-survey was conducted in Zhaibuchang Village and Beizhu Village, and the interview questionnaire and survey questionnaire were revised and improved based on the feedback during the research process to determine the final interview questionnaire and survey questionnaire. (4) From July 21 to 26 in 2024, the formal research was conducted, sampling villagers of different genders, ages, economic incomes, cultural levels and residence times to conduct the questionnaire survey, and going to the village committees of the villages to obtain the required objective data. A total of 300 questionnaires were distributed, 292 questionnaires were collected, and the effective recovery rate of the questionnaires was 97.4%. Before data processing, SPSS software was used to test the reliability and validity of the questionnaire data. The results showed that Cronbach's and reliability coefficients were 0.840, KMO = 0.836, and Bartlett's sphericity test had a significance of $P < 0.01$, indicating good reliability and validity of the data.

Table 1
Description of each village

Order number	Survey Villages	Topographic Features	Population	Annual per capita income	Feature	Sample Size
1	Yidoushui	mountain	211	18000	Ming and Qing stone house complex	27
2	Shuangmiao	mountain	236	21000	Landscape and natural scenery	22
3	Shierhui	mountain	127	12000	Red culture, war sites	20
4	Zhaibochang	Plain	3700	12000	Shennongshan natural landscape	30
5	Beizhu	Plain and hill	2373	21000	Ming and Qing architectural complex	33
6	Jiudu	mountain	543	4200	Military cultural heritage along the Song-Liao border	28
7	Zhaozhai	Plain	5010	13248	Yangshao cultural remains	32
8	Chenjiagou	Plain	2600	25000	The birthplace of Tai Chi	25
9	Mogou	hill	700	16800	South Taihang cave culture representative	27
10	Wanhua	Plain	4047	31,000	Yellow River culture core, Qinglong Palace Fair	28
11	Xiaodong	Plain	5750	20000	Cowherd and Weaver Girl story	28

2.2 Theoretical framework of the rural landscape heritage resilience

Rural landscape heritage resilience is an extension of resilience in the socio-ecological domain. Drawing on the concept of evolutionary resilience and building upon existing research (Chen & Qin, 2023; Scott, 2013), this paper defines rural landscape heritage resilience as follows: the ability of rural landscape heritage system to effectively buffer against, quickly adapt to and recover from, and ultimately achieve transformative renewal in response to multiple and complex external disturbances. Specifically, it manifests as the capacity of traditional village landscape heritage systems to respond promptly to external shocks, maintaining the stability of their structure and the continuity of their functions.

The resilience system comprises three core capabilities that collectively address external disturbances of varying intensities. The buffering capacity refers to the ability of rural landscape heritage to absorb and mitigate disturbances while maintaining the stability of its own structure and functions. It serves as the foundation and prerequisite for resilience building. The preservation level and richness of both tangible and intangible landscape heritage are the main factors influencing buffering capacity. Adaptive capacity refers to the ability of rural landscape heritage to gradually adapt to uncertain environments through adjustments and promptly restore its core structure and functions. Government governance, community participation, and funding investment are among the key factors that shape the adaptive capacity of rural landscape heritage. Transformative capacity refers to the ability of rural landscape heritage to innovate development models and pathways, promote the reorganization of landscape resources and the reconstruction of their value, ultimately achieving creative transformation and innovative development. Organizational

learning, technological progress, and integrating innovation are the primary means of cultivating the transformative capacity of rural landscape heritage.

When the resilience system of rural landscape heritage interacts strongly with external disturbances, these three capabilities activate sequentially according to disturbance intensity, forming three dynamic response phases: "buffering—adaptation—transformation" (Fig. 2). The buffering phase marks the initial stage of resilience system evolution. When facing minor external disturbances or shocks, the system utilizes accumulated resources to absorb adverse impacts, effectively mitigating disruptions and maintaining structural and functional stability. The adaptation phase emerges as the second stage. When external shocks intensify beyond the system's tolerance threshold, it activates self-optimization mechanisms to adapt to environmental changes, preventing structural degradation and collapse. The third resilience phase kicks in when traditional development models become unsustainable under intensified negative impacts. The rural landscape heritage system then introduces new elements (e.g., adopting new technologies, developing innovative business models, recruiting high-skilled professionals) to achieve developmental innovation and transformation, ultimately reaching a new equilibrium in structure and function..

2.3 Evaluation Indicator System

Abiding by the principles of systematicity, scientificity, representativeness and accessibility, and combining with the actual situation of Jiaozuo City, the rural landscape heritage resilience evaluation system is constructed by selecting 24 indicators from the three dimensions of buffering capacity, adaptive capacity and transformative capacity (Table 2).

1. Buffering capacity forms the foundational framework of the resilience system for rural landscape heritage, achieving immediate resolution of impact loads through resource mobilization. This capacity comprises two dimensions: tangible landscape heritage and intangible landscape heritage (Rescia et al., 2010; Yu et al., 2023). Tangible landscape heritage encompasses landscape elements at three levels—"point, line, and plane". Landmark nodes (e.g., traditional dwellings, public squares, ancient trees) form the "point" dimension, measured by the retention rate of traditional buildings and the richness of historical environmental elements. Historic streets and alleys constitute the "line" dimension, measured by the protection quantity of traditional streets. The "plane" dimension involves the village's overall appearance and surrounding environment, measured by the integrity of the overall layout and the protection level of the peripheral ecosystem. Intangible heritage is embedded in the internal logic of village life, including dynamic landscape elements such as folk customs, religious beliefs, village rules and regulations, handicrafts and social customs. Among them, folk customs and handicrafts are vivid manifestations of the villagers' way of life, with distinctive local heritage value. The richness of folk activities and safeguarding status of traditional craftsmanship are selected to measure their status. Clan rules, family teachings, and village rules and regulations are behavioral norms jointly formulated and followed by villagers, and are important components of the intangible heritage of villages. Clan system continuity and the impact of village regulations and agreements are selected to characterize their status. The social atmosphere directly reflects and influences the spiritual outlook and value orientation of the village, and its state is reflected through the harmony of the social atmosphere...
2. Adaptive capacity is the comprehensive capacity to achieve systematic dynamic adjustment and functional restoration by integrating external resources (e.g., government, tourism enterprises, villagers) with internal elements (e.g., tangible and intangible landscape heritage). This capacity encompasses three key dimensions: government governance, community participation, and funding investment (Berkes and Folke, 1998; Folke, 2016). The effectiveness of government governance is influenced by factors such as policies, planning, and management. Therefore, the perfection and implementation of protection policies and the establishment of protection institutions are selected as indicators to identify government governance capacity. Enterprises can integrate internal and external resources, activate landscape heritage, and villagers are the main body of traditional villages.

Their behavior directly affects the protection and inheritance effect of landscape heritage. Therefore, whether enterprises participate in construction and villagers participate in management are taken as indicators of community participation. The funding investment of the government, enterprises, and villagers can reflect the efforts of the government and enterprises to protect landscape heritage, the enthusiasm of villagers to participate in the development of village heritage protection, and thus predict the potential and space for future economic growth. Therefore, the level of government funding investment, enterprise funding investment and village funding investment are selected as indicators for funding investment.

3. Transformative capacity drives resilience enhancement through the dual processes of knowledge absorption and innovation diffusion. Within the rural landscape heritage resilience system, this capacity manifests as: the injection of exogenous knowledge (such as technology transfer, information exchange, and cultural creativity) coupled with the restructuring and renewal of endogenous resources, ultimately leading to a new system equilibrium. It encompasses three aspects: organizational learning, technological advancement, and integrated innovation (Folke, 2016; Ostrom, 2009). Organizational learning: traditional skills are a core component of rural landscape heritage, and training can ensure the continuity of traditional knowledge while enhancing villagers' cultural confidence and skill reserves; external talents can bring advanced knowledge and management experience, promoting the transformation and innovation of rural landscape heritage. Therefore, two indicators are selected: the innovative utilization of traditional skills and attracting high-skilled talent. Technological progress: the degree of promotion through new media can measure the level of promotion of rural landscape heritage on modern networks. Effective promotion can attract tourists and social attention, providing economic and cultural support for transformation. The degree of digital technology application directly affects the level of protection of rural landscape heritage and tourist experience, and is an important technical support for transformation. Integration and innovation: the the innovative utilization of traditional skills can give new vitality to rural landscape heritage and revitalize it in contemporary society, while the degree of innovation in cultural activities reflects whether traditional culture can adapt to the needs of contemporary development and realize effective inheritance through timely adjustment of content.

Table 2
Indicator system for evaluating the rural landscape heritage resilience

Target layer	Standardized layer	Factor layer	Indicator layer	Interpretation of indicators	Weights	Source of indicators
A Rural Landscape Heritage Resilience	B_1Buffering capacity	C_1Tangible heritage	D_1 Protection level of the peripheral ecosystem	Protection of the surrounding natural environment	0.020	Chen and Qin, 2023
			D_2 Completeness of the village pattern	Protection situation of the traditional village pattern	0.020	Chen and Qin, 2023
			D_3 Preservation quantity of traditional streets	Has a relatively complete number of traditional streets and lanes	0.039	Yu et al., 2023
			D_4 Retention of traditional buildings	Traditional buildings cover an area of	0.035	Berkes and Folke, 1998
			D_5 Richness of historical environmental elements	Existing historical and environmental elements	0.015	Berkes and Folke, 1998
		C_2Intangible heritage	D_6 Richness of folk activities	The number of folk-custom activities held every year	0.028	Ostrom, 2009
			D_7 Clan system continuity	Have a family tree or tree	0.038	Yu et al., 2023
			D_8 Impact of village regulations and agreements	Recognition of the village rules and regulations	0.034	Chen and Qin, 2023
			D_9 Safeguarding status of traditional craftsmanship	Inheritance of handicraft skills	0.061	Chen and Qin, 2023
			D_{10} Harmony of social atmosphere	The degree of harmony of the social atmosphere	0.044	Chen and Qin, 2023
	B_2Adaptive capacity	C_3Government governance	D_{11} Perfection of protection policies	Whether there are relevant protection policies / regulations	0.048	He et al., 2024

Target layer	Standardized layer	Factor layer	Indicator layer	Interpretation of indicators	Weights	Source of indicators
			D_{12} Implementation of protection policies	Implementation of relevant policies on protection and tourism	0.024	He et al., 2024
			D_{13} Establishment of protection institutions	Whether there is a special protection agency	0.022	Chen and Qin, 2023
		C_4Community participation	D_{14} Villager participation in management	Whether the villagers participate in the formulation of village rules and regulations and the management of heritage protection, etc	0.038	Scott, 2013
			D_{15} Enterprise participation in management	Whether any enterprises are involved in the protection and development of the heritage	0.038	Li, 2023
		C_5Funding investment	D_{16} Level of government funding investment	Government investment in protection funds	0.059	Chen and Qin, 2023
			D_{17} Level of social funding investment	Enterprise investment in protection and repair funds	0.079	Folke, 2016
			D_{18} Level of villagers' funding investment	Villagers' investment in protection and repair funds	0.072	Folke, 2016
	B_3Transformative capacity	C_6Organizational learning	D_{19} Number of traditional skills training	Traditional skills training situation	0.066	Chen and Qin, 2023
			D_{20} The scale of high-quality talent introduction	The number of talents introduced in tourism, management and other related fields	0.057	Ostrom, 2009
		C_7Technological progress	D_{21} Degree of promotion through new media	Whether to use TikTok, WeChat public account and other publicity	0.023	Li, 2023

Target layer	Standardized layer	Factor layer	Indicator layer	Interpretation of indicators	Weights	Source of indicators
			D_{22} Degree of digital technology application	Whether the village uses the relevant intelligent tourism service facilities, such as the electronic tour guide, the digital museum	0.060	Li, 2023
		C_8Integrating Innovation	D_{23} The innovative utilization of traditional skills	Whether the traditional village skills are used innovatively in combination with the modern needs	0.031	Ostrom, 2009
			D_{24} Degree of innovation in cultural activities	Cultural and creative activities, such as research, fun culture competition	0.049	Ostrom, 2009

2.4 Entropy Weight TOPSIS method

Entropy Weight TOPSIS method (Approximation of Ideal Solution Ranking Method) is based on the traditional TOPSIS method using entropy value method to find the weight of evaluation indexes first, and then using the TOPSIS method to calculate the distance between the evaluation object and the positive (negative) ideal solution to judge the resilience level, which has significant advantages in the evaluation of multi-objects and the embodiment of differences in the evaluation object (He et al, 2024). The specific calculation steps are as follows:

(1) Data standardization. The range method is employed for standardization processing. Since all metrics selected in this study are positive indicators, the formulas for negative indicators are therefore not listed. Construct the standardization matrix Y:

$$\mathrm{Y_{ij}} = \left(\mathrm{X_{ij}} - \mathrm{X_{jmin}}\right) / \left(\mathrm{X_{jmax}} - \mathrm{X_{jmin}}\right)$$

1

Where X_{ij}、Y_{ij}、X_{jmin} and X_{jmax} are the original, normalized, minimum and maximum values of the j_{th} indicator in the i_{th} traditional village, respectively.

(2) Determine the weights of indicators W and form the weighted normalization matrix Z: In this study, taking into account the different nature and characteristics of the indicators, the entropy weight method is used to find the weights of the indicators for the evaluation of the resilience of the rural landscape heritage W. The specific steps are shown in the relevant literature (Chen et al.,2019).

$$\mathrm{Z} = \mathrm{Y} \times \mathrm{W}$$

2

(3) Determine the positive and negative ideal solutions Z^+, Z^-:

$$Z^{\pm}=\{\max Z_{ij}/\min Z_{ij}|j=1,2,\ldots,n\}=\{Z_1^{\pm},Z_2^{\pm},\ldots,Z_n^{\pm}\} \quad (3)$$

(4) Calculate the distance of the evaluation object from the positive and negative ideal solutions:

$$D_i^{\pm}=\sqrt{\sum_{j=1}^{n}\left(Z_{ij}-Z_j^{\pm}\right)^2}$$

4

;

(5) Calculate the relative proximity of each evaluation object to the optimal solution C_i:

$$C_i=\frac{D_i^-}{D_i^+ + D_i^-}$$

5

Where C_i represents the rural landscape heritage resilience index, the value interval is [0, 1], the larger the value indicates that the rural landscape heritage resilience is higher, and vice versa is lower.

2.5 Geodetector

Geodetector is an effective tool for detecting spatial dissimilarities and explaining the driving forces behind them. It is suitable for analyzing the influence degree and interactive effects of various factors on the resilience of rural landscape heritage(Wang and Xu .,2017; Zhu et al, 2020).

$$q_x=1-\frac{1}{N\sigma^2}\sum_{h=1}^{L}N_h\sigma_h^2$$

6

equation: q is the explanatory power of the factor detection, taking the value range [0, 1], the larger the value of q, the stronger the explanatory power and the higher the importance of the factor; N is the number of sample units in the study area; N_h is the number of sample units in stratum h; L is the number of samples in the sub-region; σ^2 is the total dispersion variance in the study area; σ_h^2 is the dispersion variance in stratum h.

3. Results

3.1 The resilience level of rural landscape heritage

According to Formulas (1) to (5), the assessment results of landscape heritage resilience in the case study villages were calculated (Fig. 3). The rural landscape heritage resilience index in Jiaozuo City ranges from 0.192 to 0.643, with a mean value of 0.420, indicating an overall moderate level of resilience. Using the natural breaks method, the resilience levels were classified into three tiers: high (0.473–0.643), medium (0.319–0.472), and low (0.192–0.318). The

distribution of villages across these tiers is 27.2% high, 45.6% medium, and 27.2% low, structurally forming a spindle-shaped pattern characterized by a larger middle segment and smaller ends.

Three traditional villages exhibit high resilience levels: Chenjiagou Village (0.643), Wanhua Village (0.539), and Zhaozhai Village (0.515). Key factors contributing to their high scores include the inheritance of craftsmanship, robust financial support, the the scale of high-quality talent introduction, and strong villager support and cooperation in landscape heritage conservation efforts. Five traditional villages fall into the medium resilience tier: Yidoushui Village (0.472), Zhaibuchang Village (0.463), Mogou Village (0.441), Beizhu Village (0.415), and Shierhui Village (0.386). These villages demonstrate notable weaknesses, such as low quality of cultural inheritance, limited innovation capacity, and insufficient participation from villagers and enterprises, which collectively constrain their resilience levels. Three traditional villages are categorized as low resilience: Shuangmiao Village (0.318), Jiudu Village (0.246), and Xiaodong Village (0.192). Significant factors contributing to their low resilience include lagging government management, low villager participation and cultural identity, and insufficient cultural innovation capacity.

3.2 Sub-dimension evaluation of rural landscape heritage resilience

Further analysis of the three dimensions of resilience (Fig. 4) reveals that the buffering capacity index ranges from 0.306 to 0.653, with a mean of 0.476 and a coefficient of variation (CV) of 26.48%. Six villages exceed the average score, with Beizhu Village leading at 0.653. The relatively low overall CV and minimal inter-village disparities indicate that traditional villages in Jiaozuo City generally possess a stable historical and cultural foundation, demonstrating balanced buffering capacity. The adaptive capacity index ranges from 0.109 to 0.594, averaging 0.396 with a CV of 43.40%. The wide distribution and high CV suggest significant differences among villages in terms of government policy support, governance mechanisms, and funding investment. Villages such as Chenjiagou (0.594), Yidoushui (0.546), and Wanhua (0.525) stand out in this dimension. The transformative capacity index ranges from 0.087 to 0.797, averaging 0.353 with a CV of 53.11%. Only five villages exceed the average, with the highest score being 9.16 times the lowest, highlighting a stark disparity in transformative capacity across villages and far greater internal imbalance compared to the other two dimensions. In summary, buffering capacity demonstrates overall stability, adaptive capacity shows some differentiation, while transformative capacity exhibits high heterogeneity and uneven development, representing a critical shortcoming in current resilience-building efforts.

3.3 Factors influencing rural landscape heritage resilience

Using the resilience index of traditional village landscape heritage as the dependent variable and 24 indicator factors as independent variables, this study employed the factor detector within the Geodetector model to quantify the influence of individual factors on the rural landscape heritage resilience. Additionally, the interaction detector was applied to investigate how multiple factors jointly influence the rural landscape heritage resilience.

3.3.1 Factor Detection Results

Correlation analysis (Table 3) reveals eight factors demonstrating statistically significant associations, ranked in descending order of q-value: the scale of high-quality talent recruitment (D20), the utilization of traditional skill innovation (D23), integrity of the overall layout (D2), level of government funding investment (D16), protection level of the peripheral ecosystem environment (D1), retention of traditional buildings (D4), villager participation in management (D14), and enterprise participation in management (D15). This indicates that the influencing factors of rural landscape heritage resilience primarily include the conservation and richness of tangible heritage, governmental financial support and social collaboration, as well as the innovative utilization of high-quality talent and traditional skills.

Among the specific factors, the scale of high-quality talent recruitment has the most significant impact on the resilience of rural landscape heritage, with an explanatory power of 0.951. The utilization of traditional skill innovation ranks second, with an explanatory power of 0.893. The integrity of the overall layout (explanatory power 0.883) and the level of government funding investment (explanatory power 0.851) also demonstrate strong influence. All four factors exhibit q-values above 0.8, clearly demonstrating the pivotal role of talent, technology, environment, and funding investment in enhancing the resilience of rural landscape heritage.

Table 3
Detection results of impact factors of rural landscape heritage resilience

impact factor	D20	D23	D2	D16	D1	D4	D14	D15
q	0.951	0.893	0.883	0.851	0.779	0.775	0.687	0.447
p	0.009	0.027	0.029	0.098	0.055	0.098	0.002	0.025

Table note: the scale of high-quality talent introduction (D20), the innovative utilization of traditional skills (D23), Completeness of the village pattern (D2), Level of government funding investment (D16), Protection level of the peripheral ecosystem environment (D1), Retention of traditional buildings (D4), Villager participation in management (D14), Enterprise participation in management (D15).

3.3.2 Interaction Factor Detection Results

The interaction detection results (Fig. 5) show that the impact of each factor combination on the rural landscape heritage resilience exhibits non-linear enhancement or dual factor enhancement characteristics, that is, the explanatory power of the interaction between any two factors on the resilience of landscape heritage is stronger than that of one factor, and the interaction shows a synergistic enhancement feature. Specifically, the explanatory power of 36 pairs of interaction factors is greater than 0.7. Among these factors, the interaction terms involving the scale of high-quality talent recruitment and the utilization of traditional skill innovation consistently yielded explanatory power (q) exceeding 0.9. This significant synergistic enhancement indicates that these two factors are pivotal in influencing the resilience of rural landscape heritage in Jiaozuo City.

Among the various factor combinations, the interactions between utilization of traditional skill innovation∩preservation of the surrounding natural environment, utilization of traditional skill innovation∩the scale of high-quality talent recruitment, and utilization of traditional skill innovation∩level of government funding investment constitute the primary factor sets influencing rural landscape heritage resilience. Each of these combinations demonstrates an explanatory power greater than 0.987, indicating that the synergy of multiple elements "environment, funding, talent, and innovation" serves as a critical pathway for significantly enhancing the resilience of rural landscape heritage.

4 Discussion

4.1 Analysis of rural landscape heritage resilience

The evaluation of this study shows that the resilience of rural landscape heritage in Jiaozuo City is generally at a medium level, with a spindle-shaped distribution characterized by a large middle section and smaller ends. This distribution pattern contrasts with the pyramid-shaped structure dominated by low resilience observed by some China scholars (Liu et al., 2024; Zhou and Wang, 2023) in less developed regions. The spindle-shaped structure of Jiaozuo City indicates that the region has a considerable number of traditional villages with certain resilience and adaptability, but there are also a significant number of vulnerable villages. This structure may reflect the typical state of intensified differentiation in the resilience of rural landscape heritage in the core agricultural areas of the Yellow River Basin under

the dual pressures of rapid urbanization and tourism.What is more alarming is that the spindle-shaped pattern implies a systemic bottleneck for the overall resilience enhancement of cultural landscapes: the majority of medium-resilience villages are numerous, and their development models often exhibit strong path dependence and institutional inertia, making it difficult for them to spontaneously break through existing thresholds and prone to sliding into low-resilience states under external shocks. Therefore, to achieve the comprehensive enhancement of rural landscape heritage resilience, we cannot rely on natural evolution or isolated demonstration effects. Instead, it is imperative to implement long-term, systematic, and precise institutional interventions to proactively break the middle-resilience trap, guiding and driving this vast population to achieve structural resilience transformation.

The analysis shows that the success of the high-resilience villages is inseparable from the synergistic effect of four factors: excellent cultural environment, abundant funds, high-tech talents and technological innovation. For instance, Chenjiagou Village, leveraging its Tai Chi culture as a core asset, has secured policy support and attracted social capital, thereby drawing in high-quality talent. Through international competitions, media dissemination, and digital storytelling, the village has been encoded as a global cultural symbol, facilitating the transformation of cultural capital into socio-economic capital. Similarly, Wanhua Village has utilized cyclical rituals such as the Qinglong Palace Temple Fair and rain-worship performances to attract substantial external investment and encourage entrepreneurship among high-quality returning talents. These efforts have continuously revitalized collective memory and place attachment, significantly enhancing the resilience of its rural landscape heritage (Agnoletti, 2013).

In contrast, medium-resilience villages (e.g., Yidoushui, Zhaibochang), despite possessing abundant tangible heritage and well-established management plans, demonstrate relatively strong buffering and adaptive capacity—aligning with the view that tangible heritage foundations and management systems form the cornerstone of resilience (Plieninger et al., 2015; Council of Europe, 2000). However, due to low attractiveness to talent and limited cultural innovation capacity, these villages exhibit significant shortcomings in transformative capacity, leading to a structural contradiction characterized by a solid foundation yet insufficient transformative momentum. On the other hand, low-resilience villages, such as Jiudu and Shuangmiao, suffer from inadequate funding investment and severe brain drain, resulting in abandoned farmlands and dilapidated dwellings. This triggers a chain reaction of population loss, disrupted cultural transmission, and economic decline (Dzanku, 2015), ultimately causing a cascading collapse of the rural landscape heritage resilience system. This scenario closely mirrors the crises observed in hollowed-out villages or those lacking effective governance, as highlighted in previous studies (Liu et al., 2022; Li et al., 2022).

4.2 Analysis of rural landscape heritage resilience by three dimensions

The three-dimensional analysis of resilience reveals that the buffering capacity index of rural landscape heritage in Jiaozuo City averages 0.476, with CV of 26.48%. The relatively low overall CV and minimal inter-village disparities indicate that traditional villages in Jiaozuo City generally possess a stable historical and cultural foundation, demonstrating balanced buffering capacity. Field studies show that villages with high buffering capacity, such as Beizhu Village and Chenjiagou Village, benefit from relatively strong economic conditions and a high degree of agricultural specialization and productivity. While experiencing continuous improvements in material living standards, villagers place significant emphasis on spiritual pursuits and cultural inheritance, spontaneously organizing diverse folk cultural activities such as the Tai Chi Cultural Temple Fair in Chenjiagou, the Qinglong Palace Spring Festival Temple Fair in Wanhua Village, and the Ten-Thousand-Person Dumpling Banquet in Beizhu Village. These activities strengthen community cohesion and cultural identity, indirectly enhancing landscape heritage buffering capacity. In contrast, traditional villages with lower buffering capacity scores face negative impacts due to remote locations and underdeveloped economies, which have led to severe population outflow among young adults. This has resulted in land

abandonment, abandoned traditional dwellings, and the extinction of traditional crafts, collectively undermining the villages' buffering capacity.

The mean value of the rural landscape heritage adaptive capacity index is 0.396, with CV of 43.40%. The wide distribution range and high coefficient of variation indicate significant disparities among villages in terms of government policy support, governance mechanisms, and financial investment. The success of villages with high adaptive capacity, such as Chenjiagou Village and Yidoushui Village, stems not only from policy support but also crucially from the strong sense of belonging and identity among villagers. This enables them to effectively transform external resources, such as planning guidance, conservation policies, and tourism development, into endogenous motivation for local participation and support. For example, Chenjiagou Village has institutionalized traditional practices, such as the rule that “non-family members must formally apprentice to learn martial arts,” into modern management regulations through village conventions. This initiative has not only gained widespread support from villagers but has also achieved sustainable appreciation of traditional cultural capital. Villages with low adaptability, despite having similar external opportunities, are limited in their ability to improve adaptive capacity due to the failure in achieving effective integration of internal and external resources.

The average value of the rural landscape heritage transformative capacity index is 0.353, with CV of 53.11%. Only five villages exceed the average, and the difference between the highest and lowest values reaches 9.16 times, indicating a significant disparity in transformative capacity among villages. The internal imbalance is far greater than that of the other two dimensions. Chenjiagou Village and Wanhua Village scored 0.797 and 0.608 respectively, which are far ahead of other traditional villages. The key to their success lies in the modern transformation and value reconstruction of traditional cultural resources through digital technology, cultural and creative activities, and new media communication. In contrast, more than half of the villages are slow in the process of heritage resources renewal, and it is difficult to realize the transformation of development path and the transformative capacity is generally weak because of the lagging application of digital technology and the lack of cultural innovation ability.

The uneven development of three resilience dimensions (buffering capacity > adaptive capacity > transformative capacity) profoundly reveals systemic biases in current conservation paradigms: an overemphasis on static preservation of material forms while neglecting the cultivation of dynamic evolution and value regeneration capabilities. The relative advantage of buffering capacity demonstrates that traditional villages in Jiaozuo possess superior innate resource endowments, aligning with the universal characteristic of global cultural heritage sites that rely on resource endowments (Josephine and Marilena, 2017). However, weakness of transformative capacity and inter-village disparities, which have become key factors constraining the enhancement of rural landscape heritage resilience. This result aligns closely with academic consensus that transformative capacity is the core of resilience construction (UNESCO, 2021), clearly indicating that the future of rural landscape heritage in Jiaozuo and similar regions hinges on whether they can achieve a paradigm shift from static preservation to innovation-driven development. Practices in villages like Chenjiagou demonstrate that deep integration of digital empowerment and cultural creativity to drive the value reconstruction of traditional resources constitutes the critical pathway for realizing this transformation.

4.3 Analysis of factors influencing rural landscape heritage resilience

Factor analysis reveals that rural landscape heritage resilience stems not from a single factor, but is shaped by four interconnected dimensions: environment, funding, talent, and innovation (Fig. 6). The environmental dimension reflects the integrity of natural ecosystems and the overall landscape structure, forming the material foundation for resilience. Funding dimension refers to sustained support from both government and private capital, which provides critical

support for the system to withstand disturbances and implement adaptive measures. Talent and innovation serve as the core drivers of systemic transformation, where high-quality professionals not only invigorate rural areas but also effectively integrate internal and external resources to enhance systemic resilience. The creative transformation of traditional skills further bridges cultural heritage with modern demands.

The interactive detection results further reveal a significant synergistic enhancement effect between the dimensions of talent and innovation. High-quality talent not only serves as a key factor itself but also significantly amplifies the efficacy of other elements (such as environmental maintenance and capital utilization) by activating the innovative potential of traditional skills, thereby driving the entire resilient system to evolve to a higher level. For instance, after attracting high-quality talents to return, Zhaozhai Village transformed traditional dwellings through modern design concepts, enhancing both the quality of physical spaces and villagers' sense of local identity. Similarly, Chenjiagou Village successfully modernized traditional cultural resources through the innovative "live streaming + Tai Chi" model. These practices validate the theory that talent aggregation can trigger local innovation (Florida, 2002). Likewise, traditional skills, as crucial components of rural landscape heritage, carry rich historical information and cultural symbols. Their re-creation not only ensures efficient cultural transmission but also significantly boosts rural tourism appeal. Therefore, enhancing the resilience of rural landscape heritage hinges on identifying and synergistically optimizing the four-dimensional mechanism encompassing "environmental foundation, financial security, talent leadership, and innovation-driven development." Future efforts should prioritize strengthening the coupling effect between talent and innovation, systematically enhancing the adaptive capacity and sustainable development of rural landscape heritage through the creative transformation of local knowledge and technologies.

4.4 Limitations and policy recommendations

Finally, based on the four-dimensional driving mechanism of "environmental foundation, financial guarantee, talent leadership, and innovation-driven development" identified through factor detection analysis, we propose differentiated governance strategies: For high-resilience villages, the focus should be on strengthening innovation leadership and talent enhancement, establishing cultural innovation funds, promoting the deep integration of Tai Chi as a global IP with digital technologies, and achieving sustainable development. Medium-resilience villages should prioritize targeted funding investment and talent introduction, leveraging digital technology empowerment to resolve the tension between "solid foundations" and "insufficient dynamism." Low-resilience villages need to ensure basic funding inputs as a priority, implement environmental restoration and talent return programs, and carry out systematic interventions to curb system degradation.

Overall, a coordinated governance system should be established that integrates environmental baseline protection, precise funding allocation, systematic talent introduction, and sustained innovation application. This will promote a virtuous chain reaction among the four elements—"foundation, guarantee, vitality, enhancement"—providing a replicable practical pathway for the sustainable development of rural heritage in similar regions globally.

5. Conclusion

From the perspective of resilience genesis, this study constructs a rural landscape heritage resilience analysis framework comprising three subsystems: buffering capacity, adaptive capacity, and transformative capacity. Using this framework to evaluate the resilience level of traditional villages in Jiaozuo City, the following conclusions are drawn: (1) The average resilience level of rural landscape heritage in Jiaozuo City is 0.420, generally at a moderate level, with traditional villages in the high, medium, and low tiers accounting for 27.2%,45.6%, and 27.2% respectively, exhibiting a spindle-shaped structure with a larger middle segment and smaller ends. This reflects the intensified differentiation of rural landscape heritage resilience in the core agricultural region of the Yellow River Basin under dual pressures of rapid urbanization and tourism development. (2) The sub-dimensional evaluation results show buffering capacity> adaptive

capacity> transformative capacity, indicating that abundant landscape resources serve as a solid foundation for rural landscape heritage resilience. However, the systemic weakness in innovative transformation capabilities and significant inter-village disparities pose critical bottlenecks for upgrading landscape heritage resilience. (3) Factor detection analysis reveals that rural landscape heritage resilience is not determined by a single factor but is jointly influenced by four dimensions: environment, funding, talent, and innovation. Among these, high-quality talent and traditional skill innovation demonstrate significant "enhancing" effects on other indicators, serving as key influencing factors for rural landscape heritage resilience.

Unlike conventional research that employs static or single-dimensional frameworks, this innovative approach examines the dynamic process of systems responding to external disturbances. By deconstructing resilience into three sequentially progressive capacities, it better captures the complex evolution of rural landscape heritage as a "living" system. Furthermore, the study expands its empirical scope from World Heritage sites to more representative traditional villages. These living heritage communities, through continuous use and evolution, vividly demonstrate the micro-level processes of resilience construction, thereby addressing existing research gaps in case diversity and theoretical depth.

However, this study still has several areas requiring further exploration:(1) Regarding the evaluation indicator system, the rural system involves complex elements and multi-level interactions. The richness of information flow and material exchange demands higher completeness and precision in data support. Currently, the statistical scope at the rural level remains relatively broad, which objectively limits the range and accuracy of indicator selection. This results in key concepts reflecting system dynamics and cultural vitality (such as community self-organization capacity and skill inheritance intensity) still relying on indirect proxy indicators. (2) In terms of data acquisition, the resilience classification is primarily based on partial distribution within case areas due to sample size and regional limitations. Future research could enhance the generalizability and transferability of classification standards by comparing with larger-scale evaluation results.

Declarations

Author Contributions

XXX XX: Writing-original draft, Writing-review and editing; XXX XX: Software; Methodology; XXX XX: Software; XXX XX: Conceptualization, Funding acquisition.

Declaration of Competing Interests

The authors declare that they have no conflicts of interest. The opinions expressed here are those of the authors and do not necessarily reflect the position of the government or of any other organization. This study consent to publish this writing in your journal and to transfer copyright to the publisher once this study has been accepted.

Data availability

Data will be made available on request.Includes interview questionnaires, survey questionnaires, survey data, processing formulas, and data analysis results.You can access it in the supplementary file summary.

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Figures

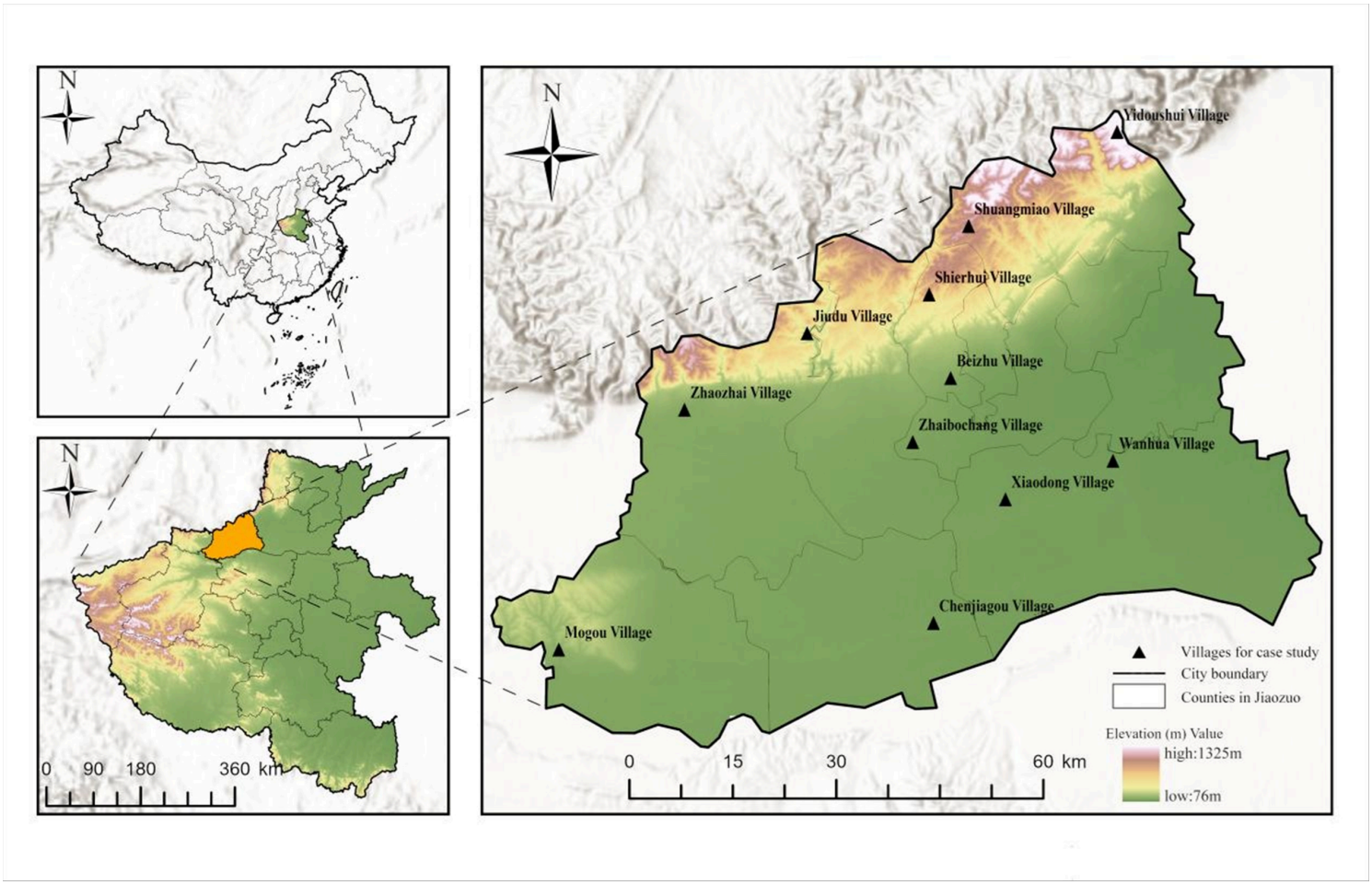


Figure 1

Sample areas of traditional villages in Jiaozuo City

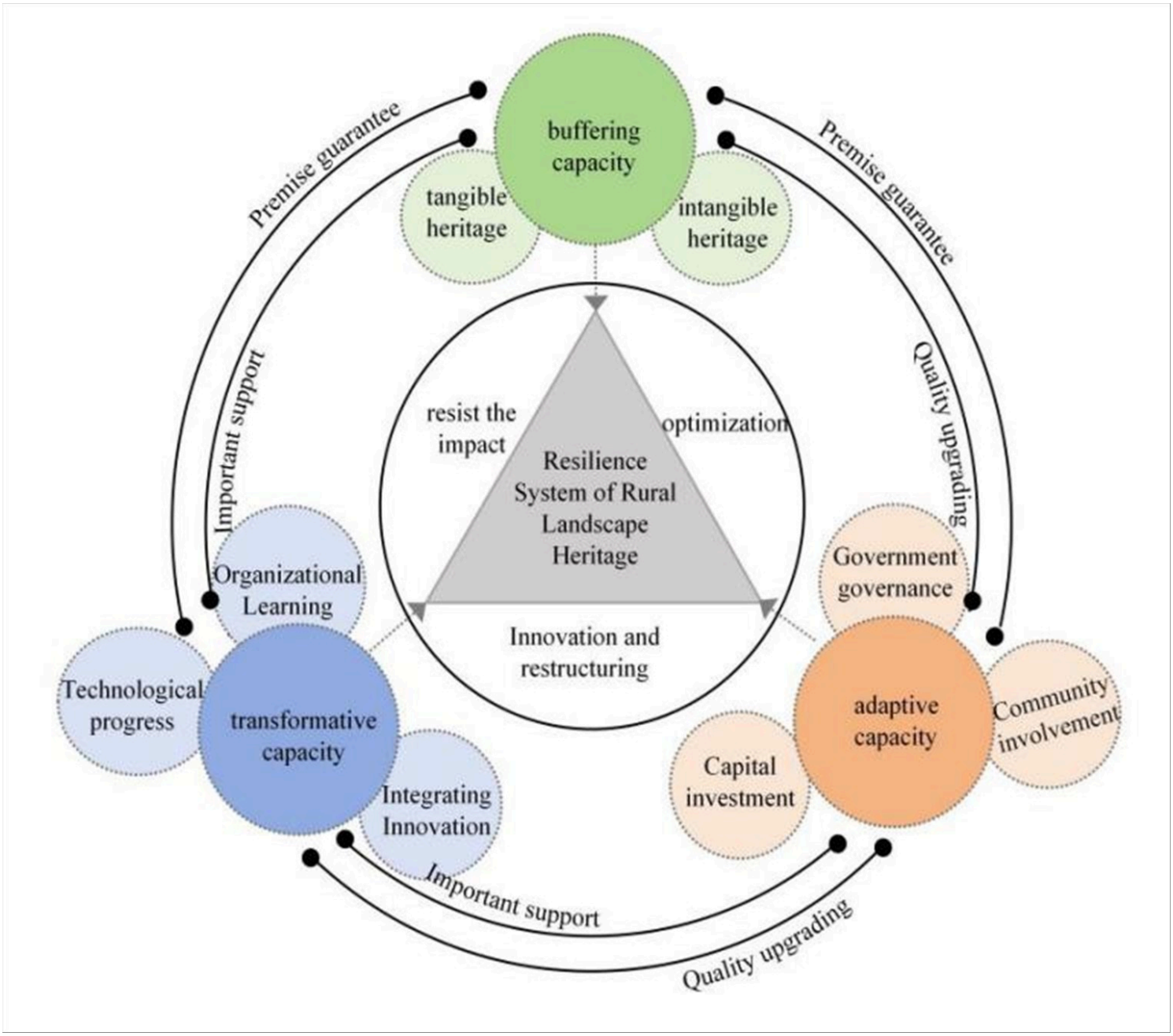


Figure 2

Framework for analyzing the rural landscape heritage resilience

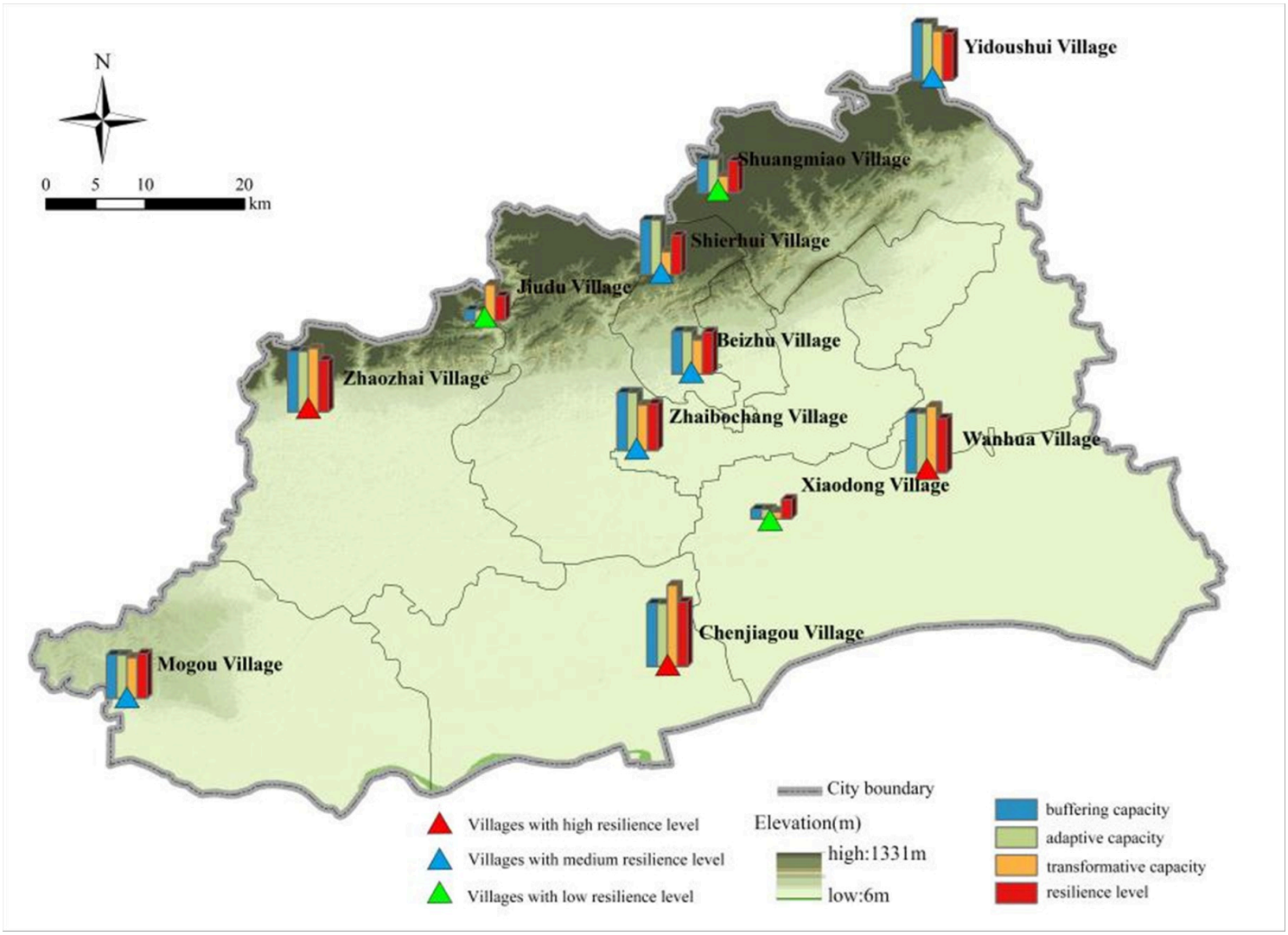
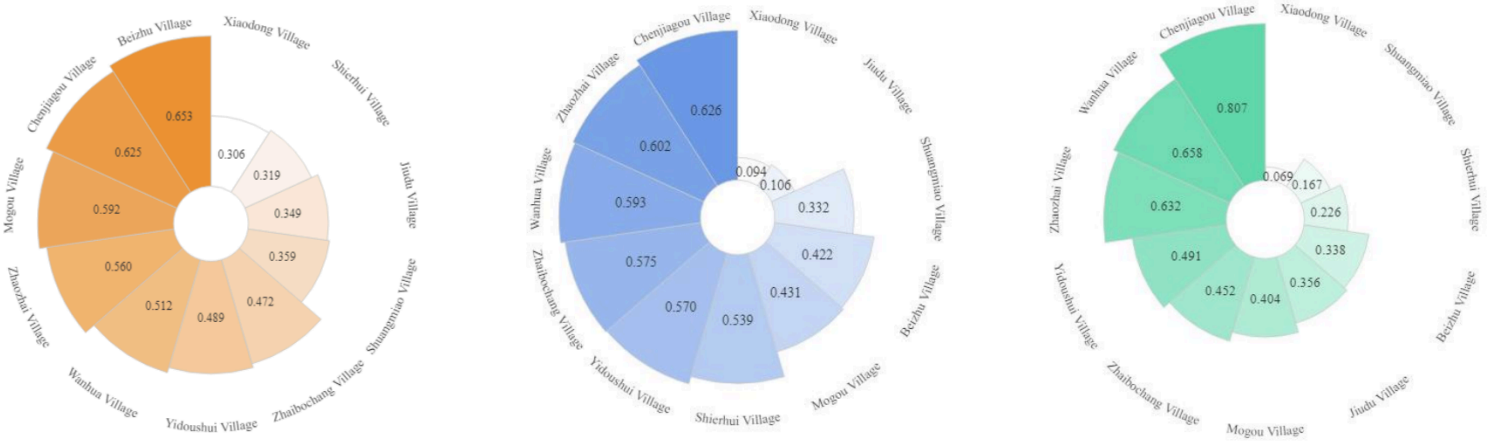


Figure 3

The evaluation results of rural landscape heritage resilience



a) buffering capacity index

b) adaptive capacity index

c) transformative capacity index

Figure 4

Countryside Landscape Heritage Resilience Index

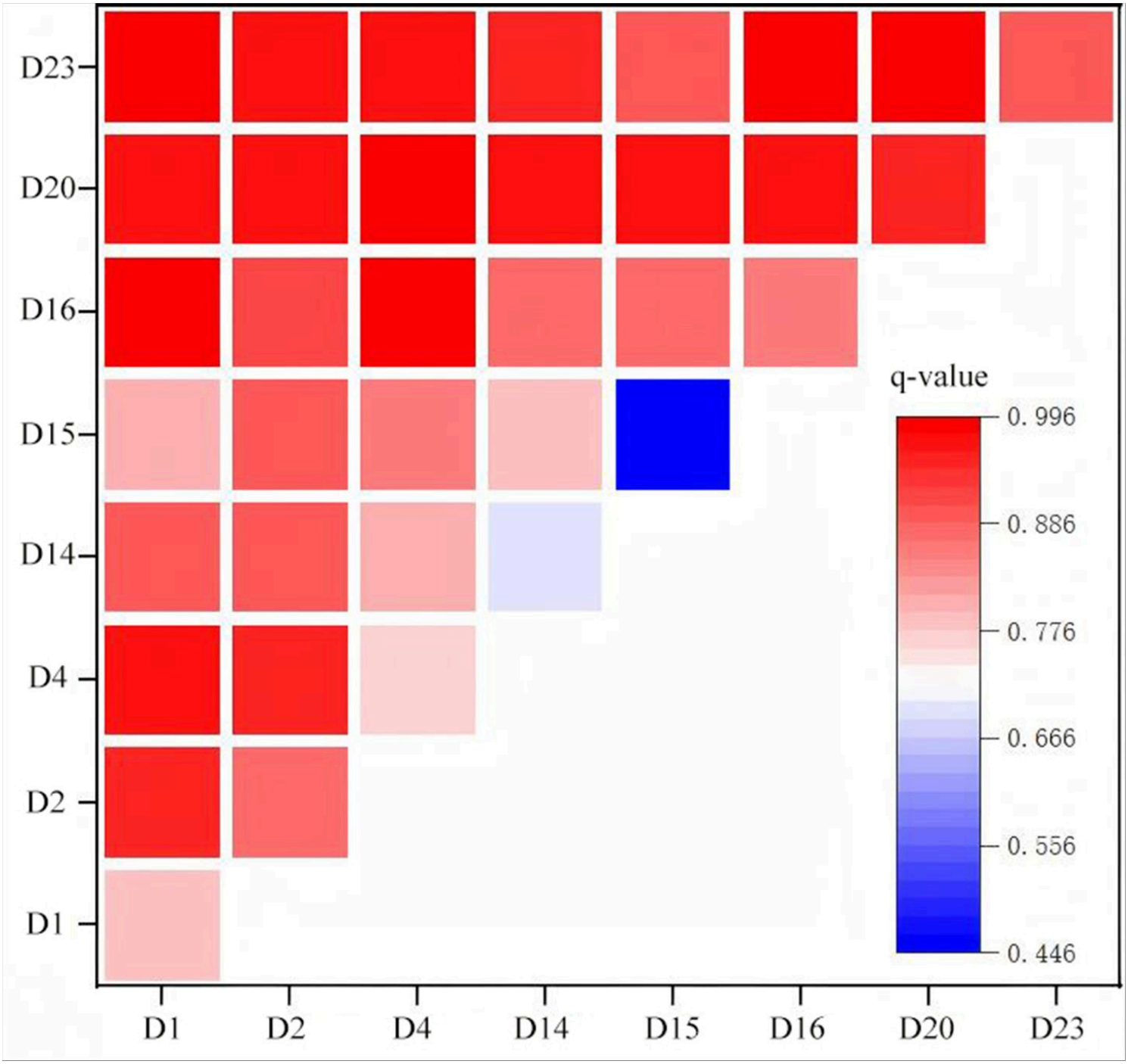


Figure 5

Results of interaction detection of impact factor indicators

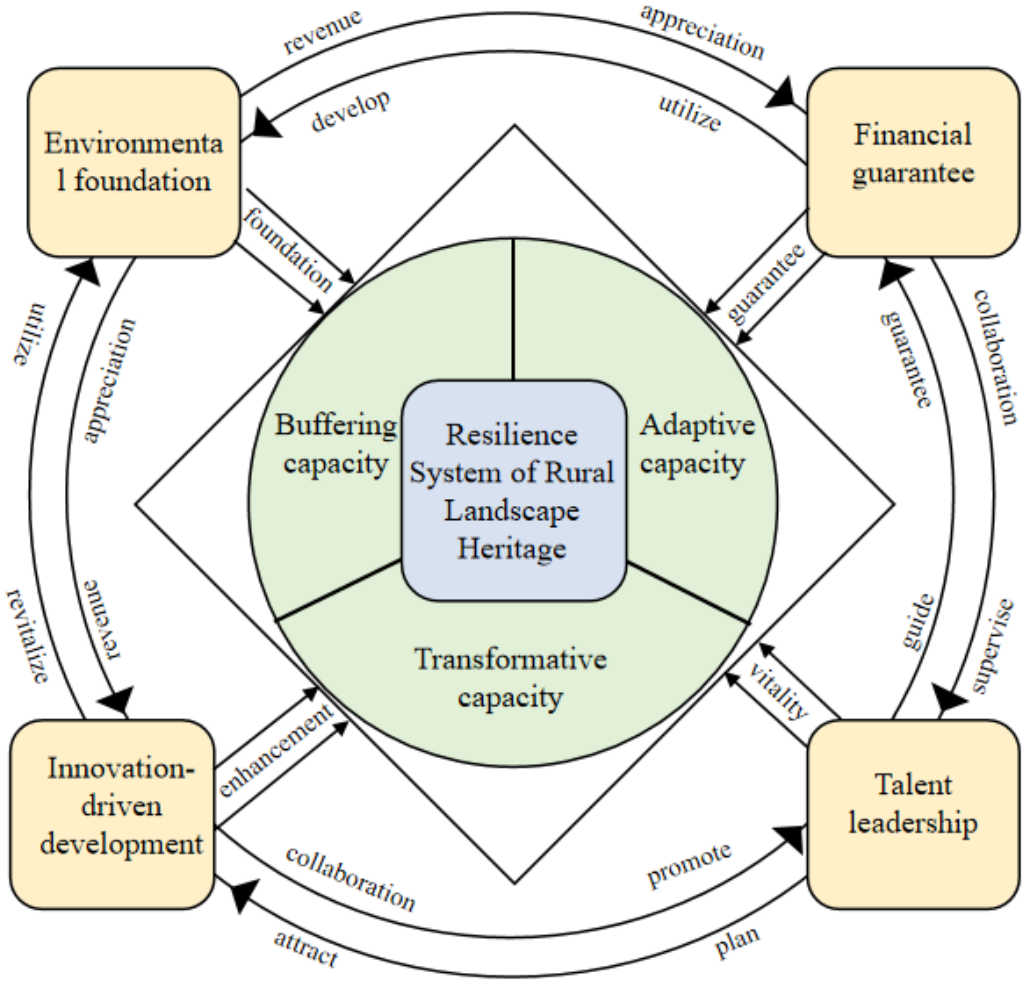


Figure 6

Resilience mechanism analysis diagram

Supplementary Files

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