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Exploring the spatial and temporal distribution mechanism and multidimensional influencing factors of traditional villages in the Huaihe River Basin of China based on geographic grids

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The origins of Chinese civilization can be traced to the Huaihe River Basin, which is rich in traditional village resources. The effective conservation, maintenance, and advancement of conventional settlements in the Huaihe River Basin can be informed by an analysis of their spatial distribution characteristics and affecting variables. This study utilized six batches of 309 traditional villages in the Huaihe River Basin from 2012 as research subjects. The geographical distribution features and spatiotemporal evolution of traditional villages in the Huaihe River Basin have been investigated using the NNI, kernel density evaluation, SDE, GeoDtector, and MGWR, along with the identification of their influencing factors. The results demonstrate that traditional villages in the Huaihe River Basin exhibit a spatial configuration of cohesive clusters. Alongside secondary-density areas in southern Shandong Province and northern Jiangsu Province, high-density zones and growth centers emerged in eastern Henan Province, at the confluence of northeastern Henan Province and southwestern Anhui Province. Geodetic probe results indicate that environmental and socioeconomic factors, including temperature, population density, and GDP, influence the geographical distribution patterns of traditional villages in the Huaihe River Basin. A noticeable tendency of heightened interaction among these components is evident. The outcomes of this study may provide scientific assistance for the development and preservation of traditional communities in the Huaihe River Basin.

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Introduction

Traditional villages are rural territorial units by ironic resources and early formation, possessing considerable historical, cultural, scientific, artistic, social, economic, and ecological significance (Guo and Sun, 2016; Liu et al. 2022). China's traditional villages carry a long history of farming civilization and the production and life of the people, and are the largest and most widely distributed cultural heritage system (Ge et al. 2022). Traditional villages are important carriers for the translation of the spirit of traditional civilization and a non-renewable cultural heritage of the farming civilization (Bian et al. 2022). With the promotion of China's rural revitalization strategy, rural areas have entered a new stage of high-quality development. However, under the influence of external environments such as modernization, industrialization and accelerated urbanization, some traditional villages have experienced problems such as remote and closed locations, destruction of spatial texture (Duan et al. 2022) and hollowing out (Wang et al. 2021), and have gradually died out (Ma and Tong, 2022). The local history and culture that it carries with it are also lost (Feng et al. 2023; Ge et al. 2022). Unscientific rural development models have led to a series of problems such as convergence, fragmentation, marginalization and excessive commercialization. Focusing on the core objectives and practical needs of China's rural revitalization and modernization strategy, this study systematically examines the development of traditional villages in the Huaihe River Basin. Through an in-depth analysis of the spatial and temporal distribution of traditional villages in the region and their influencing factors, this paper not only reveals the challenges of the transformation of traditional villages in the Huaihe River Basin in the process of modernization, but also puts forward targeted development suggestions, which provide useful references for related fields. The study fills the academic gap of traditional villages in the Huaihe River Basin in the context of China's agrarian civilization, and promotes the theoretical and practical research on rural development in the region.

Traditional villages are a significant focus for multidisciplinary research across geography, sociology, urban planning, economics, and other disciplines (Feng et al. 2023). Numerous research academics have thoroughly examined various facets of traditional communities. For example, the cultural value pertaining to conventional villages (Lu et al. 2020), ecological vitality (Liu et al. 2022), hollowing out phenomenon (Li et al. 2014), evolutionary characteristics (Chen et al. 2020; J. Wang et al. 2023), landscape pattern (Liu et al. 2019; Stirn, 2014; Xu et al. 2022), tourism development (Dai et al. 2023; Gao and Wu, 2017; F. Wang et al. 2023), conservation and development (Li et al. 2019; Xue et al. 2024), and sustainable development (Liu et al. 2022; Liu et al. 2020; Zhong et al. 2024), distribution patterns (Chen et al. 2020) and influencing factors (Ma and Tong, 2022; Wu et al. 2020; Wu et al. 2022). The configuration of traditional villages exemplifies the communication between humans and the natural environment, with social, economic, and political influences (Jones, 2010; Wu et al. 2020). Comprehending the attributes and determinants of traditional village distribution is beneficial for the preservation and advancement of existing traditional villages (Duan et al. 2022), but also for decision-making on new official traditional villages. While many findings have been derived from the current research on the distributional characteristics of traditional villages and their contributing elements, numerous limitations persist. Primarily, most prior research at the spatial level has concentrated on certain national, provincial, and local administrative units (Bian et al. 2022; A. Jia et al. 2023; M. Li et al. 2023). This has somewhat diminished the impact of the geographical environment on the dispersion of traditional communities, undermined the integrity of the natural division of areas and caused

some interference with the results of the study. Secondly, there is a paucity of studies regarding geographical differentiation and the preservation of integrity in big traditional villages within Chinese areas. Presently, there are only a limited number of studies on the Yellow River Basin (Feng et al. 2023) as well as the Yangtze River Basin (Chen et al. 2023) and the north-western and southwestern regions of China (Cao et al. 2017; Jin et al. 2022; X. Li et al. 2023; Ma and Tong, 2022). However, the majority of the research did not quantify the effects of related influences on conventional distributions. Ultimately, the majority of research concentrates on static spatial distribution, while relatively few address the spatiotemporal dynamical evolutionary processes of traditional villages.

The establishment of traditional villages mostly arises from lineage and kinship, serving as a by-product of the small-scale peasant economy (Zhao et al. 2024). The agricultural context restricts traditional villages' cultural linkages, demonstrating path reliance and river reliance in their historical development (Shen et al. 2010). Agriculture and animal husbandry, the historical livelihoods of traditional villages, are largely governed by the natural climate, soil environment and hydrogeology. In contrast to artificial administrative units, watersheds are naturally existing geographical entities. In the human-earth system, watersheds are the geographic regions most commonly influenced by human behavior (Wu et al. 2020). The watersheds have emerged as a crucial geographic unit for attaining sustainable growth goals and implementing Earth system science in numerous countries worldwide (Cheng and Li, 2015; Zhou et al. 2019). Indeed, the majority of global civilizations were sustained by rivers or formed in watershed regions (Macklin and Lewin, 2015) and disseminated along waterways. River systems, as a primary determinant of resource spatial distribution, serve as a crucial material foundation for human production and existence, as well as the origin of many cultural treasures (Li et al. 2022). The potential impacts of natural hazards on watershed environments are complex and far-reaching, often manifesting themselves in significant disruptions to hydrological processes, ecosystems, land use and biodiversity. Disasters such as floods, droughts and mudslides can trigger drastic changes in the hydrological cycle of a watershed, affecting the spatial and temporal distribution of runoff and water quality. Floods can lead to sudden rises in water levels, scouring soil, destroying vegetation, and even altering the morphology of river channels, thus leading to the degradation of ecosystem functions. Droughts directly threaten agricultural production and ecological water sources in the basin by reducing the availability of water resources, leading to the shrinkage of water bodies and the deterioration of the ecological environment. Natural disasters alter the structure and intensity of ecosystem services in watersheds, and these changes may threaten the long-term sustainability of watershed ecosystems, thereby affecting the quality of life and economic development of local communities. Therefore, the damage to watershed biodiversity and ecosystem services caused by natural disasters cannot be ignored. Watersheds fundamentally support the building and organizational framework of traditional villages, enabling the analysis of their spatial distribution characteristics and yielding scientifically credible research results (Jin and Juan, 2021; So and Lu, 2001).

Chinese civilization began in the Huaihe River Basin, which has a rich history and various traditional villages that preserve culture. Philosophers like Laozi, Confucius, Mozi, Mencius, and Zhuangzi were born in the Huaihe River Basin, the birthplace of Chinese civilization. The basin is home to several notable ancient water conservancy projects, including the Shao Pei Irrigation Project, the Gan Gou and Hong Gou Artificial Canal from the Spring and Autumn and Warring States Periods, the Bian Canal

from the Sui and Tang Dynasties, and the Beijing-Hangzhou Grand Canal and Hongze Lake Embankment from the Yuan, Ming, and Qing Dynasties. The growth of the Huaihe River Economic Belt threatens traditional communities, including dwindling populations and poor rural living conditions. The examination of traditional village distribution patterns and contributing factors in the Huaihe River Basin would help preserve them and provide a valuable reference for similar places. This study examined the geographical distribution of traditional villages in the Huaihe River Basin using kernel density, closest neighbor index, geographic concentration index, and standard deviation ellipse on a geographic grid. The main goal of this study is to determine the spatial and chronological distribution of Huaihe River Basin traditional communities. To examine the main factors impacting traditional village location in the Huaihe River Basin. Use the geographical diversity of contributing elements to provide region-specific conservation methods for the environmentally sustainable development of traditional villages in the Huaihe River Basin.

Materials and approaches

Research region. The Huaihe River basin, known for its high population density, lush land, abundant resources, and efficient transportation, is an important Chinese food, energy, mineral, and industrial center. One of China's most densely inhabited regions, the Huaihe River Basin has 191 million people and 611 persons per square kilometer. The national strategy to strengthen eastern leadership and promote central region growth makes it vital to China's economic and social success. The Huaihe River springs in the Tongbai Mountains on the Henan-Hubei border and empties into the sea separately. However, the Yellow River's appropriation of the Huaihe River, which lasted approximately 700 years from Jianyan's second year in the Southern Song Dynasty (1128), severely damaged the river system. The Huaihe River Basin encompasses five provinces and faces constraints related to geographic location, natural environment, and administrative divisions, leading to underdeveloped economic growth and minimal regional synergy. In 2018, the Huaihe River Ecological and Economic Belt was established as a national strategy in China, encompassing the majority of

cities along the Huaihe River within its planning and construction framework, which is crucial for advancing coordinated regional development and enhancing governance of the entire basin. This study utilizes the administrative divisions aligned with the design parameters of the Huaihe River Ecological and Economic Belt to construct a catalog of traditional villages within the Huaihe River Basin for further analysis. This reflects not just the aim of the Huaihe River Ecological and Economic Belt but also acknowledges the cultural heritage of the Huaihe River. This study covers all 40 prefectural-level cities in Jiangsu, Anhui, Henan, and Hubei, where the Huaihe River Basin flows, according to China's watershed planning scope (Fig. 1).

Source and processing of data. This study encompasses 309 traditional villages located in the Huaihe River Basin, all sourced from six publicly accessible collections of Chinese traditional villages released by the Ministry of Housing and Urban-Rural Development and the Ministry of Culture and Tourism of China. This research employs imagery from Google Earth and Baidu Maps to discern the geometric cores of traditional settlements. The village names or textual indicators in the traditional village photographs are thereafter employed to ascertain the coordinates. For villages absent from maps or reference images, the geographic coordinates of the primary administrative unit encompassing the traditional village are utilized. Each traditional hamlet in the Huaihe River Basin was depicted as a spatial point to establish a spatial attribute database and a geographical distribution map. ArcGIS 10.8 was subsequently employed to vectorize the map (Fig. 2).

The China Basic Geographic Information Database provided the administrative boundaries and municipal vectors of the Huaihe River Basin, whereas the Resource and Environment Science Data Center of the Chinese Academy of Sciences (http://www.resdc.cn) supplied the population and elevation data for 2023. The elevation maps have a spatial resolution of 30 m × 30 m. The socioeconomic information for the region was obtained from the Anhui Statistical Yearbook 2023, Henan Statistical Yearbook 2023, Jiangsu Statistical Yearbook 2023, Shandong Statistical Yearbook 2023, and Hubei Statistical Yearbook 2023. Spatial analytical methods were utilized to derive river system and hydrological information from DEM information.
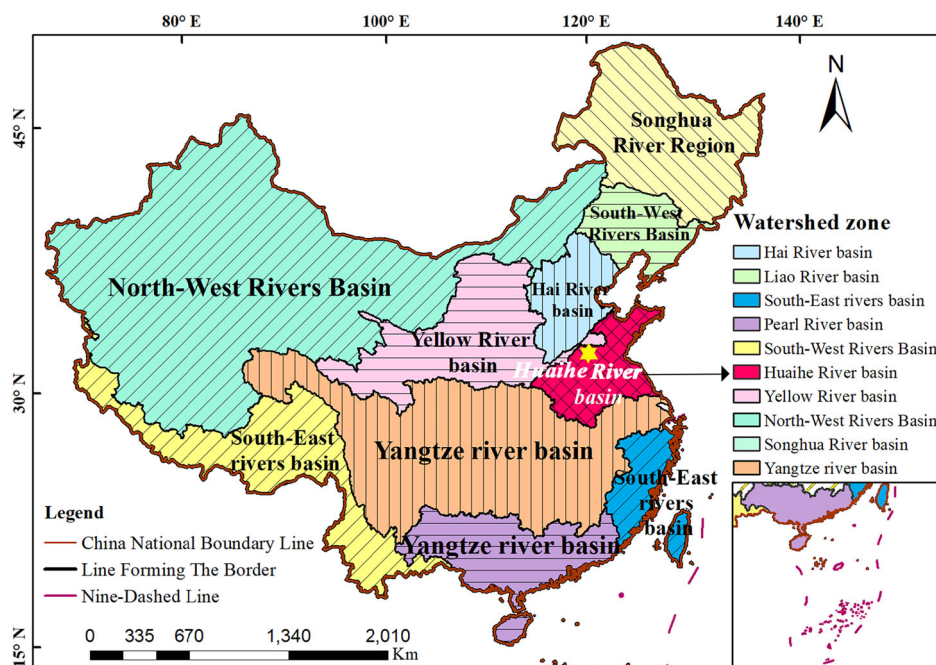

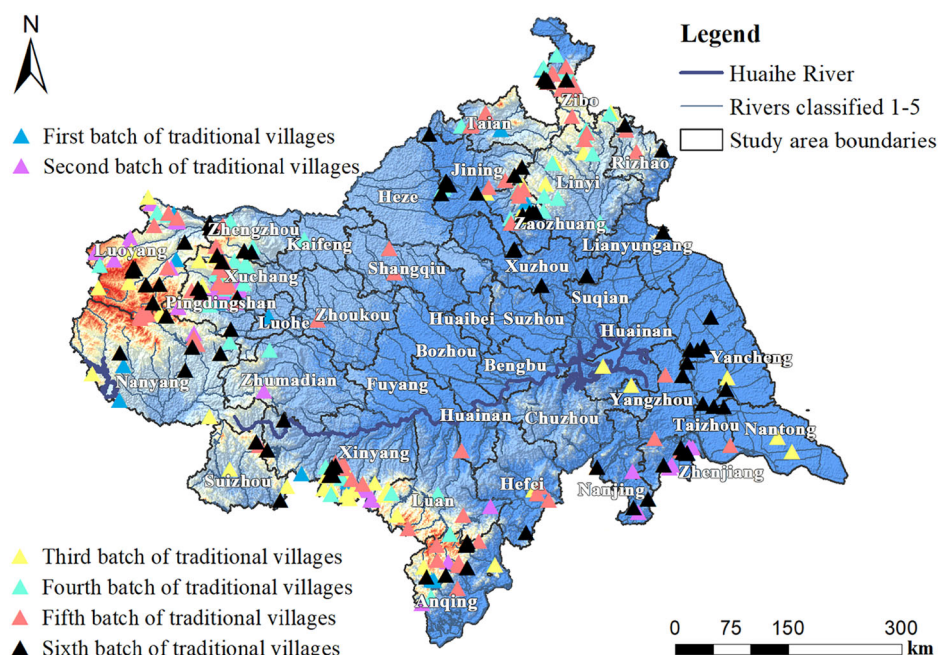**Fig. 1** China water basin division and the Location of the Huai River Basin.

Fig. 2 Spatial distribution of traditional villages in the Huaihe River Basin.

The National Earth System Science Data Center (http://www.geodata.con) provided climate data from 2020 to 2023, and averages were calculated for the analysis. This research employed road network data from the Geode Map Open Platform API (https://lbs.amap.com) for kernel density investigation, including national, provincial, and county roadways. The maps of each historical dynasty were produced utilizing materials from Harvard University Maps (https://worldmap.maps.arcgis.com).

Research methodology. This study categorizes traditional villages in the Huaihe River Basin using ArcGIS 10.8's closeness index, geographical concentration index, imbalance index, standard deviation ellipse, geodetector, OLS, and MGWR. Historical literature is summarized. Village geographical distribution was evaluated using kernel density estimation and regional and global geographic autocorrelation analysis. This study analyzes spatial-temporal evolution and finds conservation-critical components using linear distance, buffering, reclassification, and superposition. Visualizing with geophones but removing interactive elements. OLS and MGWR were used to explore the spatial diversity of factors affecting the Huaihe River Basin traditional village distribution. However, the methodology has limitations. In practice, complex topography, climate, and social culture affect the dispersion of traditional communities. Therefore, NNI may not fully capture the complicated geographical links underpinning village distribution.KDE struggles to capture the dynamic evolution of spatial structure and reveal the spatial evolution process of traditional villages with historical accumulation or long-term evolution.SDE methods focus on large-scale spatial evolution and may not be able to capture the microscopic changes of traditional villages. GeoDetector uses statistical significance to judge factor relationships, but it is less adaptable to nonlinear, multi-factor interactions or multi-level complex problems. GeoDetector also relies on data quality and completeness, and makes high data assumptions. Thus, the Huaihe River Basin's traditional villages were studied using quantitative and qualitative methodologies to overcome the methodology's shortcomings. Figure 3 demonstrates that the study's results are consolidated to offer scientific recommendations for the preservation and improvement of traditional villages in the Huaihe River Basin.

Nearest neighbor index. NNI is a fundamental instrument for evaluating spatial configurations and determining whether points are distributed arbitrarily, clustered, or consistently. Geographic clustering is determined by comparing the anticipated average distance in a random distribution with the actual average distance to the nearest neighbor. The subsequent formula delineates the NNI precisely:

$$E = \frac{\overline{r_1}}{r_E} = \sqrt[2]{D} \tag{1}$$

In this equation: E represents the nearest neighbor index (NNI); r_1 is expressed as the average of the distances between each point and its nearest neighbor;r_E represents the theoretical average closest distance; D indicates point density. When $E = 1$, denotes the random spatial distribution of point features. When $E > 1$, the point features tend to be uniformly distributed. Conversely, When $E < 1$, Point features show a clustered distribution pattern.

Geographic concentration index. The Geographic Concentration Index (G) is used to measure the degree of concentration of traditional villages within a given geographic area. The formula for calculating G is as follows:

$$G = 100 \cdot \sqrt{\sum_{i=1}^{n} \left(\frac{P_i}{Q}\right)^2} \tag{2}$$

Where:G represents the geographical concentration index; n represents the number of municipalities in the Huaihe River Basin; P_i represents the number of traditional villages in the ith municipality; Q represents the total number of traditional villages in the Huaihe River Basin. The geographic concentration index usually ranges from 0 to 100; the higher the value of G, the more traditional villages are concentrated in a certain area, while the lower the value of G, the more evenly distributed the traditional villages are.
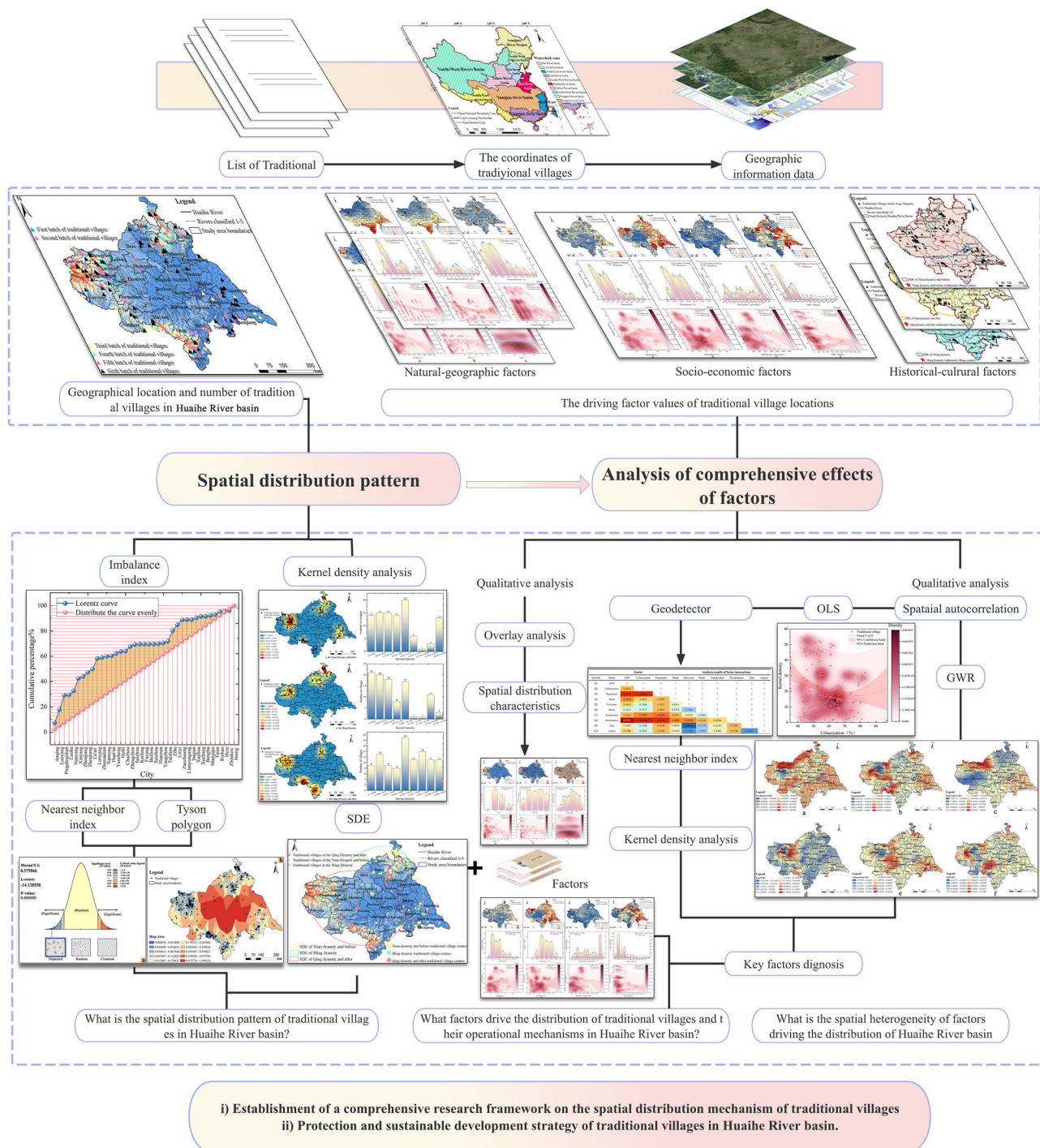
Fig. 3 Research process.

Imbalance index. The inequity index signifies the extent of equitable distribution of the research subject within a certain area. The imbalance index of traditional villages in the Huaihe River Basin can be calculated to examine their dispersion. The subsequent formula is employed to compute the imbalance index.

$$S = \frac{\sum_{i=1}^{n} M_i - 50(n+1)}{100 \cdot n - 50(n+1)} \qquad (3)$$

In the formula: n is the number of municipalities in the Huaihe River Basin; M_i denotes that the ith municipality is the cumulative percentage of the number of traditional villages in each municipality in the Huaihe River Basin to the total number of traditional villages

in the whole basin, and municipalities are listed in descending order according to the proportion of traditional villages to the total number of traditional villages; S is the imbalance index, and the value of S varies from 0 to 1; when S tends to be close to 0, it indicates that traditional villages are more uniformly distributed among municipalities, while the smaller S is, it indicates that the more unevenly distributed they are. S is the imbalance index.

Standard deviation ellipse. SDE evaluates the spatial properties of geographic entities by revealing their directionality, centroid, and distribution spread. The primary components of the technique include the centroid of the ellipse, the resulting orientation angle,

and the respective lengths of the major and minor dimensions. The primary dimension indicates the principal orientation of the distribution, whereas the secondary axis measures the dispersion of the data. The distribution's orientation is shown by the flattening ratio, calculated by dividing the major axis by the minor axis. An upper ratio indicates a more significant directional distribution, whereas a lower ratio, akin to a circle, implies reduced directionality and a broader distribution. The exact formula for the SDE is as shadows.

$$\tan\theta = \frac{\left(\sum_{i=1}^{n} w_i^2 \widetilde{x}_i^2 - \sum_{i=1}^{n} w_i^2 \widetilde{y}_i^2\right) + \sqrt{\left(\sum_{i=1}^{n} w_i^2 \widetilde{x}_i^2 - \sum_{i=1}^{n} w_i^2 \widetilde{y}_1^2\right)^2 + 4\sum_{i=1}^{n} w_i^2 \widetilde{x}_i^2 \widetilde{y}_i^2}}{2\sum_{i=1}^{n} w_i^2 \widetilde{x}_i \widetilde{y}_i^2}$$

(4)

$$\sigma_x = \sqrt{\frac{\sum_{i=1}^{n}\left(w_i \widetilde{x}_i \cos\theta - w_i \widetilde{y}_i \sin\theta\right)^2}{\sum_{i=1}^{n} w_i^2}}$$

(5)

$$\sigma_y = \sqrt{\frac{\sum_{i=1}^{n}\left(w_i \widetilde{x}_i \sin\theta - w_i \widetilde{y}_i \cos\theta\right)^2}{\sum_{i=1}^{n} w_i^2}}$$

(6)

In this formula: θ is the revolution viewpoint, and σ_y are the average deviation along the x axis and y axis, individually.

GeoDetector analysis model. The analytical technique for examining geographic variation and its determinants is referred to as GeoDetector. The primary objective of this study is to elucidate how various forces converge to impact traditional villages. This is the manner in which it is distributed. In traditional village studies, GeoDetector can be used to analyze the various types of factors that influence the spatial distribution of villages.GeoDetector assesses the drivers of spatial distribution mainly by exploring the strength of the relationship between the independent variable (traditional village distribution) and the dependent variable (influencing factors). The core idea is that a factor has a strong ability to explain spatial heterogeneity if it can significantly influence differences in spatial distribution. The formula for calculation is:

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

(7)

In this formulation: $h = 1, 2,.., L$, is the social delamination (number of traditional villages) of the reliant on flexible Y, the affecting influences X, N_h and N are the stratum h and the number of traditional villages in the study area, respectively; $\sigma h2$ and $\sigma2$ are the variance of the stratum h and the value of Y, respectively.q denotes the level of significance of the influence of each factor on the distribution of traditional villages, with $p < 0.05$ (0.01) demonstrating that the issue exerts a highly substantial influence on the spreading of traditional communities. An interaction investigation was employed to ascertain if the cumulative impact of the various elements was augmented or diminished.

OLS and GWR. Ordinary Least Squares (OLS) can be used to figure out the general geographic link between the quantity of traditional villages in the Huaihe River Basin and a number of factors that affect that link. The GWR model looks at how each factor's regional variation changes over time. The model figures out the local regression coefficients (LRC) and where each part is located in the local environment. It also figures out how the location of each part affects the spread of traditional towns. It is possible to show how each factor affects the variety of places where native villages are found. In this case, the two variables are positively (negatively) related, as shown by the positive

(negatively) LRC number. The effect gets stronger as the absolute value goes up, while the impact goes down. The formula for calculation is:

$$y_{i=} b + \sum_{k=1}^{n} a_k x_{ik} + \varepsilon_i$$

(8)

In this formulation: y_i is the density of traditional villages in space i; b is a constant term; $k = 1, 2\dots, n$, represents 9 influencing factors; x_{ik} is the data of the k_{th} influencing factor in village i; and ε_i is the error term.

$$Y_i = \beta_0\left(U_i, V_i\right) + \sum_m \beta_m\left(U_i, V_i\right)X_{im} + \varepsilon_i$$

(9)

In this formulation: where Y_i is the density of the traditional village at the spatial position i, X_{im} is the value of the m-th factor at spatial position i, the projected coordinates of spatial position i are (Ui, Vi), β_0 (Ui, Vi) represents the intercept of the regression equation, β_m (Ui, Vi) represents the regression value of the m-th factor at spatial position i, m represents the number of model factors, and ε_i is the error at i.

Results
Attributes of spatial dispersion
Categories of spatial dispersion. The geographical arrangement of conventional settlements in the Huaihe River Basin is mainly of the cluster type. NNI analysis using ArcGIS 10.8 confirms this assertion. This analysis showed that the mean value of the actual nearest neighbor distance (r_1) was 12.877 km, while the expected distance (r_E) was 22.206 km, resulting in a nearest neighbor index ratio (R) of 0.5797. The negative $Z-$value (-14.1286) and near $-$zero P value indicated that the clustering pattern was statistically significant among the 309 traditional villages studied (Fig. 4).

The geographical concentration index (GCI) and the coefficient of variation (CV) were employed for a more comprehensive examination. The computed coefficient of variation (CV) was 190.298%, indicating a departure from a uniform spatial distribution and substantially above the benchmark value of 64%. The theoretical index (G), which presupposes an equitable distribution across the 309 settlements, has been exceeded with a GCI of 25.3648. The spatial concentration index further substantiates the clustered distribution of traditional villages in the Huaihe River Basin.

Equilibrium of spatial dispersion. The imbalance index measures the level of equilibrium among traditional villages in the Huaihe River Basin regions. The quantity of traditional villages varies throughout administrative levels due to disparities in natural, cultural, and social characteristics among municipalities. The assessment of the distribution balance of traditional villages in the Huaihe River Basin yields an imbalance index $S = 0.432 > 0$, signifying that the distribution of traditional villages in the area is unbalanced. The blue curve illustrates the cumulative distribution of conventional villages within each metropolis. The curve's shape indicates the level of concentration or dispersion within the distribution of traditional communities. A curve positioned nearer to the top left corner signifies a more concentrated distribution of resources, whilst a curve closer to the diagonal denotes a more equitable distribution of resources. The red curve is the optimal uniform distribution curve, illustrating the variation in cumulative percentages if all cities have an identical quantity of resources or villages. The Lorenz curve for traditional villages in the Huaihe River Basin (Fig. 5) indicates an unequal distribution of these settlements within the basin. A wider gap signifies a more uneven distribution, whereas a smaller difference denotes a more equitable allocation of resources. The majority of traditional villages
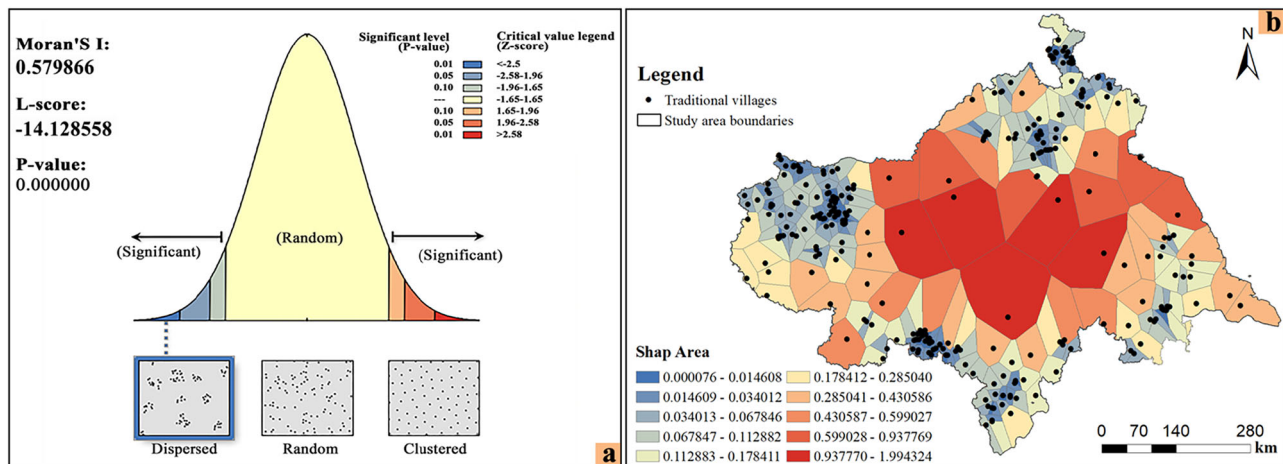
Fig. 4 Moran's index and Tyson's polygons of traditional villages in the Huaihe river basin. a Moran's index; **b** Tyson's polygons.
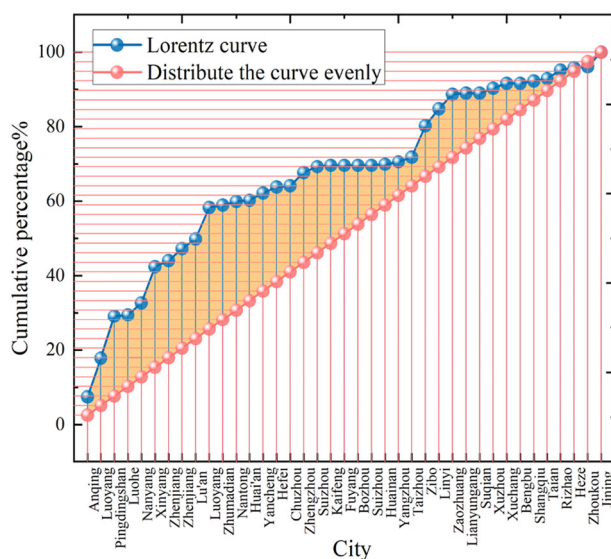

Fig. 5 Lorenz curve of the spatial distribution of traditional villages in Huaihe River Basin.

are situated in Pingdingshan, Luoyang, Xuchang, and Xinyang in Henan Province; Kailuan and Anqing in Anhui Province; Zibo, Zaozhuang, and Linyi in Shandong Province; and Zhenjiang in Jiangsu Province. These regions include ~90% of the overall count of traditional villages. The Lorenz curve delineates the Huaihe River Basin into equitable and inequitable regions of traditional communities. In the balanced zone, the primary emphasis is on enhancing the preservation of traditional villages, whereas in the unbalanced zone, the principal focus is on directing the development of traditional villages.

Density of spatial distribution. The kernel density analysis tool in ArcGIS 10.8 was used in this study to look at the kernel density of 309 traditional villages in the Huaihe River Basin. This showed how the kernel density was spread out in these villages (Fig. 6). Figure 6 illustrates that the distribution of traditional villages in the Huaihe River Basin is defined by a 'one main plus two' configuration. Traditional towns in the Huaihe River Basin are spread out in a way that suggests the high-density region is in the central part of Henan Province. There was a lot of variance in the spatial density of the conventional villages, but the pattern of distribution was mostly aggregated ($R < 1$, $Z = 22.34$). The average kernel density in the region is 24.68, and there is a clear high-

density cluster in Henan Province's Ping'dingshan City, Luoyang City, Zhengzhou City, and Xuchang City. The pattern of this distribution is "one core and multiple peripheries," with less density near the edges and more near the center. The main high-density area in Henan Province is in the middle, with core density numbers ranging from 5.9426 to 53.4840. With kernel densities between 5.9426 and 35.6560, secondary high-density regions can be found in towns like Zibo in Shandong Province and Xinyang City in Henan Province.

Characteristics of temporal and spatial evolution. Attributes of temporal and spatial development. This study examines the evolution of traditional villages in the Huaihe River Basin during three historical epochs: prior to the Yuan Dynasty, during the Ming Dynasty, and throughout the Qing Dynasty (Fig. 7). Of the 309 villages with historical reports, 101 originate from the Yuan Dynasty, 100 from the Ming Dynasty, and 108 from the Qing Dynasty and later eras. The analysis of spatial distribution via standard deviation ellipses reveals a clear pattern (Fig. 8).

Villages of the Yuan Dynasty were densely grouped, displaying reduced spatial distribution extents (SDEs) and elevated axis ratios. The Ming Dynasty witnessed an increase in villages characterized by larger SDEs and reduced axial ratios, indicating a more extensive and decentralized spread. This dispersion persisted into the Qing Dynasty, accompanied by a minor contraction in SDE. The centroids of the communities progressively migrated southwest. During the Yuan Dynasty, the focal point of high nuclear density in traditional village aggregation was located in the eastern region of Henan Province. In the Ming Dynasty, this center transitioned to the northern area of Shandong Province, and in the Qing Dynasty, it moved to the southern section of Anhui Province. The principal axis of the SDE has constantly conformed to the area topography, influenced by mountain ranges and river basins. The diverse terrain enabled agricultural advancement and the formation of settlements. Distinct physical formations, like enclosed valleys and basins, offer natural shelter for traditional settlements, rendering these regions especially conducive to habitation. The pattern was additionally strengthened by the conventional clan system. Migration typically manifested as blood-related groups organized into clans, resulting in the establishment of tiny settlements referred to as traditional villages.

Determinants of spatial distribution. The distribution of traditional villages in this study is shaped by social, historical-cultural, and physical-geographical influences. Distinct traits were discerned
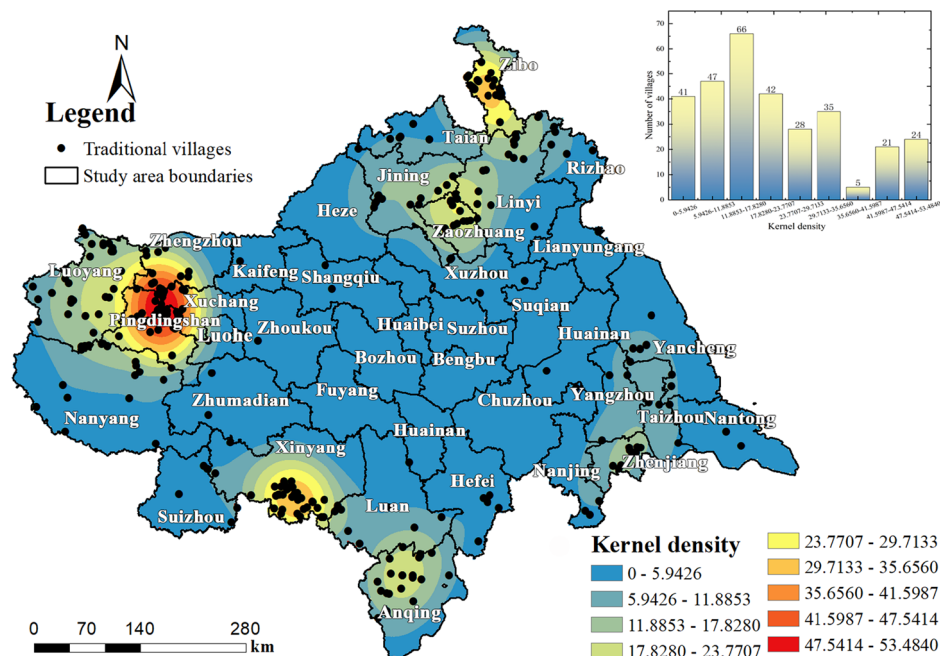
Fig. 6 Kernel density of traditional village distribution in Huaihe River basin.
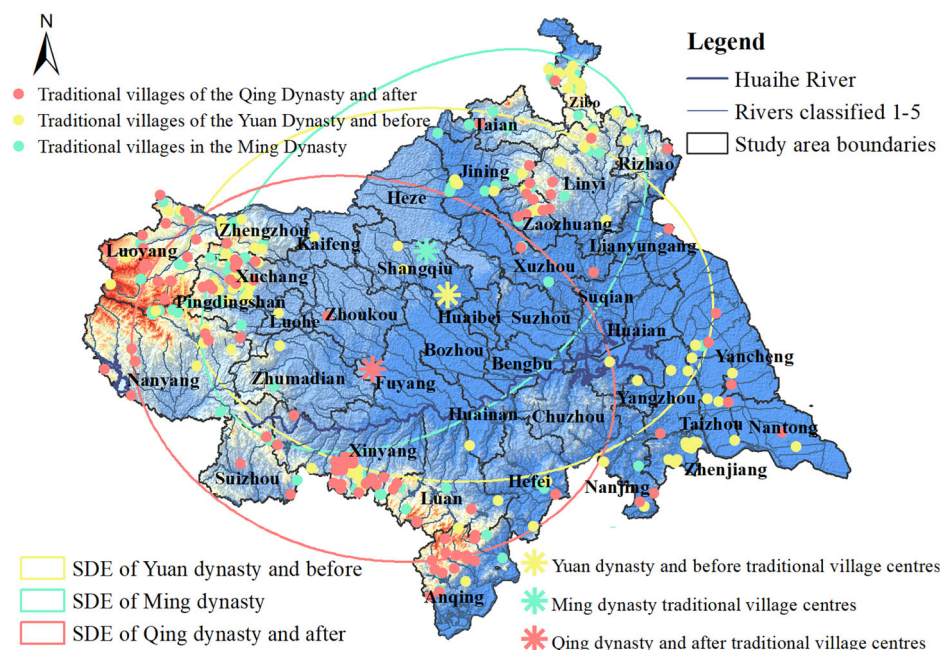

Fig. 7 The overall evolution of spatial patterns in traditional villages in the Huaihe River basin.

utilizing indicators derived from four guideline tiers (Bi et al. 2024). Factors frequently recognized in prior studies. When selecting quantitative criteria, one must consider the availability and scientific validity of the study data. Two components that are closely linked to the social transformations and geographical configurations in the research area. Although established earlier, the China Ministry of Housing and Urban-Rural Development utilized the same criteria from 2012 to 2023 to classify these villages as "traditional villages." Simultaneously, artifacts replicating their regional, ethnic, and cultural attributes—encompassing historical and cultural dimensions—were chosen in alignment with the criteria for traditional villages. Approaches are recommended to direct continuous preservation and enlargement of traditional villages

informed by the most recent data. Twelve rudiments were chosen to investigate their collective impact on the dispersion pattern of traditional villages, comprising six natural geographic factors, four socioeconomic factors, and two historical and cultural factors (Table 1).

Determinants of spatial distribution

Topographical considerations: ArcGIS 10.8 was used to combine the spatial data of traditional villages with topographic maps in this study. This helped to show how the Huaihe River Basin's natural features have affected the location of traditional village towns (Fig. 9). It is now easier to see how the complicated layout of traditional towns in the Huaihe River Basin is connected to
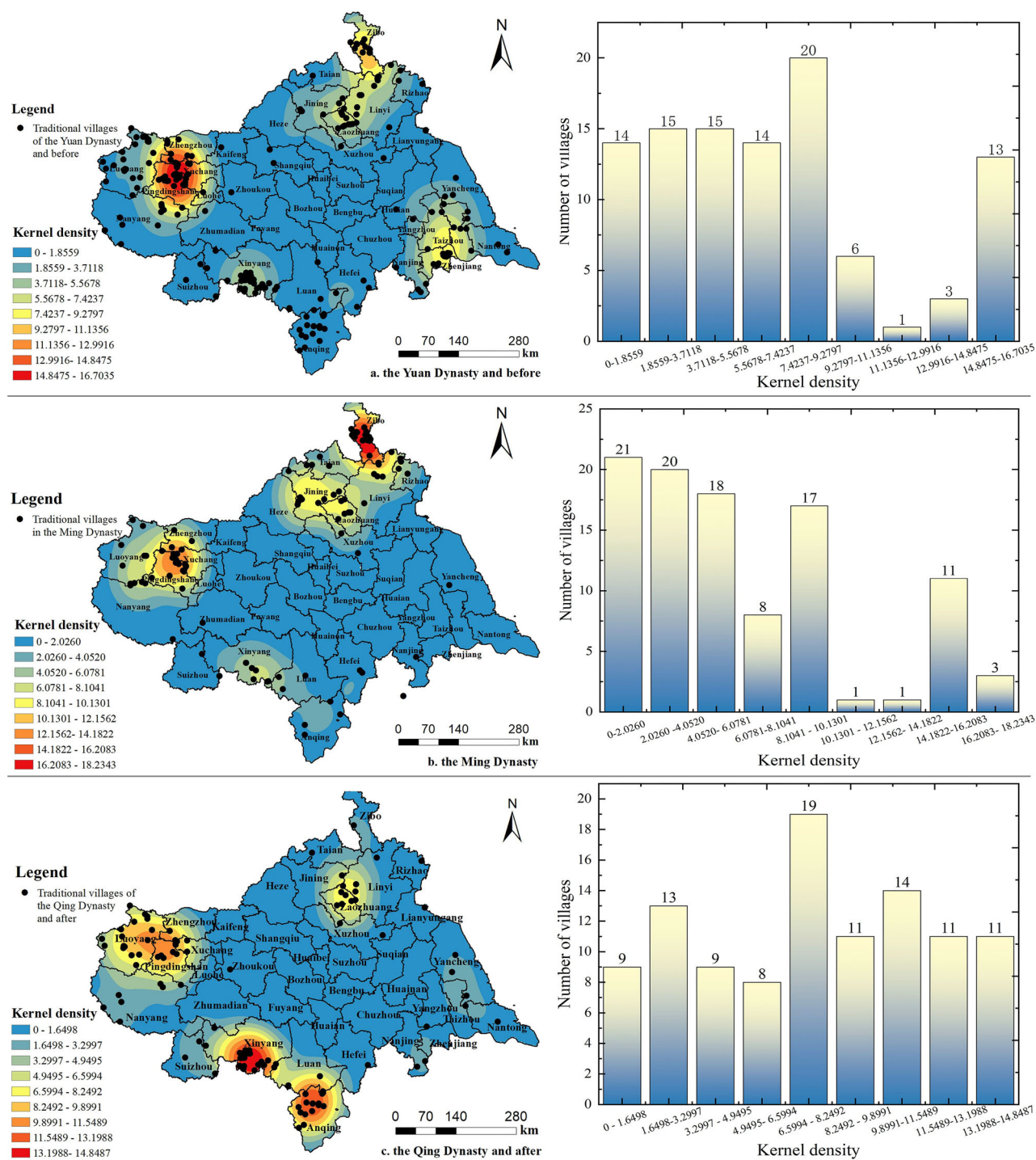
Fig. 8 The overall evolution of spatial patterns in traditional villages in the Huaihe River basin. a The Yuan Dynasty and before; **b** the Ming Dynasty; **c** The Qing Dynasty and after.

other physical features. About 94.7% of all the settlements in the study area are at an average elevation of 200 meters. These settlements are mostly found in hills, basins, and river valley flats. It's interesting to note that >60% of the towns are in hilly or basin areas. The number of villages spread out over elevations higher than 400 m has dropped by a large amount (Fig. 9a). The slope of the towns was 9° on average, and most of them were between 0° and 30.7°, which is 95.3% of the study area. Regardless, the density of village distribution definitely plays a significant role in this range. At an angle of about 15°, the number of villages spread

out starts to reduce. Forty percent of towns are on slopes that are moderate to severe. Based on this pattern, it looks like the topography and gradient effect where communities are found. Slope orientation, as one of the topographic elements, has an important impact on the distribution of traditional villages. Its influence is mainly reflected in hydrology, climatic conditions, soil quality, agricultural production and ecological environment. Changes in aspect directly affect sunlight exposure, wind power, precipitation distribution and temperature and humidity conditions, which together play a role in the selection and distribution

Table 1 Drivers of spatial density patterns of traditional villages in the Huaihe River basin.

| Primary category	Primary category	Tertiary category	Description
Natural geographic factors	Geography	Elevation (m)	The absolute altitude of the village location relative to the base level.
		Slope (°)	The angle of the land or structural line at the village location.
		Slope aspects (°)	The main facing direction and angle of the village location.
	Climate	Precipitation (mm)	The annual average precipitation received at the village location.
		Temperature (°C)	The annual average air temperature at the village location.
	Water system	Distance to River (m)	The straight-line distance from the village to the nearest River.
Socioeconomic factors	Economy	GDP (billion)	The overall economic level of the village in the study area.
	Infrastructure	Road Density	The density of the area where the village is located.
	Population	Population Density (person/ km²)	The population condition in the area where the village is located.
	Urbanization	Urbanization rate (%)	The degree of urbanization in the area where the village is located
Historical-cultural factors	Historical period	Social background	Historical events that led to the formation of traditional villages.
	National culture	Clan culture	The dominant factor in the development of traditional villages
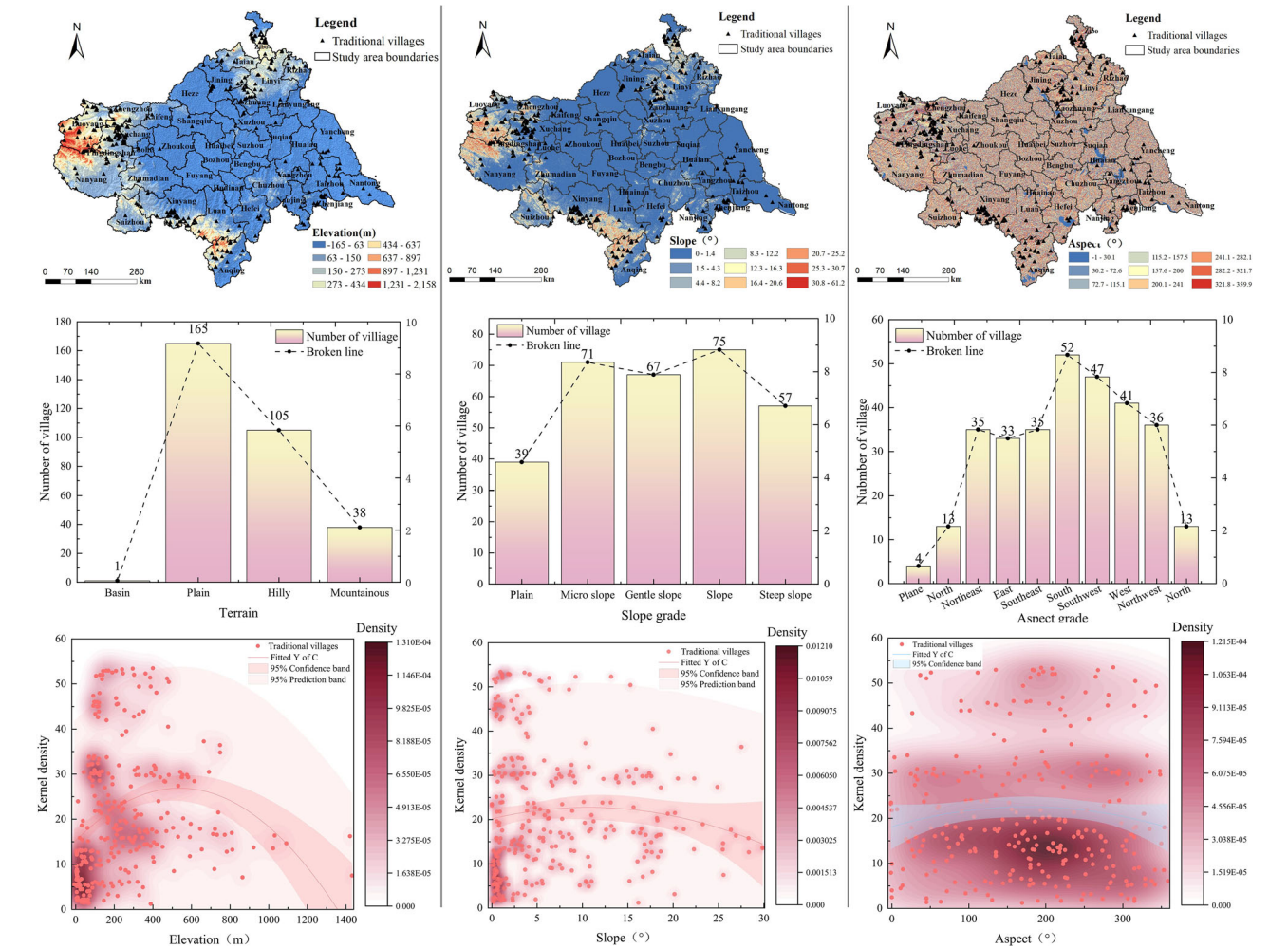
Fig. 9 Associations between traditional village distributions and topographic factors. a Elevation; **b** Slope; **c** Aspect.

of human settlements. The distribution of traditional villages on different slopes in the Huaihe River Basin is uneven, with large differences between the northern and southern slopes. In the study area, the southern slope has the largest number of traditional villages. (Fig. 9c). In the northern hemisphere, the southern slopes usually receive more sunlight radiation than the northern slopes, and therefore have higher temperatures, which are suitable for the growth of crops and human habitation. In this case, the southern slopes tend to be the first choice for traditional village roads to gather and develop.

Climatic and hydrological variables: The study's results indicate a potential correlation between the spreading of traditional villages in the Huaihe River basin and climatic and hydrological parameters. Most conventional villages are situated in regions characterized by temperate climates and ample rainfall. Nearly 83% of
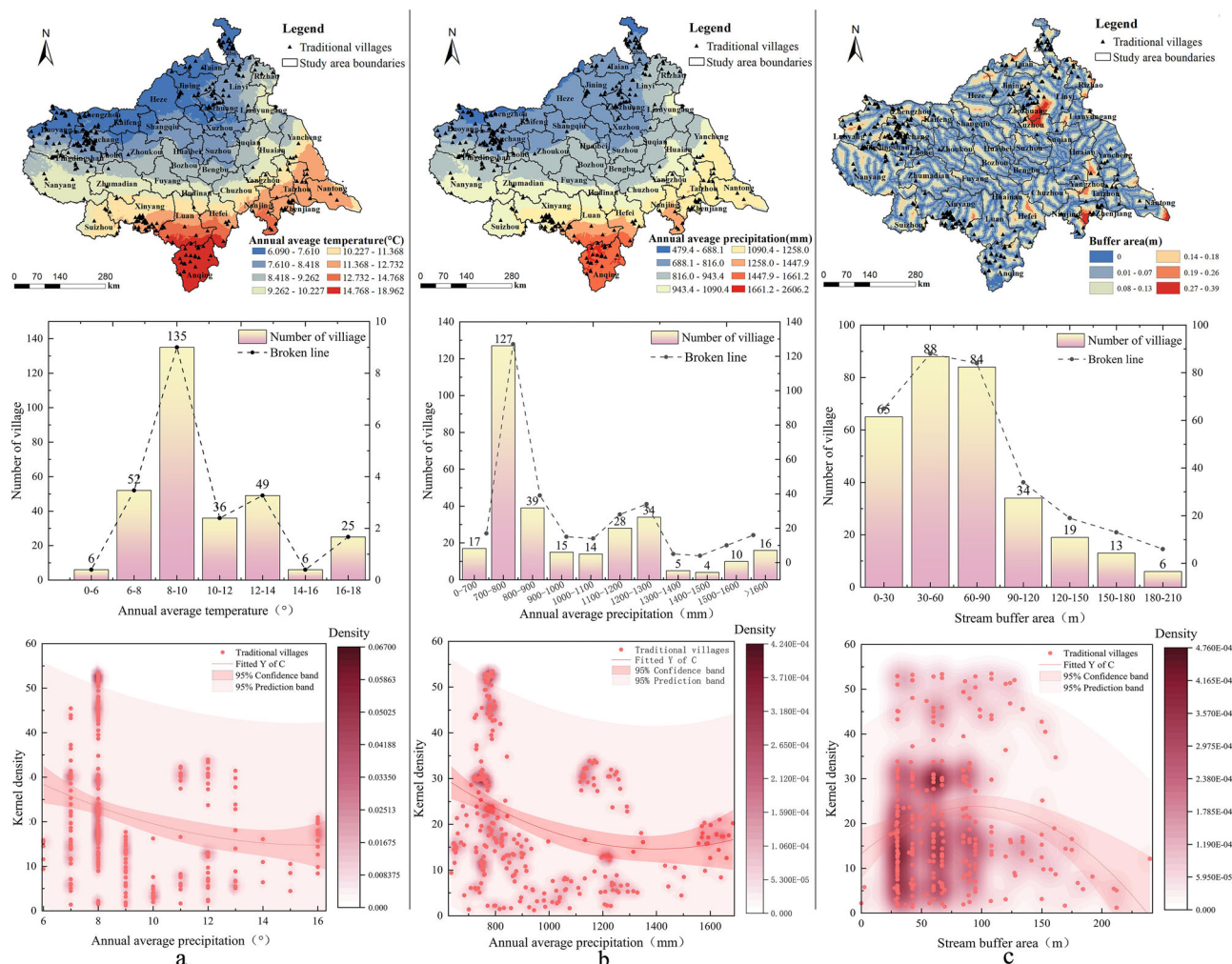
Fig. 10 Relationships between traditional village density patterns and climate and water systems. a Annual average precipitation; **b** annual average temperature; **c** stream buffer area.

the villages in the research region are situated between a yearly precipitation range of 700 mm to 1300 mm and temperatures between 8 °C to 14 °C (Fig. 10). The density of traditional communities substantially diminished as rainfall and temperature approached nearly 1200 mm and 14 °C, respectively. Furthermore, the closeness of historic communities to water sources exhibited a separate pattern. Approximately 97.1% of the communities were situated within 200 mm of water sources. Villages located within 0 to 0.01 km of the water system were the most densely populated, including 87.9% of the total villages in the investigated region. This distribution signifies that the residents of the Huaihe River Basin exhibit a distinct inclination to establish settlements near aquatic environments, underscoring the traditional reliance of village location on the nearness of water bodies.

Determinants of spatial distribution. The socioeconomic features and the location of traditional villages in the Huaihe River Basin exhibited a substantial negative correlation (Fig. 11). The average road net density in the research region was 25.03, with a range from 0.03 to 45.3 (Fig. 11a). This indicates that the density of the area's road net is quite low and exhibits significant variation between villages. The northern and southeastern sections of the Huaihe River Basin, characterized by elevated economic levels, predominantly contain the bulk of high kernel density road places. As road density exceeds ~20.5, the quadratic model indicates a swift fall in the distribution density of traditional

villages, implying that these communities in the Huaihe River Basin favor areas with lesser road densities.

Moreover, disparities exist in the distribution patterns of GDP, urbanization rates, and traditional villages within the Huaihe River Basin. For example, the central region, including Hefei and other areas, has higher economic indicators but lower traditional village densities. On the contrary, village density decreases gradually with increasing urbanization rate (Fig. 11b). Traditional village density is higher in the southern part of Anhui Province, where economic indicators are lower. The relationship between elements and village density exhibits a power function, and the correlation decreases rapidly when GDP reaches 30 billion yuan (Fig. 11d). When the population density reaches 600–1000 persons/km², the quantity of traditional villages increases rapidly (Fig. 11c).

In recent years, traditional villages in the Huaihe River basin have faced an increasingly serious problem of population exodus. In particular, the massive migration of rural labor to the cities has led to the phenomenon of 'hollowing out' in many villages, that is, the loss of a large number of young laborers from the villages, with most of those left behind being elderly people and women. The outflow of population has led to the decline of traditional villages and the disappearance of some of them, especially in economically backward regions, where the scale of villages has been reduced or their functions weakened, and the distribution of traditional villages tends to be sparse. Population migration has
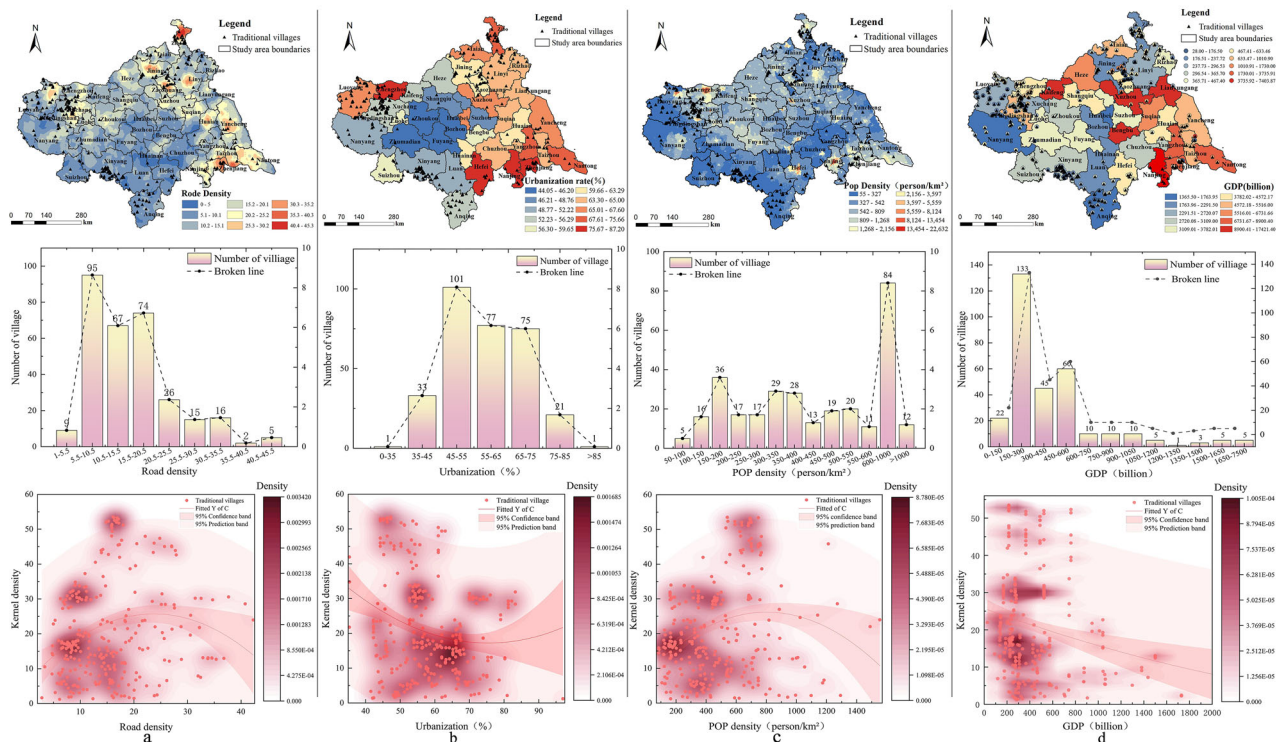
Fig. 11 Relationships between traditional village density patterns and socio-economic factors. a Road density; **b** urbanization; **c** population density; **d** GDP.

not only led to the hollowing out of some villages in the Huaihe River Basin, but has also affected the social structure and patterns of economic activity in these areas. In general, the distribution of traditional villages in the Huaihe River Basin is subject to a combination of social and economic influences. In different historical periods, the spatial layout, functional construction, and villagers' way of life of villages have been directly affected by means of land system reform, collectivization policy and rural revitalization strategy. Population changes, especially migration, mobility and demographic changes, have affected the vitality and sustainable development of traditional villages at the socio-economic level. Therefore, when promoting the sustainable development of traditional villages in the Huaihe River Basin in the future, it is necessary to take into account the comprehensive socioeconomic impacts, adopt diversified strategies, and promote the revival of villages and balanced development of the region while protecting the traditional cultural heritage.

Determinants of spatial distribution. To thoroughly analyze the impact of historical and cultural factors on the spatial distribution of traditional villages, it is essential to consider historical background elements such as migration history, land policies, and military defenses to comprehensively examine their causes. The spatial distribution of traditional villages is not only influenced by factors such as the natural environment and economic activities, but historical and cultural factors also play a crucial role. Population migration has significantly influenced Chinese history, particularly during specific historical times, serving as a crucial catalyst in the spatial organization of ancient communities. During the Qin and Han dynasties, the central government advocated for extensive land equalization and large-scale migration initiatives to alleviate border pressures. These migration patterns frequently concentrated a significant population of immigrants in specific regions, hence influencing the formation and growth of traditional villages. Comparable historical

occurrences, such as the migration policy during the 'Yongle Canon' era of the Tang and Song dynasties, or the 'Zhuangtian System' policy of the Qing dynasty, have directly influenced the spatial configuration and demographic composition of villages. Moreover, extensive wars, natural calamities, and societal disruptions throughout history have prompted significant population movements, leading to the establishment of new towns and communities. During the Ming and Qing dynasties, warfare and civil turmoil prompted significant population migrations, leading to heightened village density in formerly isolated regions, while more stable areas may have experienced relative depopulation. During the Tang dynasty, the 'equalization of land' system, which allocated land based on population, resulted in the concentration of villages in regions with adequate water and fertile soil, while extensive villages rarely emerged in areas unsuitable for agricultural cultivation. The land reforms of the Ming and Qing dynasties, along with the taxing and farming limitations imposed on farmers by each dynasty, resulted in alterations in the distribution of villages. The military defense system also facilitated the establishment of certain villages; for instance, the 'cantonment system' during the Ming and Qing dynasties led to the creation of numerous villages for military defense purposes. These communities served dual purposes: agriculture and defense, featuring permanent military installations, and their layouts frequently exhibited a degree of regularity. The governance principles, policy orientations, and local government practices of several dynasties shaped the dimensions and characteristics of traditional villages. The 'household registration system' and taxation regulations enacted under the Song dynasty necessitated that farmers congregate in administrative centers, resulting in the proliferation of villages surrounding certain central cities. During the Ming and Qing dynasties, local governments, operating under the 'internal and external' and 'local administration' models, often imposed stronger control over villages, leading to the reconfiguration of villages in certain regions due to alterations in administrative
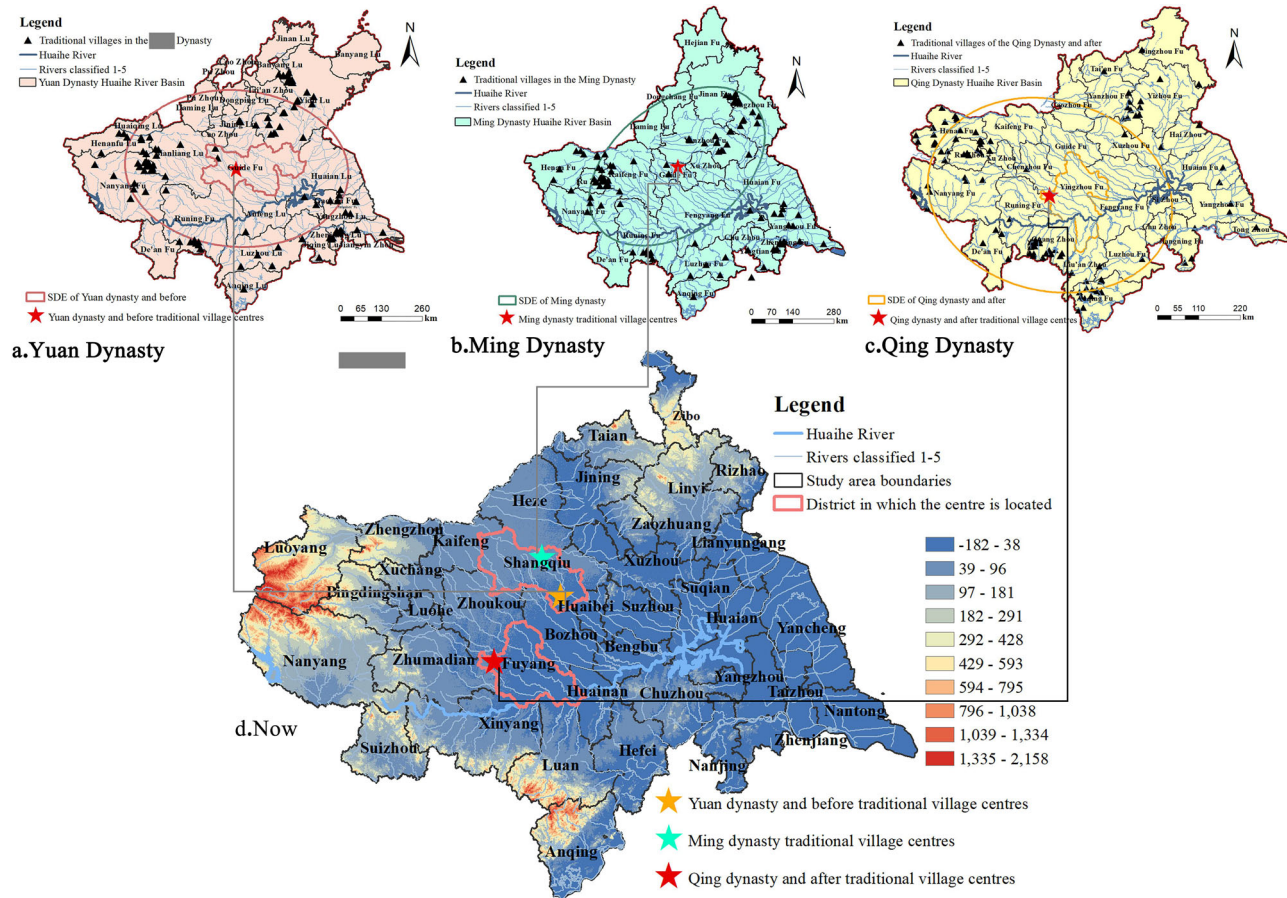
Fig. 12 Distribution of traditional villages in the Huaihe River Basin. a The Yuan Dynasty; **b** the Ming Dynasty; **c** the Qing Dynasty.

divisions. The physical arrangement of traditional communities is significantly shaped by religious and cultural circumstances. In ancient China, religious activities frequently facilitated the spatial aggregation of villages, particularly around designated centers of religious significance or pilgrimage locations, where communities tended to be densely situated.

The density dispersion of traditional villages in the Huaihe River valley is defined by "multiple peripheries surrounding a singular core." The primary zone of high-density dispersion is situated in the north-western region of the Huaihe River Basin. They are directly affected by historical and cultural factors. The arrangement of ancient villages in the region was shaped by several historical wars, including the "Yongjia Rebellion of the Jin Dynasty" (311 AD), the "Anshi Rebellion of the Tang Dynasty" (755 AD), and the "Huang Chao Rebellion of the Tang Dynasty" (874 AD). These battles immediately precipitated extensive population movements. Additionally, the two most significant population migratory surges in the region were during the "Jingkang Rebellion of the Northern Song Dynasty" (1126 AD) and the "Jingkang Rebellion of the Ming Dynasty" (1399 AD) (Barbieri-Low, 2021; Su et al. 2022). During the Ming Dynasty, traditional villages in the Huaihe River Valley demonstrated a more pronounced clustering pattern, with communities situated in hills and basins. Analysis of historical maps from the three dynasties indicates that the area of the Huaihe River Valley diminished throughout the Ming Dynasty (Fig. 12). The traditional village spatial distribution entities (SDEs) of the Qing Dynasty were more elliptical compared to those of the other three dynasties, indicating an unequal and dispersed distribution of traditional villages during that period. The conventional village
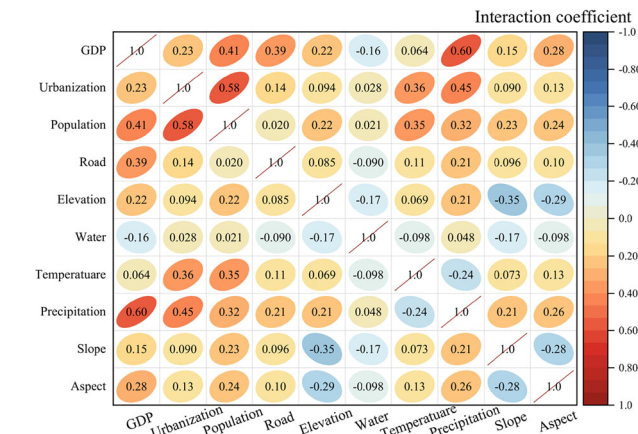

Fig. 13 Correlation analysis of interaction factors in the Huaihe river basin.

distribution center was located at Guide Fu (present-day Shangqiu, Henan Province) during the Yuan and Ming Dynasties, but relocated to Yingzhou Fu (now Fuyang, Anhui Province) during the Qing Dynasty. This indicates that the conventional village distribution center progressively shifted northward. The origins of capitalism may be traced to the late Ming and Qing eras (15th–19th centuries), during which the commodity economy in the southern regions of the lower Yangtze River thrived. The basis for ancient Huizhou's enduring economic prosperity was built during its peak mercantile advancement. The clan system, Neo-
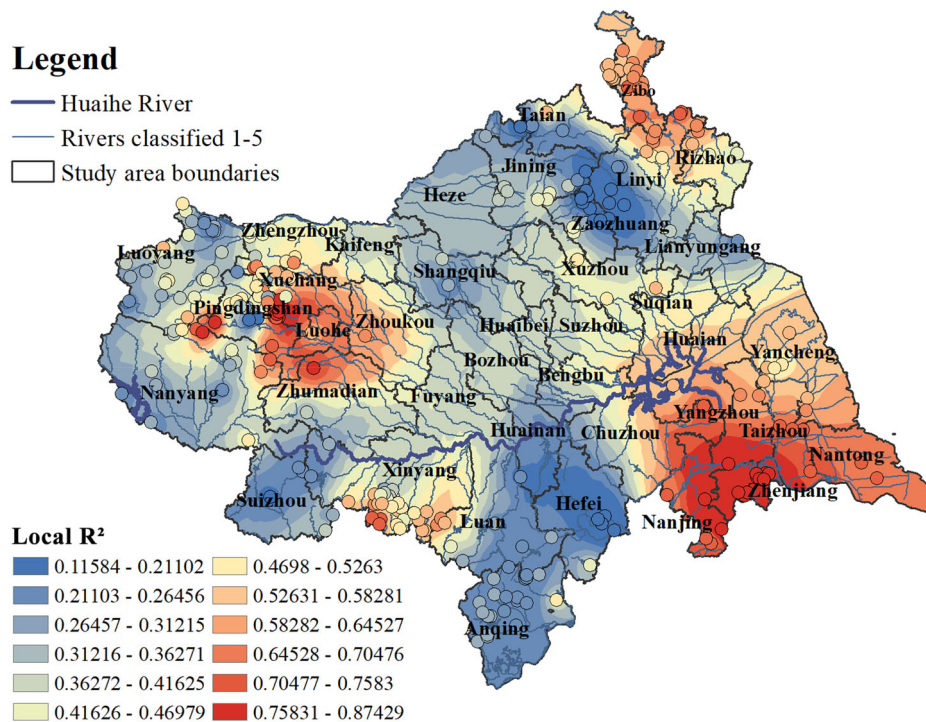
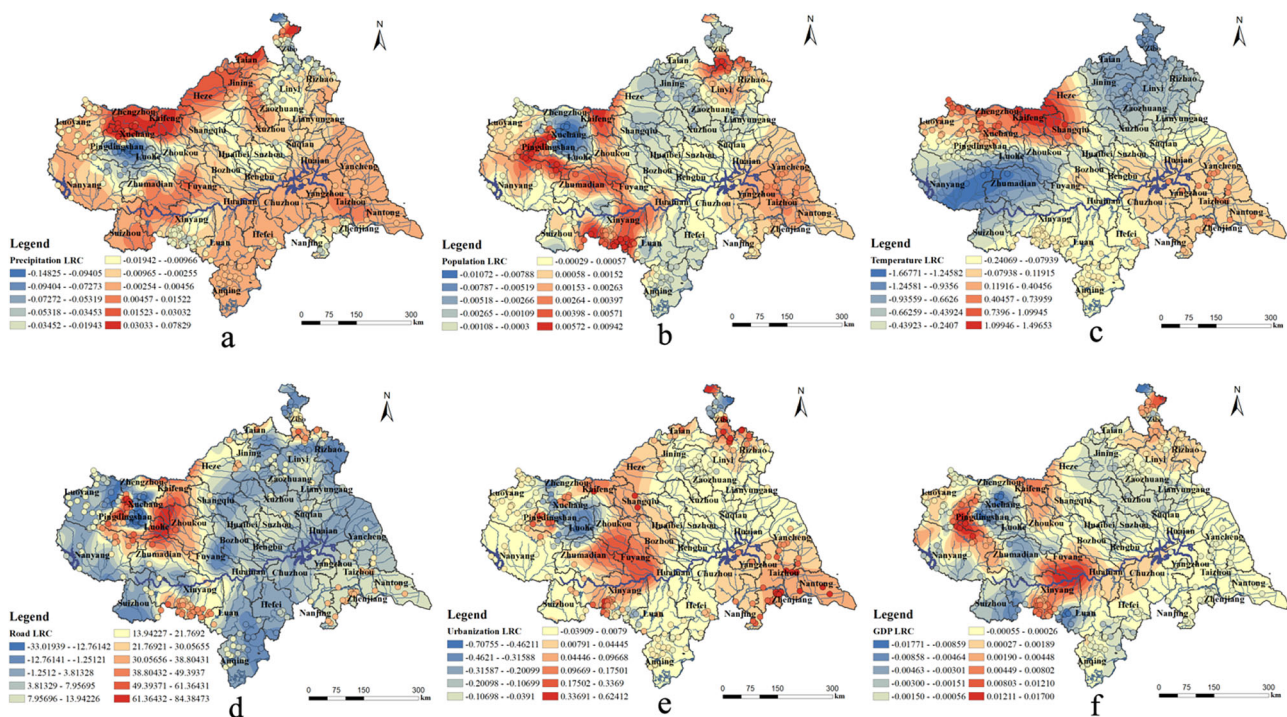**Fig. 14** LRC spatial distribution of R^2 computed by the GWR model.

Fig. 15 Spatial distribution of LRC for each driving factor calculated by the GWR model. a Precipitation LRC; **b** population LRC; **c** temperature LRC; **d** road LRC; **e** urbanization LRC; **f** GDP LRC.

Confucianism, and Feng Shui concepts were prevalent during the peak of ancient Huizhou's traditional villages (Hu et al. 2019). Consequently, during the Ming and Qing eras, the nucleus of population density in ancient communities within the Huaihe River Valley migrated southward.

The results of the study demonstrate that migration habits considerably influenced the geographical layout of traditional villages in the Huaihe River Basin, especially since most of the traditional villages were positioned between hills and basins. This may be related to the historical background of the capital city migrating south and north after the defeat of the two dynasties. The distinctive geography of the confined valleys and basins functioned as natural shelters and provided security for the residents, making these sites the greatest places to dwell. At the

Table 2 Interaction coefficient of the factors influencing the spatial density of traditional villages.

		Factor										Analysis results of factor interactions
Symbol	Name	GDP	Urbanization	Population	Road	Elevation	Water	Temperature	Precipitation	Slop	Aspect
X1	GDP	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
X2	Urbanization	0.5011	↑	↑	↑	↑	↑	↑	↑	↑	↑
X3	Population	0.6556	0.6853	↑	↑	↑	↑	↑	↑	↑	↑
X4	Road	0.5838	0.4822	0.5295	↑	↑	↑	↑	↑	↑	↑
X5	Elevation	0.4505	0.3568	0.5417	0.4011	↑	↑	↑	↑	↑	↑
X6	Water	0.3531	0.3711	0.5001	0.3755	0.2184	↑	↑	↑	↑	↑
X7	Temperature	0.5025	0.5705	0.6276	0.5081	0.4235	0.3899	↑	↑	↑	↑
X8	Precipitation	0.7171	0.6758	0.6588	0.5889	0.5554	0.5218	0.4734	↑	↑	↑
X9	Slop	0.4287	0.3549	0.5436	0.4056	0.0914	0.2179	0.42467	0.5582	↑	↑
X10	Aspect	0.4786	0.3742	0.5495	0.4116	0.1183	0.2507	0.4488	0.5738	0.1233	↑

Table 3 Geographical detectors result and ranking of impact factors.

Factor detector	Geo-detection analyses			Rankings
	Name	qv	sig	
X1	GDP	0.13687119	4.87E-07	6
X2	Urbanization	0.16397679	8.28E-08	5
X3	Population	0.39258978	9.43E-10	2
X4	Road	0.25827593	7.08E-10	4
X5	Elevation	0.08723651	2.99E-04	8
X6	Water	0.0700999	2.21E-03	10
X7	Temperature	0.31654193	1.58E-10	3
X8	Precipitation	0.4501779	1.61E-10	1
X9	Slop	0.07934245	7.41E-04	9
X10	Aspect	0.11112261	1.94E-05	7

same time, the deeply ingrained culture of the clan system in China favored this distribution pattern. During migration, people generally created clan groups based on familial links, which allowed the creation of traditional villages as tiny communities. In short, historical battles, regime changes, and the profound influence of traditional culture conspired to generate a distinctive distribution pattern of traditional villages in the Huaihe River Basin. Out of the search for security and stability, these towns were densely scattered in mountainous and basin locations with complex topography and difficult access, producing a unique residential scenery.

Major factors affecting spatial configurations and their spatial variability

Determining major factors. Table 2 illustrates the interacting influences affecting the allocation of traditional villages in the Huaihe River Basin, whereas Table 3 enumerates the separate elements impacting the density pattern of these villages. Single-factor analysis implies that the delivery pattern of traditional villages is primarily elucidated by precipitation ($q = 0.45$), subsequent to population density (0.393), air temperature (0.317), and road density (0.259). The variable related to the water supply exhibited the least explanatory power (0.07). Nonetheless, regarding village distribution, there existed a nonlinear relationship between these parameters. The geodetector-based interaction analysis demonstrated that a pair of factors interact significantly, magnifying the influence on village distribution relative to the single component. This suggests that various factors interact to affect the geographical dispersion of traditional villages in the Huaihe River Basin. The principal explanatory variables of the two-factor authentication interaction are precipitation and GDP

(0.7171), the rate of urbanization and the density of people (0.6853), and population density and temperature (0.6276). The rate of urbanization is considered the primary factor affecting population density distribution. This indicates that the spatial density pattern of traditional villages in the Huaihe River Basin is influenced by the interplay of socioeconomic and natural conditions, with socioeconomic factors exerting a more significant influence than physical-geographical aspects (Fig. 13).

Assessing the spatial variability of the impacts of critical elements. Geographic research identified six characteristics that significantly influence the location of traditional villages in the Huaihe River watershed, and their regional heterogeneity was analyzed. The results indicated that the six primary characteristics affecting the density distribution of traditional villages exhibited considerable variation at the local geographical level (Table 4). Higher R^2 and lower AICc values suggest that the MGWR model better represented the geographic connection among these characteristics and the density pattern of traditional villages compared to the OLS model ($R^2 = 0.3416$). The explanatory power of the influences affecting the density pattern of traditional villages progressively increased from the northern, western, and southeastern cores outward, as seen by the local R^2 values, which varied from 0.1 to 0.9. The predominant areas exhibiting robust model fit were situated along the boundary between Zhejiang and Jiangsu Provinces and in the western section of Henan Province, inside the Huaihe River Basin (Fig. 14). Collectively, these six criteria accounted for >65% of the conventional village density distribution pattern. Among the individual components, precipitation exhibited the greatest local R^2 value (0.9570), followed by GDP (0.663), elevation (0.9385), and road network density (0.9555). The correlation between traditional village density patterns and temperature is somewhat strong ($R^2 = 0.7448$). The study's findings indicated that the explanatory value of each component regarding the traditional village distribution pattern exceeded 60%.

The factors influencing village density in the study area exhibit both positive and negative effects, with varying proportions for each, as determined by the analysis of the distribution of these effects and the absolute values of the extreme LRC (Fig. 15a–f). The results indicate that the impact of the six components on traditional communities varies markedly by existing natural conditions. The local spatial consequences of the six elements on traditional villages, based on their extreme absolute LRC values, are as follows: Air temperature (LRC = 1.497) > road density (LRC = 84.384) > precipitation (LRC = 0.07) > urbanization rate (LRC = 0.624) > GDP (LRC = 0.02) > population (LRC = 0.001). The signs and area ratios of the regression coefficients facilitate the categorization of local geographic connections among these

Table 4 Local spatial regression results between the spatial density pattern and its main driving factors.

Parameter	GWR							OLS
	GDP	Urbanization	Road density	Temperature	Precipitation	Elevation	average	
Bandwidth	0.463	0.463	0.463	0.463	0.463	0.463	-	-
AICc	588.9999	457.0231	433.8665	72.1294	34.9520	547.5581	-	1157.7319
Sigma	0.5764	0.5895	0.4499	0.3705	0.3414	0.5363	-	-
R^2	0.9283	0.9079	0.9555	0.7448	0.9570	0.9385	0.9053	0.3416
Adj. R^2	0.9284	0.8770	0.9434	0.7282	0.9446	0.9207	0.8904	0.3287

six features and village density into three distinct groupings. Spatial consistency was evidenced by the observation that regions exhibiting positive regression coefficients for urbanization and precipitation rates constituted around 91.57% and 93.43% of the total area, respectively. The research identified these effects predominantly in regions with clustered villages, suggesting that traditional village preservation is supported by reduced GDP and road density. Conversely, in 91.39% and 85.62% of the regions, respectively, road density and GDP exhibited an inverse relationship with village density (LRC < 0). Furthermore, there existed both positive and negative correlations between temperature and population density in traditional villages, suggesting a predominantly weak negative effect. This implies that the spatial spreading of traditional communities is affected by temperature and population density. Diminished accessibility decreases the likelihood of traditional communities being invaded, despite colder weather being less conducive to human productivity.

Discussion

The Huaihe River Region represents one of China's most iconic geographical and cultural areas. A comprehensive investigation of historical and cultural influences and distribution patterns is facilitated by the region's extensive history, cultural heritage, and distinctive terrain. Furthermore, due to the region's disparate economic growth, it was selected as the foundation for a comprehensive analysis of how historical, cultural, economic, and physical-geographical forces converge to shape the configuration of traditional villages. The human topography technique analyzes the fundamental similarities of traditional villages about their cultural traits, physical features, and environmental interconnections, in contrast to the conventional study method limited to watershed size. Moreover, given the region's disparate economic growth, the Huaihe River Basin serves as a crucial lens for examining the interplay of socioeconomic, historical-cultural, and physical-geographical elements that influence traditional village configurations. This is in line with previous studies that the distribution of traditional villages is closely related to both natural geographical conditions and the historical background, socioeconomic structure and cultural factors of each region. The distribution of traditional villages in the Huaihe River Basin is more balanced, relying mainly on the agricultural economy. Traditional villages in the Yangtze River Basin, on the other hand, have a more complex distribution driven by the water-networked geography and commercial economy (Nie et al. 2024). Villages in the Yellow River Basin, on the other hand, show a more dispersed character due to historical floods, wars and migration (Chen et al. 2023; F. Wang et al. 2023). Compared to previous studies, this study employs a holistic technique that integrates socioeconomics and human geography, distinguishing it from earlier research that concentrated solely on a single watershed perspective. It examines the potential linkages among traditional villages concerning their cultural identity, physical attributes, and environmental interactions through a highly precise geographic grid. The Huaihe River Basin was selected after meticulous assessment of the corporeal, conventional, and cultural individualities of traditional villages, providing a novel insight into the

foundational logic and developmental dynamics of their spatial arrangement. This decision enhances the theoretical framework of traditional village research and establishes a robust theoretical and practical basis for future conservation and development initiatives that are more precise and effective.

Protection and development plans in traditional villages. The study's findings reveal that the distribution pattern of traditional villages in the Huaihe River Basin is shaped by the intricate interplay of natural environmental factors, socioeconomic conditions, and various other influences. The placement of these villages is profoundly influenced by the natural environment, underscoring the importance of enhancing ecological security in safeguarding the region's historic villages. A key challenge lies in balancing the demands of economic growth with the preservation of the ethnic culture and natural environment of traditional villages. This study presents a carefully crafted development plan for village clusters in the Huaihe River Basin, based on a "one core, many peripheries" density distribution model. This model shows a negative correlation with certain socioeconomic factors and a positive association with natural geographic features, viewed from both development-driven and conservation-focused perspectives. The development-oriented strategy seeks to promote harmonious coexistence between villages and their environment through scientific planning, ensuring sustainable economic and social development. Conversely, the conservation-oriented strategy emphasizes the protection of the unique landscape and cultural significance of the villages, aiming to preserve these invaluable heritages. The two strategies are mutually reinforcing, each enhancing the other's strengths.

Conservation-oriented way for lower-density traditional village clusters. In the Huaihe River Basin, characterized by economic prosperity and swift urbanization, low-density traditional villages are facing the dual effects of economic advancement and urban development, particularly the accelerated increase in GDP and the expansion of transportation networks. These alterations have not only transformed the settlements' natural landscape but also profoundly affected their cultural foundations and social framework. Consequently, these regions require an urgent conservation-oriented policy that considers reasonable growth. The primary objective is to establish and implement stringent planning and conservation standards to successfully mitigate the unchecked proliferation of non-traditional structures and to preserve the authentic character and aesthetics of the villages. At the same time, it promotes participatory decision-making in the community and enhances the villagers' sense of autonomy and responsibility, so that they can find a balance in the collision between traditional culture and modern development, and work together to promote the sustainable development of the village, which is an integral aspect of cultural heritage preservation (Zhao et al. 2020). Moreover, considering the distinctive configuration of traditional villages in the Huaihe River Basin, predominantly constructed on and reliant upon water, this natural asset can be

adeptly harnessed to cultivate water tourism and associated industries judiciously. By establishing traditional village protection demonstration zones, we may exemplify and advance the comprehensive development of preservation efforts (Ye et al. 2022). Emphasis should be placed on environmentally friendly designs in traditional village demonstration areas, such as rainwater harvesting systems, green buildings, waste recycling and other facilities, in order to reduce dependence on natural resources and the burden on the environment.

Conservation-oriented way for lower-density traditional village clusters. In regions with densely distributed traditional villages, despite adequate protection, these villages confront the challenges of depopulation and diminishing economic vitality. Indicators, for example, road net density, population density, and GDP, corroborate this assertion. A proactive development plan, supplemented by conservation efforts, is advised above. Stimulating the life of traditional villages is essential for advancing their economic growth. Initially, guided by geodetector analyses and the intricate spatial relationships among multiple variables and the spatial distribution patterns of villages (Fig. 15), high-density regions should prioritize the enhancement of rural infrastructure, including the expansion of transportation accessibility and the improvement of fundamental rural services (Verdini et al. 2017). Secondly, by facilitating the transformation and enhancement of rural enterprises and establishing a conducive entrepreneurial environment, laborers will be drawn back to the villages (Hu et al. 2023). Encourage the development of a diversified economy, including rural tourism, handicraft production and organic farming. Emerging sectors, including rural telework middles, cultural and original enterprises, and the digital economy, ought to be cultivated to diminish dependence on a singular tourism economy. Moreover, bolstering rural education projects can qualitatively and quantitatively augment the regional workforce and stimulate economic growth (Yang et al. 2016).

Conclusions

Building on previous research, this research uses both quantitative and qualitative approaches to examine the geographic dispersion characteristics of traditional villages and their impact variables in the Huaihe River Basin, providing theoretical support for the preservation and development of these communities. This study examines the Huaihe River Basin and provides a theoretical framework to explore the spatial adjustments of traditional villages through cultural and natural geographical perspectives. The conclusions of this paper are as follows.

(1) The settlement dispersion pattern of ancient villages in the Huaihe River Basin is characterized by "one nucleus and numerous enclosures," strongly associated with the intricate topography and hydrological features. The predominant varieties of settlements are located near the Huaihe River Basin. More than 95% of conventional settlements are situated on inclines ranging from 5° to 35°, and over 97.3% are positioned within 0.3 km of water bodies. They also favor intricate geography, including hills and basins. In the Huaihe River Basin, the quantity of traditional villages had a substantial inverse correlation with socioeconomic indicators involving GDP, population density, road network density, and urbanization level. A positive association exists between it and natural geographic factors. In view of this, the construction of traditional villages in hilly areas should follow the principle of 'adapting to local conditions', avoiding over-modernization and large-scale industrialization, and preserving the original architectural style and natural landscape as far as possible. The economic vitality of traditional villages in hilly areas should be enhanced through the development of special

industries such as ecological agriculture, green industry and handicraft production. Rural planning should encourage villagers to develop a green economy and sustainable industries with local characteristics through innovation and co-operation, so as to raise the income level of residents, while avoiding over-commercialization and protecting the original ecological environment of the villages.

(2) This study elucidates the intricate interplay of historical, cultural, physical-geographical, and socioeconomic aspects that shape the allocation pattern of traditional villages in the Huaihe River Basin. The positioning of these groups is directly affected by historical and cultural factors. Temperature and precipitation are the two most important geographical factors that affect where traditional groups live. The rate of urbanization and the number of roads are the two socioeconomic factors that have the most direct effect on where traditional villages are located. The combined consideration of physical and socioeconomic parameters greatly enhanced the explanatory power regarding the number of traditional villages compared to the analysis of each element in isolation. This indicates that formulating effective conservation and development programs necessitates achieving a balance between the preservation of traditional villages and socioeconomic growth. In promoting the conservation of traditional villages, it is important to adhere to the concept of sustainable development, that is, to ensure that the conservation of traditional villages does not come at the expense of the ecological environment and resources, while at the same time promoting the development of the local economy. Sustainable development emphasizes the coordination of environmental protection, social equity and economic development, and it is only through this multidimensional balance that long-term, healthy socioeconomic growth can be achieved. This also establishes a robust foundation for formulating conservation plans in the Huaihe River Basin, where disparities are present.

(3) This study conducts a thorough investigation of the distribution patterns of traditional villages and their influencing factors, proposing a series of sustainable measures to attain a peaceful coexistence between the protection and development of traditional villages. The sustainable development of traditional villages not only needs to balance the three dimensions of ecology, economy and society, but also focuses on the inheritance and protection of culture. Traditional villages are usually dependent on natural resources and are often located in ecologically sensitive areas. Therefore, in areas of rapid economic development, the first and foremost task in achieving the sustainable development of traditional villages is to protect and restore the local ecological environment. In regions characterized by a high concentration of traditional villages, it is advisable to harness economic potential through the optimization of infrastructure development and the promotion of industrial enhancement. Traditional villages should avoid an economic model that relies solely on agriculture and encourage the development of a diversified economy, including rural tourism, handicraft production and organic farming. These economic activities should be integrated with local natural resources and cultural contexts to form unique chains. Eco-agriculture is a key area, promoting sustainable agricultural technologies, reducing the use of chemical fertilizers and pesticides, protecting soil quality and increasing the added value of agricultural products. At the same time, the development of rural green industries, such as eco-tourism and agro-tourism, can also increase local sources of income and promote sustainable economic growth. Furthermore, it is essential to systematically investigate how to judiciously balance the interplay between traditional village conservation and economic development amid rapid urbanization, thereby offering robust support for the creation of an improved habitat where humanity coexists harmoniously with nature.

Despite the significant findings of this study, its shortcomings still require attention. Initially, critical elements such as road density, climate, and population are perpetually changing, and our study, constrained by the temporal context of the data collection, inadequately reflects the most recent effects of these variable components. Secondly, the impact of historical and cultural variables on traditional villages is extensive and intricate, influencing both the macro-level distribution patterns of villages and the micro-level development and evolution of these communities. Consequently, future studies should investigate the intricate mechanisms by which historical and cultural elements influence the development and transformation of traditional villages through a synthesis of macro and micro perspectives (S. Jia et al. 2023). To enhance the defense and enlargement of traditional villages, the significance of policy and economic support must be acknowledged (Z. Li et al. 2023). The formulation of scientific and reasonable support policies and the provision of necessary economic assistance will inject a strong impetus into the sustainable development of traditional villages.

Data availability

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

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Yanlong Guo, Peiyu He: conceptualization, visualization, writing—original draft, writing—review & editing. Yanlong Guo: funding acquisition, supervision. Jie Huang, Yanlong Guo, Peiyu He: writing—original draft.

Competing interests

The authors declare no competing interests.

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Not applicable.

Informed consent

All participants included in this study have provided their consent for the publication of the research findings.

Additional information

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