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Research on the construction of intangible cultural heritage corridors in the Yellow River Basin based on geographic information system (GIS) technology and the minimum cumulative resistance (MCR) model

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Abstract

Objectively and accurately identifying the spatial structure and protection scope of intangible cultural heritage and constructing intangible cultural heritage corridors are crucial for the comprehensive systematic protection of intangible cultural heritage and the synergistic development of the region. However, the current research on intangible cultural heritage is limited to the protection and development of intangible cultural heritage in specific locations or specific areas. Thus, systematic and holistic research perspectives are relatively limited. Therefore, this study employs geographic information system spatial analysis and the minimum cumulative resistance model to construct an intangible cultural heritage corridor in the Yellow River Basin. This study aims to establish a systematic protection method and framework for intangible cultural heritage. The results show the following: (1) The intangible cultural heritage in the Yellow River Basin has a large-scale centralized distribution and small-scale scattered distribution, which provides an important spatial basis for the construction of intangible cultural heritage corridors. (2) Overall, intangible cultural heritage corridors can be more effectively constructed in the eastern region of the Yellow River Basin than in the western region, with 84.6% of the area being suitable and 15.4% being unsuitable. (3) Based on the suitability analysis, the "18 + N" corridor system of intangible cultural heritage in the Yellow River Basin, distributed across the eastern, central and southern regions, is constructed. The major corridor has a suitable width of 60–100 km, a total length of 11,935 km, and an area of 625,976 km²–919,942 km², and can connect 634–711 intangible cultural heritage sites in series. On this basis, this study proposes a multilevel construction system for intangible cultural heritage corridors in the Yellow River Basin that integrates the "network structure–spatial scope" and "element–axis–region" levels. This approach culminates in a pattern of intangible cultural heritage protection and development in the Yellow River Basin characterized by "connecting points into lines, distributing in groups, and linking regions." This study reveals that combining geographic information system spatial analysis tools with a minimum cumulative resistance model effectively identifies potential heritage corridor networks and clarifies the hierarchical relationships

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of heritage element protection in the study area. This approach provides a reference model for the comprehensive protection and systematic development of intangible cultural heritage in the Yellow River Basin. Furthermore, the effectiveness and universality of this framework make it applicable to the protection and development of other similar international heritage areas.

Keywords Yellow River Basin, Intangible cultural heritage, Heritage corridor, Suitability, Minimum cumulative resistance model

Introduction

Intangible cultural heritage (hereinafter referred to as "ICH") is a living culture created by continuous communication, interaction and integration in the process of historical development, bearing the memory of human civilization. Effective protection, development and inheritance of ICH are of great significance for inheriting the historical context [1], carrying forwards a national spirit [2] and promoting regional development [3]. Recent studies on ICH have been relatively fruitful, particularly in the fields of sociology, anthropology, and tourism. Research has concentrated on various aspects, including the concept and connotations of ICH [4–6], its protection and inheritance [7–9], and education related to ICH [10–12]. Additionally, there has been a focus on management systems [13–15], social revival [3, 16, 17] and tourism development [18–20]. These efforts have collectively advanced the protection and development of ICH. In recent years, ICH has attracted widespread attention from scholars in the fields of human geography and tourism management. Scholars have studied the spatial and temporal distribution characteristics and influencing factors [21] of ICH at different Chinese geospatial scales, from region [22, 23] to province [24, 25] to district [26, 27]. However, their research has been limited to a specific type of ICH or ICH located in a specific region [28], and little attention has been given to ICH in large cross-administrative regions [23] or to the preservation and utilization of ICH from the perspectives of systematization and wholeness [25, 29]. Therefore, considering the sustainable development of ICH, systematic safeguarding and holistic development of ICH are topics worthy of more serious study in the long run.

The heritage corridor approach is a regional heritage protection method originating from the United States that focuses on the protection of related heritage along corridors and in radiation areas. It is widely used in war sites [30], river basins [31] and cultural routes [32] with linear characteristics, providing an important reference for the overall protection of cultural heritage. The World Tourism Organization (UNWTO) regards the development of "heritage networks" as an effective way to promote the sustainable development of ICH [33]. Recently, there have been successful cases of ICH

corridors worldwide [34, 35], providing new ideas for the overall protection of ICH. There are many ways to construct heritage corridors, such as the analytic hierarchy process [36], the geographic information system (hereinafter referred to as "GIS") spatial analysis [37] and the minimum cumulative resistance (hereinafter referred to as "MCR") model [38]. Among them, the GIS spatial analysis method and the MCR model are widely used in the construction of heritage corridors. The GIS spatial analysis method is an important method for spatial analysis and data processing in cultural heritage research [39], and in recent years, it has shown great potential for heritage conservation, use [40], evaluation [41] and promotion [42]. The application of GIS spatial analysis methods to study the conservation and utilization of ICH represents a novel approach [43]. The MCR model comprehensively considers the spatial heterogeneity and the horizontal relationship between spatial units in the process of building heritage corridors [44], calculates the path with the lowest cost based on the resistance index of spatial units [38], and simulates corridor generation in a visual form, which has advanced operability and feasibility. Therefore, on the basis of existing research, this paper proposes the construction of ICH corridors in the Yellow River Basin, aiming to provide a scientific basis for the overall protection of ICH.

The Yellow River Basin spans three major regions of China: the eastern, middle and western regions. It is not only an important spatial carrier for economic and social development but also a gathering area for various ethnic groups and a cross-cultural intersection in China. The long history of the Yellow River Basin has cultivated a rich and colourful ICH with significant historical and cultural value, as well as potential for activation and utilization. However, due to problems such as a scattered distribution, uneven protection ability and insufficient development and utilization, this region has not been able to reach its maximum value [43]. At the same time, there have been few studies on the ICH of the Yellow River Basin [45], and these studies have focused only on the protection of specific segments of the Yellow River Basin [46]; there is still a lack of comprehensive arrangement, macroanalysis and systematic protection of the ICH of the Yellow River Basin. Therefore, it is necessary

to determine the spatial distribution characteristics of the ICH in the Yellow River Basin and to further construct ICH corridors within this region. This initiative will facilitate the coordinated protection of the ICH [34], foster interactions among similar types of heritage, and enhance regional characteristics. Moreover, it will promote inter-provincial cultural exchanges and communication [35], ensuring the living transmission and sustainable development of ICH.

Understanding and identifying the spatial distribution characteristics of ICH is the foundation for realizing the integration and utilization of ICH resources. Therefore, GIS spatial analysis was used to clarify the spatial distribution characteristics of the ICH in the Yellow River Basin to effectively identify the gathering areas of the ICH and determine whether there are gathering areas that can be integrated and planned. By applying the MCR model, a suitable area was delineated for the construction of ICH corridors in the Yellow River Basin. Building on this foundation, this study aims to construct an ICH corridors in the Yellow River Basin. It proposes a systematic protection framework and methodology for ICH, providing a spatial planning basis for the protection and development of ICH in the region. In addition, this study provides a theoretical reference for the coordinated promotion of major development strategic planning and decision-making in China, such as the construction of the Yellow River National Cultural Park, the construction of the Yellow River Cultural Tourism Belt and the construction of cultural and ecological protection zones. This study expands the research perspective of heritage protection and provides guidance for the protection and development of other similar heritage areas in the world.

This study solves two main problems:

- (1) What are the geographic distribution characteristics of the ICH in the Yellow River Basin? Does it show obvious agglomeration characteristics?
- (2) What are the suitability zoning distribution characteristics of the ICH corridor in the Yellow River Basin? Is there spatial continuity? Does it form the basis for building a corridor?

Materials and methods

Research area

The Yellow River Basin flows in a "几" shape from west to east, traversing Qinghai Province, Sichuan Province, Gansu Province, Ningxia Hui Autonomous Region, Inner Mongolia Autonomous Region, Shaanxi Province, Shanxi Province, Henan Province and Shandong Province. The main stream spans approximately 5464 km and is a significant area for population activities and economic development in China. However, the Yellow River Basin only

passes through Aba and Ganzi prefectures in Sichuan Province [47], where ICH is primarily concentrated in the central and southern regions [48]. Given that Sichuan Province is part of the Yangtze River Economic Belt [49], it is excluded from this study's scope. Additionally, five eastern cities in Inner Mongolia—Chifeng, Tongliao, Xing'an League, Hulunbeier, and Xilin Gol League—are closely connected to Northeast China [50]. Haixi Mongolian and Tibetan Autonomous Prefecture in Qinghai Province, along with Jiayuguan, Jinchang, Zhangye, and Jiuquan cities in Gansu Province, have minimal interaction with the Yellow River Basin and contain only small amounts of ICH. Including data from these areas could potentially skew the research results. Therefore, this study focuses on the natural basin of the Yellow River, emphasizing the integrity of prefecture-level (or state and league) administrative divisions and the strength of social and economic ties along the lower reaches of the Yellow River [51]. Prefecture-level administrative divisions are used as the unit of analysis. Based on relevant research [52], the study area is defined to include Qinghai (excluding Haixi Mongolian and Tibetan Autonomous Prefecture), Gansu (excluding Jiayuguan, Jinchang, Zhangye, and Jiuquan), Inner Mongolia (excluding the five eastern cities), Ningxia, Shaanxi, Shanxi, Henan and Shandong, encompassing a total of 84 prefecture-level cities (or states and leagues). This approach ensures the spatial integrity and cultural continuity of the ICH in the Yellow River Basin while maintaining the largest possible geographical scope.

Data sources

In this study, GIS 10.2 software was utilized to visualize 811 ICH data points (according to batch, name, type, project establishment time, protection unit and other indicators) and geographical data and to classify and log the ICH data one by one to construct the Yellow River Basin ICH database and geographical information vector database. These resources were developed to provide robust data support for the subsequent construction of ICH corridors. The data and sources involved are as follows:

- (1) As of 2024, the Ministry of Culture and Tourism has published five batches of national ICH lists, with a total of 3,610 items (including expansion items), of which 811 items (including expansion items) are in this research area, accounting for approximately 22% of the national total. The ICH data were obtained from the National ICH List of the China ICH Protection Center (<https://www.ichina.cn/>). ICH is classified into ten categories according to the classification of ICH types in the National ICH List (Table 1). Referring to previous studies [21, 53], the

Table 1 Classification of the ICH in the Yellow River Basin

Province	Traditional craftsmanship	Traditional drama	Traditional music	Traditional art	Folk custom	Traditional dance	Folk literature	Quyi	Traditional sports, recreation and acrobatics	Traditional medicine	Total
Qinghai	10	3	14	11	14	9	8	4	3	5	81
Gansu	12	10	10	7	8	11	4	6	1	2	71
Ningxia	7	1	3	5	5	1	1	1	0	4	28
Inner Mongolia	5	4	10	6	8	2	3	0	5	4	47
Shaanxi	12	18	15	12	9	6	7	8	2	2	91
Shanxi	35	38	18	19	23	14	10	11	6	8	182
Henan	14	27	13	14	14	10	10	6	10	6	124
Shandong	19	34	18	28	14	13	27	13	15	6	187
Total	114	135	101	102	95	66	70	49	42	37	811

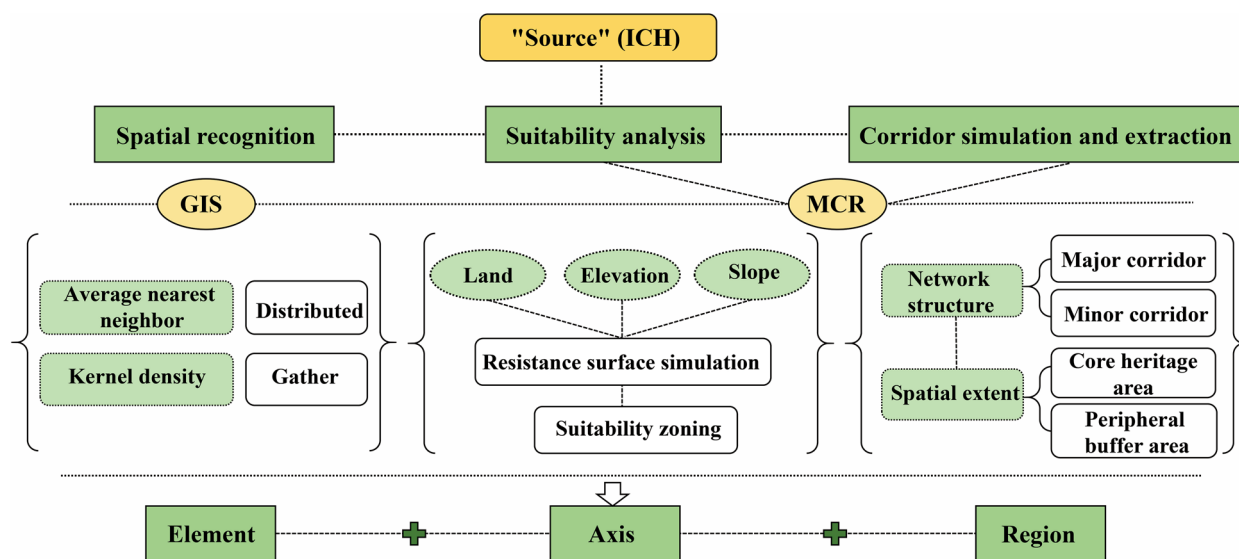


Fig. 1 Research framework

geographical coordinates of each ICH origin were precisely mapped to the community, township, or county cultural center where the reporting unit and inheritance site are located. The corresponding geographical coordinate data of the ICH were obtained using Google Earth.

- (2) Remote sensing monitoring data of land use were obtained from the CLCD land cover classification dataset of Wuhan University (<http://doi.org/https://doi.org/10.5281/zenodo.4417809>), with a spatial resolution of 30 m × 30 m. Based on previous studies [54], the land-use types were divided into six categories: grassland, woodland, water area, cultivated land, unused land and construction land.
- (3) The 30-m DEM elevation raster data of the provincial administrative units in the Yellow River Basin were obtained from the Geospatial Data Cloud (<https://www.gscloud.cn/>).
- (4) OSM vector data for provincial administrative units, river systems, and transportation road networks in the Yellow River Basin were obtained from the official OSM website (<https://openmaptiles.org/languages/zh/#0.47/0/0>).

Research methods

This study takes the Yellow River Basin as the research object and proposes a method and framework for the construction of ICH corridors. The technical steps

are shown in Fig. 1, and the four key steps include the following:

- (1) The average nearest neighbour and kernel density tools in the GIS spatial analysis tools are used to identify the distribution characteristics of the ICH in the Yellow River Basin, and the types, structures and spatial agglomeration of ICH resources in this region are clarified.
- (2) The MCR model is used to analyse the suitability of areas for the construction of ICH corridors in the Yellow River Basin.
- (3) The cost path and cost backlink analysis tools of the GIS spatial analysis tools are used to construct the Yellow River Basin ICH corridor network within the Yellow River Basin and to perform data visualization.
- (4) Drawing lessons from "point-axis system" theory, a multilevel development pattern of ICH corridors in the Yellow River Basin is proposed.

Nearest neighbour index analysis method

The nearest neighbour index is a geographical index that evaluates spatial distribution. This method is used to express the mutual proximity of each data point in a geographical spatial distribution to accurately reflect the distribution type of the point elements. This study uses the nearest neighbour index to analyse the geographical spatial distribution pattern of ICH point elements in the Yellow River Basin to determine whether it has spatial agglomeration characteristics. The calculation formula is

$$\bar{r} = \frac{1}{n} \sum_{i=1}^n r_i$$

$$\bar{r}_i = \frac{1}{2\sqrt{\frac{n}{A}}} = \frac{1}{2\sqrt{D}}$$

$$R = \bar{r} / \bar{r}_i$$

where R is the nearest neighbour index; \bar{r} is the actual nearest neighbour distance value; \bar{r}_i is the theoretical nearest neighbour distance value; n is the number of ICH resources; D is the point density; and A is the regional area. When R=1, the ICH is randomly distributed, whereas R > 1 indicates a uniform distribution, and R < 1 indicates an agglomeration distribution. The smaller R is, the greater the degree of agglomeration.

Kernel density estimation method

The kernel density estimation method can reflect the degree of agglomeration of geographical elements in space. This study uses the kernel density estimation method to characterize the agglomeration pattern of the ICH in the Yellow River Basin to clearly reflect the spatial distribution and aggregation characteristics of the ICH in the Yellow River Basin. The calculation formula is

$$f_n(x) = \frac{1}{(nh)} \sum_{i=1}^n k\left(\frac{x-x_i}{h}\right)$$

In the formula, $f_n(x)$ is the kernel density estimate; h is the kernel density radius, that is, the search radius; n is the number of point elements; $k\left(\frac{x-x_i}{h}\right)$ is the kernel function; and $(x-x_i)$ is the distance from the estimated point x to the sample point x_i .

Entropy method

The methods commonly used to determine the weights are principal component analysis, the analytic hierarchy process and the entropy method. Principal component analysis leads to a lack of information due to data compression [55], and the analytic hierarchy process has a large subjective component [56]. The entropy method determines the index weight according to the variation degree of each index value, which is an objective weighting method and avoids the randomness and subjective deviation caused by human factors [57]. Considering the limitations of the other methods and the advantages of the entropy method, this study uses the entropy method

to determine the weight of each resistance factor. Its model framework is as follows:

- (1) Dimensionless transformation of the original data matrix. Let the original data matrix of m evaluation indices and n evaluation units (grid pixels) be $X = [X_{ij}]_{m \times n}$. Dimensionless transformation is performed on the original data to obtain matrix $Y = [Y_{ij}]_{m \times n}$. This study stipulates that the greater the score of each index is, the lower the suitability of the ICH corridor. Thus, all evaluation indicators are negative, and the corresponding calculation model is as follows: $Y_{ij} = \frac{\max(X_{ij}) - X_{ij}}{\max(X_{ij}) - \min(X_{ij})}$
- (2) The information entropy value of the jth index e_j is calculated as follows:

$$e_j = -k \sum_{i=1}^n p_{ij} \ln(p_{ij})$$

where $k = \frac{1}{\ln(n)}$, $p_{ij} = \frac{Y_{ij}}{\sum_{j=1}^n Y_{ij}}$, and Y_{ij} is the attribute value of the jth grid cell of the ith indicator.

- (3) The weight of index j is determined:

$$w_j = \frac{1 - e_j}{n - \sum_{j=1}^n e_j} \left(0 \leq w_j \leq 1, \sum_{j=1}^n w_j = 1 \right)$$

Minimum cumulative resistance model

The MCR model was proposed by Knaapen [58], and Yu et al. [59] introduced the MCR model into the construction of heritage corridors with the support of GIS platforms. This model simulates the resistance experienced by the "source" in the process of horizontal movement in spaces with different resistance values. The greater the resistance is, the less suitable the movement, and the lower the suitability. Based on the distribution of various resistance factors in the Yellow River Basin, this study uses the MCR model to calculate the minimum cumulative resistance experienced by the "source" (ICH) through different factors with varying resistance values [60] and simulates the shortest (optimal) path for building ICH corridors. The mathematical formula of the MCR model is as follows

$$MCR = \int \min \sum_{j=n}^{i=m} (D_{ij} \times R_i)$$

In the formula, D_{ij} represents the diffusion distance from ICH point J to resistance element i, and R_i

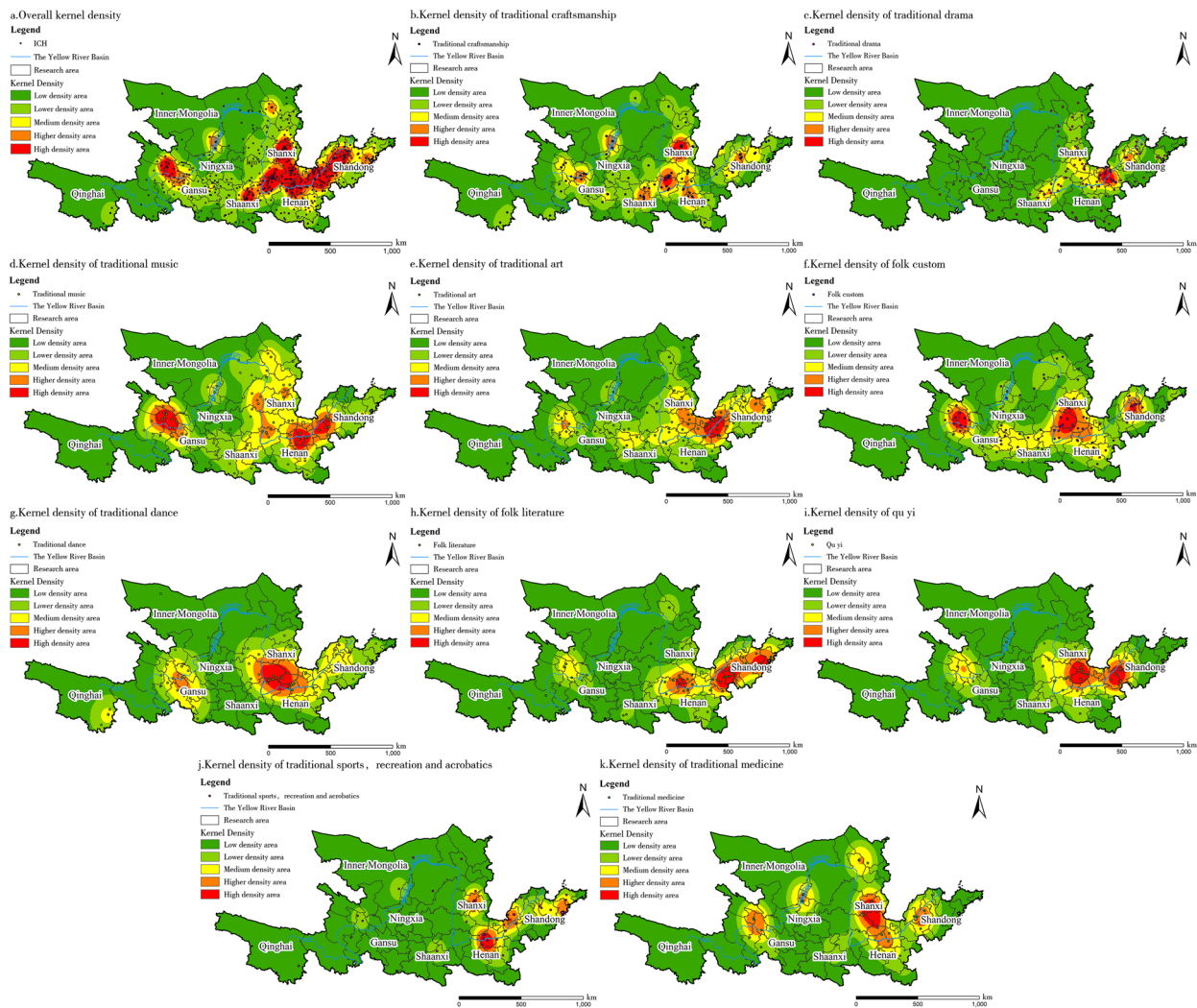


Fig. 2 Analysis of the kernel density of the ICH in the Yellow River Basin

represents the resistance value of resistance element *i* to the construction of the heritage corridor.

Spatial identification of the ICH

Spatial distribution types of the ICH

The average nearest neighbour tool in GIS 10.2 software was used to perform statistical calculations on 811 ICH items in the Yellow River Basin (Table 2). The data show that the actual nearest neighbour distance of the 811 ICH items in the Yellow River Basin is $\bar{r} = 10,356.3454$ km, the theoretical nearest neighbour distance is $\bar{r}_i = 27,719.1668$ km, the average nearest neighbour index is $R = 0.37 < 1$, the significance level is $P < 0.01$, and the Z score is -34.13 . The Z value test shows that the confidence level of the ICH is approximately 99%, indicating that the ICH in the Yellow River Basin generally exhibits

significant clustering distribution characteristics in its geographical spatial distribution. According to the analysis of various types of ICH in the Yellow River Basin is less than one, which indicates that all types of the ICH show spatial distribution agglomeration, among which traditional craftsmanship (0.50) and traditional medicine (0.59) are more concentrated, while quyi (0.86) and folk custom (0.77) are less concentrated.

Characteristics of spatial agglomeration of ICH

Using the kernel density tool in GIS 10.2 software, the structural form of the distribution of the ICH in the Yellow River Basin is visually expressed on a map. The calculation results of the kernel density are divided into five grades by using the natural fracture point classification

method [61], and the dividing thresholds are 2.3102, 6.1606, 10 and 13. The spatial distribution map of the total kernel density of the ICH (Fig. 2a) is drawn to reflect its agglomeration characteristics. As shown in Fig. 2a, the ICH in the Yellow River Basin is spatially distributed on a large scale and scattered in a small area, which is characterized by "more in the south and less in the north, dense in the east and sparse in the west", forming a "2+2" and "π"-shaped local agglomeration spatial distribution pattern (two high-density agglomeration areas and two higher-density agglomeration areas). One of the high-density agglomeration areas consists of concentrated contiguous areas composed of Shaanxi, Shanxi, Henan and Shandong in central Shandong Province (Heze, Jinan, Zibo and Tai'an), northern Shandong Province (Liaocheng, Dezhou, Binzhou and Dongying), northern Henan Province (Zhengzhou, Jiaozuo, Luoyang, Anyang and Puyang) and central Shanxi. Another high-density agglomeration area is located at the junction of eastern Qinghai (Xining and Haidong) and southwestern Gansu (Lanzhou and Linxia). The two higher-density agglomeration areas are scattered at the junction of northern Ningxia (Yinchuan and Shizuishan), southwestern Inner Mongolia (Wuhai), and southern Inner Mongolia (Hohhot).

As shown in Fig. 2b–k, the gathering areas of different types of the ICH in the Yellow River Basin vary significantly. Traditional drama, centred on the northern junction of Shandong and Henan, spreads to southern Shanxi and central Shaanxi; traditional art and quyi are concentrated in western Shandong and southern Shanxi; and the distribution of folk literature is the densest in most parts of Shandong Province and at the junction of Shanxi and Henan. Traditional dance is most densely distributed in southern Shanxi and at the junction between central Gansu and eastern Qinghai. Traditional music and folk custom are widely distributed and concentrated in Qinghai, Gansu, Shandong, Henan and Shanxi; traditional craftsmanship, traditional medicine, traditional sports, recreation and acrobatics are scattered, showing multipoint scattered distributions. The above results create basic conditions for the effective integration of ICH resources in the Yellow River Basin and are an important reference for the construction of ICH corridors.

Construction of ICH corridors

Analysis of the suitability of ICH corridor construction

Resistance factor selection and weight value determination

Due to differences in the regional characteristics and surrounding environment of the Yellow River Basin, different sections are affected by various environmental factors, and their resistance costs will differ accordingly.

Therefore, considering the actual situation of the Yellow River Basin and the availability of data, the environmental factors affecting corridor construction are divided into land-use type, elevation and slope. Twenty experts from urban and rural planning, ecology, landscape architecture, design and other professional fields were invited to determine the resistance factor classifications and resistance values of various elements to the construction of ICH corridors. The resistance values range from 0 to 500 (relative resistance level), where the higher the score is, the greater the resistance generated by the elements, and the lower the suitability of building ICH corridors in this area. The accuracy of the resistance weight determines the rationality of the suitability result, which is the core research topic in the process of constructing ICH corridors. The entropy method was used to statistically calculate the entropy value and entropy weight of each indicator through the GIS spatial map and SPSS statistical analysis tools. Finally, the weight values for the land-use type, elevation and slope are 0.1783, 0.3765 and 0.4452, respectively (Table 3).

Comprehensive cost resistance surface simulation

Resistance surface simulation can be used to better define the spatial scope of ICH corridors and is a key step in the construction of ICH corridors. First, GIS 10.2 software was used to construct single-factor visual resistance value distribution maps (Fig. 3a–c) based on the hierarchical assignment of each resistance factor. Second, based on the weight of each resistance factor, the single-factor resistance distribution was analysed via a weighted overlay through the weighted overlay tool, and a comprehensive cost resistance value distribution map of the Yellow River Basin was generated (Fig. 3d), that is, the cumulative cost raster. The highest resistance coefficient is 292.344, and the lowest is 9.557. Finally, using the cost distance analysis function in GIS 10.2 software and taking ICH sites as "sources" and the comprehensive cost resistance distribution as resistance factor data, based on MCR, the minimum cumulative resistance value was calculated by simulating the minimum cost consumed by overcoming comprehensive resistance from the "source" (ICH) to the nearest "source" (ICH). Consequently, the minimum cumulative cost resistance surface of the ICH in the Yellow River Basin was obtained (Fig. 3e). As shown in Fig. 3e, the spatial distribution pattern of the comprehensive cost resistance surface of the ICH in the Yellow River Basin exhibits significant regional differences, with resistance values gradually decreasing from west to east. This pattern is characterized as follows: the northwestern region (Alashan League, Inner Mongolia) and southwestern (Yushu Tibetan Autonomous Prefecture, Qinghai Province) regions have greater resistance,

Table 3 Different types of resistance values and weights

Resistance factor	Weight	Resistance grading	Resistance value
Land use type	0.1783	Grassland	20
		Woodland	40
		Waters	50
		Arable land	150
		Unused land	160
		Construction land	180
Elevation	0.3765	≤ 500 m	10
		500–1000 m	20
		1000–1500 m	40
		1500–2000 m	70
		> 2000 m	100
Slope	0.4452	≤ 2	5
		2–6	10
		6–15	50
		15–25	100
		> 25	500

most of which are plateaus, mountains and desert landscapes, which are heavily influenced by the resistance of slope and elevation, resulting in sparse populations and a low density of ICH. Conversely, the eastern and central regions experience minimal resistance, as these areas are flat and have high levels of economic and cultural development, leading to intensive human activities.

Suitability zoning of ICH corridors

GIS 10.2 software was utilized to analyze and evaluate the comprehensive resistance surface of the ICH in the Yellow River Basin through the natural discontinuity classification method [38]. This analysis identified the comprehensive resistance turning point value, which serves as the basis for suitability zoning of the ICH corridor and guides the route planning for the ICH corridor.

The turning points of the resistance values in this study are 2301.140, 6289.784, 13,346.614, and 24,085.269. The suitability evaluation results are divided into five levels: 0–2301.140, highly suitable area (1,159,321 km²); 2301.140–6289.784, medium–high suitable area (405,803 km²); 6289.784–13,346.614, medium suitable area (175,852 km²); 13,346.614–24,085.269, low suitable area (69,352 km²); and 24,085.269–39,119.387, unsuitable area (38,707 km²) (Fig. 3f). The suitability analysis indicates that the area of suitable habitat (high, medium–high and medium suitable area) in the study area is 1,565,124 km², accounting for 84.6% of the total study area. These areas are concentrated near transportation corridors and rivers, situated predominantly in basin regions characterized by relatively flat terrain and dense water networks.

They also encompass economically developed regions and areas with ethnic concentrations. The unsuitable areas (medium, low and unsuitable area) cover an area of 283,911 km², accounting for 15.4% of the total study area. These areas are primarily distributed in mountainous, hilly, and desert zones. The above results provide an important reference for the construction of ICH corridors.

Construction of the ICH corridor based on suitability analysis

ICH corridor network structure

Based on the suitability analysis of the ICH corridor, this study employs the cost path and cost backlink analysis tools within GIS 10.2 spatial analysis tools. These tools are used to simulate and calculate the minimum-cost paths between the "source" (each ICH point) and the target points (from one point to 810 other points). This process identifies the optimal connectivity pathways for ICH points, ultimately simulating and generating a potential network of ICH corridors in the Yellow River Basin.

Based on the principles of continuity and integrity of the corridors, this study optimizes the structure of the potential ICH corridor network by comparing and analyzing the layout of the actual traffic road network (e.g., Longhai Line, G108 Line, etc.) and river systems (e.g., Fen River, Wei River, Han River, etc.) in the ICH region. Optimization measures include eliminating routes that do not pass through existing roads and connect ICH sites in a straight line, eliminating routes with duplicated and redundant connections, and eliminating routes with excessively long connecting distances. These measures aim to satisfy the need for the shortest routes to maximize the connectivity of ICH between regions. A total of 18 major ICH corridors and several minor ICH corridors were identified, leading to the final conceptual planning system of the "18+N" ICH corridor network in the Yellow River Basin (Fig. 4a). The major corridors radiate throughout the study area and are distributed radially with the urban agglomerations of Xi'an, Zhengzhou-Luoyang, and Heze-Jinan as the centers. The direction of some routes aligns with the regional traffic road network and river systems. The minor corridors are distributed across all provinces of the Yellow River Basin, with denser distributions in areas such as Shandong Province, Henan Province, Shanxi Province, and Shaanxi Province.

The spatial scope of the ICH corridor

The scope (width) of the corridor is particularly important in heritage (ICH) corridor planning and can directly determine the comprehensiveness and efficiency of the protection of ICH sites [62]. Referring to relevant research results [34], GIS 10.2 software was used to

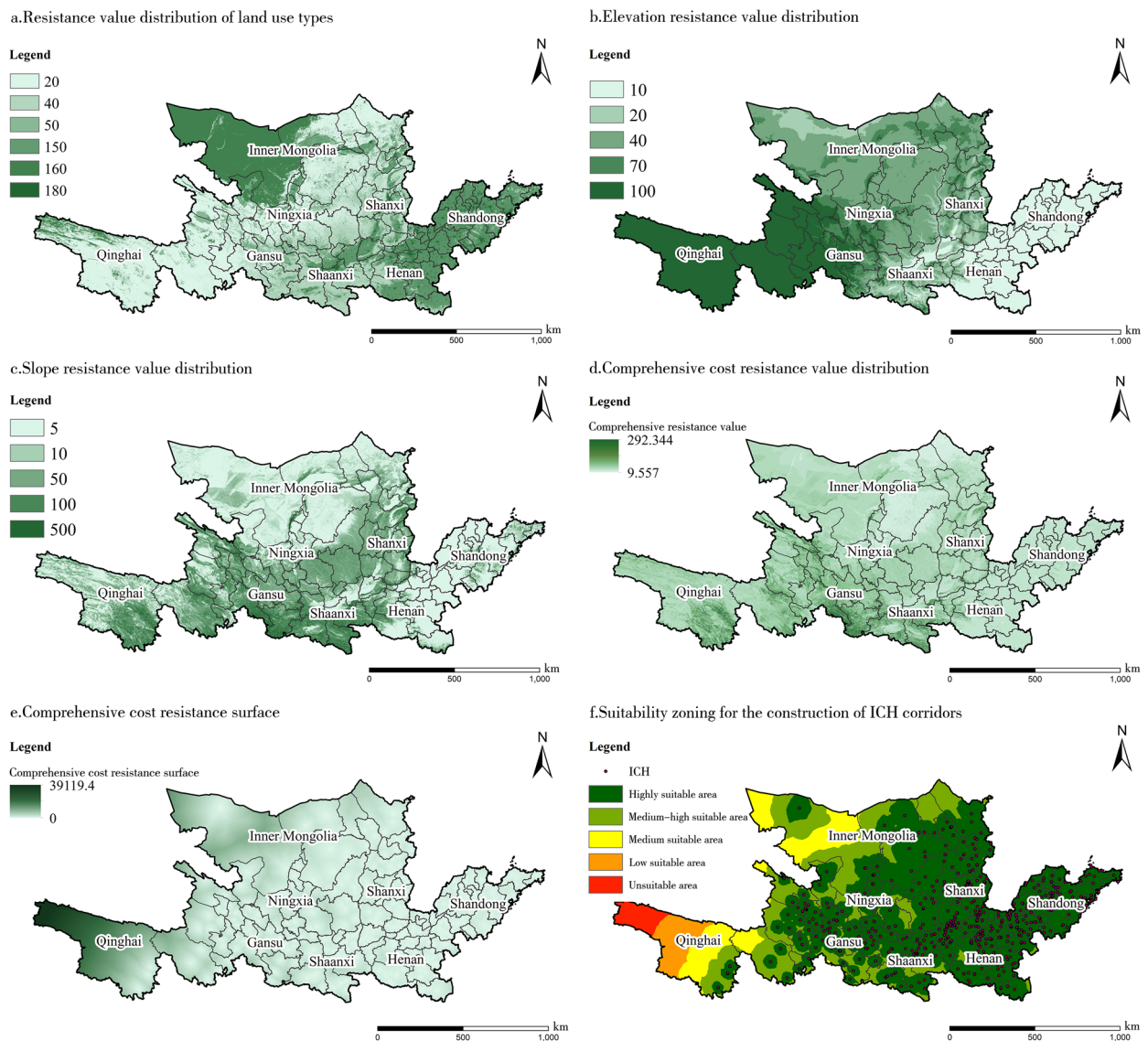


Fig. 3 Construction of a comprehensive cost resistance surface and corridor suitability zoning for the ICH in the Yellow River Basin

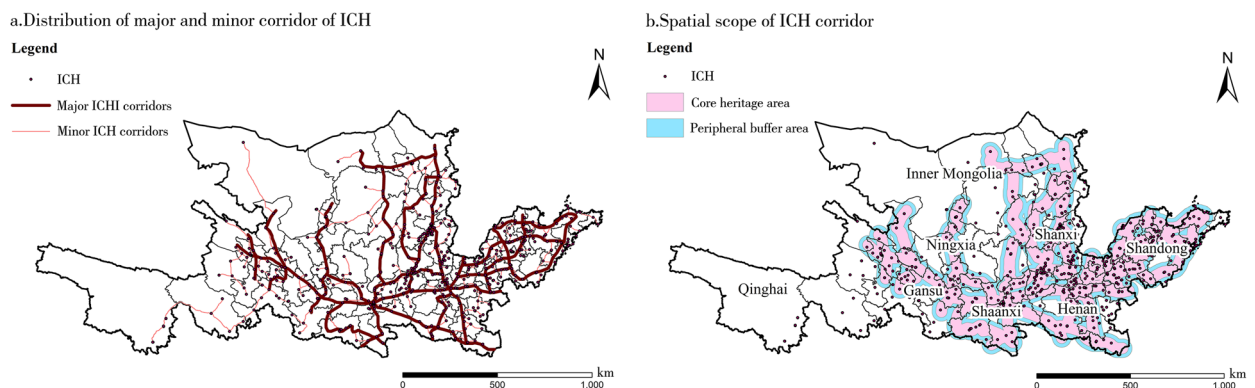


Fig. 4 Distribution and spatial scope of major and minor ICH corridors in the Yellow River Basin

calculate the nearest straight-line distance from each ICH point to the ICH corridor to determine the spatial linear relationship between the ICH and the corridor. This information is used as an important basis for determining the reasonable width of ICH corridors.

According to the results of spatial linear analysis, there are 634 ICH sites within 30 km of the ICH corridor, accounting for 78.2% of the total, and 711 ICH sites within 50 km of the ICH corridor, accounting for 87.7% of the total. Using the "proximity buffer" tool in the spatial statistics toolset of GIS 10.2 software, a buffer analysis was conducted based on the spatial relationship characteristics of the ICH and corridors. Buffers with radii of 30 km and 50 km were created (Fig. 4b), resulting in the delineation of the impact areas of the buffer zones. Additionally, with reference to the "core-peripheral" ICH cultural ecological community structure proposed by Li [63], the ICH corridor area was divided into a "core heritage area-peripheral buffer area". The "core heritage area" is 0–30 km wide on one side, covering 78.2% of the ICH. The ICH in these areas is concentrated in scale, and they are the core part of the ICH corridor. The radiation effect and agglomeration effect of the ICH in the region should be fully considered. The cultural connotations and value function will be deeply excavated, and the in-depth integration and coordinated development of the ICH and tourism will be promoted. The "peripheral buffer area" is 30–50 km wide on one side and contains 9.5% of the ICH. This area and the "core heritage area" form a complete ICH network system. Due to the relatively scattered distribution of ICH in this area, we should gradually connect and integrate regional ICH resources by constructing ICH tour routes with different themes (slow travel systems, green corridors, etc.) to provide space and an environment for the inheritance and display of ICH support. Finally, it is estimated that the suitable width of the major ICH corridor in the Yellow River Basin is 60–100 km, the total length of the corridor is approximately 11,935 km, and the area is approximately 625,976 km²–919,942 km², which can connect 634–711 ICH sites in series.

Development pattern of the ICH corridor

The ICH corridor plays a crucial role as a connecting bridge between the various elements of the ICH in the Yellow River Basin. How can the Yellow River Basin ICH corridor transition from "spatial integration" to "strategic planning" in the future? This study draws on "point-axis system" theory [64] and proposes a three-level ICH corridor development pattern, namely, "element-axis-region", in the Yellow River Basin to explore and respond to the abovementioned issues.

Element levels

ICH (elements) are the foundation of the ICH corridor. The Yellow River Basin boasts a diverse array of ICH elements with uneven regional distribution and significant structural differences among types. Therefore, it is necessary to conduct a detailed registration and census of the 811 ICH items in the Yellow River Basin, such as by creating a complete ICH digital archive and oral history database based on the location, grade, type, and inheritance of ICH. To effectively preserve and promote ICH, such as folk custom and traditional craftsmanship, a model integrating "ICH+museum" should be established. This model should support the creation of various establishments, including ICH folk museums, handicraft inheritance and experience centers, and ICH workshops. These establishments should serve as multifaceted platforms for the display of collections, the transmission of skills, research and development, and innovation. They should also facilitate immersive experiences of ICH and support scholarly research in the field. By fostering these establishments, we aim to shift the focus of ICH from "static protection" to "dynamic inheritance". ICH such as quyi, traditional sports, recreation and acrobatics, traditional music, traditional dance, traditional drama, and folk literature should be thoughtfully developed and utilized based on their specific types and spatial distribution characteristics. This can be achieved through ICH exhibitions, theatrical performances, cultural exchanges, and other activities that enhance the visibility and influence of ICH. By integrating "static exhibitions" with "live performances," we can further promote the preservation and evolution of ICH culture. ICH with high market value, such as traditional medicine and traditional art, should be actively integrated into industry. An industrial system should be developed using the "ICH+X" model (e.g., ICH+food, ICH+tourism and cultural creation, ICH+festivals) to facilitate the industrialization of ICH projects and enhance the utilization efficiency of ICH resources.

Axial level

At present, the provinces along the Yellow River are actively integrating ICH with tourism, resulting in initial achievements. For instance, the Ministry of Culture and Tourism of China has designated 10 national tourist routes themed around the Yellow River, including the "Yellow River ICH Tour". Shandong Province has also initiated the construction of the Yellow River ICH Corridor. However, currently, ICH routes primarily represent conceptual planning on a macro scale. In the future, building upon the Yellow River ICH corridor network (comprising major and minor corridors), it will

be essential to refine the research scope, foster collaborative development across provinces and regions, promote regional co-construction and sharing of ICH, and leverage economies of scale. Utilizing infrastructure like the Qin Jin Highway along the Yellow River can facilitate the joint establishment of the "Qin Jin ICH Corridor along the Yellow River", enhancing cross-regional exchange and mutual learning of ICH resources. For example, leveraging the extensibility of the Qin Jin Highway along the Yellow River to jointly build the "Qin Jin ICH Corridor along the Yellow River" and strengthen cross-regional exchange and mutual learning of ICH resources. Based on the strengths of the Lu Yu ICH agglomeration, the ICH corridor in the Lu Yu section of the Yellow River Basin will be constructed. Leveraging the distributional advantages of the Wei River and Fen River water networks, we will establish a "Wei-Fen River ICH Corridor" to realize a small-scale ICH tour. To ensure seamless connectivity of ICH sites in the region, it is essential to strategically plan the transportation system within the corridor to enhance regional accessibility. Therefore, building upon existing expressways, national highways and provincial highways, we will further improve the comprehensive transportation system of highways and expressways along ICH corridors to improve the traffic capacity between regions and the convenience of the corridor systems. On the basis of the cultural belts and trails of the ICH, a number of flexible belt-shaped green corridor systems, hiking trails and cycling trails suitable for sightseeing are being constructed to form a solid slow-moving trail running through the whole line to strengthen the connection between the ICH and the surrounding ecological environment. At the same time, different interpretation systems (interpretation themes and means) are being constructed in different sections to promote the spread of ICH and promote the sustainable development of the regional economy.

Regional level

According to the abovementioned research on the agglomeration and distribution characteristics of ICH resources in the Yellow River Basin, it is found that the ICH in the Yellow River Basin has formed four areas with different densities. These areas are spatially clustered as follows: the Shandong-Henan-Shanxi-Shaanxi ICH cluster, the Qinghai-Gansu ICH cluster, the northern Ningxia-southwestern Inner Mongolia heritage cluster, and the southern Inner Mongolia ICH cluster. Therefore, it is essential to enhance top-level design, leverage the unique resource advantages of ICH clusters in the Yellow River Basin, break administrative divisions, explore the "ICH+tourism" multisystem approach, sequentially integrate various types of ICH with adjacent resources,

guide ICH expansion into multidimensional tourism spaces, and introduce appealing ICH tourism destinations. These steps are crucial to effectively integrating and developing ICH resources in the region. For example, the Shaanxi and Shanxi regions can combine Yan'an spirit, Nanniwan spirit, Taihang spirit and other red cultures to develop the "ICH+red" tourism model. The Qinghai and Gansu regions can rely on frontier culture and national culture to refine ICH tourism brands and launch the "ICH+research" model with the theme of nature exploration. From northern Ningxia to southwestern Inner Mongolia, we should refine nomadic culture and farming culture, develop an integrated development model of "ICH+blocks/villages/scenic spots", expand the influence of ICH culture in multiple ways, and make ICH a new growth point for promoting local economic development. At the same time, we can also build "cultural ecological protection zones" according to the degree of concentration of ICH, following national policy, such as the "Lu Yu Jin shaan" cultural ecological protection zone (Guanzhong/Xi'an cultural ecological protection zone, Zhongyuan/Zhengzhou cultural ecological protection zone, etc.). ICH projects are prominently showcased within these cultural ecological protection zones, emphasizing the demonstration and leadership roles of ICH agglomeration areas. This approach drives collaborative development among adjacent ICH agglomeration zones, thereby advancing comprehensive regional protection and effective development of the ICH in the Yellow River Basin.

Discussion and conclusion

Discussion

Using GIS spatial analysis tools and an MCR model to identify the spatial distribution characteristics of the ICH in the Yellow River Basin and to construct a corridor network of the ICH, this research has important theoretical and practical significance for the sustainable development and inheritance of the ICH in this area. The empirical study results essentially confirm the previous question: (1) The ICH in the Yellow River Basin has significant agglomeration and distribution characteristics, which provides an important spatial basis for the construction of ICH corridors. (2) Overall, the eastern region of the Yellow River Basin is superior to the western region for the construction of ICH corridors, and the overall suitable area presents obvious spatial continuity, which is important for the construction of ICH corridors. While this study has established an initial corridor of the ICH in the Yellow River Basin, there are still several areas worthy of further discussion.

Comparison with previous studies

Based on the GIS platform, this study uses the average nearest neighbour and kernel density tools to identify the distributional characteristics of the ICH in the Yellow River Basin and to clarify the types, structures and spatial agglomeration of ICH resources in this region. The examination of the spatial distribution of ICH forms the foundational basis for researching the construction and protection of heritage corridors. This effort enriches the theoretical framework surrounding heritage corridors to a significant extent and enhances the scientific approach to their construction and management [65]. In recent years, GIS technology has been widely used in the spatial identification of geographical elements. For example, Luan et al. [66], Zheng et al. [67] and Meng et al. [68] conducted similar studies on the China National Geopark, ethnic minority villages in Guizhou Province, China, and the ICH in Shandong Province, China, respectively, which confirmed the reliability of this technology and method. Research has shown that the ICH in the Yellow River Basin exhibits a spatial distribution trend of agglomeration, which is characterized by a spatial distribution of dense eastern areas and sparse western areas. This result is consistent with the results of Chang et al. [43] and Nie et al. [48]. From the perspective of distribution patterns, there are significant differences in the quantity distributions of various ICH types among provinces. Traffic trunk lines, rivers, basin areas with relatively flat terrain and dense water networks, and economically developed or ethnic agglomeration areas have the most far-reaching influence on the distribution of ICH resources in the Yellow River Basin. For example, most areas in Shandong, Shanxi and Henan are located on plains and basin areas with high levels of economic and cultural development and large populations, which have nurtured a variety of ICH resources. The junction of Qinghai and Gansu exhibits strong local ethnic characteristics and has given rise to ICH with distinct regional traits, including traditional drama, traditional music, traditional dance, and folk customs. This observation aligns with the work of Wang et al. [45] and Zhang et al. [69], who highlight a significant spatial dependence of the ICH in the Yellow River Basin. ICH predominantly concentrates in plains and basins characterized by flat terrain, abundant water resources, and low elevation, or in economically developed and accessible regions. These conditions are conducive to the development and continuity of ICH.

In this study, the MCR model is used to construct a corridor network of the ICH in the Yellow River Basin. Sun et al. [70] and Yang et al. [71] conducted similar studies on the Dongjiang-Hanjiang River Basin in Guangdong Province and the Silk Road Economic Belt, which

further confirmed the reliability of this method. The resistance factors and resistance values involved in the construction of ICH corridors have important influences on the construction of heritage corridors. In this study, land-use type, elevation and slope were selected as the environmental factors for corridor construction. This is consistent with the criteria of Li et al. [72] and Hu et al. [73] for choosing the resistance factors of corridor construction in their research. In the past, the analytic hierarchy process [74, 75] was mainly used to determine the resistance weight. To improve the objectivity and credibility of the analysis results, the entropy method was used to calculate the resistance weight of each resistance factor in this study, which is also an innovation of this study. The results of this study show that the major corridors of the ICH in the Yellow River Basin are radially distributed around urban agglomerations such as Xi'an, Zhengzhou-Luoyang and Heze-Jinan and that minor corridors are densely distributed in Shandong Province, Henan Province, Shanxi Province and Shaanxi Province, which is closely related to the distributional characteristics of the ICH in the Yellow River Basin. The research of Zhang et al. [35] confirms this point. Taking the Yangtze River Economic Belt in China as an example, this study proposes construction and development strategies for ICH corridors. ICH corridors are mainly located in areas with high corridor construction suitability and dense distribution characteristics in the middle and eastern parts of the Yangtze River Economic Belt, that is, the corridor distribution is closely related to the distribution characteristics of the ICH. According to the spatial distribution map of the nuclear density of the ICH and the analysis results, we find that the distribution of the ICH in the Yellow River Basin presents two high-density gathering areas, which is similar to the analysis results of Chang et al. [43]. However, the high-density gathering area located at the junction of eastern Qinghai and southwestern Gansu is less suitable for corridor construction due to the influence of elevation and slope, which makes corridor construction difficult in this area; therefore, corridor construction is also closely related to the geographical characteristics of the location of the ICH. Finally, based on the spatial network of ICH corridors, this study proposes a three-level development pattern for ICH corridors in the Yellow River Basin, namely "element-axis-region", which is similar to the "point, line and surface" corridor levels proposed in previous related studies [74]. This study effectively solves the problems of single forms [76] and the lack of integrity of ICH protection [77].

Overall, the results of this study align with previous research and are supported by a strong scientific basis.

The inheritance and development of ICH from the perspective of time and space

ICH is a combined heritage composed of people, time, space and culture and is constructed by the corresponding people practising specific cultural activities in a relatively fixed place [78]. Although ICH has a fixed place of transmission and a designated unit, some ICH elements possess spatial mobility due to their unique nature. This mobility allows them to serve as important resources for transcending administrative boundaries and promoting cross-regional sharing. For example, traditional drama, traditional music and quyi are cultural activities characterized by their cyclical nature and continuity. This finding indicates that we should explore the temporal and spatial distribution characteristics of the ICH in the Yellow River Basin, reveal the hidden patterns of regional civilization processes, explore the inheritance and development of the ICH, and further promote Yellow River culture.

Through analyzing the spatial distribution map of the nuclear density of various types of the ICH in the Yellow River Basin, it is found that the ICH in the Yellow River Basin are partially clustered in types, that is, ICH of the same type are located in close proximity to one another. The construction of ICH corridors facilitates interactions among ICH of the same type and fosters the development of regional protection characteristics. Therefore, constructing type-specific ICH corridors for the same type of ICH is beneficial. For example, eastern Qinghai and southwestern Gansu are multiethnic gathering areas with diverse ethnic customs and a substantial presence of traditional music. This has been continuous since the formation of these ethnic minorities, demonstrating the temporal continuity of the ICH. By leveraging regional advantages, we can establish ICH corridors themed around traditional music, thereby achieving temporal continuity and spatial inheritance of similar thematic cultures. Traditional drama areas are concentrated in Shanxi, Shandong, Henan and other places, closely clustered together. Therefore, based on their spatial distribution, constructing ICH corridors for traditional dramas can facilitate exhibition activities featuring traditional dramas from "Shanxi, Hebei, Shandong, and Henan," creating a "walking ICH" that promotes the spatial flow of these cultural elements. Shanxi Province, enriched by its geographical and historical context along the Yellow River, has created abundant folk cultural resources and has developed unique and diverse traditional dances, especially in southern Shanxi. Therefore, establishing ICH corridors for traditional dances based on the regional characteristics of southern Shanxi to realize the live transmission and sustainable development of traditional dances. Shandong Province, revered

as the cradle of Qilu culture, possesses a profound cultural heritage and a rich tapestry of ICH. The region's folk literature is particularly abundant, preserving countless stories and legends that have circulated among its people since ancient times. Constructing ICH corridors for folk literature in Shandong Province can trace historical migrations through these literary works and continue to narrate historical tales to the present day.

Countermeasures and suggestions for the construction of ICH corridors in the Yellow River Basin

Constructing heritage corridors is a multifaceted and dynamic practical endeavor. Therefore, robust policy guarantees and effective management mechanisms are essential to ensure sustainable development. In the process of ICH corridor construction in the Yellow River Basin, we should learn from the United States [79] regarding the laws, regulations and management of heritage corridors to formulate suitable management mechanisms and modes in China. On this basis, the governments should coordinate the provinces and regions in the Yellow River Basin, as well as the relevant functional departments and industry associations, to cooperate and rationalize the procedure for constructing a heritage corridor and the institutionalization of its management.

To effectively protect and develop the ICH of the Yellow River Basin, it is recommended that a hierarchical and multidimensional planning system be constructed for the ICH corridor of the Yellow River Basin to achieve synergistic regional development. For example, at the macro level, a master plan for the heritage corridor should be formulated by defining the basic structure and strategy for protection and development, identifying the key protection objects and protection areas, and stressing the global and holistic nature of ICH protection in the region. At the meso level, special plans for the heritage corridor should be formulated for specific regions, defining the scopes of protection and development, proposing specific protection programmes and management strategies, and focusing on specific implementation methods. At the micro level, a comprehensive ICH resource census will be carried out, a heritage database will be established, and differentiated protection and development strategies will be formulated. This planning system ensures comprehensive support for the construction, protection, and development of the ICH corridor in the Yellow River Basin.

In addition, given the vast scale and diverse regions of the Yellow River Basin, a strategy of segmented development and focus should be adopted for the construction of the Yellow River Basin ICH corridor to gradually achieve comprehensive planning. The Yellow River Basin can be divided into upstream, midstream, and downstream

regions based on geographic location and river characteristics. In the upstream area, ecotourism and ICH experience projects should be developed by leveraging the natural landscape and unique ethnic and cultural characteristics. The midstream area is the core area of Yellow River civilization and a hub for diverse ICH. This heritage should be systematically catalogued and researched, integrating it with tourism, education, and community development to foster cultural tourism and educational activities. The downstream area, with its proximity to the economically developed eastern coast, can capitalize on this advantage to enhance international communication and cooperation, and promote the market-oriented development of ICH.

Limitations of the study and future research

Although original contributions were made in this research, there are still some limitations that may call for further research. This paper initially constructed a network of ICH sites in the Yellow River Basin based on a macroscale perspective but did not focus on a specific spatial scale (such as provinces or regions) of corridor construction. Moreover, the research only studied the transmission and development of ICH from a spatial perspective and seldom considered the temporal evolution of ICH.

Therefore, an important direction for the future is to specify a smaller geographic scale of ICH, such as the provincial or city (county) level, for multicategory spatial identification and to further construct a more accurate and specific ICH corridor. In addition, ICH has overlapping temporal and spatial relationships; a single area often includes ICH content in multiple periods, and there are significant differences in intangible culture in different historical stages. Therefore, more research is needed to explore the protection and development of ICH from both temporal and spatial perspectives.

Conclusion

This study proposes a systematic protection framework and method for ICH and constructs ICH corridors in the Yellow River Basin as an example, which effectively solves the problem of a single mode of ICH protection at the present stage, which is novel in the field. The ICH of the Yellow River Basin has a large-scale centralized distribution and small-scale scattered distribution, forming a local agglomeration spatial distribution pattern, which provides an important spatial basis for the construction of ICH corridors. The eastern part of the Yellow River Basin is more suitable for the construction of ICH corridors, accounting for 84.6% of the total area we studied. Eighteen major ICH corridors and a number of

minor corridors were formed within the suitable zones as the spatial patterns and pathways for the protection and development of the ICH in the Yellow River Basin. These findings and the proposed framework expand the research perspectives of heritage conservation and can help researchers, planning managers and policy-makers scientifically formulate policies and programmes for the overall conservation and systematic development of heritage in the future. The framework has a clear operational process and therefore has good potential for practical application to other similar heritage regions internationally.

Abbreviations

ICH	Intangible cultural heritage
MCR	Minimum cumulative resistance
GIS	Geographic information system

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Author contributions

LXB was responsible for conceptualization, data collection and quality, and formal analysis. ZR and SCY were responsible for editing the manuscript. YXK was responsible for interpretation, visualization and methods. CJZ and WKX were responsible for translation and collected relevant data. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analysed during the current study are available from Xiaobin Li upon reasonable request, and his email address is 7230306019@stu.jiangnan.edu.cn.

Declarations

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Competing interests

The authors declare no competing interests.

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