ARTICLE

Check for updates

The spatial relationship and influence mechanism of traditional villages and intangible cultural heritage: a case study of the upper reaches of the Yellow River Basin

Qianming Xue[1] & Yuehao Huang 🄿 [1✉]

This paper focuses on 262 traditional villages (TVs) and 189 nationally recognized intangible cultural heritage (ICH) items in the upper Yellow River basin (YRB). Using nuclear density, distribution equilibrium and other research methods., this paper tries to reveal the spatial relationship between TVs and ICH, and analyzes its influencing factors. Through an analysis of influencing factors, the study identifies pathways for their integrated development. The findings are as follows: (1) There are significant differences in the spatial distribution of TVs and ICH in the upper YRB. TVs exhibit a "multi-core aggregation, dispersed concentration" pattern, with a high degree of imbalance at the provincial (or autonomous region) level. In contrast, ICH shows a "sparse south, dense center, and sparse north" distribution, with a lower degree of imbalance at the provincial level. (2) Although there is generally a high degree of spatial alignment between TVs and ICH, but at the provincial (or autonomous region) level, three types of regional displacements have been identified: high positive displacement, low positive displacement, and high negative displacement. (3) Factors such as altitude, river systems, temperature conditions, regional economy, accessibility, population density, urbanization rate, cultural characteristics, and funding policies significantly influence the spatial distribution of TVs and ICH. urbanization rate has a common influence and explanatory power on the spatial distribution of both TVsand ICH in the YRB, with altitude, financial policies, cultural history, and other factors having secondary influence and explanatory power.These factors are crucial in determining the pathways for their integrated development.

[1] School of Architecture and Urban Planning, Lanzhou Jiaotong University, Lanzhou City, China. ✉email: huangyh@mail.lzjtu.cn

Introduction

River basins are the cradle of settlements and city-states, with settlements being products of the human-environment coupling and harmonious coexistence within the basin. These settlements are significant representations of the cultural landscape of the basin and crucial components of heritage resources (Shao et al. 2021). The YRB is not only a vital water source and ecological barrier for northern China but also a hub of cultural heritage, rich in ecological culture and wisdom in human habitation construction. It serves as a critical carrier for promoting human-environment harmony and high-quality development, playing an important role in the national economy and urban development (Huang and Xue 2024; Qiao et al. 2024). ICH is a valuable asset of a nation, representing cultural confidence and diversity (Michael 2007; Zhang et al. 2024; The State Council of the People's Republic of China 2024). TVs, commonly known as "ancient villages", are early-established, well-preserved rural settlements with high cultural, social, aesthetic, and economic value that merit protection (Yu and Zhao 2024; Kang and Liu 2024; Kang and Liu 2024). Furthermore, as one of the birthplaces of Chinese civilization, the upper reaches of the YRB host numerous TVs and ICH. However, due to the region's unique geographical position, underdevelopment, and poor transportation, many TVs and forms of intangible heritage face threats of disappearance and assimilation. Therefore, promoting coordinated planning between TVs and intangible heritage, and strengthening their interconnections in spatial areas, is a key topic of current research.

In recent years, substantial research results on TVs and ICH have been achieved both domestically and internationally, with some consensus reached on conceptual definitions and research methods. International scholars began studying rural settlements relatively early, with most referring to TVs as "small villages" or "rural settlements" (Yu et al. 2024; Wang et al. 2021). Their research topics cover village landscapes (Ye et al. 2024; Santoro 2024), clustering digitalization (Sa et al. 2024), symbiotic transportation networks (Peng et al. 2024), local adaptation (Wang et al. 2024), village heritage (Tan et al. 2024), and sustainable development (Long et al. 2024). Research on ICH is relatively extensive abroad, with fruitful outcomes. Current studies primarily focus on the modernization and digitalization of ICH (Li et al. 2025; Zhou 2024), its restoration and preservation (Zheng 2024; Li et al. 2024), and digital creation (Wu 2024; Wang et al. 2024; Kai 2024). These studies often examine ICH from perspectives such as revitalization and inheritance (Hua and Dai 2024; An and Tan 2024), the "Internet + " model (Cai et al. 2024), ICH's role in assisting disabled economies (Hu 2024), and the integration of cultural tourism (Yang 2024). They explore and analyze certain cultural elements within ICH, aiming to further promote its preservation and transmission. In general, most scholars abroad focus on topics such as the techniques of ICH transmission (Chen 2024), spatial distribution and genealogy (Zhang et al. 2024), as well as spatiotemporal distribution and influencing factors (Zhang et al. 2024). This indicates that the main directions of international research on TVs and ICH revolve around technical realization, preservation, restoration, and spatiotemporal distribution. Additionally, ICH research is gradually shifting towards the integration with modernization and information technology, promoting the preservation and inheritance of ICH through specific cultural elements. Compared with domestic research, the study of TVs and ICH in China started relatively late, but the research output is relatively abundant. In terms of research methods, most scholars utilize methods such as KDE, standard deviational ellipse (SDE), nearest neighbor index (NNI), Moran's I, and geographic detectors to depict the spatial distribution characteristics of TVs across the country (Bian et al.

2022; He et al. 2024), in Meishan region (Huang et al. 2024), in Xiangxi region (Liu et al. 2024), in central China (Wang et al. 2024), in northeastern China (Zhu et al. 2022), and in Guizhou Province (Luo and Luo 2021), Jiangsu Province (Zhang et al. 2024), and Zhejiang Province (Chen and Li 2024). They also analyze the formation mechanisms to understand the development trends of TVs in these regions, thereby promoting their sustainable development. Using the same methods, scholars have studied the distribution characteristics of ICH at national (Li and Wang 2022), regional (He et al. 2023; Zhu 2024), and provincial (Han et al. 2021; Kang et al. 2022) scales and have explored and analyzed the factors influencing ICH to promote its overall protection in these regions. Overall, both domestic and international scholars have mostly conducted research on TVs or ICH from independent perspectives, with research primarily focusing on spatial distribution and its influencing factors. Most studies are conducted from the perspective of individual protection and single research angles, delving deeply into TVs or ICH. Few scholars have incorporated TVs and ICH into a comprehensive protection scope and research framework. In light of this, some scholars have explored the relationship between TVs and ICH to better understand their connection. They aim to establish a spatial relationship network between the two to achieve comprehensive protection and development. For example, studies have been conducted on the spatial relationships and formation mechanisms between TVs and ICH at regional (He et al. 2023) and provincial levels (Yu et al. 2024). However, to more effectively protect TVs and their ICH, academia and government departments need to place greater emphasis on the relationship between the two and develop comprehensive preservation strategies. This will help preserve cultural diversity and promote the sustainable development of rural areas.

Returning to the perspective of river basins, some scholars have studied the spatial correlation and influencing factors of TVs and ICH in the Yangtze River Basin (Li and Shi 2022), YRB (Tian et al. 2023; Li and Shi 2022), Jinsha River Basin (Wang et al. 2024), and Grand Canal Cultural Belt (Li et al. 2024). Although the aforementioned studies have recognized the spatial relationship between TVs and ICH and analyzed the factors influencing both. However, from the perspective of river basins alone, the scope of current research is too broad. For instance, the YRB is vast, and TVs are widely distributed. The spatial distribution characteristics and influencing factors of TVs and ICH vary across the upstream, midstream, and downstream stages, reflecting a lack of fundamental research from a local perspective within the basin, leaving room for further exploration. Currently, research on TVs and ICH in the YRB is limited, primarily focusing on the spatial correlation between the two and their influencing factors. Some scholars have studied the spatial morphology of TVs in the Shaanxi section of the YRB from an ICH perspective (Huang 2023), while others have only explored ICH in individual provinces (Guo and Xing 2022). Although scholars have recognized the spatial relationship between TVs and ICH and have analyzed their influencing factors, from the perspective of the river basin, current studies are too broad and lack in-depth regional analysis. In summary, existing research has paid little attention to TVs and ICH in the upstream area of the YRB. There is a lack of fundamental and typical studies on the spatial relationship and influencing mechanisms between the two. This leaves room for deeper exploration of their adaptability and locality in future studies.

TVs in the YRB account for 17.66% of the national total, and national-level ICH accounts for 23.35% of the national total (Li and Shi 2022). Currently, most scholars' research on the upper reaches of the YRB focuses on vegetation coverage (Zhang et al.
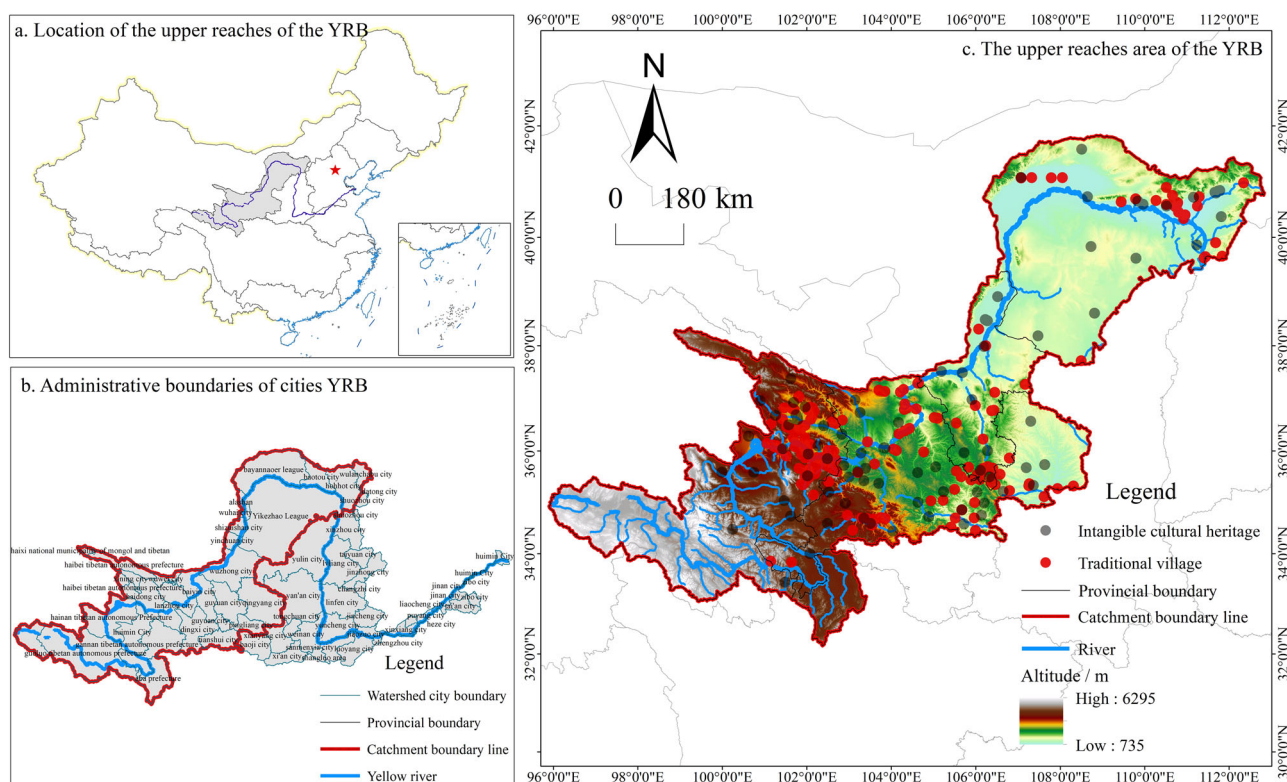
Fig. 1 Overview of study area. a Location of the upper reaches of the YRB; **b** Administrative boundaries of cities YRB; **c** The upper reaches area of the YRB.

2024), coordinated development (Qiao et al. 2024), coupling coordination degree (Yang et al. 2024), and ecosystems (Pang et al. 2024). Today, the upper reaches of the YRB face problems such as the imbalance between economic development and conservation, the decline and disappearance of TVs and ICH culture, and real conflicts between village development and ICH protection. As a result, the sustainable development of TVs in the upper reaches lacks effective momentum, and the transmission of ICH lacks effective guarantees. Moreover, few scholars have conducted in-depth research on the spatial relationship between TVs and ICH in the upper reaches of the YRB. In short, this paper takes the upper reaches of the YRB as a typical research area, using quantitative analysis methods to explore the spatial distribution characteristics and spatial correlation of TVs and ICH in the local area. It also deeply analyzes the formation mechanisms of their relationship from the perspectives of internal interaction mechanisms and external influencing factors, proposing an integrated protection and development path for TVs and ICH, an innovative path for the integrated protection and development of TVs and ICH is proposed, with the expectation of providing a theoretical basis for the protection and integrated development of rural settlements and ICH in the YRB and even in the river basin areas of other countries around the world.

Research Area and Data Methods
Research area. The upper reaches of the Yellow River, located between 96° to 114° east longitude and 32° to 42° north latitude, refer to the area stretching from the river's source to Hekou Town in the Inner Mongolia Autonomous Region, flowing through five provinces: Qinghai, Gansu, Sichuan, Ningxia Hui Autonomous Region, and Inner Mongolia Autonomous Region. The terrain is generally higher in the southwest and lower in the northeast, spanning the Qinghai-Tibet Plateau, the Inner Mongolia Plateau, and the Loess Plateau from west to east (Qiao et al. 2024; Liang et al. 2024) (Fig. 1). The river is 3472 km long, with a drainage

area of 386,000 km², accounting for 51.3% of the total area of the YRB. Rainfall decreases from northeast to southwest, with most of the upper reaches characterized by an arid climate with little rainfall, and the annual average precipitation is around 450 mm (Yang et al. 2024; Hong et al. 2024; Cao et al. 2014). However, with the advancement of urbanization, industrialization, and modernization, interpersonal relationships in rural areas have undergone drastic changes, and the quality of living environments has been declining year by year. The continuous outflow of rural populations and the invasion of capital enterprises into rural areas have further exacerbated rural decay and decline, with problems such as the assimilation or disappearance of ICH becoming increasingly evident. Therefore, the development of rural settlements and the transmission and protection of ICH in the upper reaches of the YRB have become particularly urgent. The key task now is to seize the opportunity presented by national strategic guidelines to address the sustainable development of TVs in the upper reaches, achieve the living transmission of ICH, and promote the overall development of regional TVs and ICH culture.

Research data. The data on TVs come from the lists of Chinese TVs published by the Ministry of Housing and Urban-Rural Development and other ministries in six batches, totaling 8155 villages. Detailed data are sourced from the Ministry of Housing and Urban-Rural Development of the People's Republic of China (https://www.mohurd.gov.cn). The data on ICH are derived from five batches of national project lists announced by the State Council in 2006, 2008, 2011, 2014, and 2021, comprising a total of 3610 sub-items of national-level ICH representative projects. Detailed data are sourced from the China ICH Network (http://www.ihchina.cn). According to the statistics from these lists, as of September 2024, there are 262 TVs and 189 ICH sites distributed across different provinces (autonomous regions) in the upper reaches of the YRB (Table 1). The Points of Interest (POI) data

Table 1 Statistics on the number of TVs and ICH in the upper reaches of the YRB.

Region	Province (Autonomous Region)	TVs(Count)	Proportion (%)	ICH (Items)	Proportion (%)
Upper Reaches of the Yellow River	Qinghai	153	0.58	66	0.35
	Sichuan	0	0.00	0	0.00
	Gansu	55	0.21	60	0.32
	Ningxia	24	0.09	28	0.15
	Inner Mongolia	30	0.11	35	0.19
	Total	262	1.00	189	1.00

for TVs and ICH were obtained by sampling their geographic coordinates using the Gaode Map Coordinate Picker, and their spatial vector databases were constructed using ArcGIS 10.8 software. The temperature data, with a resolution of 1 km, was obtained from the National Earth System Science Data Center (https://www.geodata.cn). The Digital Elevation Model (DEM) data were sourced from the China Geospatial Data Cloud Platform (https://www.gscloud.cn). Data on the economy, population, road transportation, urbanization rate, and other factors were obtained from the statistical bureaus, statistical yearbooks, statistical bulletins, and government work reports of the provinces (autonomous regions) in the upper reaches of the YRB.

Research methods

Quantitative relationship and barycenter model. The quantitative spatial relationship model is primarily used to measure the correlation between TVs and ICH, revealing the quantitative spatial relationship that exists between them (Yu et al. 2024; Tian et al. 2023). The calculation formula is as follows:

$$R = \frac{ad-bc}{\sqrt{(a+b)(c+d)(a+c)(b+d)}} ; X^2 = \frac{n(ad-bc)^2}{(a+b)(c+d)(a+c)(b+d)}$$ (1)

In Eq. (1): R ranges from $[-1, 1]$, where R > 0 indicates a positive correlation, and R < 0 indicates a negative correlation. a represents the total number of sample plots containing both TVs and ICH; b is the number of sample plots containing only traditional village points; c is the number of sample plots containing only ICH points; d is the number of sample plots that do not contain either traditional village or ICH points; n is the total number of sample plots. Among them, when $|X^2|>X_a^2(1)$, it shows that the quantitative spatial correlation between TVs and ICH is strong ; when $|X^2|< X_a^2(1)$, the correlation between the two is weak.

The gravity center model refers to a point within a region where the forces of elements achieve balance. In this study, the spatial gravity center model is used to visually describe the spatial distribution differences between TVs and ICH, as well as their dynamic evolution process. It can further reveal the overall spatial distribution characteristics between TVs and ICH (Tian et al. 2023; Liang et al. 2022). The calculation formula is:

$$X = \frac{\sum_{i=1}^{n} s_i x_i}{\sum_{i=1}^{n} s_i} ; Y = \frac{\sum_{i=1}^{n} s_i y_i}{\sum_{i=1}^{n} s_i}$$ (2)

In Eq. (2): X and Y represent the horizontal and vertical coordinates of the gravity center distribution for ICH or TVs, respectively; n is the number of provinces (autonomous regions); x_i and y_i represent the horizontal and vertical coordinates of the geometric center of the i-th province (autonomous region); S_i is the number of ICH or TVs in the i-th province (autonomous region).

Spatial displacement distance and deviation index. The spatial displacement distance is primarily used to reflect the overlap of different elements on the regional gravity center, that is, the displacement distance between the gravity centers of different elements. The displacement index can reveal the degree of spatial displacement among different elements (Zhang et al. 2024; Fan et al. 2010). The calculation formula is:

$$D = R\sqrt{(X_i - X_j)^2 + (Y_i - Y_j)^2} ; r = \frac{D}{\sqrt{S}} \times 100$$ (3)

In Eq. (3): D represents the spatial displacement distance, X_i and Y_i are the horizontal and vertical coordinates of the gravity center for TVs, and X_j and Y_j are the horizontal and vertical coordinates of the gravity center for ICH. R is a constant with a value of 111.11. When D = 0, the gravity centers of TVs and ICH coincide, indicating that their gravity centers have the same spatial distribution within the region, with no displacement. When D>0, it indicates that there is spatial displacement between the two gravity centers; the larger the value, the smaller the spatial overlap between TVs and ICH, and the more significant the spatial displacement. Conversely, a smaller value indicates less noticeable spatial displacement. r represents the deviation index relative to the geometric area, with S being the geometric area of the region. A larger r value indicates a higher degree of spatial displacement between TVs and ICH, while a smaller value suggests a lower degree of displacement.

Spatial mismatch Index. Based on the theory of spatial misalignment, the Spatial Misalignment Index (SMI) model is applied to further analyze the spatial distribution equilibrium of TVs and ICH in the upper reaches of the YRB, thereby quantitatively describing the coupling relationship between them in the regional space. This approach reveals the spatial misalignment intensity between TVs and ICH in the upper reaches of the YRB. A higher SMI value indicates a greater spatial misalignment intensity between the two, and conversely, a lower value indicates lesser misalignment (Zhang et al. 2024; Richard and Martin 2004). The calculation formula is:

$$SMI_i = \frac{1}{n}\left(\frac{m_i}{m}n - n_i\right) \times 100$$ (4)

In Eq. (4): SMI represents the spatial misalignment index for the i-th province (or autonomous region); m_i and n_i are the numbers of ICH and TVs, respectively, in the i-th province (or autonomous region); m and n are the total numbers of ICH and TVs, respectively, in the upper reaches of the YRB. SMI_i reflects whether the spatial distribution of the two elements is highly aligned; the greater the $|SMI_i|$ value, the more significant the spatial misalignment. When $|SMI_i|>1$, it indicates a significant spatial misalignment between TVs and ICH, on the contrary, it is not obvious. If $|SMI_i| = 0$, it suggests that the spatial misalignment disappears.

To further analyze the spatial misalignment between TVs and ICH in the upper reaches of the YRB, this study introduces a contribution model to explore the degree of spatial misalignment between the two elements (Zeng and Zhao 2019; Wang and Lin

2023). The calculation formula is as follows:

$$R_i = \frac{1}{m}\sum_{j=1}^{m}\left(\frac{SM_{ij}}{\sum_{i=1}^{n}|SMI_{ij}|}\right) \quad (5)$$

In Equation (5), m represents the length of the study period, n represents the number of provinces (or autonomous regions), and R_i represents the average contribution rate of the i-th province (or autonomous region) to the degree of regional spatial misalignment during the study period.

Geographical detector. The geographical detector is mainly an analytical tool used to detect and utilize spatial heterogeneity. It can not only detect the spatial heterogeneity of a single factor but also explore whether there is a coupling correlation between two factors. Referring to references (Huang and Xue 2024), the relationships among traditional villages, ICH, and other elements in the upper reaches of the YRB are explored. The calculation formula is as follows:

$$q = 1 - \frac{\sum_{L}^{h=1} N_h \sigma_h^2}{N\sigma^2} \quad (6)$$

In formula (6), the q value is a measure of the detection ability of the independent variable, with a value range of [0, 1]. The larger the q value is, the greater the explanatory power and influence of factor x on the spatial distribution y of traditional villages. $h = 1, 2, …, L$ represents the stratification of variable y or factor x, that is, classification or partitioning. N_h is the number of units in layer h; N is the number of units within the basin; σ_h^2 is the variance of layer h; and σ^2 is the variance of the y value within the basin. It detects the influence and explanatory power of the interaction between the influencing factors x_1 and x_2 on variable y in terms of enhancement, weakening effects or remaining independent and unchanged.

Results and Analysis
Analysis of the spatial characteristics of TVs
Spatial quantitative characteristics. As shown in Table 1, there are 262 villages in the upper reaches of the YRB that have been included in the national list of TVs, out of a total of 892 TVs in the entire YRB. This accounts for 29.37% of the total TVs in the basin and 3.21% of the total number of TVs nationwide. Analyzing the distribution and proportion across the five provinces (or autonomous regions) in the upper reaches of the YRB, it is evident that the distribution of TVs varies significantly among these regions. Qinghai Province has the highest number and proportion of TVs, with 153 villages, accounting for 58% of the total. This is followed by Gansu Province, Inner Mongolia Autonomous Region, and Ningxia Province. There is no traditional village distribution in Aba Prefecture of Sichuan Province within the boundary of the upper reaches of the YRB.

Spatial distribution characteristics. According to the kernel density distribution shown in Fig. 2A, the distribution of TVs in the upper reaches of the YRB exhibits a pattern of "multi-core clustering with dispersed concentration." This pattern includes one high-density core area, four secondary-density core areas, and several small core areas. The northeastern part of Qinghai Province forms a typical high-density core cluster with a radiating effect towards the eastern regions. Three of the core dense areas are mainly concentrated in Gansu Province and Ningxia Province, with only one located in Inner Mongolia. Several small core clusters are primarily concentrated in the central region. Therefore, it can be concluded that TVs in the upper reaches of the

YRB are mainly concentrated in the central region, with a higher number of villages distributed across the Gansu-Qinghai-Ningxia zone, showing a clustering tendency. In contrast, the northern and southern regions have fewer TVs, with more scattered distributions. In terms of the concentration analysis of TVs, the geographic concentration index is G = 63.76, with G_0 = 52.40, and since $G > G_0$, it indicates that TVs in the upper reaches of the YRB exhibit a highly concentrated distribution. Regarding spatial distribution equilibrium, the imbalance index calculated using Excel is S=0.6431, indicating that the distribution of TVs in the upper reaches of the YRB is uneven. The Lorenz curve of TVs in this region, generated from statistical data (Fig. 2B), clearly shows that the curve is relatively distant from the line of uniform distribution, with a pronounced curvature, indicating an overall uneven distribution of TVs in the upper reaches of the YRB. The TVs in the three provinces of Qinghai, Gansu, and Inner Mongolia account for over 90% of the total, while Ningxia and Sichuan have a relatively small distribution of TVs.

Analysis of the spatial characteristics of ICH
Spatial quantitative characteristics. As shown in Table 1, the upper reaches of the YRB currently have 189 national-level ICH items, with a total of 430 ICH items in the YRB, accounting for 43.95% of the total ICH in the basin and 5.24% of the national ICH total. Analyzing the distribution and proportion across the five provinces (or autonomous regions) in the upper reaches of the YRB, there are significant spatial distribution differences in ICH among these regions. Qinghai, Gansu, and Inner Mongolia have the highest numbers of ICH, with 66, 60, and 35 items respectively, accounting for 35%, 32%, and 19% of the total ICH. Therefore, Qinghai Province has the highest number and proportion of ICH, while Sichuan Province has the least. Overall, ICH is more concentrated in the Gansu-Qinghai region of the upper YRB, while fewer ICH items are distributed in Sichuan and Ningxia. Given that Sichuan has a smaller area within the upper reaches of the YRB, the number of ICH items is correspondingly lower.

Spatial distribution characteristics. According to Fig. 3A, the spatial distribution density structure of ICH in the upper reaches of the YRB exhibits a pattern of "empty in the south, dense in the center, and sparse in the north." The southern Sichuan Province has the fewest ICH items and the lowest density, showing a distinct "hollow" pattern; the central provinces of Qinghai, Gansu, and Ningxia have a higher number of ICH items with higher density; while the northern region of Inner Mongolia has a relatively scattered distribution of ICH with lower density. The spatial distribution of ICH presents a characteristic of "one core, two secondary cores, and multiple small core areas", with an overall pattern of "small clusters and large dispersion." Specifically, the central dense area has further formed one high-density core area, centered in the Gansu-Qinghai-Ningxia region, radiating to surrounding areas; the two secondary core areas are mainly located in northern Ningxia and Inner Mongolia, while the remaining ICH core areas are scattered as small core areas across various regions.

The concentration analysis results indicate that the current region has a geographic concentration index of G = 52.82, with G_0 = 37.80, and since $G > G_0$, it indicates that ICH in the upper reaches of the YRB exhibits a highly concentrated distribution. In terms of spatial distribution equilibrium, the calculated imbalance index is S=0.4339, indicating that the distribution of ICH in the upper reaches of the YRB is uneven. The Lorenz curve of ICH (Fig. 3B) shows that although the distribution of ICH across
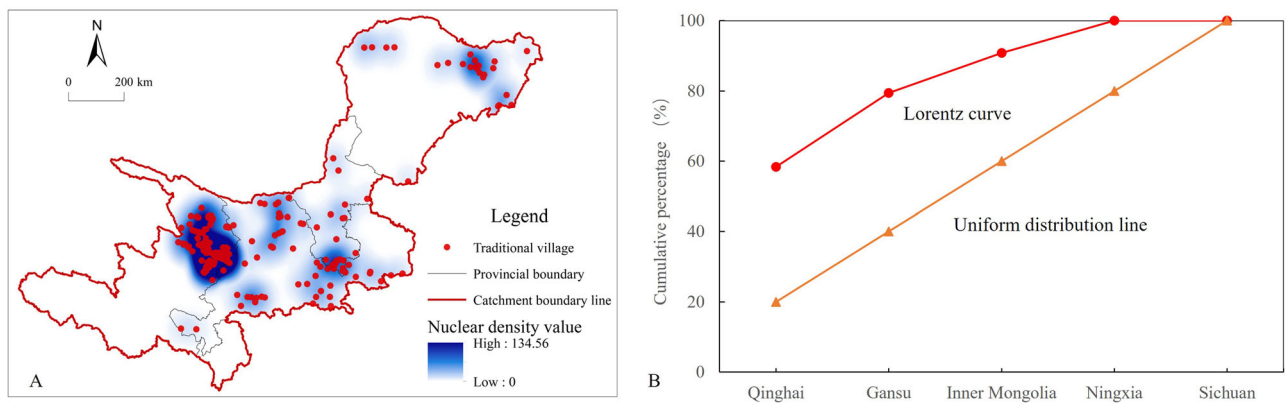
Fig. 2 Analysis of nuclear density and Lorenz curve of TVs. A Nuclear density of TVs; **B** Lorenz curve of TVs.
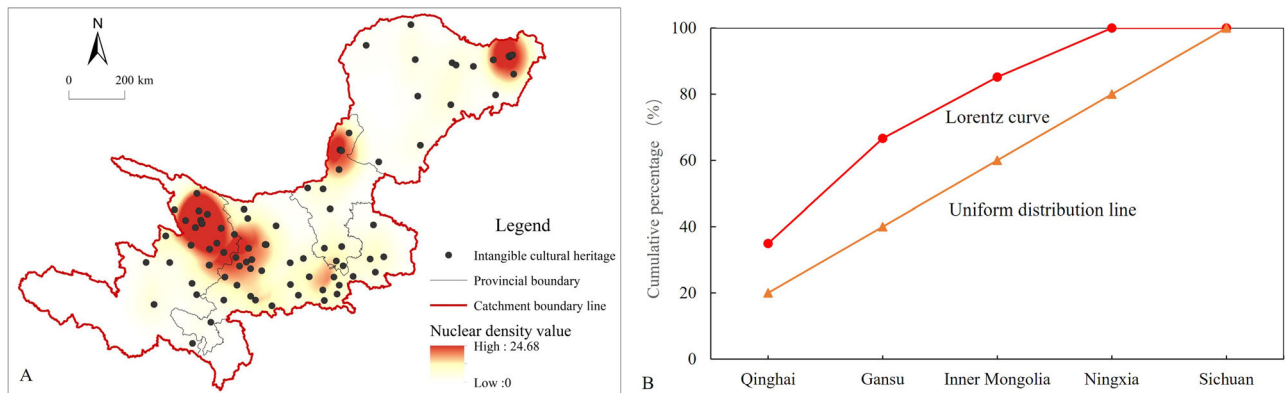

Fig. 3 Analysis of nuclear density and Lorenz curve of ICH. A Nuclear density of ICH; **B** Lorenz curve of ICH.

provinces in the upper reaches of the YRB is uneven, the differences are relatively small. The ICH items in the three provinces of Qinghai, Gansu, and Inner Mongolia account for more than 85% of the total, while Ningxia and Sichuan have fewer ICH items, with sparse distribution.

Analysis of the spatial relationship between TVs and ICH
Quantitative spatial relationship. The 262 TVs and 189 ICH sites in the upper reaches of the YRB were mapped onto a spatial vector map, creating a spatial distribution layer of TVs and ICH in this region. Following the approach of Tian Lei et al (Tian et al. 2023), ArcGIS software was further used to create sample grids of the administrative map of the upper YRB, with grid squares of 50 km in both length and width. The map layer was then masked and clipped according to the upper YRB's boundaries. The sample grid layer was then overlaid with the point data distribution layer, ultimately resulting in the spatial distribution and sample decomposition map of TVs and ICH in the upper YRB. Research shows that the distribution of TVs and ICH in the upper YRB is highly consistent. Specifically, areas with a dense distribution of TVs also correspond to areas with a dense distribution of ICH. Conversely, in areas where TVs are sparsely distributed, the distribution of ICH is relatively scarce. This strongly proves the correlation between the spatial distributions of TVs and ICH.

Using a quantitative spatial relationship model, the spatial quantities of both were analyzed, resulting in 122 grid cells containing both TVs and ICH, 78 grid cells containing only TVs, 73 grid cells containing only ICH, and 329 grid cells containing neither TVs nor ICH, with a total of 451 grid cells in the region. Thus, the values are $a = 122$, $b = 78$, $c = 73$, $d = 329$, and

$n = 451$. The spatial relationship index between the two was then calculated using the following formula:

$$R = \frac{122 \times 329 - 78 \times 73}{\sqrt{(122 + 78)(73 + 329)(122 + 73)(78 + 329)}} = 0.0000108$$

The results show that R > 0 indicates a positive correlation. The following formula is then used for further calculation:

$$X^2 = \frac{329 \times (122 \times 329 - 78 \times 73)^2}{(122 + 78)(73 + 329)(122 + 73)(78 + 329)} = 61.17$$

By referring to the distribution table of $X_a^2(1)$, it can be seen that at the significant level of a = 0.05, $X_a^2(1) = 3.68$, $\left|X^2\right| > X_a^2(1)$, which indicates that there is a strong spatial correlation between TVs and ICH.

Centroid misalignment analysis. According to the centroid model calculation formula (Table 2), it can be observed that there is a spatial misalignment between TVs and ICH in the upper reaches of the YRB. Specifically, the centroid positions of TVs and ICH in the upper YRB show a significant spatial deviation. As shown in Fig. 4, the centroid of TVs (103.971°E, 36.402°N) is located to the northwest of the geometric center, while the ICH centroid (104.851°E, 36.941°N) is situated to the northeast of the geometric center. Both centroids are located within Gansu Province, but there is a certain degree of spatial misalignment, with a deviation distance of 114.98 km between the centroids of TVs and ICH. This indicates that there is a spatial differentiation between TVs and ICH in the upper YRB.

The calculation results for each province (or autonomous region) also show a similar misalignment between the spatial distributions of TVs and ICH. In terms of misalignment distance,

Table 2 TVs and ICH distribution center of gravity dislocation.

Province (Autonomous Region)	TVs Center		ICH Center		Displacement Distance (D) /km	Deviation Index (r)
	Longitude/°	Longitude /°	Longitude /°	Longitude /°		
pper Reaches of the YRB	103.968	36.402	104.851	36.941	114.98	-
Qinghai	102.139	35.926	101.714	36.209	56.66	0.0119
Gansu	104.643	35.607	104.345	35.351	43.72	0.0094
Inner Mongolia	110.281	40.428	110.602	40.453	35.78	0.0070
Ningxia	106.188	36.221	106.142	37.685	162.77	0.0572
Sichuan	-	-	-	-	-	-

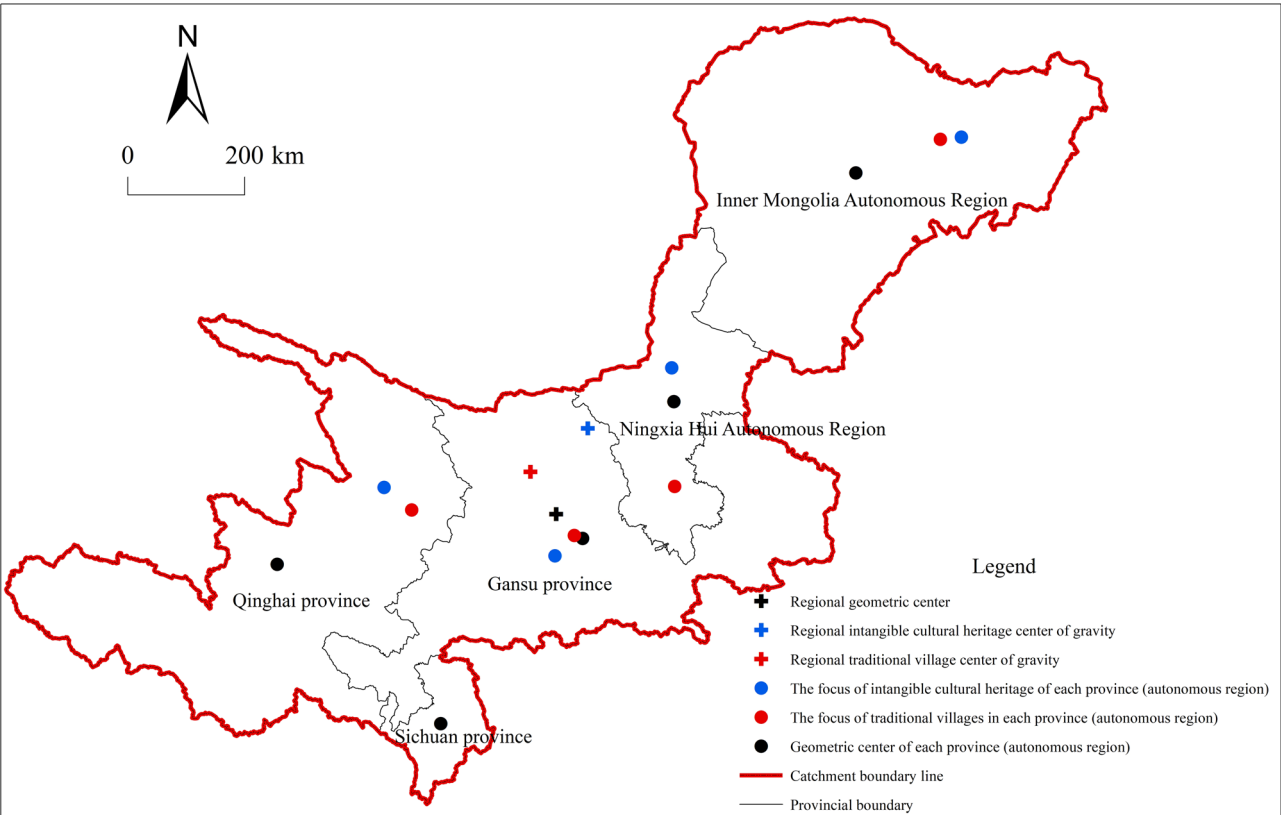"-" in the table indicates that there is currently no data available for this region.

Fig. 4 The TVs in the upper reaches of the YRB are misaligned with the center of gravity of the distribution of ICH.

Ningxia Province exhibits the most significant misalignment, with a distance of 162.77 km, followed by Qinghai, Gansu, and Inner Mongolia, with misalignment distances of 56.66 km, 43.72 km, and 35.78 km, respectively. Since Sichuan Province has no distribution of TVs and ICH in the upper YRB, the misalignment distance for this region is zero. Analyzing the deviation index, Ningxia and Qinghai have the highest deviation indices, at 0.0572 and 0.0119, respectively. Gansu and Inner Mongolia have lower deviation indices of 0.0094 and 0.0070, respectively, while Sichuan Province has a deviation index of zero. It is evident that all deviation indices are below 0.1, indicating that the spatial misalignment between TVs and ICH in the upper YRB is relatively small, showing a relatively balanced and favorable pattern.

Analysis of scale misalignment in regional distribution. The centroid model analysis can only observe the spatial misalignment between TVs and ICH from a macro perspective; it cannot reveal the degree, intensity, and pattern types of local spatial

misalignment. Therefore, to further analyze the spatial misalignment between ICH and TVs, the SMI was introduced for analysis. The results indicate that in terms of misalignment direction, the distribution scale of ICH in Gansu, Inner Mongolia, and Ningxia is larger than that of TVs (SMI > 0), while Qinghai's TVs have a more advantageous distribution scale (SMI < 0). Analyzing the degree of misalignment, the contribution rate of each province (autonomous region) in the upper reaches of the YRB was calculated using the contribution model. Table 3 shows that Qinghai Province has the highest degree of misalignment, with a contribution rate of 0.81%. Gansu and Inner Mongolia also rank in the top three, with contribution rates of 0.37% and 0.24%, respectively, contributing a total of 1.42%. Sichuan and Ningxia have the lowest degrees of misalignment, with contribution rates of 0.19% and 0%, respectively. This indicates that the misalignment phenomenon between TVs and ICH in the upper reaches of the YRB is mainly caused by the spatial distribution imbalance in a few provinces (autonomous regions) and partially due to the relatively small number of TVs and ICH sites in this region.

Table 3 Spatial mismatch index and type division of provinces (autonomous regions).

Autonomous Regions	SMI	R_i	Type
Qinghai	−23.476	0.81	Negative High Misalignment Area
Gansu	10.754	0.37	Positive High Misalignment Area
Inner Mongolia	7.068	0.24	Positive High Misalignment Area
Ningxia	5.655	0.19	Positive High Misalignment Area
Sichuan	0.000	0.00	Positive Low Misalignment Area

Table 4 SMI value range and type division corresponding table.

Value Range	Regional Type
SMI ≥ 5	Positive High Misalignment Area
0 ≤ SMI < 5	Positive Low Misalignment Area
−5 ≤ SMI < 0	Negative Low Misalignment Area
SMI < −5	Negative High Misalignment Area

Based on the Spatial Misalignment Index, the five provinces (autonomous regions) in the upper reaches of the YRB are classified into four types (Table 4): positive high misalignment areas (SMI ≥ 5), including Gansu, Inner Mongolia, and Ningxia; positive low misalignment areas (0 ≤ SMI < 5), which only include Sichuan; negative low misalignment areas (−5 ≤ SMI < 0), with no provinces (autonomous regions); and negative high misalignment areas (SMI < −5), which only include Qinghai Province. It can be observed that, at the provincial (autonomous region) level, three types of regional misalignments are formed: positive high misalignment, positive low misalignment, and negative high misalignment. Positive misalignment areas, where ICH has a relatively more advantageous distribution, are mainly located in the central and northern regions of the upper reaches of the YRB. Negative misalignment areas, where TVs have a relatively more advantageous distribution, are mainly concentrated in the western regions, particularly in eastern Qinghai Province. This region has a relatively low level of economic development, diverse and complex landforms, and is located at the intersection of the Loess Plateau and the Tibetan Plateau, which has allowed TVs to maintain their original appearance and concentrated distribution. In contrast, the distribution of ICH in this region is relatively scattered, reflecting more frequent human activities in the area and a strong coupling with the natural geographical environment and transportation routes.

Analysis of the influence mechanisms between TVs and the spaces of ICH

Analysis of the endogenous correlation between the two. TVs serve as the spatial carriers and external manifestations of ICH. They are not only crucial sites for the birth and survival of ICH but also the original soil for its continuation and development. TVs provide the cultural foundation and life source for the transmission and expansion of ICH (He et al. 2024). The upper reaches of the Yellow River are key areas for high-quality development and ecosystem protection within the YRB. This region suffers from severe soil erosion, fragile ecological environments, complex geographical conditions, underdeveloped economies, and inconvenient transportation, leading to limited human activity. As a result, most TVs and ICH have been preserved and passed down in their original ecological states. The culture, customs, and architecture of these areas are deeply rooted in the Loess Plateau environment and the local regional culture. Once separated from this original ecological environment, TVs would lose their foundation for survival, and ICH would lose its material

carrier, making the sustainable development of ancient villages and the living transmission of ICH difficult to sustain. TVs are the carriers of ICH, and ICH is the continuation of TVs; the two are mutually reinforcing and coexist harmoniously. Therefore, promoting their integrated protection and sustainable development is a key issue in current regional rural development and heritage preservation. Thus, this study recognizes the unique environmental conditions of the upper YRB and its cultural, economic, and human differences from the broader region. It examines the spatial distribution patterns of TVs and ICH in this area by analyzing three key aspects: natural geographic environment, socio-economic conditions, and cultural policies. This includes factors such as elevation, river systems, temperature, regional economy, accessibility, population density, urbanization rates, cultural characteristics, and funding policies. By revealing the influencing factors and mechanisms between the two, and drawing on the spatial distribution relationships and influence mechanisms of TVs and ICH, this study proposes specific strategies for their integrated development, ultimately outlining a strategic pathway suitable for the fusion of TVs and ICH in the upper YRB. Therefore, this study focuses on three dimensions and eight factors as the core of the influencing mechanisms analysis, aiming to reveal the typicality, representativeness, and regional specificity of the integration path of TVs and ICH in the current area (Fig. 5).

Natural geographic environment

Elevation and slope. As shown in Fig. 6A, B, and Table 5, the elevation in the upper reaches of the YRB ranges from 735 meters to 6295 meters. For TVs, the natural geographic environment significantly influences their distribution, with noticeable geographic disparities. Using ArcGIS to overlay the TVs in the upper reaches of the YRB with elevation and slope, the elevation is divided into five levels using the natural breaks method: 735 ~ 1588 m, 1589 ~ 2326 m, 2327 ~ 3182 m, 3183 ~ 3996 m, and 3997 ~ 6295 m. There are 61 TVs at 735 ~ 1588 m, accounting for 23% of the total; 74 villages at 1589 ~ 2326 m, accounting for 28%; 122 villages at 2327 ~ 3182 m, making up 47%; 5 villages at 3183 ~ 3996 m, accounting for 2%; and no TVs at 3997 ~ 6295 m. This indicates that the spatial layout of TVs in the upper reaches of the YRB is significant and relatively concentrated in low-altitude areas, with most villages located below 3000 meters in elevation. Due to the high average altitude of the Loess Plateau, the climate in high-altitude areas is cold and unsuitable for development, resulting in less human activity and fewer village distributions. Analyzing the slope, the slopes in the upper reaches of the YRB are divided into five levels using the natural breaks method: 0 ~ 6°, 7 ~ 13°, 14 ~ 20°, 21 ~ 30°, and 31 ~ 90°. Most TVs are located in areas with slopes below 20°, especially between 0 ~ 6°, where 141 villages are distributed, accounting for 54% of the total, exceeding half of the region's total. It is evident that the distribution of TVs in the upper reaches of the YRB is closely related to elevation and slope. Lower elevations with gentler slopes are more conducive to the formation and development of villages, making them suitable for human activities and
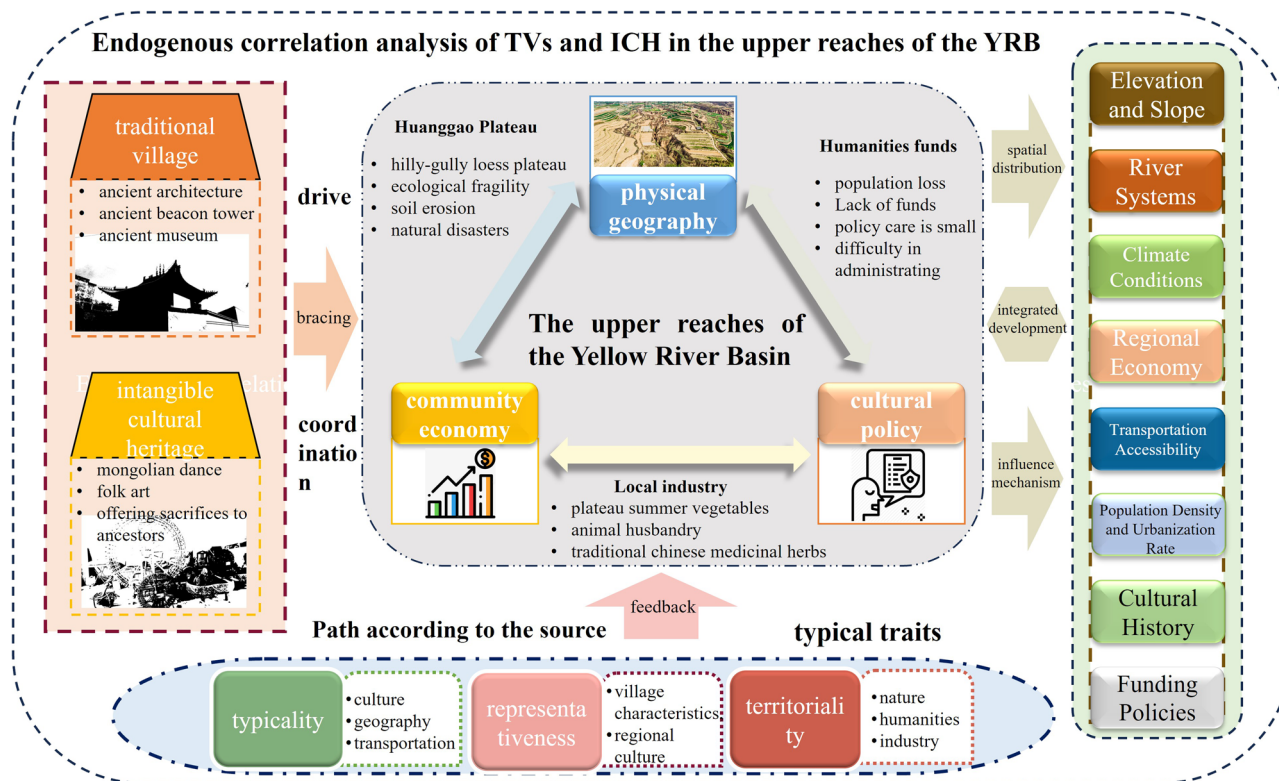
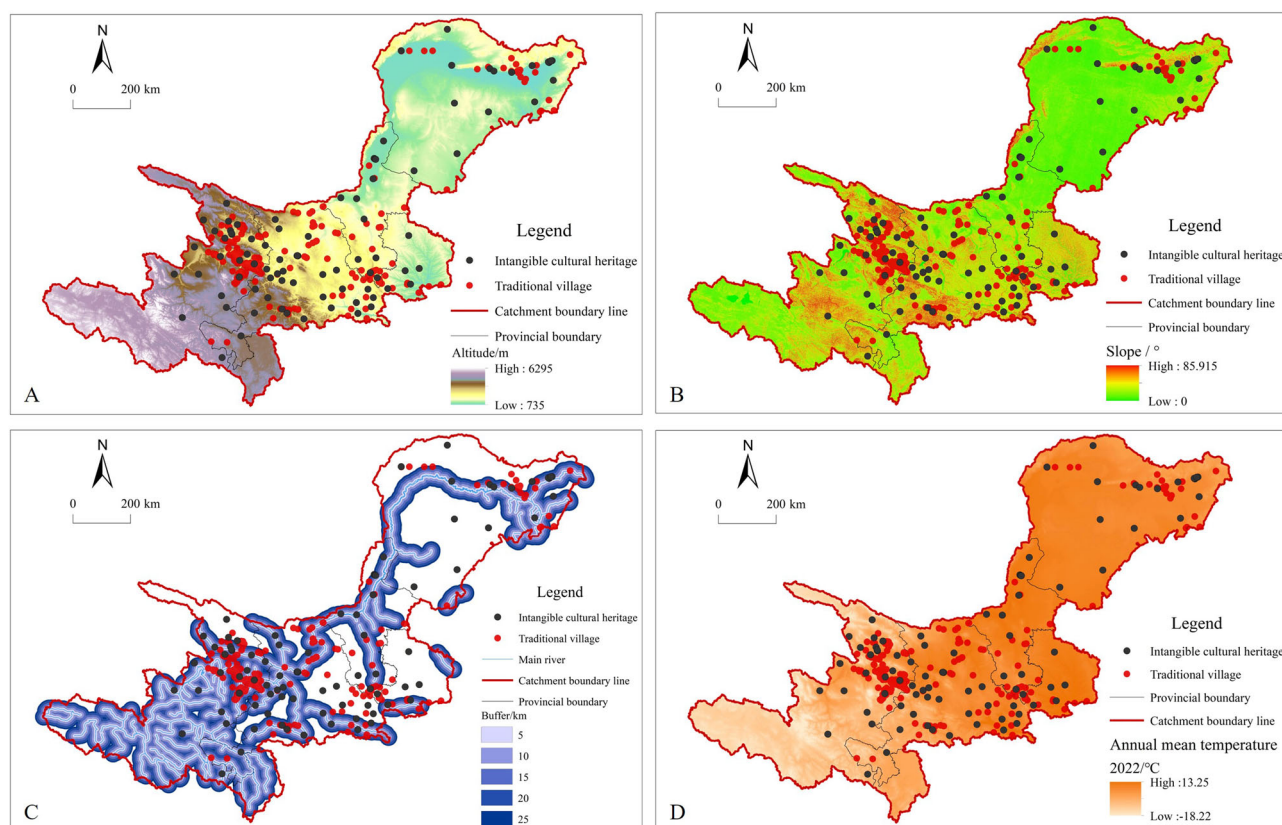**Fig. 5** The typical analysis framework of the endogenous relationship between TVs and ICH.

Fig. 6 The superposition analysis of TVs, ICH and natural geographical elements in the upper reaches of the YRB. A TVs and ICH and altitude overlay analysis; **B** TVs and ICH and slope overlay analysis; **C** TVs and ICH and river overlay analysis; **D** TVs and ICH and temperature overlay analysis.

Table 5 Statistics on the geographical spatial distribution of TVs and ICH in the upper reaches of the YRB.

Geographical Factors	Classification	TVs		ICH	
		Number/Count	Proportion/%	Number/Count	Proportion/%
Elevation /m	735 ~ 1588	61	0.23	78	0.41
	1589 ~ 2326	74	0.28	58	0.31
	2327 ~ 3182	122	0.47	45	0.24
	3183 ~ 3996	5	0.02	8	0.04
	3997 ~ 6295	0	0.00	0	0.00
Slope/(°)	0 ~ 6	141	0.54	120	0.63
	7 ~ 13	93	0.35	52	0.28
	14 ~ 20	22	0.08	17	0.09
	21 ~ 30	6	0.02	0	0.00
	31 ~ 90	0	0.00	0	0.00
River/km	0 ~ 5	143	0.55	80	0.42
	6 ~ 10	38	0.15	36	0.19
	11 ~ 15	21	0.08	10	0.05
	16 ~ 20	12	0.05	19	0.10
	21 ~ 25	18	0.07	11	0.06

livelihoods. In terms of ICH, an elevation analysis shows that ICH is mainly distributed in areas with elevations between 735 ~ 1588 m, 1589 ~ 2326 m, and 2327 ~ 3182 m, with the most ICH found between 735 ~ 1588 m, totaling 78, the highest proportion at 41%. However, TVs are sparsely distributed in areas above 3183 m. Analyzing the slope, ICH is primarily concentrated in areas with slopes between 0 ~ 6°, with 120 TVs distributed in this range, accounting for 63%, while no ICH is found in areas with slopes above 21°. This shows a positive correlation between the distribution of ICH and the natural geographic environment; the flatter the slope and the lower the elevation, the more ICH is distributed and the higher its proportion, and vice versa.

River systems. As shown in Fig. 6C and Table 5, most TVs are located in the central and southern parts of the region, often near the main branch of the Yellow River. Using ArcGIS to overlay TVs in the upper reaches of the YRB with the main river, the rivers are classified into five levels using the natural breaks method: 0 ~ 5 km, 6 ~ 10 km, 11 ~ 15 km, 16 ~ 20 km, and 21 ~ 25 km. Among them, 143 TVs and 80 ICH items are distributed within 5 km of the river, accounting for 55% and 42% of the total TVs and ICH in the region, respectively. There are 38 TVs and 36 ICH items located within 6 ~ 10 km of the river, accounting for 15% and 19% of the total, respectively; 21 TVs and 10 ICH items within 11 ~ 15 km, accounting for 8% and 5%; 12 TVs and 19 ICH items within 16 ~ 20 km, accounting for 5% and 10%; and 18 TVs and 11 ICH items within 21 ~ 25 km, accounting for 7% and 6% of the total. It is evident that river systems are an important factor in the distribution of TVs and ICH. The closer to the river, the greater the number of TVs and ICH items, and vice versa.

Climate conditions. Climate conditions are a critical factor in preserving and developing TVs and ensuring the active transmission of ICH in the upper reaches of the YRB. According to Fig. 6D, the annual average temperature in this region ranges between −18 ~ 14 °C, with a general trend of higher temperatures in the northeast and lower temperatures in the southwest. Both TVs and ICH are mainly concentrated in areas with moderate temperatures. Using ArcGIS, the temperature distribution in the upper YRB was classified into five categories based on natural breaks: −18.00 ~ −3.59 °C, −3.60 ~ 0.22 °C, 0.23 ~ 4.16 °C, 4.17 ~ 7.48 °C, and 7.49 ~ 14 °C. TVs are distributed within the 0 ~ 14 °C range, with the highest concentration (128 villages, or 48.85% of the total) found in the 4.17 ~ 7.48 °C range. In contrast, ICH is mainly concentrated

in areas with temperatures between 7.49 ~ 14 °C, where 108 items are located, accounting for 41.22% of the total. Additionally, 56 items (21.37%) are found in the 4.17 ~ 7.48 °C range, and 24 items (9.16%) in the 0.23 ~ 4.16 °C range. Therefore, temperature plays a significant role in determining the distribution of TVs and ICH. Generally, the more moderate the temperature, the higher the concentration of both. This suggests a strong correlation between climate conditions and the development of TVs as well as the transmission of ICH. The positive correlation implies that as temperature increases, so does the number of TVs and ICH items.

Socio-economic environment
Regional economy. As shown in Fig. 7A, the distribution pattern of TVs in the upper reaches of the YRB is closely related to the economic development of each province (autonomous region) in two main ways. First, TVs are concentrated in cities such as Lanzhou, Yinchuan, Baotou, and Hohhot, where the level of economic development is relatively high. The reason for this is that these cities have better economic development, providing essential material resources and financial policy support for the survival and development of TVs. In terms of ICH, the number of ICH projects in economically developed regions is greater than in less developed regions such as Gannan, Haibei, and Haixi, indicating a positive correlation between their distribution and the level of regional economic development. Second, TVs are also concentrated in cities with lower levels of economic development, such as Xining, Qingyang, and Longnan. These areas are rich in traditional culture and have a long history of settlement development, being home to ethnic minorities such as the Hui, Tibetan, Mongolian, and Tujia. Due to limited human activity, the original appearance of TVs has been well preserved, and the memory of ICH has been effectively retained. The backward economy and poor location of TVs in these regions have to some extent limited urban and rural construction and development, thus providing a good environment for the survival and development of TVs and ICH.

Transportation accessibility. This study considers four factors— highways, national roads, provincial roads, and railways—as the primary elements for analyzing transportation accessibility in the region. Based on field surveys of the upper YRB and existing literature analysis (Hu et al. 2014), TVs and ICH are more concentrated near transportation roads at critical distances of 5 km, 15 km, and 25 km. Therefore, 5 km, 15 km, and 25 km were defined as buffer zones around roads in the upper YRB.
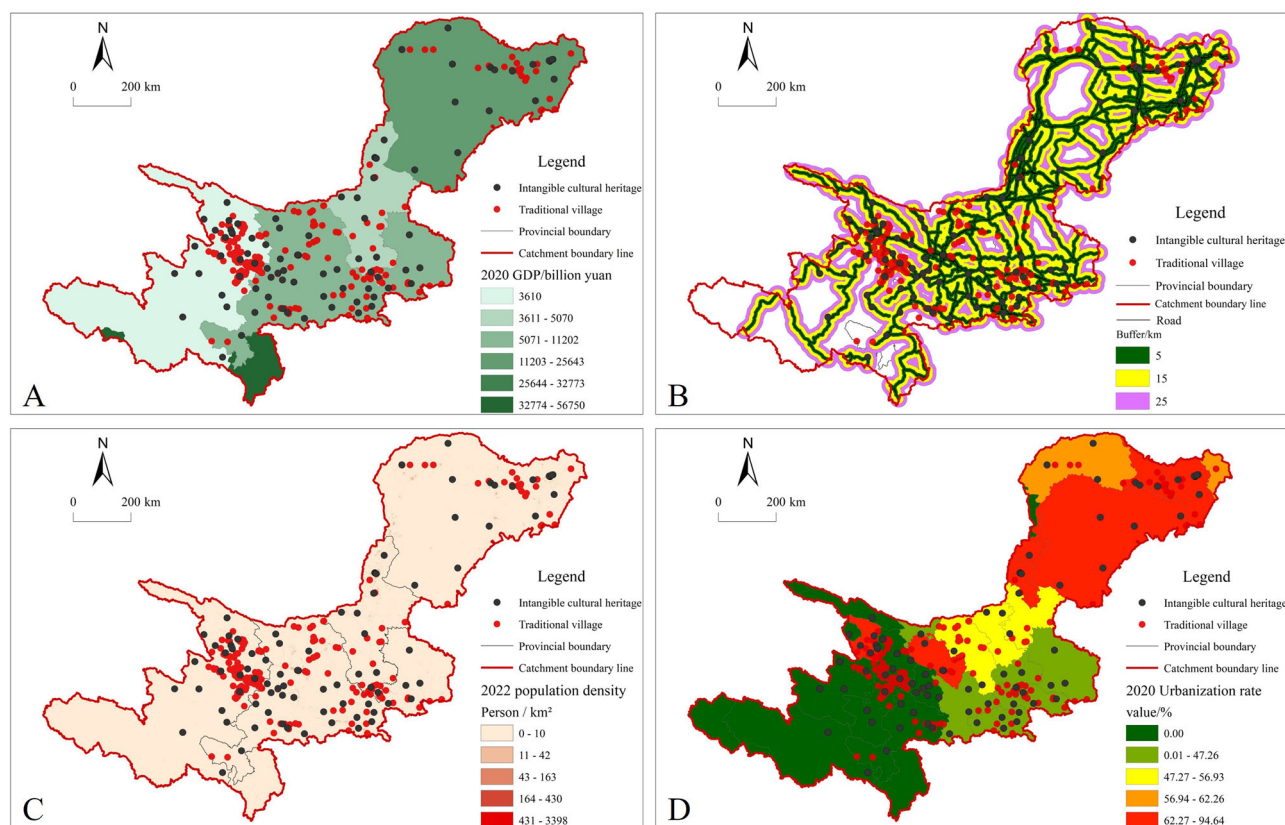
Fig. 7 Superposition analysis of TVs, ICH and various social and economic factors in the upper reaches of the YRB. A TVs and ICH and GDP overlay analysis; **B** TVs and ICH and transportation overlay analysis; **C** TVs and ICH and population density overlay analysis; **D** TVs and ICH and urbanization rate overlay analysis.

Multi-ring buffer zone analysis was then conducted with transportation roads as the focal point. The transportation buffer zones were overlaid with point data of TVs and ICH to explore the correlation between TVs or ICH and the distance to transportation routes. As shown in Fig. 7B, a total of 147 TVs are located within 5 km of roads in the region, accounting for 56.11% of the total number of TVs. Within the 15 km buffer zone, there are 80 TVs, making up 30.53% of the total, and within the 25 km buffer zone, there are 29 TVs, accounting for 11.07% of the total. It can be seen that the spatial distribution of TVs in the upper reaches of the YRB is positively correlated with the distance to roads. The closer the area is to roads, the more TVs are distributed there. Since ancient times, the upper reaches of the YRB have been important transportation hubs, serving as key bridges and distribution centers for the flow of people and goods, and as significant trading ports between the East and the West. Therefore, the formation of TVs is closely linked to transportation accessibility. Regarding ICH, all 189 ICH sites in the region are located within 5 km of roads, indicating that the distribution of ICH is more influenced by transportation than that of TVs. As the dissemination of ICH requires strong support from transportation infrastructure, its distribution is more inclined towards areas with better transportation access. For example, as one approaches the ancient Silk Road, the number of ICH sites along the old trade routes gradually increases. However, in regions with underdeveloped economies and lower transportation accessibility, the transmission of ICH culture gradually declines and withers.

Population density and urbanization rate. The population density in 2022 and the urbanization rate of prefecture-level cities in 2020 in the upper reaches of the YRB were selected as analysis factors in this study. As shown in Fig. 7C, D, the distribution of TVs in this region exhibits a generally negative correlation with population density and urbanization levels. In other words, areas with a higher density of TVs tend to have lower population density and urbanization rates. Most TVs in the region are located in areas with a population density of less than 10 people per square kilometer and an urbanization rate of less than 60%. This indicates that the population density is relatively low, and TVs are primarily distributed in cities such as Haidong, Linxia, and Guyuan, where both population density and urbanization rates are low. Compared to TVs, the distribution of ICH shows a different trend in relation to population density and urbanization levels. ICH is scattered in areas with an urbanization rate above 60%, but it is also found in central and southern regions with urbanization rates below 60%. In terms of population density, the distribution of ICH is roughly similar to that of TVs, with most being located in areas where the population density is below 10 people per square kilometer.

Humanistic and policy environment

Cultural history. TVs and ICH, as the foundation of human civilization in the YRB and as significant windows showcasing agrarian culture, have maintained their vitality through the historical evolution over time. The cultural heritage and settlement culture in the basin are closely linked to the production and living practices of local people, achieving dynamic transmission within relatively stable social networks and culturally recognized spaces (Lu and Bai 2017; Tian et al. 2024). In the upper reaches of the YRB, the formation and development of TVs and ICH both depend on the local ecological and cultural environment. This region is a typical agricultural area,

where places like the Hehuang Valley and the Hetao Plain are suitable for farming. The self-sufficient agrarian culture has not only boosted the regional economy but also strengthened kinship ties based on blood relations. Additionally, this area is home to a rich tapestry of cultural heritage, including Yellow River culture, Hehuang culture, Paleolithic culture, and Neolithic culture. It also boasts numerous World Cultural Heritage sites and important agricultural heritage, making it a melting pot of multi-ethnic cultures and various ideologies. ICH activities such as sacrificial fires, folk culture, and performing arts remain closely connected to the daily lives of TVs, continually playing a role in shaping the rural living environment and reinforcing family identity and values. Moreover, villagers, as the mainstay of local settlements, are the leading force in the transformation and transmission of ICH. ICH inheritors and local sages are the core forces that keep ICH vibrant and alive. The deep-rooted traditional culture in the upper YRB, influenced by Taoism, Buddhism, Confucianism, and a small-scale peasant economy, has fostered a strong sense of nostalgia centered on family and homeland in this region. The agrarian-based way of life has persisted under the influence of cultural and kinship ties, and ICH, as an integral part of the lives of residents in TVs, has been passed down through generations. However, in recent years, regionally distinctive architectural styles, such as zhuangbao (fortress-style) and siheyuan (courtyard-style) buildings, have been damaged. The ecological and cultural environment that sustains them has also been eroded, adversely affecting the dynamic development of TVs and the living preservation of ICH.

Funding policies. In recent years, the protection of TVs and ICH in the YRB has garnered considerable attention from both local governments and the national level. In terms of traditional village protection, after the official reclassification of "ancient villages" to "TVs" in 2012, the nation has been steadily advancing protective efforts and enacting relevant laws and policies. In 2021, the Central Committee of the Communist Party of China and the State Council issued the "Outline of the YRB Ecological Protection and High-Quality Development Plan", which emphasized the integration and collaboration of resources across regions in the YRB. In 2023, the "Opinions of the Central Committee of the Communist Party of China and the State Council on Effectively Promoting Key Tasks in Rural Revitalization in 2023" called for the steady advancement of livable and workable beautiful village construction, and the acceleration of integrated construction and coordinated development of tourist attractions and key tourist villages [59]. In terms of ICH protection, the Ministry of Culture and Tourism issued the "14th Five-Year Plan for the Protection of ICH", which explicitly called for strengthening the protection and transmission of ICH in the YRB. Clearly, the protection, inheritance, and promotion of Yellow River culture have become key tasks in the current phase of ecological protection and high-quality development of the YRB. Protecting the unique cultural characteristics of the Yellow River, preserving regional civilization, safeguarding rural customs, and passing down cultural heritage in the basin are crucial paths to achieving this goal.

Discussion
Detection and analysis of the interaction of influencing factors.
Factor detection can be used to explore the driving force between two independent variables, identifying the dominant factors affecting the spatial differentiation of TVs and ICH by comparing the magnitude of the two factors. Based on the previous analysis of driving factors, the spatial distribution of TVs and ICH is influenced by a combination of multiple factors. This study subdivides the eight basic driving factors into ten specific indicators: altitude, slope, river, temperature, economy,

transportation, population density, urbanization rate, cultural history, and financial policies, which are treated as independent variables (x). The kernel density of TVs is taken as the dependent variable (y_1), and the kernel density of ICH is the dependent variable (y_2). Using ArcGIS, the independent variables are classified into five or more levels according to natural breaks, followed by discrete analysis after raster reclassification. The interaction results of the factors are calculated using GeoDetector, as shown in Table 6, to assess the influence and explanatory power of each factor on the spatial differentiation of TVs in the Upper YRB. It can be concluded that altitude, urbanization rate, temperature, and economy are the primary factors affecting the distribution of ICH in the upper reaches of the YRB. Slope, financial policies, transportation, and population density are secondary factors, with the least influence coming from the river and cultural history. Due to the complexity of natural and cultural conditions in the upper reaches of the YRB, the distribution of ICH largely depends on the distribution of traditional villages. ICH tends to thrive in areas with low altitude, moderate temperature, and high economic development. Therefore, it can be observed that urbanization rate is the common dominant factor influencing the distribution of both TVs and ICH in the upper reaches of the YRB, while the river is a secondary factor affecting the distribution of both.

Based on the results of single-factor detection, multi-factor interaction detection of the spatial distribution of TVs and ICH in the YRB was conducted according to reference (Huang and Xue 2024), leading to the interaction detection results of the spatial differentiation of TVs and ICH in the YRB (Fig. 8A, B). The research results show that the types of interaction detection results for TVs and ICH in the YRB are mainly dual-factor enhancement and nonlinear enhancement. It can be concluded that urbanization rate is the key factor among the interacting variables. In summary, urbanization rate has a common influence and explanatory power on the spatial distribution of both TVsand ICH in the YRB, with altitude, financial policies, cultural history, and other factors having secondary influence and explanatory power.

Strategies for integrated development paths and other arguments.
(1) Based on the analysis of influencing factors, this paper focuses on examining the integration and development path between TVs and ICH through factors such as altitude and slope, river systems, temperature conditions, regional economy, transportation accessibility, population density, urbanization rate, cultural characteristics, and funding policies, and proposes the following strategies. Firstly, from the elevation slope, Building designs should be tailored to local conditions, considering the characteristics of different elevations and slopes. Second, from the river system, utilize the natural landscapes and cultural resources of the YRB to develop ecological tourism in TVs, thereby protecting both the villages and ICH while generating economic benefits. Strengthen the integration of intangible heritage transmission and ecological restoration by incorporating local intangible cultural elements, such as traditional crafts and folk techniques, during soil and water conservation efforts to enhance local residents' sense of involvement. Third, from the climate conditions, climate-adaptive design in traditional architecture: Utilize locally abundant renewable resources such as soil, stone, and wood to build courtyard-style homes with effective insulation and heat retention, thereby adapting to the region's large temperature fluctuations. Fourth, from the regional economy, develop the rural cultural and creative industry. Encourage the use of traditional musical elements such as the suona horn and labor chants to create cultural products with distinctive features of the Loess Plateau, attracting young consumers to experience

Table 6 Geographical Exploration Results of Factors Influencing Spatial Differentiation of TVs and ICH in the Upper YRB.

Serial number	Detection factor	Index factors	$q(y_1)$ statistic	$p(y_1)$ value	$q(y_2)$ statistic	$p(y_2)$ value
x_1	Elevation	Elevation/m	0.126	0.000	0.263	0.000
x_2	Slope	Degree/°	0.026	0.000	0.044	0.000
x_3	River	Distance to river/km	0.004	0.148	0.002	0.517
x_4	Temperature	Annual average temperature/°C	0.055	0.000	0.157	0.000
x_5	Economy	Total annual GDP/yuan	0.052	0.000	0.082	0.000
x_6	Transportation	Traffic distance/km	0.017	0.000	0.027	0.000
x_7	Population density	Density/km²	0.001	0.903	0.016	0.017
x_8	Urbanization rate	Rate/%	0.175	0.000	0.256	0.000
x_9	Cultural history	-	0.305	0.000	0.001	0.380
x_{10}	Funding policies	-	0.584	0.000	0.032	0.000

The larger the q value, the stronger the driving force of the factor, and the smaller the p value, the more significant the result.
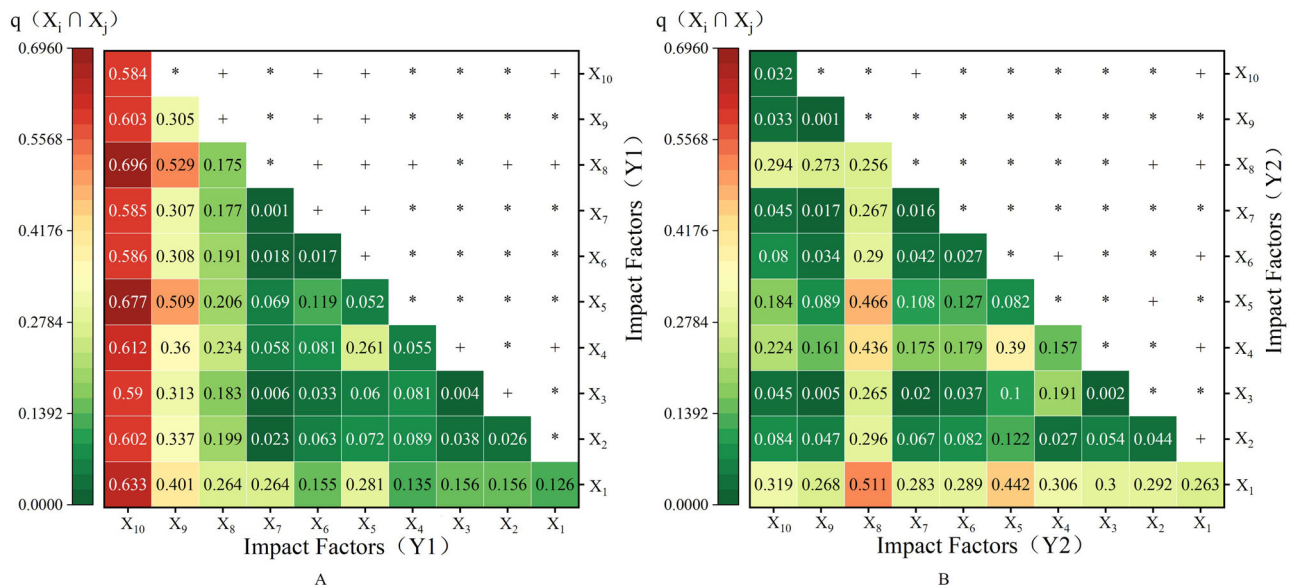

Fig. 8 The interaction test results of the influencing factors of the spatial distribution of TVs (y_1) and ICH (y_2) in the Upper YRB. A The interaction results of influencing factors of spatial distribution of TVs; **B** The interaction results of influencing factors of spatial distribution of ICH. Note: * denotes nonlinear enhancement [q($x_i \cap x_j$)> ($x_i + x_j$)]; + denotes two-factor interaction enhancement [q($x_i \cap x_j$)>Max (x_i, x_j)].

Yellow River drama and enjoy Yellow River culture, thus forming a new economic growth point. Fifth, from the transportation accessibility, protect and restore TVs along historic routes in the YRB, such as the ancient Silk Road, Tangfan Road, and Tea-Horse Road, while preserving their unique ancient architectural styles and cultural history in the northwest Yellow River region to ensure the traditional appearance of these villages is not damaged. Sixth, from the population density and urbanization rate, balance protection and development. In high-population-density areas, such as Yinchuan, Lanzhou, Hohhot, and Xining in the upper YRB, strengthen the protection of TVs and avoid over-development. In areas with lower population density, such as Haidong, Gannan, Guyuan, and Bayannur in the upper YRB, the promotion of village-based ICH should be strengthened. Seventh, from the cultural history, promote the integrated development of rural culture and tourism. Combine the folk culture and performing arts of the upper YRB to design sightseeing routes and Yellow River scenic corridors along the cultural tourism route. This will attract tourists to participate in traditional festivals and social fire activities, promoting both economic and cultural development. Eighth, from the funding policies, establish a special fund for the integrated protection of ICH in the upper YRB. Establish a regional fund specifically for ICH protection to support ICH projects in TVs, such as Mongolian clothing, the making of water pipes, paper-cutting crafts, ancient building pigments, etc., and raise funds through government grants, social donations, and other forms.

(2) Many existing studies discussing the protection of TVs and the inheritance of ICH (Zeng et al. 2024; Xiong and Lee 2020) suggest strategies that combine the protection and development of ICH with the revitalization of TVs. However, they lack strategies for the integrated development of TVs and ICH in specific regional contexts. Different regions possess unique cultural characteristics and varying levels of economic support, influenced by both natural and social environments. Consequently, the protection and development of TVs and ICH have distinct goals and requirements. However, the existing research lacks locality-specific strategies for integrating these two elements. To further promote the overall protection of TVs and ICH in the upper reaches of the YRB, this study conducts a quantitative analysis of the spatial relationships between TVs and ICH from macro and meso perspectives. The analysis reveals a strong coupling in their spatial relationships, with several factors positively correlated, indicating that the characteristics of coupling and integration between TVs and ICH still exist within this unique regional context. At the micro level, this study

innovatively proposes pathways for the integrated protection and development of TVs and ICH. It explores strategies for their integration concerning factors such as altitude, rivers, temperature, transportation, population, urbanization, culture, funding, and policy. This discussion is tailored specifically to the unique regional characteristics of the upper YRB.

Conclusions

Taking the TVs and ICH in the upper reaches of the YRB as the research subjects, this study employs a combination of scientometric and spatial analysis methods. The conclusions are as follows:

(1) There are significant differences in the spatial distribution of TVs and ICH in the upper YRB. TVs exhibit a "multi-core aggregation, dispersed concentration" pattern, with a high degree of imbalance at the provincial (or autonomous region) level. In contrast, ICH shows a "sparse south, dense center, and sparse north" distribution, with a lower degree of imbalance at the provincial level.

(2) In terms of spatial relationships, the alignment between TVs and the distribution of ICH in the upper reaches of the YRB is generally high. However, there are significant misalignments in terms of spatial centers and regional distribution scales. At the provincial (autonomous region) level, three types of spatial misalignment are identified: positive high misalignment, positive low misalignment, and negative high misalignment.

(3) Factors such as altitude, river systems, temperature conditions, regional economy, accessibility, population density, urbanization rate, cultural characteristics, and funding policies significantly influence the spatial distribution of TVs and ICH. urbanization rate has a common influence and explanatory power on the spatial distribution of both TVsand ICH in the YRB, with altitude, financial policies, cultural history, and other factors having secondary influence and explanatory power. These factors are crucial in determining the pathways for their integrated development.

Data availability

Data are contained within the article.

References

An ZY, Tan W (2024) Inspiration and Suggestions for the Revitalization and Inheritance of Intangible Cultural Heritage in the Tianjin Section of the Grand Canal National Cultural Park. Landsc Urban Horticulture 6(1):52–60

Bian JJ, Chen WX, Zeng J (2022) Spatial Distribution Characteristics and Influencing Factors of Traditional Villages in China. Int J Environ Res Public Health 19(8):4627

Cai ZJ, Yin XL, Yan YY, He B (2024) Research on the Design and Branding of Intangible Cultural Heritage Products Based on the "Internet+" Model: Taking the Oil-Paper Umbrellas as an Example. Account Corp Manag 6(3):127–164

Cao R, Jiang WG, Yuan LH, Wang WJ, Lv ZL, Chen Z (2014) Inter-Annual Variations in Vegetation and Their Response to Climatic Factors in the Upper Catchments of the Yellow River from 2000 to 2010. J Geographical Sci 24(6):963–979

Chen YH, Li R (2024) Spatial Distribution and Type Division of Traditional Villages in Zhejiang Province. Sustainability 16(12):5262

Chen N (2024) Retraction Note: VR System Application in the Inheritance of Intangible Cultural Heritage Gongs and Drums Based on Video Simulation. Soft Computing. n.pag. https://doi.org/10.1007/S00500-024-09994-4

Fan J, Tao AJ, Lü C (2010) Coupling Status of China's Economic and Population Centers and Its Impact on Regional Development. Prog Geogr 29(1):87–95

Guo YP, Xing XR (2022) Inheritance and innovation of intangible cultural heritage in the high-quality development of the Yellow River Basin in Shanxi. Shaanxi Henan J Yunnan Univ Nationalities (Philos Soc Sci Ed) 39(2):58–65

Huang YH, Xue QM (2024) Spatio-Temporal Distribution Characteristics and Driving Factors of Traditional Villages in the Yellow River Basin. PLoS ONE 19(5):e0303396

He YC, Shi XL, Zeng BD, Wang JW (2023) Spatial Distribution Characteristics and Influencing Factors of Intangible Cultural Heritage in Southwest China. J Zhejiang Univ(Sci Ed) 50(5):628–638+650

Hua GQ, Dai QF (2024) Research on the Protection and Inheritance of the Traditional Handicraft Techniques and Innovative Design under the Vision of Intangible Cultural Heritage—Taking Rongchang Pottery as a Case Study. Front Art Res 6(8):40–45

Hu YX (2024) Research on the Inheritance and Protection of Xiabu Embroidery in the Context of Intangible Cultural Heritage-Assisted Disability Economy. Sci Soc Res 6(8):121–126

He XQ, Li F, Gao JB, Lei B (2024) Spatial Distribution and Influencing Factors of Traditional Villages in China Based on Geographical Grids. Sci Geographica Sin 44(6):995–1004

Huang XJ, Shen SY, Hu XJ, Liao QL, Tong Y, Cao YC, Sun XP (2024) Spatiotemporal Characteristics of Cultural Heritage Distribution and Its Relationship with the Natural Environment in the Meishan Area. Economic Geogr 44(3):218–228

Han SF, Xu PF, Ma PL (2021) Temporal and Spatial Distribution and Influencing Factors of Intangible Cultural Heritage in Jiangsu Province. Sci Geographica Sin 41(9):1598–1605

Huang JJ (2023) Research on the spatial form of traditional villages in Shaanxi section of the Yellow River Basin from the perspective of intangible culture [C] // China Urban Planning Society. People's City, Planning Empowerment - Proceedings of the 2023 China Urban Planning Annual Conference (16 Rural Planning). Chang'an University, 2023,11. https://doi.org/10.26914/c.cnkihy.2023.051295

Hong KH, Zhang W, Ma AX, Wei YC, Cao MX (2024) Multi-Objective Synergetic Operation for Cascade Reservoirs in the Upper Yellow River. Water 16(10):1416

He C, Liang YW, Zhang SY (2024) A Study on the Spatial Structures and Mechanisms of Intangible Cultural Heritage and Traditional Villages in the Dongting Lake Basin. Buildings 14(6):1736

Hu Y, Chen S, Cao W, Cao CZ (2014) The Concept and Cultural Connotation of Traditional Villages. Urban Dev Stud 21(1):10–13

Kang N, Liu CQ (2024) Assessment of Visual Quality and Social Perception of Cultural Landscapes: Application to Anyi Traditional Villages, China. Herit Sci 12(1):235

Kang N, Liu CQ (2022) Towards Landscape Visual Quality Evaluation: Methodologies, Technologies, and Recommendations. Ecol Indic 142:109174

Kai K (2024) An Exploration of Cultural Programs Contributing to the Digital Conservation of Intangible Cultural Heritage. Front Art Res 6(8):12–17

Kang L, Yang ZP, Han F (2022) Spatial Distribution and Influencing Factors of Intangible Cultural Heritage in Xinjiang. J Desert Res 42(1):158–166

Long TX, Işık C, Yan JL, Zhong QK (2024) Promoting the Sustainable Development of Traditional Villages: Exploring the Comprehensive Assessment, Spatial and Temporal Evolution, and Internal and External Impacts of Traditional Village Human Settlements in Hunan Province. Heliyon 10(11):e32439

Li SS, Li SN (2025) When intangible cultural heritage meets modernization–Can Chinese opera with modernized elements attract young festival-goers? Tour Manag 107:105036

Li XY, Yang HQ, Chen CW, Zhao G, Ni JH (2024) Deterioration identification of stone cultural heritage based on hyperspectral image texture features. J Cultural Herit 69:57–66

Liu YL, Liu L, Xu R, Yi X, Qiu H (2024) Spatial Distribution of Toponyms and Formation Mechanism in Traditional Villages in Western Hunan, China. Herit Sci 12(1):171

Luo XJ, Luo GC (2021) Analysis of spatial distribution characteristics and influencing factors of traditional villages in Guizhou Province. Heilongjiang Hum Resour Soc Security 11:48–54

Li JX, Wang ZB (2022) Research on the Spatial Distribution and Pedigree Age of National Intangible Cultural Heritage Projects. Acta Geographica Sin 77(12):3162–3179

Li RY, Shi ZY (2022) Spatial Dislocation and Formation Mechanism of Traditional Villages and Intangible Cultural Heritage in the Yangtze River Economic Belt. Geography and Geo-Information. Science 38(5):129–137

Li RY, Shi ZY (2022) Spatial Relationship and Formation Mechanism of Traditional Villages and Intangible Cultural Heritage in the Yellow River Basin. Economic Geogr 42(8):205–212

Li JM, Zhao MY, Li M (2024) Spatial Dislocation Characteristics and Influencing Factors of Traditional Villages and Intangible Cultural Heritage in the Grand Canal Cultural Belt. J Xi' Univ Architecture Technol(Soc Sci Ed) 43(2):50–59

Liang G, Fang FM, Lin YS, Zhang ZM (2024) Spatiotemporal Characteristics of Typical Ecosystem Services and Their Spatial Responses to Driving Factors in Ecologically Fragile Areas in Upper Yellow River, China. Chin Geographical Sci 34(4):674–688

Liang LW, Xian L, Chen MX (2022) Evolution Trend and Influencing Factors of Regional Population and Economic Center in China since the Reform and Opening Up. Economic Geogr 42(2):93–103

Lu SJ, Bai GX (2017) Coordinated Development of Tourism Poverty Alleviation and Intangible Cultural Heritage Protection in Ethnic Areas. J South-Cent Minzu Univ(Humanities Soc Sci) 37(2):74–79

Michael W (2007) Engaging the Global Countryside: Globalization, Hybridity and the Reconstitution of Rural Place. Prog Hum Geogr 31(4):485–507

Martin RW (2004) Spatial Mismatch and the Structure of American Metropolitan Areas, 1970–2000. J Regional Sci 44(3):467–488

Pang CY, Wen Q, Ding JM, Wu XY, Shi LN (2024) Changes in Ecosystem Services and Their Trade-Offs and Synergies in the Upper Yellow River Basin. Acta Ecologica Sin 44(12):5003–5013

Peng JY, Tang M, Li Q, Yang L, Qiao L, Xie WH, Zhou CS (2024) Construction of a Symbiotic Traffic Network of Traditional Villages in the Western Hunan Region of China Based on Circuit Theory. Sustainability 16(13):5468

Qiao ZX, Li JY, Zang BL (2024) Evaluation and Regional Differences Analysis of Green Development Level in the Upper Reaches of the Yellow River. People's Yellow River 46(5):18–24+67

The State Council of the People's Republic of China (2024) Opinions of the General Office of the State Council on Strengthening the Protection of China's Intangible Cultural Heritage. https://www.gov.cn/zwgk/2005-08/15/content_21681.htm. Accessed 29 July 2024

Santoro A (2024) Why Traditional Rural Landscapes Are Still Important to Our Future. Landsc Ecol 39(8):135

Sa QE, Qu ZM, Liu YY, Shan WL (2024) The Strategy of Traditional Chinese Settlement Digitization: A Landscape Gene Information Chain Theory-Based Perspective. Herit Sci 12(1):234

Shao XY, Liu YL, Wang XD, Zhai ZH, Li ZY (2021) Research on Tourism Responsiveness and Influencing Factors of Traditional Villages in the Yellow River Basin. J Arid Land Resour Environ 35(6):200–208

Tan GY, Zhu JK, Chen ZX (2024) Deep Learning-Based Identification and Interpretability Research of Traditional Village Heritage Value Elements: A Case Study in Hubei Province. Herit Sci 12(1):200

Tian L, Shi BX, Sun FZ, Zhang SX, Wang BB (2023) Spatial Correlation and Influencing Factors of Traditional Villages and Intangible Cultural Heritage in the Yellow River Basin. J Arid Land Resour Environ 37(3):186–194

Tian L, Liu YT, Lü D, Sun FZ (2024) Spatial Combination Pattern and Interaction of Traditional Villages and A-Level Scenic Spots in the Yellow River Basin. J Arid Land Resour Environ 38(7):182–191

Wu JB (2024) Research on Interaction Design Strategies for Digital Cultural Creations of Changzhou's Intangible Cultural Heritage. Front Art Res 6(8):72–79

Wang SS, Lei Z, Liu X (2024) AI Empowering Intangible Cultural Heritage: Research on the Integration and Creation Strategy of Jingchu Textile Culture Resources in Art Education in the New Era. J High Educ Teach 1(5):83–87

Wang W, Liu YJ, Liu AQ, Chen G (2024) Spatial Distribution Characteristics and Its Influencing Factors of Traditional Villages in the Yangtze River Delta. Ind Constr 54(4):10–19

Wang KL, Tan X, He JL (2024) Connectivity Pattern and Integration Strategy of Traditional Villages andIntangible Cultural Heritage from a Spatial Perspective: A Case Study of the Jinsha River Basin World Regional Studies 2024:1–16 https://link.cnki.net/urlid/31.1626.P.20231019.1748.002

Wang SS, Lin ZM (2023) Research on Spatial Dislocation of Tourism Resources and Tourism Economy in Guilin. J Arid Land Resour Environ 37(5):198–208

Wang PJ, Zhang JH, Sun F, Cao S, Kan Y, Wang C, Xu D (2021) Spatial Distribution Characteristics and Influencing Mechanisms of Traditional Villages in Southwest China. Economic Geogr 41(9):204–213

Wang F, Xue PC, Su WY, Hu X (2024) The Locality-Adaptation Theory of Traditional Villages. Indoor Built Environ 33(6):979–984

Xiong YZ, Lee M-S (2020) "Research on the Symbiosis and Coevolution of Intangible Cultural Heritage Tourism of Rural Traditional Skills – Taking Shuiguotou Village as an Example.". J Asian Stud 23(4):323–334

Yang QL, Chen HY, Wen Q (2024) Coupling Coordination Degree and Improvement Path of Digital Economy and Green Development in Cities of the Upper Reaches of the Yellow River. Economic Geogr 44(5):22–32

Yang ZY (2024) Research on the Pathways for Deep Integration of Intangible Cultural Heritage and Study Travel in Chengdu under the Background of Cultural-Tourism Integration: A Case Study of Xinjin Rope Weaving. Stud Soc Sci Res 5(3):127–164

Yu ZY, Zhao S (2024) Research on the Spatial Characteristics and Influencing Mechanisms of Traditional Villages and Intangible Cultural Heritage in Southwest China. Area Res Development 43(3):90–96

Yu ZY, Zhao S, Chen X (2024) Research on the Spatial Relationship Characteristics and Formation Mechanisms of Traditional Villages and Intangible Cultural Heritage in Sichuan Province. J Nat Sci Hunan Norm Univ 47(4):13–24

Ye F, Yin M, Cao LL, Sun SQ, Wang XZ (2024) Predicting Emotional Experiences through Eye-Tracking: A Study of Tourists' responses to Traditional Village Landscapes. Sensors 24(14):4459

Zhang XR, Gu TF, Wei H (2024) Spatial Distribution Patterns and Influencing Factors of Intangible Cultural Heritage and Traditional Villages in Yunnan-Guizhou-Sichuan Region. Resour Dev Mark 40(1):33–41

Zhou MH (2024) Retraction Note: Musical poetics in instrumental music: China's intangible cultural heritage in the information age. Herit Sci 12(1):332

Zheng S (2024) Intangible heritage restoration of damaged tomb murals through augmented reality technology: A case study of Zhao Yigong Tomb murals in Tang Dynasty of China. J Cultural Herit 69:135–147

Zhang SY, Zhang X, Liu JM (2024) Correction: Spatial Distribution and Pedigree Age of Intangible Cultural Heritage Along the Grand Canal of China. Herit Sci 12(1):277

Zhang SY, Zhang X, Liu JM (2024) Spatial Distribution and Pedigree Age of Intangible Cultural Heritage Along the Grand Canal of China. Herit Sci 12(1):246

Zhu BY, Shi D, Chen XY (2022) Spatial Differentiation and Influencing Factors of Traditional Villages in Northeast China. J Hainan Norm Univ(Nat Sci) 35(2):229–234

Zhu SF (2024) Research on the Spatial Distribution Characteristics of National Intangible Cultural Heritage in the Yangtze River Delta. Urban Architecture 21(12):72–75+112

Zhang HW, Bie Q, Shi Y, Su XJ, Li XZ (2024) Vegetation cover change characteristics and its influencing factors in the upper reaches of the Yellow River Basin. Study arid areas 41(8):1385–1394

Zeng TG, Zhao Y (2019) Temporal and Spatial Evolution of China's Aging Cause Development Level and Its Spatial Matching with Economic Development Level. Geographical Res 38(6):1497–1511

Zeng S, Zhou XS, Wang YF (2024) The Integration of Tradition and Modernity: an Investigation on the Safeguarding of Intangible Cultural Heritage in Dongguan Traditional Villages. Art and Design 7(8). https://doi.org/10.31058/J.AD.2024.78006

Zhang PG, Qu PH, Yang NN, Luo XL (2024) Research on the Spatial Distribution Characteristics and Influencing Factors of Traditional Villages in Jiangsu Province. Mod Urban Res 4:70–77

Author contributions

Methodology, Review, edit, direct and supervise, Q.X.; Data Collection, data analysis and writing—original draft preparation, Q.X.; Y.H. and Q.X. complete this article together.

Funding

Competing interests

The authors declare no competing interests.

Ethical approval

Ethical approval was not required as the study did not involve human participants.

Informed consent

Informed consent was not necessary, due to the nature of this research as a basic research.

Additional information

Correspondence and requests for materials should be addressed to Yuehao Huang.

Reprints and permission information is available at http://www.nature.com/reprints

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.