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A Study on the Reconstruction of Linear Cultural Heritage Corridors and Regional Collaborative Development: The Case of the Shu dao in China

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A Study on the Reconstruction of Linear Cultural Heritage Corridors and Regional Collaborative Development: The Case of the Shu dao in China

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Abstract: As key links connecting regional cultural, economic, and social development, linear cultural heritage corridors have exhibited significant spatial discontinuities and structural fragmentation due to long-term natural evolution and urbanization, resulting in a gradual loss of their regional synergy functions. Based on this, this study adopts a regional coordinated development perspective to construct a research framework comprising "resistance modeling—discontinuity identification—network construction—regional synergy." The study comprehensively employs Geographic Information System (GIS) and Multi-Criteria Decision Analysis (MCDA) methods to establish an integrated resistance evaluation system covering three dimensions: ecological environment, socio-economics, and cultural heritage. Based on the Minimum Cumulative Resistance (MCR) model and cost-path analysis, it identifies potential discontinuous sections of the Shu dao and simulates spatial pathways to explore how linear cultural heritage corridors can drive the coordinated development of the regional cultural and tourism industries. The research results indicate that: (1) The cultural heritage of the Shu dao exhibits a spatial pattern characterized by "core clustering—linear connectivity—peripheral dispersion," with discontinuities primarily concentrated in areas marked by significant modern transportation alternatives and urban expansion; (2) Cultural heritage density is the primary factor influencing the formation of potential corridors, with a weight of 0.29, followed by cultural heritage type (0.17) and slope (0.14); (3) Through the reconstruction of the minimum cumulative resistance path, a four-axis, three-cluster cultural heritage corridor network pattern emerged within the study area, characterized by "northern clustering—central connectivity—eastern and western extensions—southern supplementation." This study expands the value of linear cultural heritage corridors by closely integrating heritage conservation with regional development to achieve living heritage conservation. It can serve as a model for research on world linear cultural heritage sites, such as the Way of St. James in Spain and the Sacred Sites and Pilgrimage Routes in the Kii Mountain Range in Japan.

Introduction

Linear cultural heritage corridors, as an important spatial organizational model that integrates cultural heritage preservation, ecological restoration, and regional development, have garnered widespread attention from the international community in recent years[1,2] (U.S. National Park Service, "What Is a National Heritage Area?", National Heritage Areas: Heritage Areas 101 (2019), https://www.nps.gov/subjects/nationalheritageareas/what-is-a-national-heritage-area.htm). Practices exemplified by the U.S. National Cultural Heritage Corridor[1] and the European Cultural Routes[2] demonstrate that cultural heritage corridors not only promote the holistic preservation and showcase of cultural heritage but also strengthen cultural exchange, resource integration, and economic ties among regions[2,3] (Council of Europe, "Cultural Routes of the Council of Europe: Reference Texts and

Conventions", https://www.coe.int/en/web/cultural-routes/reference-texts-and-conventions). From a spatial perspective, cultural heritage corridors are essentially regional connectivity systems formed on the basis of historical transportation routes and networks of cultural resources. By linking settlements, cultural heritage sites, and ecological spaces along their routes, they construct a cross-regional, multi-level network of spatial connections and serve functions such as facilitating population mobility, the transport of goods, and the dissemination of culture[3]. Therefore, cultural heritage corridors are not only vital vehicles for cultural heritage conservation but also crucial links for promoting regional connectivity and coordinated regional development[2,3].

However, under the combined effects of long-term natural environmental changes and human activity, many linear cultural heritage corridors have gradually experienced issues such as spatial discontinuity, structural fragmentation, and functional decline. While the development of modern transportation systems, urban expansion, and changes in land use have improved regional transportation efficiency, they have also, to some extent, severed the original spatial continuity of historical and cultural heritage corridors[4]. The gradual fragmentation of the corridor network has weakened the cultural and regional connections that were originally fostered by these corridors, not only affecting the holistic presentation of cultural heritage value but also diminishing their role in promoting coordinated regional development[4,5]. It is worth noting that whether in the case of the Erie Canal National Heritage Corridor in the United States, the Camino de Santiago in Europe, or China's Grand Canal and the Ancient Post Roads of Nanyue, the development objectives of these exemplary projects have gradually expanded from the mere preservation of cultural heritage to include regional resource integration, cultural dissemination, and the promotion of regional development[6,7]. For example, the construction of the Grand Canal National Cultural Park emphasizes the coordinated development of cities along its route[6,7], while the development of the Ancient Post Roads of Southern Guangdong promotes the integration of culture and tourism in the region by connecting villages and towns along the route[8,9]. However, existing research has focused primarily on the identification of cultural heritage resources, value assessment, spatial pattern analysis, and conservation and utilization models. While a relatively rich body of research has been produced regarding the protection and revitalization of intact corridors[4,10], there remains a severe lack of research on how to scientifically reconstruct linear cultural heritage corridors and thoroughly explore their relationship with the coordinated development of regional culture and tourism[5,10]. Therefore, how to restore the spatial connections of fragmented cultural heritage corridors, reconstruct the structure of cultural heritage networks, and further leverage their role in linking regional resources and promoting regional coordinated development has become a critical issue that current research on linear cultural heritage corridors urgently needs to address.

China possesses a wealth of linear cultural heritage resources, including iconic cultural routes such as the Great Wall, the Grand Canal, the Silk Road, and the Ancient Tea-Horse Road[11,12]. Throughout history, these linear cultural heritage sites have played vital roles in fostering regional connections, facilitating cultural dissemination, and promoting economic exchange, while profoundly influencing the settlement patterns and regional development models along their routes[11,12]. Among them, the Shu dao, as a major historical transportation corridor and channel for cultural exchange in Southwest China, serves as a prime case study for researching the reconstruction of linear cultural heritage networks and regional coordinated development[4,13]. However, in current conservation practices, research remains primarily focused on the identification and protection of cultural heritage resources, route verification, and the interpretation of cultural value, with relatively insufficient attention paid to the overall network structure of cultural heritage corridors and their regional connectivity functions[4,11]. In particular, against the

backdrop of regional coordinated development, there remains a lack of systematic research on how to restore historical connectivity structures through the reconstruction of cultural heritage corridor networks and further leverage the regional driving role of linear cultural heritage[4,13].

The Shu dao was a vital transportation system connecting the Guanzhong Plain and the Sichuan Basin. Over the course of more than 2,000 years of historical evolution, the Shu dao not only served as a military passage and transportation route but also functioned as a crucial link facilitating economic exchanges, cultural interactions, and population mobility between the Guanzhong and Ba-Shu regions. The Shu dao was not a single, fixed route but rather a complex transportation network that gradually evolved into a system comprising multiple main arteries and branch lines, exhibiting distinct characteristics of multi-path alternatives and dynamic evolution[13]. From a historical development perspective, the embryonic form of the Shu dao can be traced back to the Pre-Qin period, when it primarily consisted of natural mountain trails and rudimentary passageways, serving as a preliminary means of interregional connection[14,15]. By the Qin and Han dynasties, with the intervention of state power, road construction entered a systematic phase. Engineering facilities such as plank roads and mountain passes were gradually improved, forming a network of major routes represented by the Jinniu Road and the Micang Road, among others[14,15]. During the Han, Wei, and Six Dynasties periods, the Shu dao system was further expanded upon its existing framework. During the period of the Three Kingdoms, the Shu Han regime launched multiple northern campaigns via the Shu dao and carried out repairs on key sections such as the Jianmen Pass Passage. During the Northern and Southern Dynasties, the Shu dao became a strategic military artery contested by the northern and southern regimes, serving both troop transport and logistical supply functions. The continuous use and maintenance during this period laid a solid foundation for the comprehensive flourishing of the Shu dao system during the Sui and Tang dynasties[15]. From the Sui and Tang dynasties through the Ming and Qing dynasties, the Shu dao reached its peak of development, with multiple routes coexisting and complementing one another. It played a crucial role in military mobilization, the transport of goods, and cultural exchange, gradually forming a networked structure characterized by the interconnection of “trunk lines, branch lines, and nodes”[13,15]. As a major historical transportation corridor in southwest China, the Shu dao long served as a conduit for population movement, goods transportation, and cultural exchange between the Guanzhong Plain and the Sichuan Basin. Relying on the transportation network formed by the Shu dao, towns, settlements, and various cultural heritage sites along its route were able to develop sustainably, gradually shaping the unique regional connectivity pattern of northern Sichuan. However, since the modern era, with the rise of modern transportation systems and the decline of traditional transportation functions, the original routes of the Shu dao have gradually been replaced. A large number of sections have been abandoned or damaged, transforming what was once a continuous transportation corridor into spatially dispersed fragments of cultural heritage[16,17]. Most of the surviving cultural heritage is scattered in the form of bridges, plank-road ruins, mountain passes, and ancient trail remnants; the overall corridor structure has been disrupted, exhibiting distinct characteristics of fragmentation and discontinuity[16,17] (Fig. 1). This transformation from a “continuous transportation network” to a “fragmented cultural heritage space” not only complicates the overall conservation and interpretation of the Shu dao’s value but also leads to the gradual weakening of the regional connectivity network formed throughout history, thereby diminishing the potential for the integration of cultural resources along the route, the coordinated development of culture and tourism, and regional interaction. Therefore, identifying the spatial fragmentation of the Shu dao, reconstructing the cultural heritage corridor network, restoring its historical connectivity, and further leveraging its role in linking regional resources and promoting coordinated development in Northern

Sichuan have become urgent issues requiring resolution in current research on the conservation and utilization of the Shu dao.

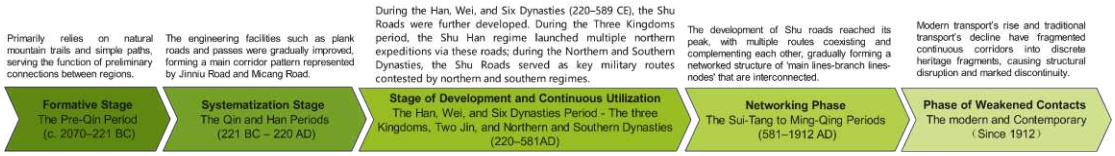


Fig. 1 Timeline of the development of the Shu dao

In recent years, with the ongoing efforts to secure World Heritage status for the Shu dao and the implementation of the "Archaeology China" Shu dao research project, studies on the Shu dao have yielded fruitful results[17,18]. Current research primarily focuses on the verification of the Shu dao's routes and historical evolution, surveys of cultural heritage along the route, analysis of regional landscape characteristics, interpretation of cultural value, and the protection and utilization of cultural heritage. Through methods such as textual criticism, archaeological surveys, and GIS spatial analysis, scholars have continuously refined the route identification system for the Shu dao, revealing its significant historical role in transportation, military defense, trade, and cultural exchange[17,18]; simultaneously, they have explored pathways for the comprehensive conservation and revitalization of the Shu dao from perspectives such as cultural routes, cultural heritage corridors, and landscape genes[15], providing important theoretical support for the conservation and management of the Shu dao. However, existing research has focused primarily on identifying the historical routes of the Shu dao, surveying cultural heritage resources, and interpreting cultural values, while paying relatively less attention to the spatial organizational characteristics of the Shu dao as a regional connectivity network. Existing studies on cultural heritage corridors have mainly focused on linking and protecting cultural heritage resources along the route, lacking a systematic analysis of the Shu dao's overall network structure, patterns of spatial discontinuity, and the mechanisms underlying their formation[12,19]. At the same time, most studies treat the Shu dao as a carrier of cultural heritage, with few exploring its historical functions and contemporary value from the perspectives of regional connectivity and development[12,15]. In fact, the Shu dao is not only a vital transportation corridor linking the Guanzhong Plain and the Sichuan Basin but also a crucial spatial framework that has long shaped population mobility, resource exchange, and cultural dissemination in northern Sichuan[15,18]. With the restructuring of the modern transportation system, the Shu dao's original network of connections has gradually been fragmented, and its role in supporting regional connectivity and resource integration has steadily weakened[15]. However, systematic research remains lacking on how to identify fragmented sections, how to reconstruct the cultural heritage corridor network, and whether the reconstructed cultural heritage network can restore the historical connectivity structure and promote coordinated regional development in northern Sichuan. Overall, existing research has provided an important foundation for understanding the historical evolution of the Shu dao, as well as the value and conservation and utilization of its cultural heritage; however, insufficient attention has been paid to the restoration of spatial continuity, the optimization of network structures, and the effects on regional coordinated development involved in the Shu dao's transformation from a "historical transportation network" to a "cultural heritage corridor network"[12,19]. In particular, against the backdrop of national regional coordinated development and the holistic protection of cultural heritage, there is an urgent need to reexamine the conservation and utilization value of the Shu dao from the perspective of reconstructing regional connectivity networks[15,20].

In summary, although existing research has yielded rich results in areas such as the verification of the Shu dao's routes, cultural heritage surveys, and value assessments, there remains a lack of

systematic exploration regarding the characteristics of spatial discontinuities along the Shu dao, pathways for reconstructing the cultural heritage network, and its effects on regional coordinated development. At the same time, current research on cultural heritage corridors focuses more on cultural heritage protection itself, with insufficient attention paid to the mechanisms through which cultural heritage corridors promote regional coordinated development. Based on this, this paper takes the Shu dao (Sichuan section) as its research object and constructs a research framework of "resistance modeling—discontinuity identification—network construction—regional synergy." Through field surveys, the Analytic Hierarchy Process (AHP), and the Minimum Cumulative Resistance (MCR) model, this study clarifies the current state of spatial discontinuities along the Shu dao, reconstructs the Shu dao cultural heritage corridor network by integrating ecological, environmental, socioeconomic, and cultural value factors, and explores the Shu dao's role in promoting the current and future cultural and tourism industries in Northern Sichuan from the perspective of regional coordinated development, with the aim of providing new theoretical perspectives and practical pathways for global research on the conservation of linear cultural heritage and coordinated regional development. To achieve these objectives, this study will address the following questions in sequence.

(1) What is the spatial distribution pattern of the existing cultural heritage along the Shu dao (Sichuan section), and what is the current state of its spatial fragmentation?

(2) What is the resistance model for reconstructing the Shu dao cultural heritage corridor, and what are its key influencing factors? How do these factors operate in the reconstruction of the corridor network?

(3) What spatial pattern will the reconstructed cultural heritage corridor network form in the region, and how will it synergize with the development of the region's cultural and tourism industries?

Study area and research framework

Study area

This study focuses on the Shu dao (Sichuan section). The study area (Fig. 2) encompasses seven prefecture-level cities in Sichuan Province: Chengdu, Mianyang, Deyang, Guangyuan, Bazhong, Nanchong, and Suining (103.95° to 107.15° E, 30.25° to 32.90° N), The specific subjects of study encompass cultural heritage sites of the Shu dao, such as plank walkways, stone-paved paths, bridges, and stone-slab roads. This study focuses on the Shu dao itself (corridor relics such as plank roads, stone-paved paths, bridges, and stone-slab roads). At the same time, considering that the spatial distribution of cultural heritage sites along the route can, to a certain extent, reflect the clustering characteristics of regional cultural resources, this study treats the cultural heritage sites along the Shu dao as auxiliary objects of analysis to characterize the impact of cultural resource distribution on the spatial connectivity of the corridor. It should be noted that the cultural heritage sites along the route are not the direct subject of reconstruction in this study; their primary role is to assist in characterizing the regional cultural spatial features and to provide a basis for the identification and construction of the Shu dao corridor network. Existing research has largely focused on the Shaanxi section of the Shu dao, while systematic studies of the Sichuan section remain insufficient. This research gap constitutes the main entry point for this study and also confers academic significance on it in terms of regional cultural heritage understanding and holistic conservation.

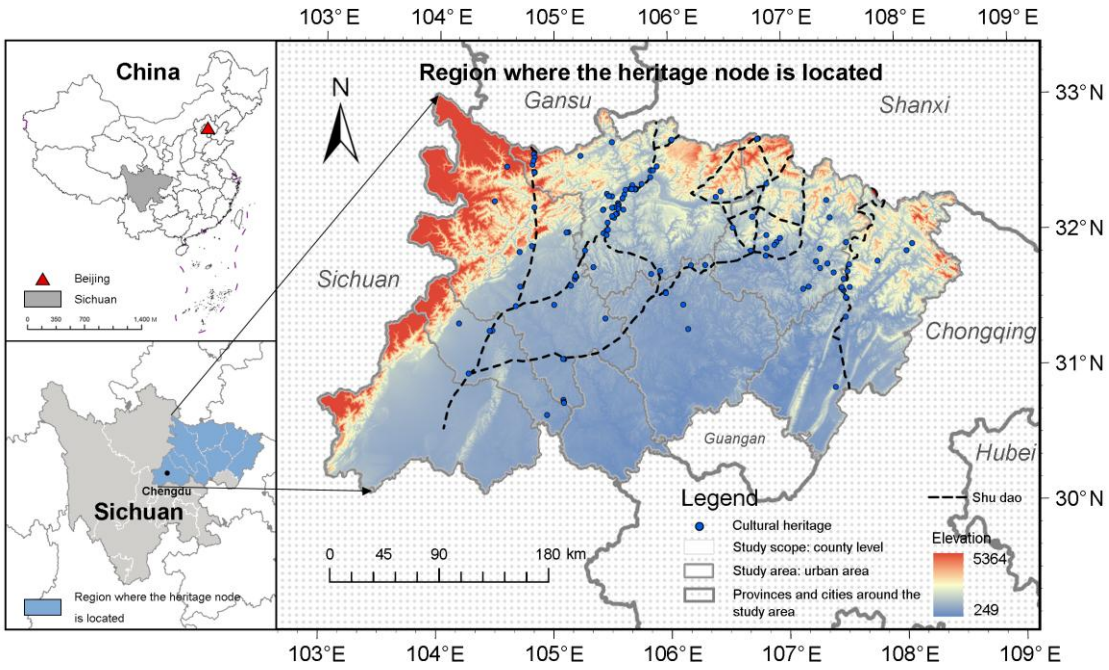


Fig. 2 Map of the study area

Research framework

First, through methods such as literature review, historical map interpretation, remote sensing image analysis, and field surveys, we systematically identified and cataloged the existing remains of the Shu dao (Sichuan section), established a basic database for the Shu dao, and identified its cultural heritage. Second, based on Multi-Criteria Decision Analysis (MCDA) theory and incorporating factors such as the ecological environment, socioeconomic conditions, and cultural heritage, we constructed an evaluation indicator system for resistance factors in the Shu dao cultural heritage corridor. We used the Analytic Hierarchy Process (AHP) to determine the weights of each indicator and, through consistency checks ($CR < 0.1$), developed an evaluation model for resistance in the Shu dao cultural heritage corridor. Subsequently, the evaluation indicators were standardized and assigned resistance values; single-factor resistance surfaces were constructed for each indicator and then weighted and superimposed based on their respective weights to form a comprehensive resistance surface for the Shu dao cultural heritage corridor. Finally, using the Shu dao heritage sites and the endpoints of the ancient trail segments as key nodes, cost-distance analysis and minimum-cost path analysis were conducted based on the comprehensive resistance surface to identify potential discontinuities in the Shu dao. The disconnected sections of the corridor were then connected and reconstructed, ultimately establishing a Shu dao cultural heritage corridor network system that provides a basis for spatial optimization in the holistic protection and continuous transmission of the Shu dao (Fig. 3).

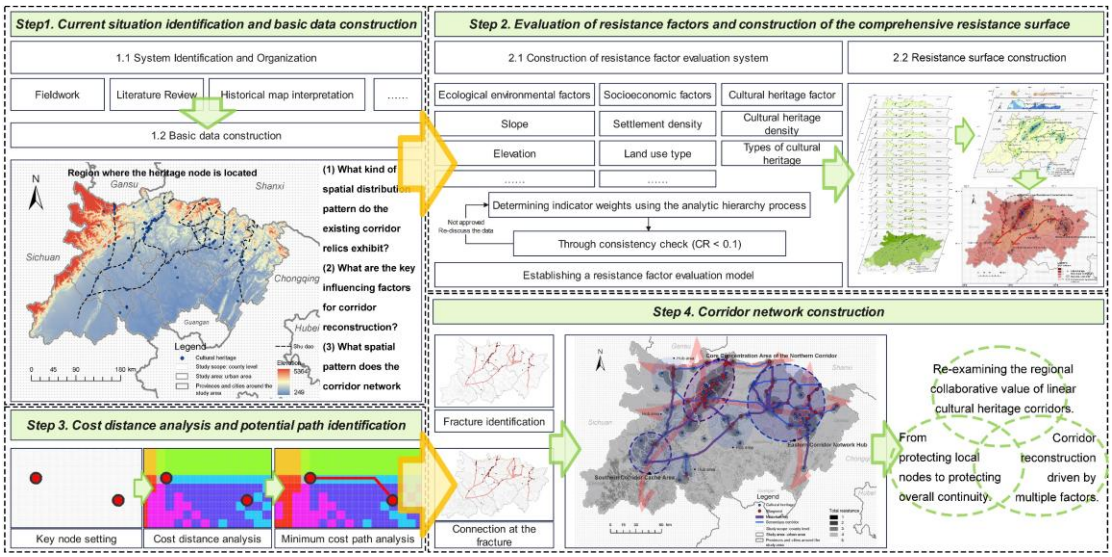


Fig. 3 Research framework

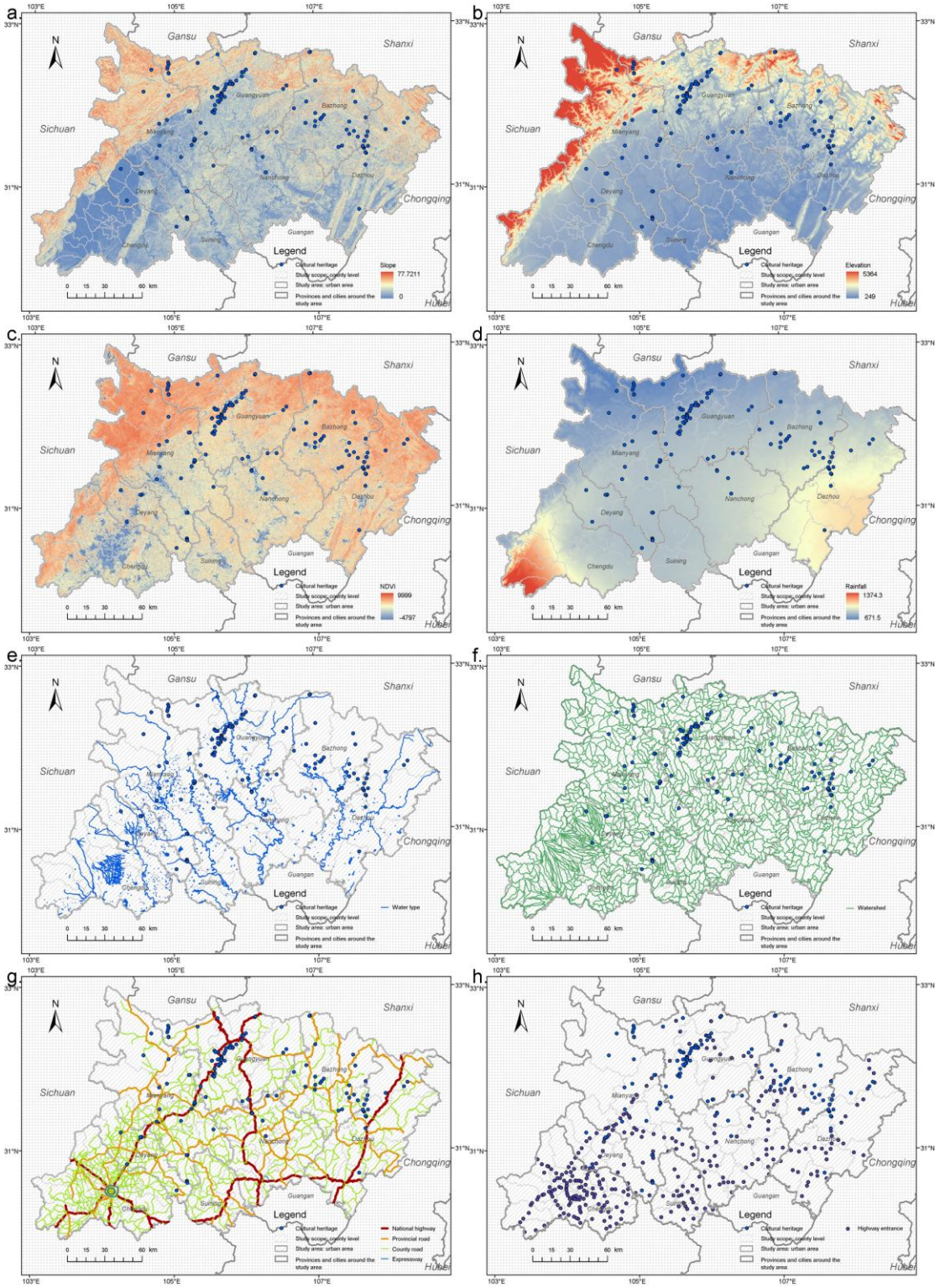
Method

Field survey

This study conducted a 31-day systematic field survey from September 3 to October 3, 2025. Based on preliminary data organization, a review of historical documents, and the interpretation of remote sensing imagery, the survey provided a comprehensive preliminary assessment of the existing corridor remains and potential route segments of the Shu dao (Sichuan section), thereby identifying key survey areas and representative route segments. The study covered approximately 90% of the administrative areas, with the sections surveyed on-site accounting for about 70% of the total length of the Shu dao's existing route. Unlike traditional surveys focused on individual cultural heritage sites along the route, this study focused on the Shu dao's corridor remains and their spatial continuity, covering a total of 49 sites, including plank roads, stone-paved paths, and bridges, with a total of 153 cultural heritage sites along the Shu dao. By integrating environmental factors such as river valleys, water systems, and settlements, this study also provides a solid foundation for subsequent identification of discontinuities, construction of comprehensive resistance surfaces, and the establishment of the Shu dao linear cultural heritage corridor, as well as for coordinated regional development.

Data Sources and Preprocessing

The data sources, data types, and spatial resolutions of each indicator are shown in Tab. 1. This study established a comprehensive resistance evaluation system based on three dimensions—ecological environment, socioeconomic factors, and cultural heritage—and further selected NDVI, elevation, slope, precipitation, settlement density, land use types, and cultural heritage types as sources for third-level indicators (Fig. 4). Due to differences in data formats, spatial resolutions, and units among the various indicators, the raw data were first subjected to coordinate transformation, study area cropping, rasterization, and resampling, and standardized to a spatial resolution of 30 m × 30 m to provide a foundation for the subsequent calculation of the comprehensive resistance surface.


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Nanchong
Dazhou
Deyang
Chengdu
Suining
Guangan
N
103°E
105°E
107°E
33°N
31°N
0 15 30 60 km
Legend
Cultural heritage
Study scope: county level
Study area: urban area
Provinces and cities around the study area
Slope
77.7211
0
Elevation
5364
249
NDVI
9999
-4797
Rainfall
1374.3
671.5
Water type
Watershed
National highway
Provincial road
County road
Expressway
Highway entrance

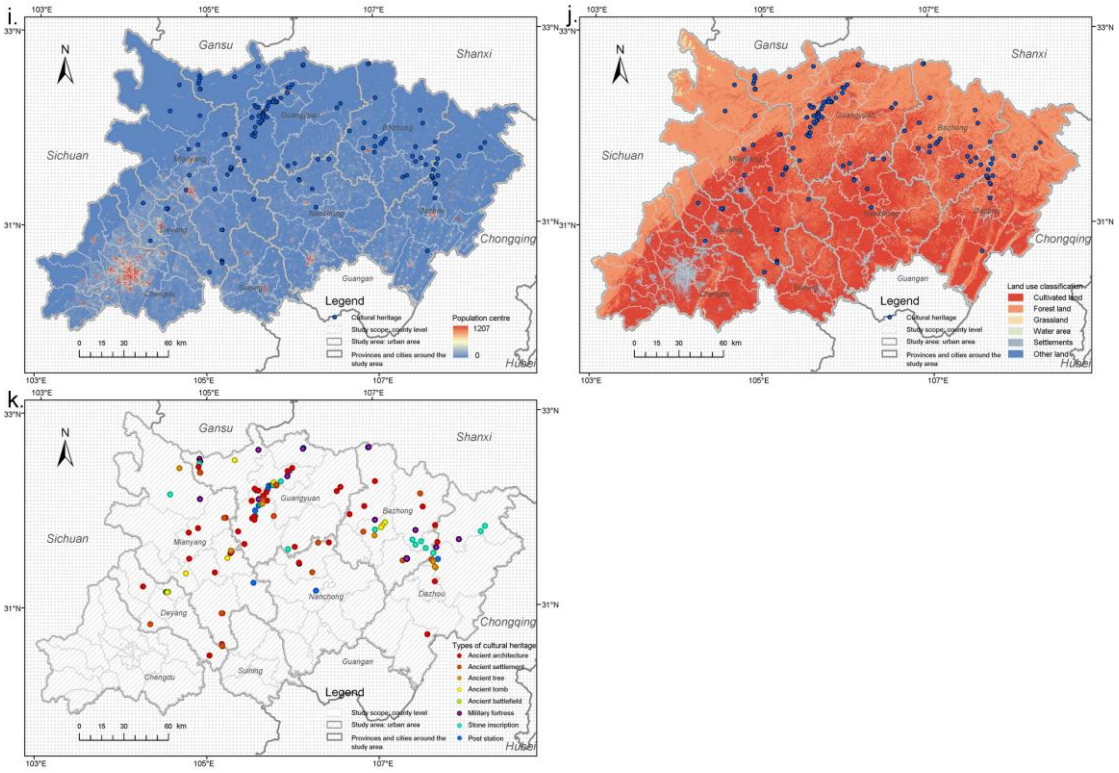


Fig.4 Basic Data for the Study (a. Slope, b. Elevation, c. NDVI, d. Rainfall, e. Water type, f. Watershed, g. Roads（including national highways, provincial road, and county road, as well as expressways）, h. Highway extrance, i. Population centre, j. Land Use classfication, k. Types of cultural heritage)

Tab. 1 Details of the study's baseline data

Data name	ID	Data source	Data type	Spatial resolution
Slope	a.	https://www.ngcc.cn/dlxxzy/gjjcdlxxsjk/	Raster data	30m×30m
Elevation	b.	https://www.ngcc.cn/dlxxzy/gjjcdlxxsjk/	Raster data	30m×30m
NDVI	c.	https://earthengine.google.com/	Raster data	30m×30m
Rainfall	d.	https://www.ngcc.cn/dlxxzy/gjjcdlxxsjk/	Raster data	30m×30m
Water type	e.	https://www.ngcc.cn/dlxxzy/gjjcdlxxsjk/	Raster data	30m×30m
Watershed	f.	https://www.ngcc.cn/dlxxzy/gjjcdlxxsjk/	Raster data	30m×30m
Roads（including national highways, provincial road, and county road, as well as expressways）	g.	https://www.ngcc.cn/dlxxzy/gjjcdlxxsjk/	Raster data	30m×30m
Highway extrance	h.	https://www.ngcc.cn/dlxxzy/gjjcdlxxsjk/	Vector Point Data	30m×30m
Population centre	i.	Chen, Yuehong, Congcong Xu, Yong Ge, Xiaoxiang Zhang, and Ya'nan Zhou. "A 100 M Gridded Population Dataset of China's Seventh Census Using Ensemble Learning and Big Geospatial Data." Earth System Science Data,16(8), 3705-3718, 2024	Vector Point Data	30m×30m
Land Use classfication	j.	https://earthengine.google.com/	Raster data	30m×30m
Types of cultural heritage	k.	Field survey records	Vector Point Data	30m×30m

Comprehensive evaluation method for the reconstruction of linear cultural heritage corridors

Determination of weights based on the pairwise comparison method

Following preliminary surveys and discussions among multiple experts, resistance factors were identified, and the resistance grading method was employed to standardize each indicator. Based on the

historical patterns of traffic along the Shu dao and relevant research findings, each indicator was classified into different resistance levels and assigned corresponding resistance values (1–9). After finalizing the questionnaire for the comprehensive resistance evaluation of the Shu dao cultural heritage corridor indicators, the pairwise comparison method was used to calculate the indicator weights. Twelve experts were invited to conduct pairwise comparisons of indicators at each level, construct individual judgment matrices, and perform consistency checks (CR < 0.10). A total of 12 questionnaires were distributed and 12 were returned, resulting in a 100% response rate, with all 12 questionnaires deemed valid. Subsequently, the validated expert judgment matrices were aggregated using the geometric mean method to calculate the group weights and conduct a consistency check. The results showed that both the individual judgment matrices of the 12 experts and the group judgment matrix met the requirement of CR < 0.10. The final weights for each evaluation indicator were thus obtained and used to construct the comprehensive resistance matrix.

The final weights for the comprehensive resistance evaluation indicators of the Shu dao Cultural Heritage Corridor are determined as follows (Tab. 2); detailed weights are provided in Appendix 1.

Tab. 2. Evaluation Indicator System for Resistance Factors of the Shu dao (Sichuan Section) Cultural Heritage Corridor (Excerpt)

Primary resistance factor	Primary weight	Secondary resistance factor	Secondary weight
Ecological and environmental resistance value	0.37	Slope/（°）	0.14
		Elevation/（m）	0.07
		Normalised Difference Vegetation Index（NDVI）	0.08
		Hydrological process factors	0.08
Socioeconomic resistance value	0.17	Transport accessibility/（m）	0.08
		Settlement density	0.03
		Land use type	0.06
Cultural Heritage resistance value	0.46	Cultural heritage density	0.29
		Types of cultural heritage	0.17

Method for constructing a comprehensive resistance surface

To scientifically reconstruct the Shu dao linear cultural heritage corridor, this paper constructs a comprehensive resistance surface based on the results of a multi-factor comprehensive evaluation. Taking into account the characteristics of the mountainous environment where the Shu dao is located and the spatial distribution of cultural heritage sites, indicators such as elevation, slope, land use type, distance to water bodies, and distance to roads were selected to establish a system of resistance factors, and the weights of each indicator were determined using the Analytic Hierarchy Process (AHP). Subsequently, using GIS spatial analysis methods, each evaluation indicator was rasterized and assigned resistance values to form single-factor resistance surfaces.

(1) Construction of Single-Factor Resistance Surfaces

Based on the ArcGIS platform, this study constructed single-factor resistance surfaces corresponding to each evaluation indicator. Specifically, this included: extracting elevation and slope factors based on DEM data; investigating the influence of vegetation on the formation of the Shu dao based on the Normalized Difference Vegetation Index (NDVI); calculating distance-attenuation resistance based on river and modern road data; constructing land-use resistance surfaces based on land-use data; assessing the suitability of corridor construction based on the density of human settlements in Sichuan Province; and establishing a cultural heritage orientation factor based on the distribution of Shu dao cultural heritage sites. Each factor expresses spatial resistance characteristics in raster form, with a

uniform raster resolution of 30 m × 30 m (Fig. 5).

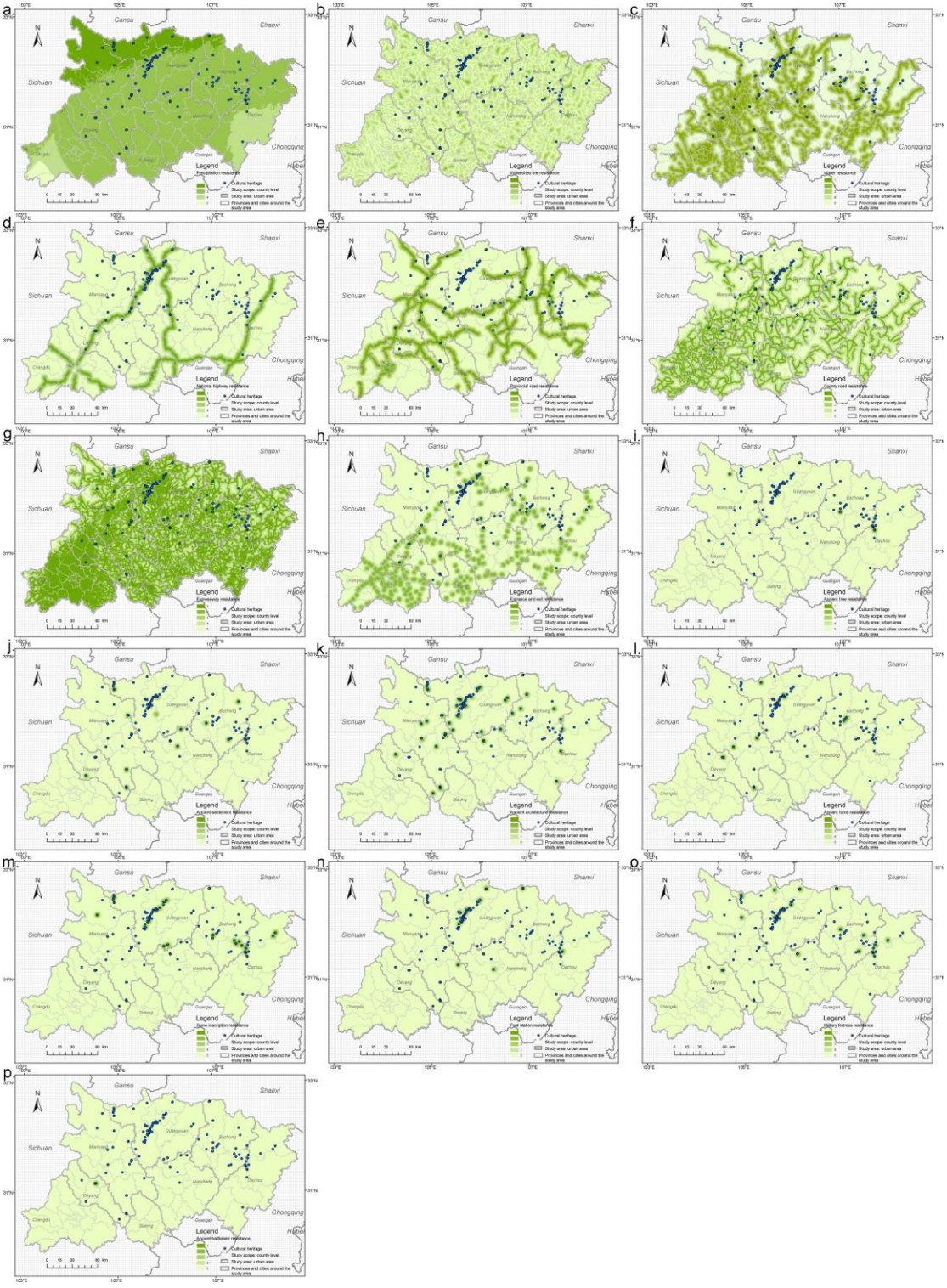


Fig. 5 Various third-level resistance surfaces. (a. Precipitation resistance surface, b. Watershed line resistance surface, c. Water resistance surface, d. National highway resistance surface, e. Provincial road resistance surface, f. County road resistance surface, g. Expressway resistance surface, h. Entrance and exit resistance surface, i. Ancient tree resistance surface, j. Ancient settlement resistance surface, k. Ancient architecture resistance surface r, l. Ancient tomb resistance surface , m. Stone inscripton resistance surface, n. Post station resistance surface, o. Military fortress resistance surface, p. Ancient Battlefield resistance surface. Each barrier is divided into 5 levels; as the color becomes lighter, the barrier increases, making it more suitable for corridor connectivity.)

(2) Superposition of Composite Resistance Surfaces

After the single-factor resistance surfaces have been constructed, the weighted superposition method is used to construct the composite resistance surface. The calculation formula is as follows:

$$R = \sum_{i=1}^{n} W_i \times X_i$$

Here, R represents the comprehensive resistance value; W_i is the weight of the i-th evaluation indicator; X_i is the resistance value of the corresponding factor; and n is the number of evaluation indicators.

Subsequently, the Weighted Overlay tool in ArcGIS was used to perform a weighted overlay of the individual resistance surfaces for each factor, ultimately generating the comprehensive resistance surface for the Shu dao cultural heritage corridor. A lower comprehensive resistance value indicates that the area is more consistent with traffic flow patterns and is more likely to form a potential cultural heritage corridor route.

Construction of the Corridor Network

The construction of a corridor network is a core component in achieving spatial connectivity among cultural heritage nodes. In selecting a method for corridor construction, this study attempted to use the hydrological analysis analogy method and the ArcGIS Optimal Region Connections tool to extract corridors; however, the former lacks direct constraints on cultural heritage nodes, while the latter generates some paths that do not adequately respond to spatial variations in comprehensive resistance, making it difficult to meet the requirements for networked connections among cultural heritage nodes. Therefore, this study constructs potential cultural heritage corridors based on the Minimal Cumulative Resistance (MCR) model's cost-distance–cost-path pairwise connection method. Using cultural heritage nodes as connection objects and comprehensive resistance surfaces as the cost basis, the study calculates the paths of minimal cumulative resistance between nodes to form a potential corridor network. The MCR model posits that establishing connections between different spatial units requires overcoming landscape resistance, and that the propagation process tends to follow the direction of minimum cumulative resistance. Therefore, the optimal connection path between nodes can be characterized by the minimum cumulative resistance value. Its basic expression is:

$$MCR = f_{min} \sum_{i=1}^{n} (D_{ij} \times R_i)$$

Here, MCR denotes the minimum cumulative resistance; D_{ij} denotes the spatial distance from the source to the destination unit; R_i denotes the resistance value of the corresponding unit; and f_{min} denotes the minimum resistance function.

This study ultimately adopted a pairwise connection strategy: pairing the Shu dao cultural heritage nodes in pairs (Tab. 3), and for each source-destination node pair, sequentially performing cost-distance and cost-path analyses to generate the minimum-cost path connecting that pair of nodes. Since batch methods such as Optimal Region Connections tend to degenerate into geometric straight-line connections when numerical differences in the resistance surface are insignificant, the pair-by-pair connection method—though computationally intensive—ensures that each path is planned in strict accordance with the resistance surface. Finally, the paths generated for all node pairs were merged to obtain the initial structure of the Shu dao (Sichuan section) cultural heritage corridor network.

Tab. 3 Number of nodes along each route of the Shu dao

Shu dao	Yinping Road	Jinniu Road	Micang Road	Lizhi Road
Number of nodes along the route	11	61	24	20
Percentage	9%	53%	21%	17%

Results

Classification of Key Remains of the Shu dao

This study surveyed and documented a total of 49 Shu dao remains, which were classified into five types (Tab. 4): Plank road, mountain foot path, paved stone road, bridges and horse barrier wall. Among these, bridges accounted for the highest proportion at 46%, while stone-paved paths and horse barrier wall accounted for the lowest proportions at 4% (Fig. 6). The Shu dao sites are concentrated in the north, extend through the central region, and are scattered in the east and south, exhibiting a combination of point-like clusters and strip-like distributions. In the north, sites in Jiange, Zhaohua, and Lizhou are dense and diverse in type, forming a clustered area; in the central region, the number decreases, with a scattered distribution; while the eastern and southern regions consist primarily of a small number of dispersed nodes. The combination of multiple site types reflects spatial complexity. Overall, the distribution exhibits the characteristics of an unbalanced pattern comprising clustered areas, transitional zones, and dispersed areas.

Tab. 4 Statistics on the types of Shu dao remains

Types of Shu dao Remains	Number	Percentage	Regions
Plank road	11	22%	Bazhong , Guangyuan
Mountain foot path	2	4%	Bazhong , Guangyuan
Paved stone road	12	24%	Deyang , Bazhong , Nanchong , Guangyuan
Bridges	22	46%	Nanchong , Guangyuan , Dazhou
Horse barrier wall	2	4%	Guangyuan

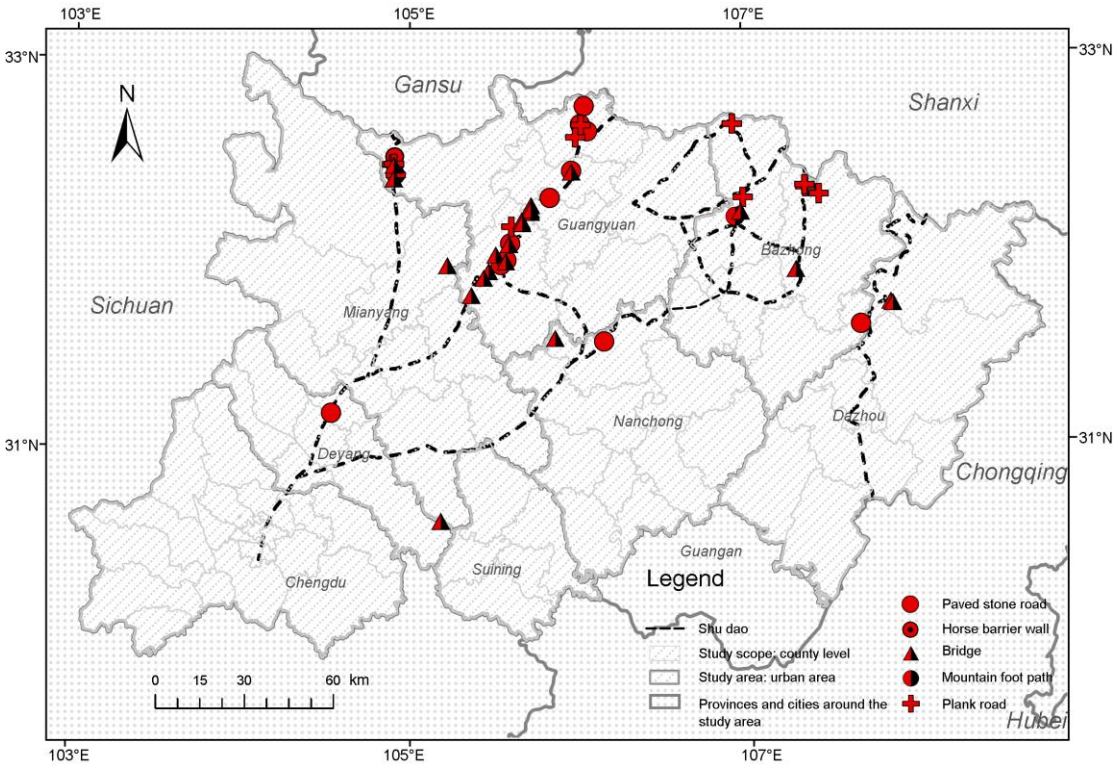


Fig. 6 Distribution of Shu dao archaeological site types

Analysis of Resistance Factors for Corridor Reconstruction

Single-Factor Resistance Analysis

1) Ecological and Environmental Resistance

Resistance values are rated on a scale of 1 to 5, where 1 indicates low resistance and 5 indicates high resistance; see Appendix Table 1 for specific scoring criteria. Ecological and environmental resistance is composed of slope, elevation, NDVI, and hydrology (Tab. 5). As shown in Fig. 7, slope resistance exhibits relatively distinct spatial variation. Overall, resistance levels are more concentrated in the southwestern and western parts of the study area, while the northeastern and eastern parts are dominated by continuous areas of medium-to-low resistance levels. Compared to factors such as slope, elevation, and NDVI, hydrological resistance exhibits more pronounced network-like spatial characteristics.

Tab. 5 Percentage distribution of ecological and environmental resistance factors by resistance value

Resistance factor	1 point	2 points	3 points	4 points	5 points	Average resistance
Slope	18.68%	18.68%	15.15%	13.55%	37.45%	3.43
Elevation	78.22%	11.87%	6.76%	2.50%	0.65%	1.35
NDVI	78.65%	14.11%	5.11%	2.12%	0.01%	1.31
Hydrology	0.20%	26.33%	35.98%	37.39%	0.1%	3.11

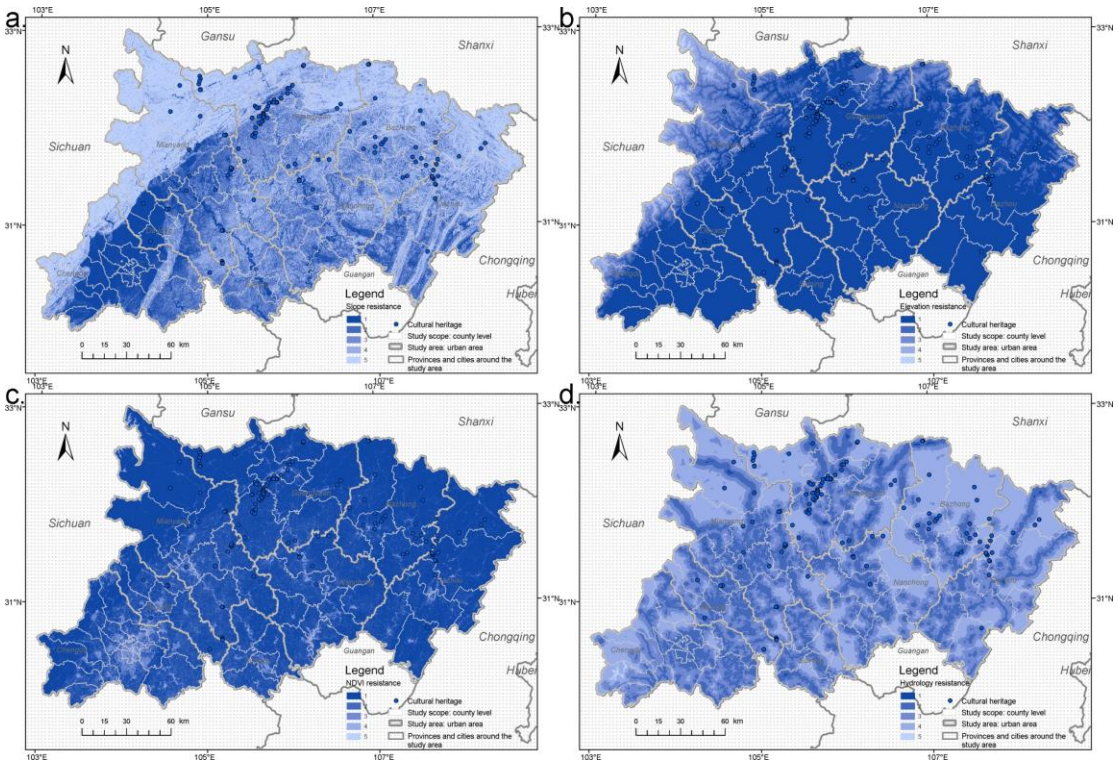


Fig. 7 Distribution of various ecological and environmental resistance factors at different levels (a. Slope, b. Elevation, c. NDVI, d. Hydrology)

By integrating these four factors and based on the standardization of ecological environment-related evaluation factors and the assignment of resistance values, a comprehensive ecological resistance map for the study area was constructed (Fig. 8). As shown in the figure, the ecological resistance of the Shu dao exhibits distinct spatial variation, with higher resistance generally observed in the north and northwest and lower resistance in the central and southern regions. Areas of low resistance are primarily concentrated in the Chengdu–Deyang region, forming a relatively continuous cluster of low-resistance zones; areas of high resistance are mainly distributed in the northwestern part of the study area, exhibiting a concentrated and contiguous pattern; the Bazhong–Dazhou region is characterized by moderate resistance, while the central Nanchong area and its surroundings display distinct transitional characteristics. Overall, ecological and environmental resistance in the study area gradually transitions from the low-resistance zone in the southwest to the high-resistance zone in the northwest, with a transitional zone of moderate resistance forming in the east. There is a distinct spatial gradient between different resistance levels, providing a foundation for the subsequent identification of spatial connections under ecological and environmental constraints.

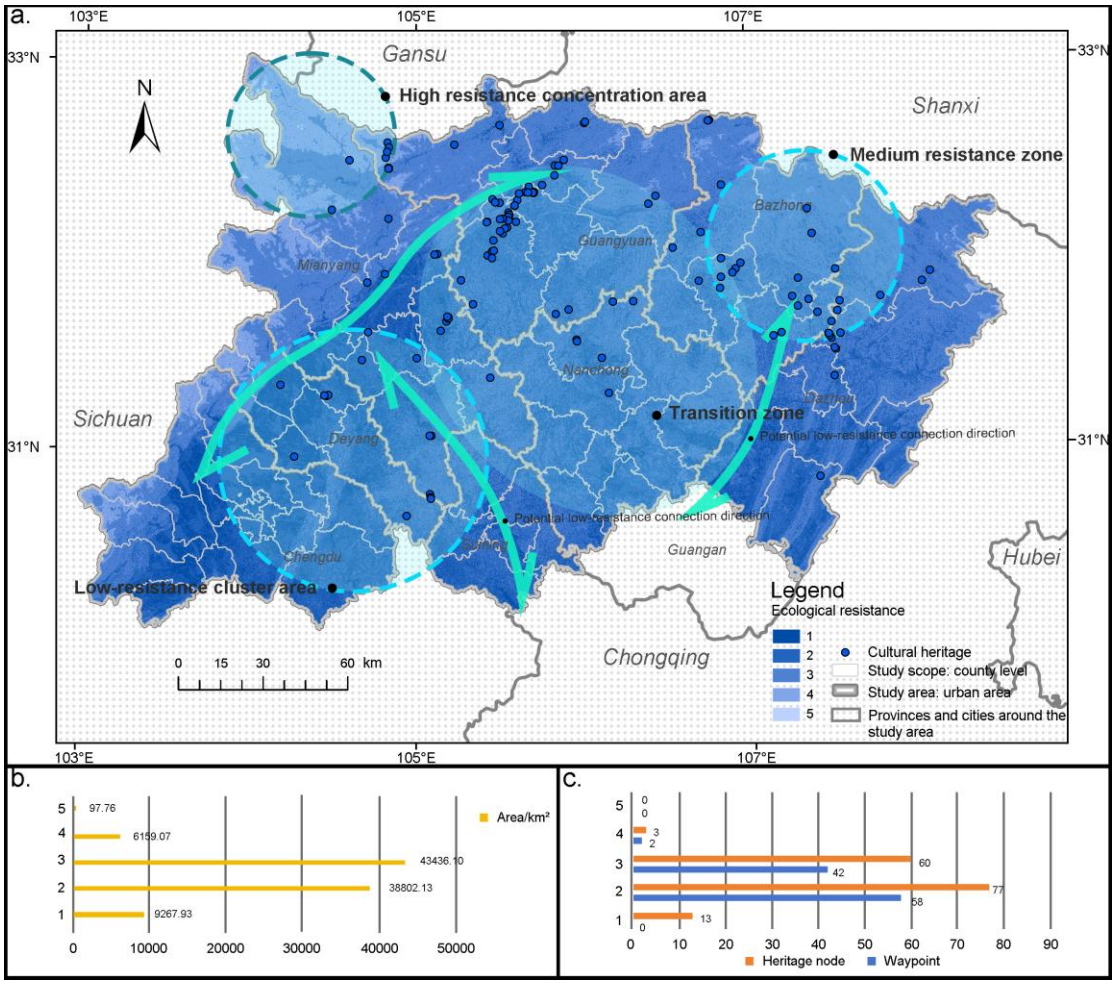


Fig. 8 Analysis of ecological and environmental barriers. (a. Analysis of the ecological and environmental barrier map; b. Statistical table of barrier areas by level; c. Statistical table of the number of heritage nodes and route points with different levels of ecological and environmental barriers)

Socioeconomic Barriers

Land use barriers exhibit distinct spatial heterogeneity overall (Fig. 9). The Chengdu–Deyang–Mianyang region is characterized primarily by low-to-moderate barriers, while parts of the northern and northeastern study area are characterized primarily by moderate-to-high barriers (Tab. 6). Overall, this results in a spatial pattern where barriers are lower in the southwest and higher in the north and peripheral areas. Taken together, the spatial patterns of resistance associated with the three types of socioeconomic factors show distinct differences: land use exhibits primarily patchy differentiation, transportation displays a networked distribution, and settlement density is characterized by localized clustering. Collectively, these factors form the spatial foundation of the socioeconomic resistance landscape.

Tab. 6 Percentage distribution of values for each socioeconomic resistance factor

Resistance Factor	1 point	2 points	3 points	4 points	5 points	Average resistance
Land use	0.04%	45.14%	0.93%	3.17%	50.72%	3.59
Traffic	0.65%	9.39%	36.05%	51.61%	2.3%	3.46
Settlement density	0.01%	0.04%	0.16%	0.53%	99.26%	4.99

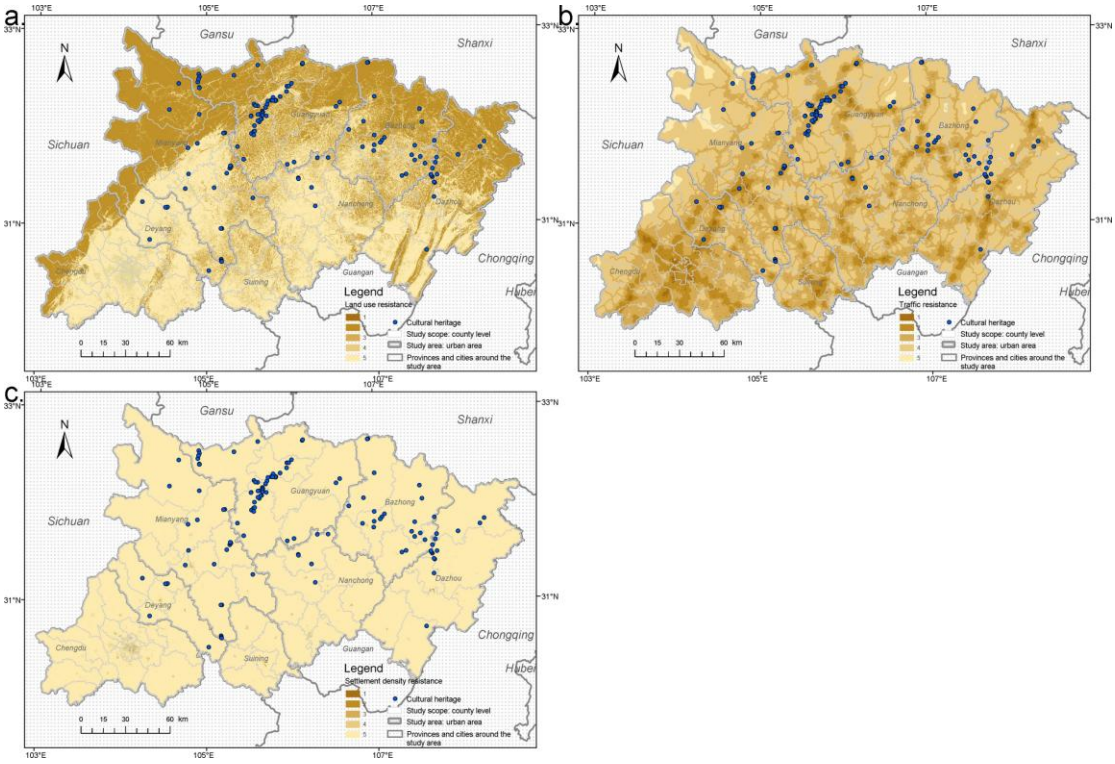


Fig. 9 Distribution of various socioeconomic constraints at different levels (a. Land use, b. Traffic, c. Settlement density)

There is significant spatial variation in socioeconomic barriers (Fig. 10). The northern region is characterized primarily by low-to-moderate barriers (1–3 points), with continuous low-barrier zones forming in Guangyuan and northern Mianyang, where heritage sites are concentrated and restrictions are relatively weak. Barriers are higher in the central and southern regions, where continuous high-barrier zones (4–5 points) have formed in the Chengdu–Deyang–Suining area and parts of Nanchong. These zones closely correspond to areas of high urban density, population concentration, and heavy traffic, creating significant barriers to spatial connectivity among heritage sites. In the eastern region, the Bazhong–Dazhou area is dominated by resistance levels of 2–4, exhibiting a transitional distribution; some heritage sites are located at the boundaries between resistance zones, demonstrating characteristics of spatial transition. Overall, the spatial pattern is characterized by “low resistance in the north, high resistance in the central and southern regions, and transitional resistance in the east.” Low-resistance connectivity primarily unfolds along areas of gentle resistance, reflecting the potential for connectivity and laying the foundation for the construction of a comprehensive resistance map and the identification of corridors.

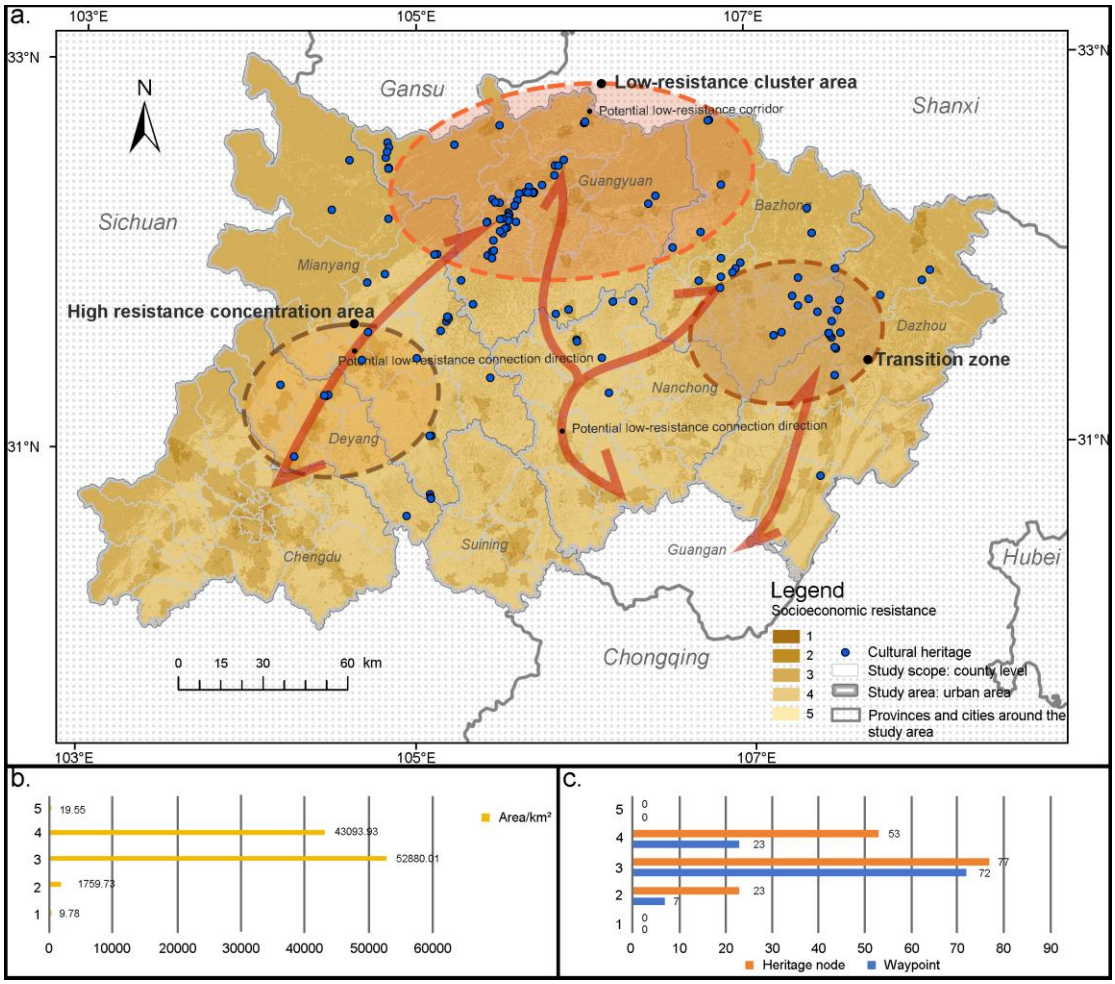


Fig. 10: Analysis of the socioeconomic resistance surface. (a. Analysis of the socioeconomic resistance surface; b. Statistical table of resistance areas by level on the socioeconomic resistance surface; c. Statistical table of the number of resistance heritage nodes and route points on the socioeconomic resistance surface)

Cultural Heritage Constraints

First, in terms of cultural heritage types, the Shu dao cultural heritage within the study area includes eight categories: ancient trees, ancient settlement, ancient tomb, ancient architecture, stone inscrpitons, post station, military fortress, and ancient battlefield, totaling 153 sites (Tab. 7). An analysis of the composition by number shows that ancient architecture is the most numerous category, with 57 sites, accounting for 37.5% of the total cultural heritage sites, while ancient battlefields are relatively few, with only 1 site, accounting for 0.7% of the total.

Tab. 7: Classification of Cultural Heritage Sites Along the Shu dao

Cultural Heritage Category	Number (units)	Percentage (%)
Ancient tree	7	4.5
Ancient settlement	21	13.7
Ancient architecture	57	37.3
Ancient tomb	11	7.2
Stone inscrpitons	22	14.4
Post station	13	8.5
Military fortress	21	13.7
Ancient battlefield	1	0.7

Next is cultural heritage density. As shown in Fig. 11, areas of low resistance are primarily distributed in Guangyuan, where Lizhou District, Zhaohua District, and Jiange County in Guangyuan form the most prominent high-density clusters, with a cultural heritage density of 0.025 sites per km²; Areas of medium density are primarily distributed in the western part of Qingchuan County in Guangyuan , the central part of Bazhou District in Bazhong , the border between Bazhong and Dazhou , the border between Guangyuan and Nanchong , and the border between Deyang and Mianyang , forming relatively continuous transitional zones (Tab. 8). In terms of spatial continuity, high-density cultural heritage sites are primarily characterized by localized clusters, while low-density areas are predominantly scattered, indicating that the Shu dao cultural heritage in the study area exhibits distinct spatial clustering and unevenness.

Tab. 8 Percentage distribution of cultural heritage resistance factors by value

Resistance factor	1 point	2 points	3 points	4 points	5 points	Average resistance
Cultural heritage density	1.05%	1.33%	4.54%	6.16%	86.92%	4.77
Cultural heritage type	/	0.03%	0.56%	9.96%	89.45%	4.89

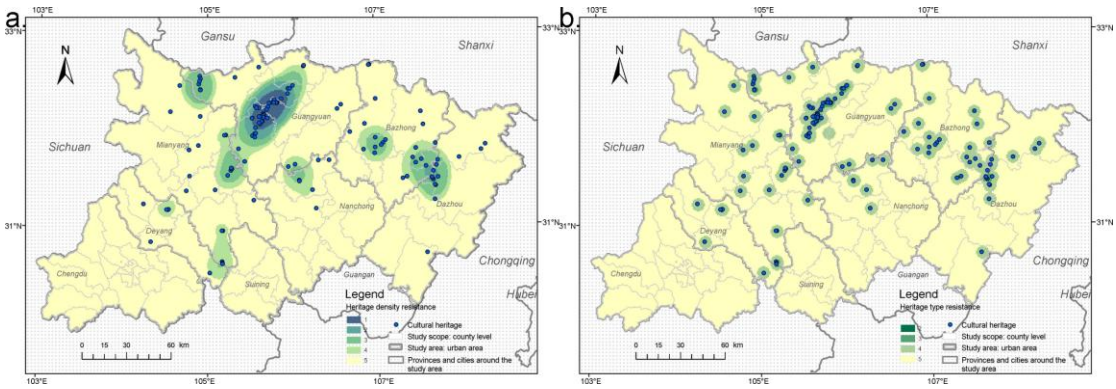


Fig. 11 Distribution of various obstacles to cultural heritage preservation across different levels (a. Cultural heritage density; b. Types of cultural heritage)

After integrating all influencing factors and assigning resistance values, a comprehensive resistance surface for the Shu dao cultural heritage was constructed (Figure 12). Overall, the resistance of the Shu dao cultural heritage exhibits distinct spatial differentiation: low-resistance areas are primarily distributed in patchy and strip-like patterns in regions where cultural heritage sites are relatively concentrated, while high-resistance areas are widely distributed in peripheral regions with fewer cultural heritage sites. The transition between different resistance levels is not uniform; rather, low-resistance clusters with a certain degree of continuity form in localized areas, gradually transitioning from these low-resistance zones to the surrounding regions.

The cultural heritage resistance surface in the study area exhibits a spatial structure characterized by “core clusters—secondary zones—transitional links.” The Guangyuan–Jiange area serves as the core cluster—the largest in area and most continuous—extending in a north-south strip that closely aligns with the Shu dao nodes, offering the strongest conditions for spatial connectivity. Secondary low-resistance zones are formed in northern Mianyang, the eastern border between Bazhong and Dazhou, and the southern border between Mianyang and Deyang; though smaller in scale, these zones exhibit localized clustering and possess potential connectivity pathways extending toward the core area. Resistance transition zones exist between these zones, constituting spatial boundaries and areas requiring priority breakthroughs. This pattern indicates that spatial connections within the heritage area exhibit marked asymmetry; it is necessary to identify low-cost pathways based on resistance models and reveal

the spatial organizational relationships of potential corridors.

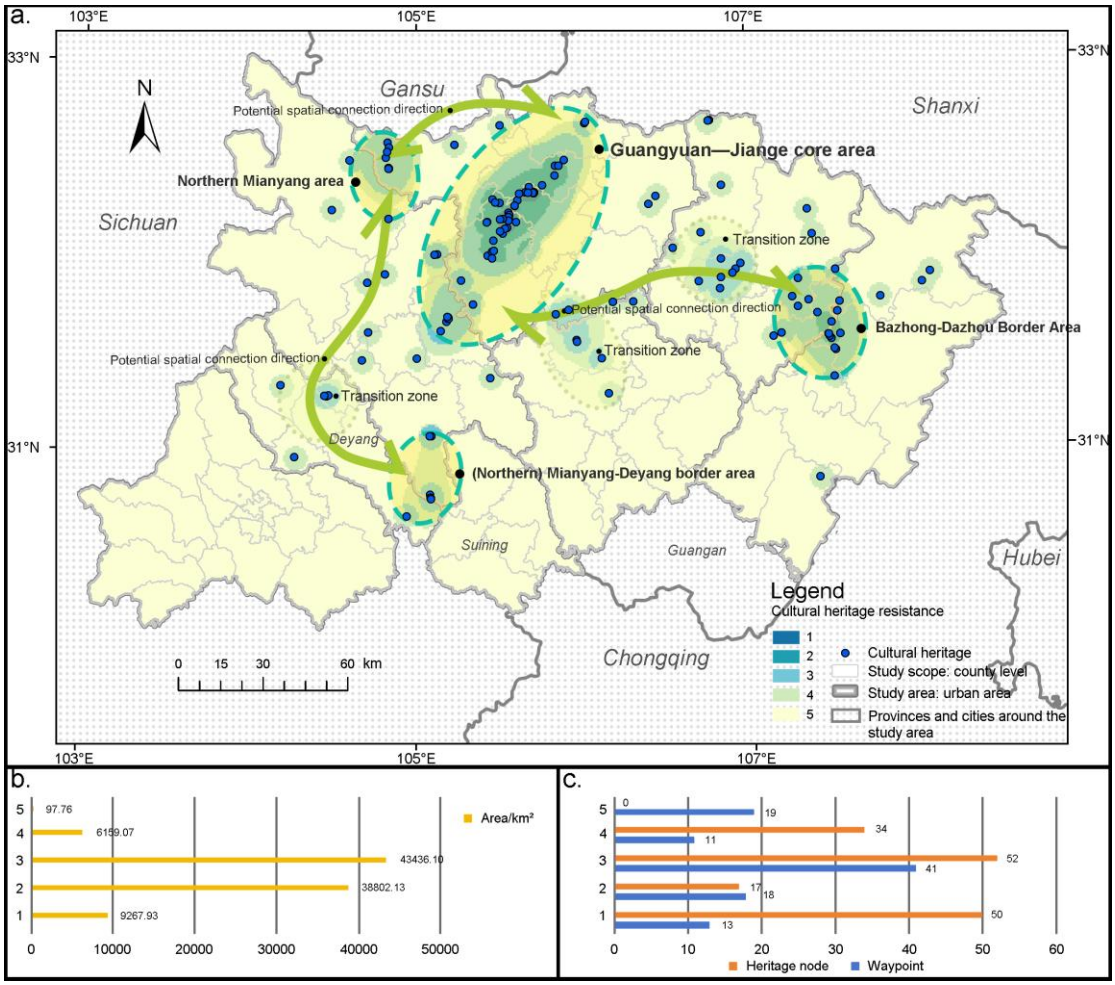


Figure 12 Analysis of cultural heritage obstacle surfaces. (a. Analysis of cultural heritage obstacle surfaces; b. Statistical table of obstacle areas by level for cultural heritage obstacle surfaces; c. Statistical table of the number of heritage nodes and route points with different levels of obstruction on cultural heritage obstacle surfaces)

Spatial Pattern of the Comprehensive Resistance Surface

Based on a comprehensive analysis of ecological, environmental, socioeconomic, and cultural heritage factors, and through weighted superposition according to the weights of each indicator, the comprehensive resistance surface for the Shu dao (Sichuan Section) was ultimately established (Fig. 13). Overall, the northern region is dominated by areas of relatively low resistance, while the eastern region forms a concentrated zone of moderate resistance. The southwestern region and certain other areas exhibit distinct characteristics of resistance transition. There is a certain degree of spatial continuity and gradient variation between different resistance levels, providing a foundation for the subsequent identification of potential corridors.

In terms of spatial distribution, the comprehensive resistance map of the study area exhibits a pattern characterized by “concentrated low resistance in the north, clustered moderate resistance in the east, and gradient transitions in the central and southwestern regions.” The Mianyang–Guangyuan area in the north forms a continuous low-resistance zone that closely corresponds to the area with a high density of heritage sites, constituting an important low-resistance spatial unit. The eastern Bazhong–Dazhou region constitutes a moderate-resistance zone, with internal low-resistance patches serving as transitional spaces connecting the north and east. Multiple resistance transition zones have formed

between regions: the area south of Guangyuan to Nanchong exhibits northeastern transition characteristics, while the Mianyang–Deyang–Chengdu corridor and the area surrounding Suining form a southwestern transition zone, serving as spatial connectors. Based on low-resistance continuity, three potential low-cost connection directions can be identified: extending from the north to the southwest; extending from the north to the central region and further connecting to the southwest; and extending from the central region to the east. These directions provide a crucial foundation for subsequent MCR modeling to identify potential corridors. The low-resistance continuous zones provide the basis for connectivity, while transition zones with distinct resistance gradients serve as key nodes. The next step involves using the Minimum Cumulative Resistance (MCR) model to identify low-cost connection paths and construct a regional cultural heritage corridor network.

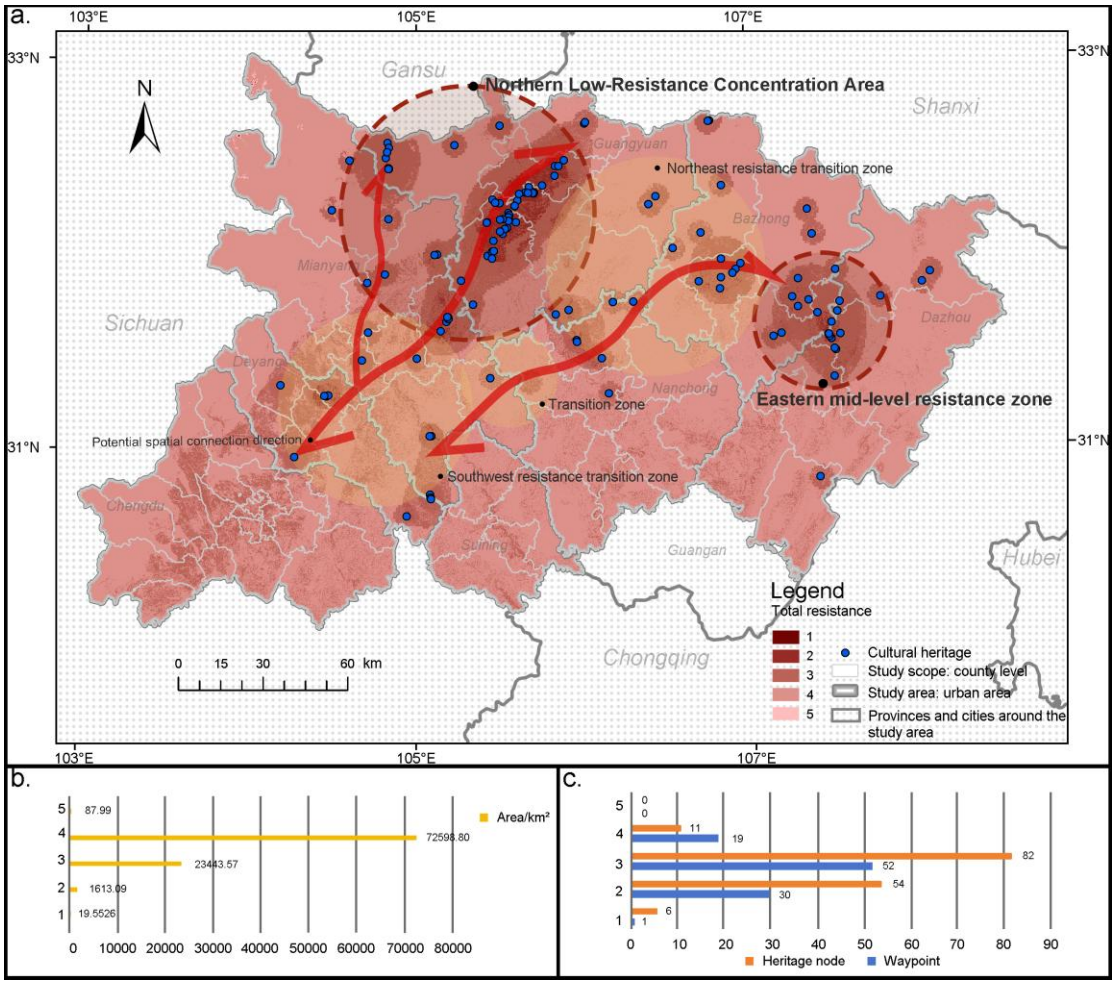


Fig. 13: Comprehensive resistance surface analysis. (a. Analysis of the comprehensive resistance surface; b. Statistical table of resistance areas by level on the comprehensive resistance surface; c. Statistical table of the number of resistance heritage nodes and route points on the comprehensive resistance surface)

Results of the Corridor Network Construction

Based on the potential cultural heritage corridors generated by the MCR model and GIS cost-path analysis, and using 49 Shu dao heritage sites as the foundation and 153 cultural heritage sites along the route as supporting nodes, the generated potential corridors were manually interpreted and optimized. This process drew on the approach used in existing research, which combines professional knowledge with actual conditions to manually optimize and adjust the hierarchy of potential corridors. Based on the scope of connectivity, the entities connected, and the role within the network structure, corridors that

span regions to connect different cultural heritage clusters and key nodes—and serve as the network's backbone—were designated as primary corridors. Corridors connecting primary corridors to surrounding cultural heritage nodes—and serving as supplementary links within regions—were designated as secondary corridors. Pathways that were duplicative, redundant, or of limited connectivity significance were manually adjusted. The final result is a hierarchical cultural heritage corridor network featuring a "four axes, three clusters" structure, comprising 9 primary corridors and 9 secondary corridors that pass through a total of 115 cultural heritage nodes (of which 38 were excluded due to passing through high-resistance areas) (Fig. 14).

From a spatial structural perspective, the corridor network as a whole exhibits the characteristics of "northern clustering, central connectivity, east-west extension, and southern supplementation." In the northern low-resistance area, cultural heritage sites are relatively concentrated in the southern part of the Guangyuan–Mianyang region, where primary corridors intersect frequently, making it the core cluster area of the network; in the eastern region, multiple primary and secondary corridors interconnect, forming important network hubs that integrate cultural heritage sites and facilitate regional connections; in the southern region, the number of corridors is relatively small, with connections to the northern and central regions primarily established through primary corridors, while secondary corridors extend to surrounding cultural heritage sites. Overall, the main corridors constitute the primary framework for cross-regional cultural heritage spatial connections, while the secondary corridors provide supplementary connections to the main corridors and surrounding cultural heritage nodes, collectively forming a potential cultural heritage corridor system characterized by hierarchy and networked structure.

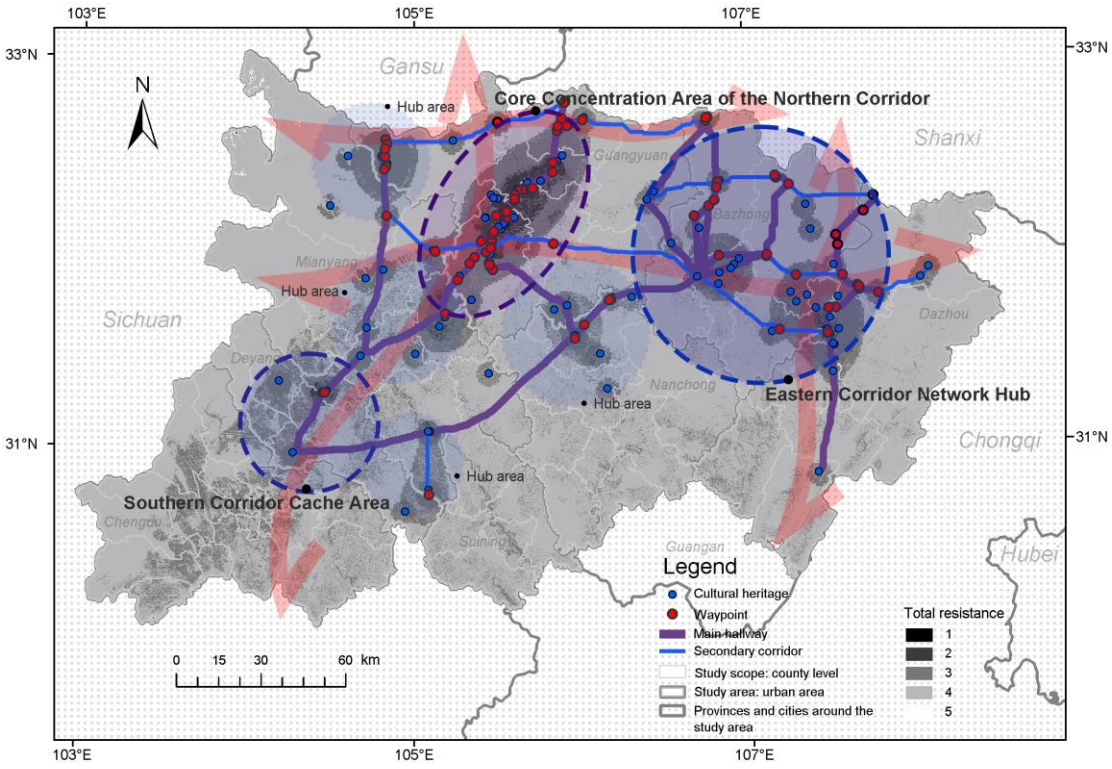


Fig. 14 Cultural heritage corridor network of the Shu dao (The blue-purple dotted circles represent the three main areas formed, and the four light-red arrows represent the four axes formed.)

Discussion

It is worth noting that this study also identified several phenomena that differ from traditional

understandings of the Shu dao. Traditional research typically views the Shu dao as a linear cultural heritage corridor with a relatively clear historical trajectory, and its spatial reconstruction often focuses on inferences based on historical documents, extant ruins, and traditional routes[17,21]. However, the results of this study indicate that the spatial distribution of existing cultural heritage nodes does not fully align with the continuity of historical routes; significant spatial discontinuities still exist between these nodes, and modern transportation alternatives, urban expansion, and changes in the regional spatial environment have further altered the original continuous connections of the historical routes. Therefore, spatial reconstruction of the Shu dao based solely on existing remains or historical routes cannot fully reflect its actual spatial relationships as a regional connectivity network.

This study further found that the formation of potential corridors for the Shu dao is not determined by the distribution of a single cultural heritage site or the direction of a historical route, but is instead influenced by a combination of factors, including slope, cultural heritage density, cultural heritage types, as well as socioeconomic and ecological conditions. Potential corridors constructed based on the integrated resistance surface and the MCR model can identify potential connection paths with lower integrated resistance between different regions while preserving the spatial constraints of cultural heritage nodes. Consequently, the spatial identification of the Shu dao is no longer limited to "searching for historical routes"[22,23], but has shifted toward identifying spatial networks with realistic connectivity potential between cultural heritage nodes. This understanding expands the traditional research approach—which primarily focused on route verification and the identification of cultural heritage sites—and provides an operational methodological framework for the spatial reconstruction of discontinuous linear cultural heritage.

Re-examining the Value of Regional Synergy in Linear Cultural Heritage Corridors

This study demonstrates that the value of linear cultural heritage corridors lies not only in the preservation of the heritage itself but also in their role as important spatial vehicles that connect heritage resources, urban spaces, and regional functions. Previous research on the Shu dao has largely focused on the intrinsic value of the heritage, while paying insufficient attention to the relationship between heritage spatial networks and regional development. By examining heritage nodes within a regional network, their value extends beyond that of individual resources to encompass regional spatial connections and the potential for coordinated development. The network constructed in this study demonstrates that connecting different heritage clusters and regional nodes can strengthen the spatial links among dispersed resources and provide a spatial foundation for the coordinated allocation of regional resources such as cultural tourism and transportation. Therefore, the protection of linear heritage should not focus solely on the number of heritage nodes but should also emphasize the spatial connections between them and their capa to serve regional development. This implies that linear cultural heritage sites, such as the Shu dao, should transition from being traditional "objects of protection" to spatial vehicles that promote regional connectivity and coordinated development.

Shifting from the Protection of Individual Nodes to the Protection of Overall Continuity

This study further emphasizes that the conservation of linear cultural heritage should not be based solely on individual heritage nodes or localized sections of the route[1], but should place greater emphasis on its integrity and continuity. The historical value of the Shu dao lies not only in individual cultural heritage nodes—such as mountain passes, ancient trails, bridges, historic buildings, and ancient settlements—but also in the transportation links, spatial organization, and cultural dissemination relationships that have long existed between these sites. If conservation efforts focus solely on relatively well-preserved cultural heritage nodes while ignoring the spatial discontinuities that have formed

between them, it will be difficult to fully showcase the overall value of the Shu dao as a linear cultural heritage site. Therefore, this study identifies spatial discontinuities between cultural heritage nodes and further constructs a network of potential cultural heritage corridors, thereby expanding the scope of conservation from individual nodes to an integrated "node-corridor-network" structure. This shift from point-based conservation to network-based conservation not only helps restore the spatial connections among cultural heritage resources but also provides a spatial basis for the holistic conservation and coordinated utilization of cultural heritage resources across different regions and of various types. For linear cultural heritage with a long evolutionary history and a broad spatial span, reconstructing its overall spatial connections should be a key objective of conservation research, rather than merely engaging in fragmented conservation of locally well-preserved sections of the route.

Reconstruction of Cultural Heritage Corridors Driven by Multiple Factors

This study indicates that the reconstruction of linear cultural heritage corridors should not rely on subjective judgments based solely on natural conditions or heritage distribution, but rather should integrate ecological, environmental, socioeconomic, and cultural heritage factors[24]. The comprehensive resistance model developed in this study incorporates multiple factors into a unified framework, shifting corridor identification toward quantitative analysis based on differences in resistance. Slope, cultural heritage density, and type exert significant influences, indicating that corridor formation is subject not only to natural constraints but also to the clustering of heritage sites and cultural attributes. This method avoids the subjectivity associated with inferences based on historical routes or the shortest distances, making potential corridors better aligned with the actual environment. The MCR model does not directly plan or construct routes but rather identifies potential directions of low-resistance connections. Therefore, the combined approach of "comprehensive resistance evaluation—potential corridor identification—professional optimization" balances the objectivity of the model with expert refinement, providing a research pathway that integrates quantitative analysis with professional judgment for the reconstruction of complex linear cultural heritage networks.

Research Limitations

Although this study constructed a comprehensive resistance model based on the existing cultural heritage resources, natural environment, and socioeconomic factors of the Shu dao to identify spatial discontinuities and reconstruct a potential cultural heritage corridor network, certain limitations remain. First, the incompleteness of historical and cultural heritage information may affect the results of spatial reconstruction. Due to limitations in the completeness of historical records, the extent of archaeological discoveries, and the state of preservation of the remains, it is difficult to accurately locate some ancient road remains that have disappeared or are poorly preserved. Their spatial locations are primarily inferred based on historical materials, oral accounts, and geographical features, which may have some impact on the identification of discontinuous sections and the reconstruction of potential corridors. Second, the study primarily conducts static analysis based on current spatial data. As a cultural route that evolved over a long period, the Shu dao's route, transportation functions, and regional connections may have changed across different historical periods. The corridor network constructed in this study primarily reflects potential spatial connections under current natural environmental, cultural heritage resource, and socioeconomic conditions; it has not yet fully revealed the dynamic evolutionary process of the Shu dao across different historical periods. Third, the actual effects on regional coordinated development still require further verification. This study primarily discusses the potential supportive role of cultural heritage corridors in regional coordinated development from the perspectives of spatial connections and network structure. The relevant findings mainly highlight the potential for optimizing the spatial

organization of cultural heritage resources and strengthening regional connections; however, there is a lack of long-term dynamic monitoring and quantitative verification regarding the actual effects—such as tourism synergy, industrial collaboration, population mobility, and economic development—that arise after the formation of the corridor network. In the future, by integrating historical data from multiple periods with tourism flows, population mobility, and regional economic data, a dynamic evaluation system linking cultural heritage corridors and regional coordinated development could be established to further validate the actual mechanisms through which the reconstruction of linear cultural heritage networks influences regional development.

Conclusion

From the perspective of regional coordinated development, this study constructed a research framework comprising "resistance modeling—disruption identification—network construction—regional coordination." By comprehensively applying GIS and MCDA methods, the study established an integrated resistance evaluation system covering ecological environment, socioeconomic factors, and cultural heritage, and conducted an empirical study on the Shu dao based on the MCR model and cost-path analysis. The conclusions of the study are as follows: (1) In terms of spatial patterns, the cultural heritage of the Shu dao exhibits characteristics of "core clustering—linear connectivity—peripheral dispersion," with discontinuity points primarily concentrated in areas marked by significant modern transportation substitution and urban expansion; (2) Regarding influence mechanisms, cultural heritage density is the primary driver of potential corridor formation, with a weight of 0.29, followed by cultural heritage type (0.17) and slope (0.14); (3) Regarding network reconstruction, simulations using the path of minimum cumulative resistance revealed a cultural heritage corridor network pattern characterized by "northern clustering—central connectivity—eastern and western extensions—southern supplementation," comprising four axes and three clusters. The findings of this study provide a theoretical basis for the conservation of the Shu dao cultural heritage corridor network and serve as a model for the conservation of cultural heritage corridor networks worldwide. More importantly, the core of this study is not to restore a "historic ancient road" that perfectly aligns with the modern spatial context, but rather—while respecting the historical and cultural heritage pattern—to re-establish connections between fragmented cultural heritage spaces through the scientific identification of potential connecting pathways, and to integrate these spaces into modern urban and regional development systems via the corridor network. This offers new possibilities for linear cultural heritage to transition from "static preservation" to "dynamic connectivity" and "vital utilization."

Author Contributions

KSY analyzed the raw data obtained in the earlier phase and was responsible for writing the manuscript. LLK was responsible for overseeing the overall framework of the study. GY is responsible for checking the experimental data. All authors read and approved the final manuscript.

Data Availability

All data generated or analysed during this study are included in this published article [and its supplementary information files].

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Attachment

Appendix 1: Classification of resistance along the Shu dao corridor

Primary resistance factor	Primary weight	Secondary resistance factor	Secondary weight	Tertiary resistance factor	Tertiary weight	Standard	Resistance value	References
Ecological and environmental resistance value	0.37	Slope/（°）	0.140	/	/	0°≤X < 5°	1	Yu, W. & Lin, J. G. Construction of a coastal ecological network in the Bohai Rim region from the perspective of integrated land–sea planning. *Mar. Environ. Sci.* 44, 731–738 (2025).
						5°≤X < 10°	2	
						10°≤X < 15°	3	
						15°≤X < 25°	4	
						X≥25°	5	
		Elevation/（m）	0.070	/	/	X<1000	1	Fan, J. R., Zhang, Z. Y. & Li, L. H. Mountain demarcation and mountainous area divisions of Sichuan Province. *Geogr. Res.* 34, 65–73 (2015).
						1000≤X < 1500	2	
						1500≤X < 2500	3	
						2500≤X < 3500	4	
						X≥3500	5	
		Normalized Vegetation Index（NDVI）	0.080	/	/	0.74≤X < 1.00	1	Yang, L. Z., Niu, T., Yu, Q. et al. Ecological space optimization based on complex network theory: a case study of the Songhua River Basin. *J. Beijing For. Univ.* 44, 91–103 (2022).
						0.60≤X < 0.74	2	
						0.39≤X < 0.60	3	
						0≤X < 0.39	4	
						X < 0	5	
		Hydrology	0.080	Average annual precipitation	0.020	0≤X < 600	1	Zhang, Y. X., Wei, H., Na, J. M. et al. Construction of an urban ecological security pattern based on the MCR model: a case study of Pingliang City, Gansu Province. *J. Nanjing Norm. Univ. (Nat. Sci.)* 44, 54–62
						600≤X < 800	2	
						800≤X < 1000	3	
						1000≤X < 1200	4	
						X≥1200	5	

								(2021).
				Distance from the watershed line	0.020	X≥7000	1	
						5000≤X＜7000	2	Yu, K. J., Li, W., Li, D. H., Li, C. B., Huang, G. & Liu, H. L. Suitability analysis of heritage corridors in rapidly urbanizing regions: a case study of Taizhou City. *Geogr. Res.* 24, 69–76 (2005).
						3000≤X＜5000	3	
						1000≤X＜3000	4	
						0≤X＜1000	5	
				Distance from Water	0.060	0≤X＜1000	1	
						1000≤X＜3000	2	
						3000≤X＜5000	3	
						5000≤X＜7000	4	
						X≥7000	5	
		Traffic		Distance from the national highway	0.020	0≤X＜1000	1	
						1000≤X＜3000	2	
						3000≤X＜5000	3	
						5000≤X＜7000	4	
						X≥7000	5	
				Distance from the provincial road	0.010	0≤X＜1000	1	Yan, Y., Chen, X. M., Xie, Y. W. et al. Research on the construction of urban composite green-space ecological networks based on diverse objectives: a case study of the central urban area of Quanzhou. *J. Ecol. Rural Environ.* 41, 308–322 (2025).
						1000≤X＜3000	2	
						3000≤X＜5000	3	
						5000≤X＜7000	4	
						X≥7000	5	
				Distance from the county road	0.010	0≤X < 500	1	
						500≤X < 1000	2	
						1000≤X < 2000	3	
						2000≤X < 5000	4	
						X≥5000	5	
				Distance from the expressway	0.010	0≤X < 500	1	Wu, Y., Jiang, Y., Wu, Y. et al. Heritage corridor construction of classical gardens of Suzhou using minimum cumulative resistance model. *npj Herit. Sci.* 13, 530 (2025).
						500≤X < 1000	2	
						1000≤X < 2000	3	
						2000≤X < 5000	4	
						X≥5000	5	
				Distance from the highway entrance	0.030	0≤X < 500	1	
						500≤X < 1000	2	
						1000≤X < 2000	3	
						2000≤X < 5000	4	
						X≥5000	5	
社会经济阻力值	0.17		0.080					
		Settlement Density / (People per km²)	0.030	/	/	0≤X＜100	1	Yang, L. Z., Niu, T., Yu, Q. et al. Ecological space optimization based on complex network theory: a case study of the Songhua River Basin. *J. Beijing For. Univ.* 44, 91–103 (2022).
						100≤X < 400	2	
						400≤X＜700	3	
						700≤X＜1000	4	
						X≥1000	5	

		Land use	0.060	/	/	Unutilized Land Forest Land Grassland Water Areas Land for Construction Arable Land	1 2 2 3 4 5	Wang, W. Y., Su, W. C., Dong, W. Z. et al. Spatiotemporal evolution of the ecological security pattern and assessment of ecological resilience in Chongqing based on the MSPA-InVEST model. *Environ. Sci.* (2025), 1–27.
		Cultural heritage density /(persons/km²)	0.290	/	/	X≥0.025 0.014≤X < 0.025 0.010≤X < 0.014 0.003≤X < 0.010 0≤X < 0.003	1 2 3 4 5	Lu, D. F., Zheng, Y. R., Han, T. T. & Chen, S. H. Construction and overall protection of ecological and marine cultural composite landscape network in Quanzhou, Fujian. *Landsc. Archit.* 32, 114–122 (2025).
Cultural heritage Resistance Value	0.46	Cultural heritage type	0.170	Radius of influence of ancient trees/(m)	0.005	0≤X < 1000 1000≤X < 3000 3000≤X < 5000 5000≤X < 7000 X≥7000	1 2 3 4 5	Wang, J. C., Zhang, H. Y., Xie, C. Y. & Chen, M. Research on the suitability evaluation of the construction of intangible cultural heritage corridors in the Grand Canal Cultural Belt based on GIS. *Acta Ecol. Sin.* 45, 5322–5339
				Radius of influence of ancient Settlement /(m)	0.040	0≤X < 1000 1000≤X < 3000 3000≤X < 5000 5000≤X < 7000 X≥7000	1 2 3 4 5	
				Radius of influence of ancient architecture/(m)	0.025	0≤X < 1000 1000≤X < 3000 3000≤X < 5000 5000≤X < 7000 X≥7000	1 2 3 4 5	
				Radius of influence of ancient Tomb/(m)	0.014	0≤X < 1000 1000≤X < 3000 3000≤X < 5000 5000≤X < 7000 X≥7000	1 2 3 4 5	
				Radius of	0.013	0≤X < 1000	1	

influence of stone inscrpitons /(m)		1000≤X < 3000	2
		3000≤X < 5000	3
		5000≤X < 7000	4
		X≥7000	5
Radius of influence of post station /(m)	0.026	0≤X < 1000	1
		1000≤X < 3000	2
		3000≤X < 5000	3
		5000≤X < 7000	4
		X≥7000	5
Radius of influence of military fortress /(m)	0.031	0≤X < 1000	1
		1000≤X < 3000	2
		3000≤X < 5000	3
		5000≤X < 7000	4
		X≥7000	5
Radius of influence of ancient battlefield /(m)	0.016	0≤X < 1000	1
		1000≤X < 3000	2
		3000≤X < 5000	3
		5000≤X < 7000	4
		X≥7000	5