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Spatiotemporal evolution characteristics and influencing factors of traditional villages: the Yellow River Basin in Henan Province, China

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Abstract

Henan Province is the birthplace of Chinese civilization and one of the earliest human settlements, which means that the area has an important national cultural heritage. Traditional villages are an important facet of this cultural heritage, and studying their spatiotemporal characteristics in different periods has important theoretical and practical significance for the sustainable development and protection of cultural heritage in the region. This paper takes the traditional villages of the Yellow River basin in Henan Province that were formed before 1919 as the research object. Information on the ancient river was obtained through a literature search as well as via field research, and the important tributaries of the Yellow River in different periods were mapped using ArcGIS 10.0 software. The nearest neighbor index, kernel density estimation, standard deviation ellipse and other methods were adopted to analyze the spatiotemporal characteristics of the traditional villages. The factors that influenced the evolution of traditional villages were explored in depth by combining changes in the course of the river and water conservancy projects. The results show that the formation of traditional villages along the Yellow River in Henan Province has experienced a historical track of growth, contraction, growth and prosperity and stability. The traditional villages along the Yellow River in Henan Province generally show a clustered pattern, forming a dense concentration of traditional villages in the middle reaches of the Yellow River. The center of gravity shows a migration trend from southeast to northwest. In terms of influencing factors, the spatiotemporal evolution of the relationship between villages and their distance to water is closely related to climatic fluctuations, changes in channel, water conservancy projects and social and cultural factors. This paper deepens our understanding of the relationship between traditional village evolution and watersheds by improving the consistency between village spatial distribution and historical geography and provides a useful theoretical reference for the sustainable development of China's traditional villages.

Keywords Traditional villages, Spatiotemporal evolution characteristics, Influencing factors, China, The Yellow River Basin

Introduction

Traditional villages are an important factor of China's cultural heritage. As living fossils and important representatives of farming culture, they show the results of long-term interaction between people and nature [1]. Traditional villages embody the cultural heritages of material and non-material forms that offer non-renewable historical, cultural, architectural and research value [2]. In 2020, China carried out a practical demonstration of the protection and utilization of areas in which

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traditional villages were set in a concentrated area and under significant forms of legal and academic protection. These villages have now become the world's largest and most distinctive example of agricultural settlements [3]. Guided by the Rural Revitalization Strategy, the economic and living environment of China's traditional villages have been significantly improved, but at the same time they are facing problems such as depopulation and loss of traditional character. The sustainable development of traditional villages has therefore become a subject of widespread concern among academic circles [4–6]. Henan Province is the only province in China that is set in the middle and lower reaches of the Yellow River, and is not only the birthplace of Chinese civilization but also an example of one of the earliest human settlements. Records include the remains of traditional villages over different periods from prehistory (2000 BC) to modern times (1919 AD), and research subjects include politics, economy, culture, military activity and many other highly representative fields. The area and the villages it contains are therefore strongly representative in terms of our research.

The study of traditional villages involves a wide range of disciplines and subdisciplines, including ecology, sociology, anthropology and geography, and the results demonstrates the characteristics of interdisciplinary and multi-perspective research, which is related to the comprehensiveness and marginality of traditional villages as research objects. In other countries, research on traditional villages mainly focuses on the protection of heritage [7–9], tourism [10–12] and the cultural landscape [13–15], while some scholars have also studied the site selection model of villages [16, 17]. In China, however, the study of traditional villages mainly focuses on residential buildings [18, 19] and spatial forms [20, 21]. In recent years, research into the spatiotemporal evolution and spatial differentiation of traditional villages has gradually increased [22, 23], mostly focusing on traditional villages of a certain type or region. For example, Tan et al. studied the spatiotemporal evolution and driving factors of rural settlements in low-hilly areas [24], while Meng et al. explored the spatiotemporal characteristics and evolution of alpine nomadic settlements from the perspective of ecological intelligence [25]. Chen et al. studied historical rural landscape changes in coastal fishing villages of the Yangtze River Basin based on multifunctional methods [26], and using a variety of different scales, He researched the spatial differentiation of traditional villages in Hunan, Hubei and Jiangxi Provinces in China [27].

As the research developed further, some scholars studied the factors influencing the spatiotemporal evolution of traditional villages [28–30], holding that it resulted from multiple effects such as topography, the water system, population, transportation and economic factors. Physical geographical attributes are the primary drivers of village layout and planning, while topographic conditions and hydrological resources also play an important role [31], with altitude and slope affecting the distribution, scale and form of rural settlements [32]. Rivers have a significant influence on village locations [33–35], and the spatial distribution of traditional villages shows an obvious hydrotaxis [36]. Because rivers provide vital water sources for human survival, they play a critical role in the formation and development of traditional villages, and some villages show water-driven characteristics. However, flooding has also brought disastrous consequences to ancient villages, and in many cases these villages show characteristics of moving away from the immediate vicinity of rivers [37]. With the maturity of village industry and economic development, the influence of fundamental factors such as the natural environment has gradually weakened, while t socio-economic factors such as market demand has gradually increased [38]. In terms of research methods, at national and provincial scales [23, 39–41], ArcGIS is used as the main research tool to interpret and judge the geographic detection of spatial correlations and geographic clustering by constructing the analytical hierarchy of influencing factors [42–44].

Previously, the scope of academic research was limited mostly to administrative units, which easily led to limitations in research outcomes. Most of the world's civilizations have originated along the courses and in the basins of rivers [45]. As an independent geographical unit, watersheds and catchment areas are closely related to human settlement activities, and provide an excellent perspective for studying the spatiotemporal evolution of civilization and observing the relationship between people and the land. In terms of spatiotemporal evolution research, most studies are based on the current topography and water system using the timescale of the post-modern era. This means that there is less research and examination of the carriers of early text materials, which can result in inconsistencies between village locations and the historical and geographical map. The influence of channel changes and hydraulic engineering on the distribution of villages is often ignored, as are the peculiarities of village evolution in different eras. This in turn leads to a great deal of incoherence in the spatiotemporal study of driving mechanisms, a lack of systematic and comprehensive research into the spatiotemporal patterns and influencing factors of traditional villages. To this end, this study performed the following steps:

(1) We used statistical data to analyze the development stages of traditional villages along the Yellow River in Henan Province.
(2) In this study, information on the ancient river was obtained through a literature search as well as field research, and the important tributaries of the river in different periods were mapped using ArcGIS 10.0 software to improve the consistency between the spatial distribution of villages and the historical geography of the region.
(3) Geographical methods and techniques such as the nearest neighbors index and kernel density estimation were used to analyze the distribution characteristics of traditional villages along the Yellow River in Henan Province. Meanwhile, the temporal distribution and evolution characteristics of traditional villages were analyzed according to standard deviation ellipse data.
(4) The influencing factors of traditional villages along the Yellow River in Henan Province were explored by means of literature search and data analysis.

This study attempts to develop a spatiotemporal analysis of traditional villages by improving the analysis of the consistency of villages and the area's historical geography. The study can thus present a more comprehensive analysis of the evolution characteristics of traditional villages, deepening the concept of the protection and development of traditional villages.

Materials and methods

Henan Province is conducted in the central of China, between 31 °23 ' to 36 °22' North and 110 ° 21 ' to 116 ° 39' East. It is the transition zone between China's second and third tiers, where the Yellow River flows through the Qinling and Taihang Mountains. In this section, the river transitions from the mountains to the plains downstream (Fig. 1). The entire Yellow River Basin can be divided into nine geographical types based on the main conditions of its physical geography. Henan is situated in the Xiaoshan-Xiong'er-Taihang Mountain area and the downstream alluvial plain area [46]. The average altitude of the mountain area is no more than 1000 m, and the highest peak is 2413.8 m above sea level. The Yellow River Basin in Henan Province is divided into middle and lower reaches, bounded by the Taohuayu Valley. The mountains in the area have been eroded into gorges and ravines, and the downstream alluvial plain is also referred to as the alluvial cone of the Yellow River. There are some

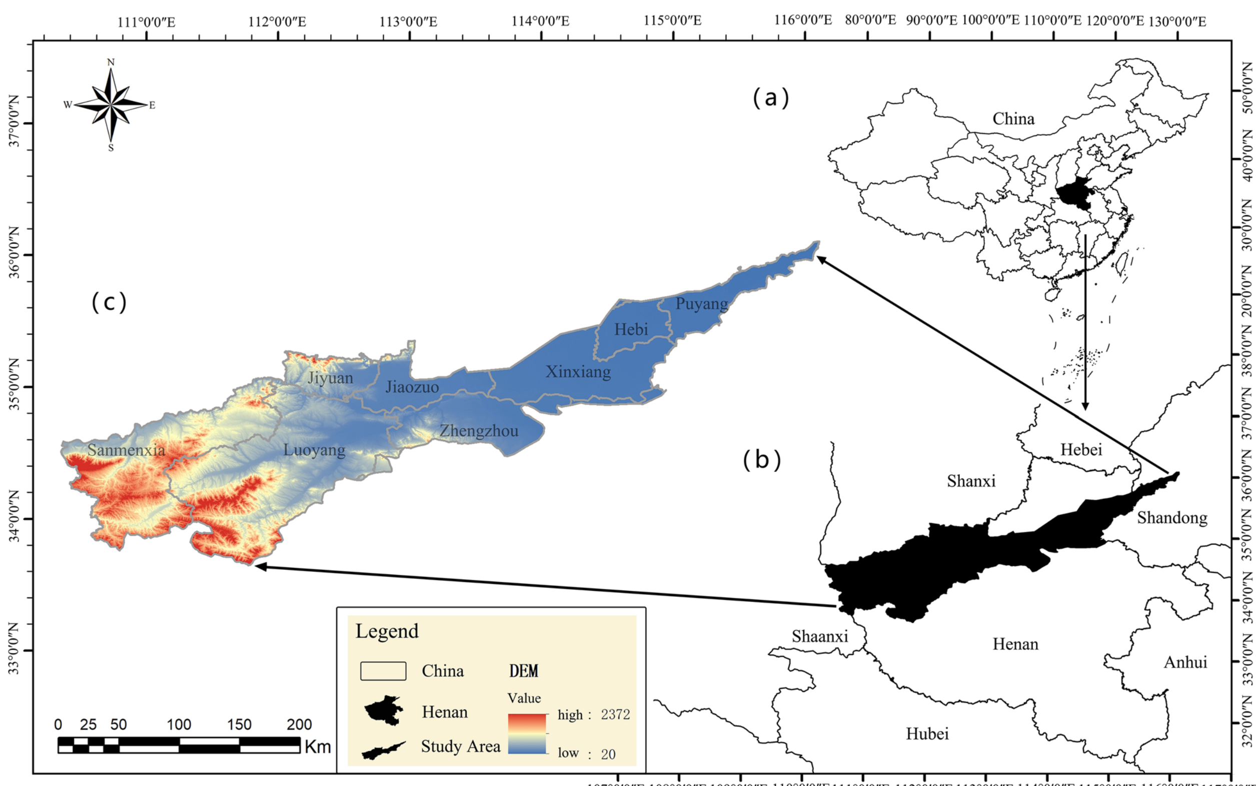

Fig. 1 The location and topographic features of Traditional Villages, the Yellow River Basin in Henan Province

large tributaries in the area, such as the Luo River and Yi River in the south and the Qin River in the north, all of which flow into the Yellow River to the south of Mengjin County.

The river flows through 28 counties (prefecture-level cities and districts) set in eight province-governed municipalities. The river in this area has a total length of 711 km and a basin area of 36,200 km^2, accounting for 5.1% of the total area of the Yellow River Basin. Protected areas include 105 counties in 13 province-governed municipalities in Henan Province, covering an area of 96,000 km^2, accounting for 57% of the province's area [47].

Traditional villages

Taking the selected villages identified by the Ministry of Housing and Urban–Rural Development of China as the original data for preliminary statistics and excluding those in catchment areas not surrounded by the Yellow River Basin, as of 2022 there were a total of 119 traditional villages in the southern section of the Yellow River Basin, including 92 in the Xiaoshan and Xiong'er-Taihang Mountain area, (accounting for 77.5% of the total), and 27 in the downstream alluvial plain (accounting for 22.5% of the total). Combined with the declaration on the materials of traditional villages of various batches from the Henan Provincial Department of Housing and Urban–Rural Development and the county records and village histories, the formation age of traditional villages was determined, and through field interviews, the formation periods of villages were checked, corrected and listed (Table 1). Five stages of civilization were chosen, including the growth of the pre-Qin and Han dynasties (221 BC–220AD), the fall of the Wei, Jin, Sui, and Tang dynasties (220—960), the expansion period of the Song and Yuan dynasties (960–1368), the heyday in the Ming Dynasty (1368–1644), the saturation period in the Qing dynasty, and modern history (1636–1949).

Historical river reconstruction

During the period of this study, the Yellow River and its main tributaries in Henan Province were reconstructed according to historical records from *Notes on Book of Waterways* and the *Atlas of Historical Geography of China*, the extraction of digital elevation models (DEMs) of ancient river channels, remote sensing imagery and field surveys. The course changes of the Yellow River are concentrated downstream, and the *Notes on Book of Waterways* in the late Northern Wei Dynasty (386-534AD) describes the sequence, geographical location, and flow direction of rivers before the Han Dynasty (220 AD). The book confirms that there were three channels in the lower reaches of the Yellow River, namely the Shanjing River, the Yugong River and the Hanzhi River, which had formed relatively fixed channels by the end of the Western Han Dynasty (around 9 AD). Their approximate spatial distribution was determined during the Northern Wei period. The lower reaches of the Yellow River changed little between the time of the Wei and Jin dynasties and the Sui, Tang and Wu Dai dynasties (960 AD) [48]. During the Northern Song Dynasty, the course of the Yellow River began to gradually move southwards, forming a hanging river on the ground, and for more than 700 years after that, most of the Yellow River flowed south of its current course, which was marked by a period of extreme instability for the river. In this study,

Table 1 Statistics on spatiotemporal distribution of traditional villages along the Yellow River in Henan

Evolution stage	Dynasty	Watershed type		Total	Accumulative total
		Xiao Xiong Tai mountain area	Downstream alluvial plains		
Rising period	Pre Qin Dynasty	14	4	18	18
	Chin and Han Dynasty	7	3	10	28
Falling period	Wei and Jin Dynasty	2	1	3	31
	Sui and Tang Dynasty	8	3	11	42
Expansion period	Song and Jin Dynasty	8	3	11	53
	Yuan Dynasty	9	3	12	65
Heyday	Ming Dynasty	26	8	34	99
Saturation period	Qing Dynasty	10	2	12	111
	the Republic of China	4	4	8	119
	Subtotal	88	31	119	119

the direction of the Yellow River from the Song Dynasty to the Qing Dynasty is determined with the reference to the *Atlas of Historical Geography of China* [49], and the location of the Yi, Luo and Qin Rivers, which are important tributaries of the Yellow River, were recorded and verified through field investigation. On this basis, river courses were drawn according to modern remote sensing images, and the hydrological DEM data processing module in the spatial analysis tool of ArcGIS 10.0 software was used to construct a vector map of the rivers.

Since the administrative units above the county level in China have always been relatively stable grassroots units over history, the location of the county seat in each period was determined firstly with the help of the *Atlas of Historical Geography of China* in order to improve the accuracy of the relationship between villages and water locations during different historical periods. The ancient and modern orientation was corrected by latitude and longitude so that the relative position of the Yellow River and the county seat could be adjusted accordingly. These rivers are considered historical rivers in the study. Modern remote sensing images came from Google Earth, DEM data came from SRTM DEM (90-m resolution) and ASTER GDEMV2 DEM (30-m resolution). These data were provided by the Geospatial Data Cloud Site of the Computer Network Information Center of the Chinese Academy of Sciences (www.gscloud.cn).

Research methods

The nearest neighbor index

There are three types of spatial distribution of point features, and these are agglomeration distribution, uniform distribution and random distribution. The nearest neighbor distance is a geographic metric that shows how close the point elements are to each other in geographic space. The nearest neighbor index can be used to reflect the type of spatial distribution of point features [50], and is calculated as the ratio of the actual nearest neighbor distance to the theoretical nearest neighbor distance according to the following formula:

$$rE = \frac{1}{2\sqrt{n/A}},\ R = \frac{r_1}{r_E}. \tag{1}$$

In the formula, R represents the nearest neighbor index; r_1 is the actual nearest neighbor distance in geographic space; r_E represents the theoretical nearest neighbor distance; A is the study area, and n represents the number of subjects studied within the area. When the R index is 1, the point features are randomly distributed. If R is greater than 1, the point features tend to be uniformly distributed, and if R is less than 1, point features are distributed in clusters.

Kernel density

Kernel density analysis can be used to calculate the density of features in their surrounding neighborhoods, which clearly express the scattered or discrete characteristics of these features and can be used to produce high-quality density estimates on point data [51]. This paper used this method to make a kernel density map of traditional villages' spatial distribution in Henan Province and explores the characteristics of villages' temporal evolution using the following formula:

$$f(x) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{x-x_i}{h}\right). \tag{2}$$

In this formula, x is the position of the object to be estimated; x_i represents the position of the i-th estimated object that falls within the range of a circle with x as the center and h as the radius; and

$$K\left(\frac{x-x_i}{h}\right) \tag{3}$$

is the kernel function. The larger the value of *f (x)* is, the denser the concentration of points is and the higher the probability of occurrence.

Coefficient of variation

The coefficient of variation, also known as the coefficient of standard deviation, is expressed by the ratio of standard deviation to mean in statistical terms. The analysis of the relative change degree of the point target in space can reflect the degree of data dispersion objectively [52]. In this paper, the coefficient of variation of the Tyson polygon area was used to further verify the spatial distribution type of traditional villages in Henan Province according to the following formula:

$$R = \sqrt{\sum_{i=1}^{n} \frac{(S_i - S)^2}{n}},\ CV = \frac{R}{S} \times 100\%. \tag{4}$$

In the formula, R represents the standard deviation, S_i is the i-th Voronoi polygon area, S is the average of polygon areas, and n represents the number of polygons. A CV of $\leq$33% means the distribution is uniform, a CV of between 33 and 64% represents a random distribution, and a CV of $\geq$64% indicates an agglomeration distribution.

Standard deviation ellipse

The standard deviation ellipse is based on the spatial region and the spatial structure of the research object and is used to quantitatively explain the characteristics of the central tendency, the degree of dispersion, the direction trend of the spatial distribution of the geographical features from the perspective of global space, and to reveal the spatial distribution and spatiotemporal evolution process of the geographical features [23]. The shorter the semi-axis is, the more obvious the centripetal force of the data will be, and the longer the axis, the higher the degree of dispersion will be. The standard deviation ellipse contains three main parameters: the elliptic center of gravity, the azimuth, and the major and minor axes of the standard deviation ellipse. Based on this method, this paper explores the evolution of standard deviation ellipses in different eras of traditional villages in Henan Province and identifies the development direction and migration trajectory of these villages.

This research used Arcgis10.0 to perform all the analyses described above.

Results

Spatial distribution characteristics

Spatial distribution types

Using the Average Nearest Neighbor tool in ArcGIS 10.0 software, $\overline{r_1}$=7.38 km, $\overline{r_E}$=10.38 km, the average nearest neighbor index R, calculated according to the nearest neighbor index formula, is 0.71, Which is less than 1 and indicates that the traditional villages in the Yellow River Basin are distributed in clusters. The coefficient of variation method of the Tyson polygon area was later used to verify this result. Taking 119 ancient villages in the Yellow River Basin as the generator, the ArcGIS 10.0 software was used to generate a Tyson polygon of the distribution of ancient villages, and it was found that the average area of 119 polygons $\overline{S}$ was 942.55, the standard deviation δ is 1599.09, and the coefficient of variation (CV), calculated according to the formula, was 169.46% > 64%, indicating that the traditional villages in the Yellow River Basin were generally distributed in an agglomeration pattern.

Spatial density distribution characteristics

Using the kernel density tool in ArcGIS 10.0 software to study the spatial distribution (Fig. 2), it was found that the traditional villages along the Yellow River in Henan showed significant characteristics of agglomeration. The high-kernel-density area was located in the Xiaoshan-Xiong'er Taihang Mountain area and was closely related to the tributaries in the second and third levels of the Yellow River, including the Yi, Luo, Chan and Qin rivers, in which a dense area of traditional villages was situated. In the area, Sanmenxia and Luoyang have the largest numbers of traditional villages, both with 40, accounting for a total of 67.2% of the total, and this plays an important role in the protection of the culture and the landscape of the Yellow River Basin.

Changes to the center of gravity

The Average Center tool in ArcGIS 10.0 software was used to calculate distribution centers over historical periods. The results showed that the distribution center (112.25E, 34.74N) of traditional villages along the Yellow River in Henan is the standard threshold located in the Yiluo River Basin. The center coordinate moves between 111.92°E, 34.60°N and 112.64°E, 34.83°N, with

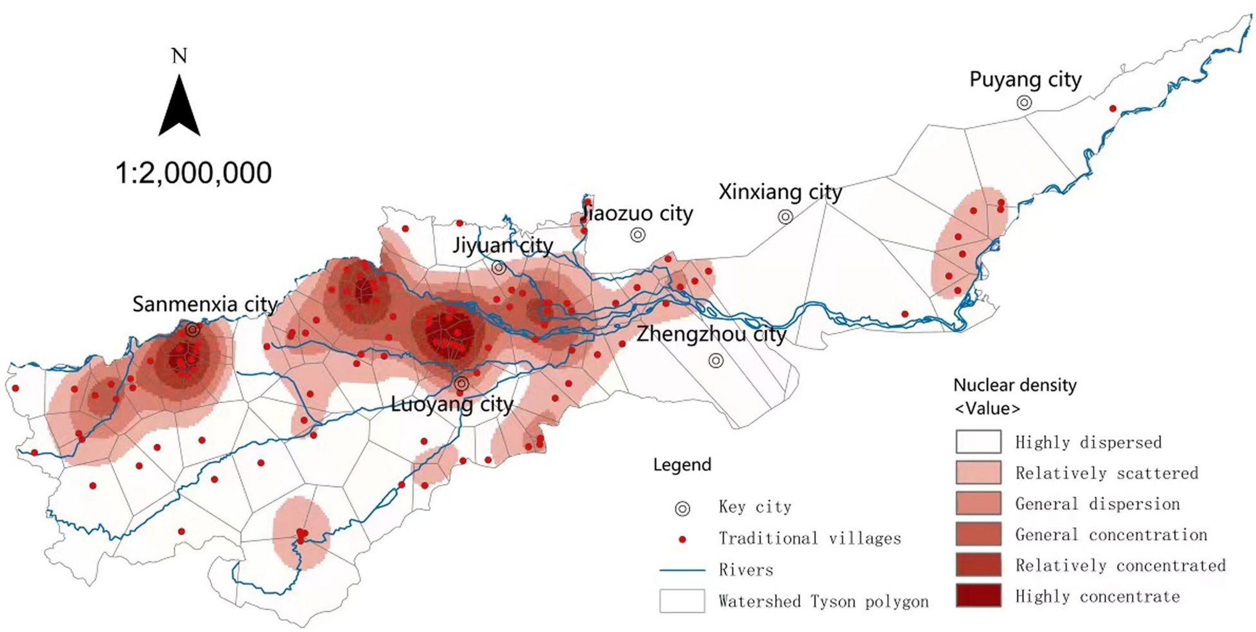

Fig. 2 The kernel density of traditional villages along the Yellow River in Henan

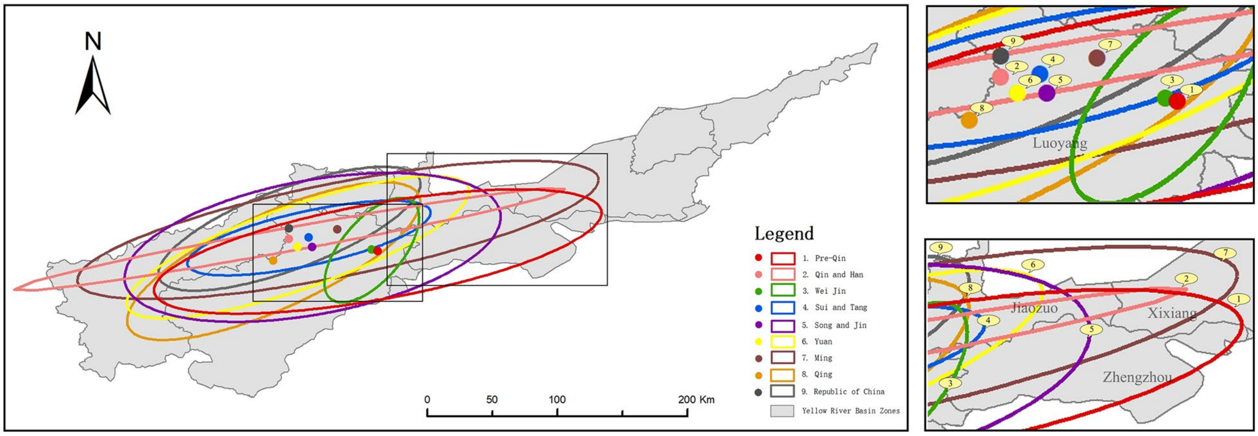

Fig. 3 Standard deviational ellipse of traditional villages along the Yellow River in Henan in each historical period

an east–west span of about 0.7° and a north–south span of about 0.2°, showing a migration trend from southeast to northwest. Standard deviation ellipses were used to explain the spatial distribution and spatiotemporal evolution of traditional villages from the perspective of global space, and the results show that the traditional villages in the Qin, Han, Sui and Tang dynasties revolved around the center of gravity with a strong level of centrality, although this was at its weakest during the Song and Yuan dynasties. The distribution shows the characteristic of an east-northeast to west-southwest distribution (Fig. 3).

Analysis of the time series pattern scale and type structure

The kernel density tool was also used to analyze the distribution characteristics of traditional villages along the Yellow River in Henan at different times (Fig. 4). The results show the distribution in agglomeration in each time period, and the traditional villages in the middle reaches are mostly distributed on the south bank of the Yellow River, while those in the lower reaches are mainly distributed on the north bank. More specifically, prehistoric traditional villages were concentrated in the middle and low mountainous areas in the middle reaches of the Yellow River, and as civilization evolved the site selection gradually transitioned to the hilly area at the boundary between the middle and lower reaches, while a small number of villages also emerged in the lower reaches, which conformed to the basic understanding of migration from the mountains to the plains in early ancient China. During the Eastern Han Dynasty and the Northern Wei Dynasty, the climate in Luoyang gradually changed from waterlogging to drought, and the long-term social effects of this caused a reduction in forest vegetation in the upper reaches of the Jian and the Chan Er Rivers, resulting in sediment accumulation in the rivers and irrigation channels, causing serious soil erosion and a decrease in water diversion efficiency [53], which slowed the development of villages. During the Sui and Tang dynasties, with the development of politics and economy, the number of villages gradually increased, and most of them were distributed near the second- and third-level tributaries. During the Song and Yuan Dynasties, settlement on the lower reaches of the Yellow River migrated abruptly, resulting in a huge impact on production and the life of the population in the area. The soil near the Yiluo River and the Chan River was fertile and water sources were abundant, so the villages in the surrounding hilly areas developed rapidly. The villages in the lower reaches of the Yellow River were mainly distributed on the alluvial plains downstream, and the village development pattern had basically been completed. The Ming Dynasty was the heyday of the development of traditional villages along the Yellow River in Henan, and the distribution remained relatively stable in the lower reaches of the Yellow River. During this era, engineering and soil improvement techniques were greatly improved, and villages in the central hills and lower plains developed steadily. The water conservancy engineering technology matured between the Qing Dynasty and modern times, the river course remained stable, and development in the mountainous areas was intensified. The distribution of villages at different periods generally shows a trend of long-term agglomeration in hilly areas in the middle reaches of the Yellow River catchment, and a gradual expansion into plains and mountainous areas, reflecting the temporal characteristics of land development from simple to complex.

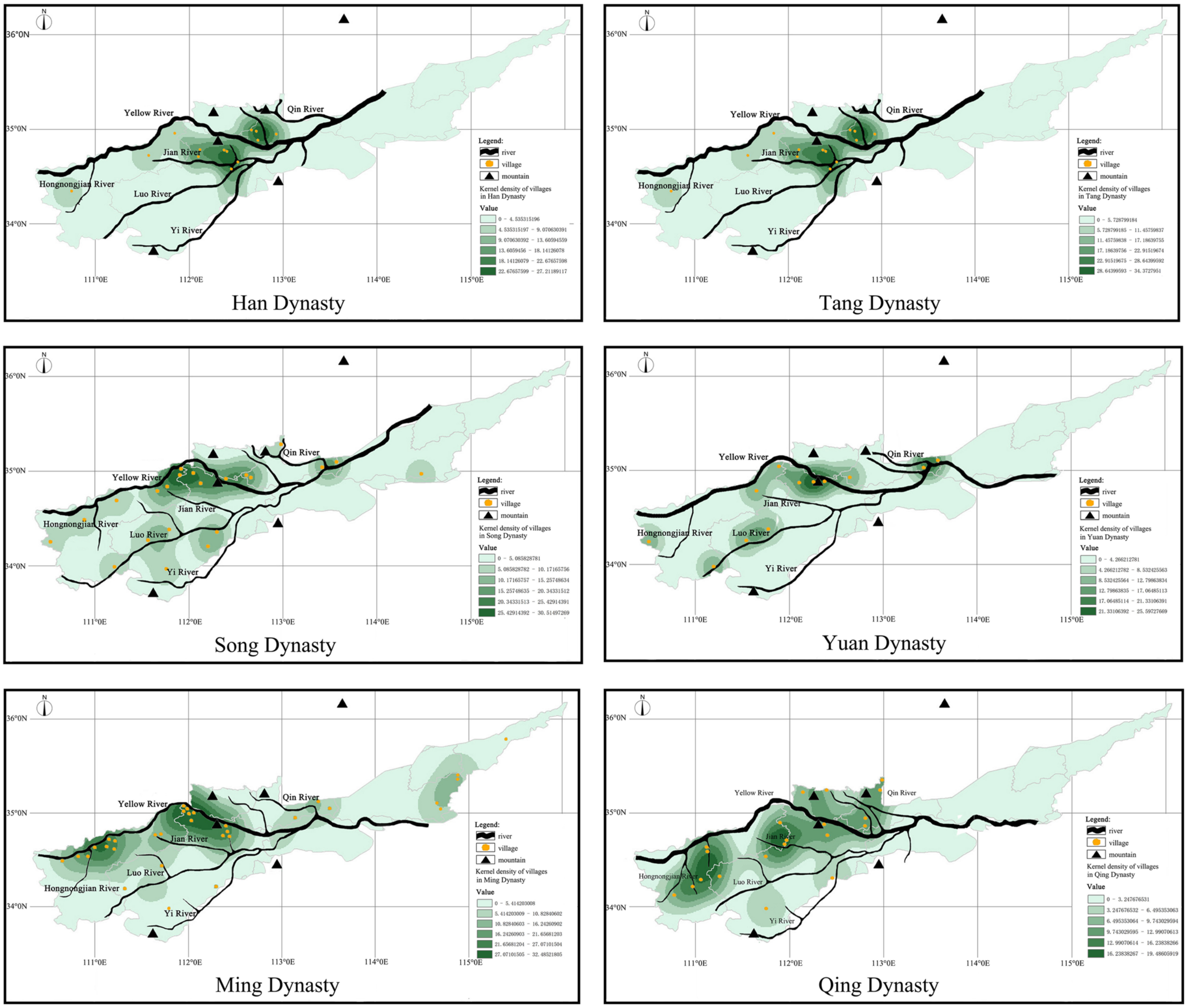

Fig. 4 Density distribution of traditional villages along the Yellow River in Henan in different historical stages

Table 2 Statistics for flood and drought disaster years in the Yellow River Basin of Henan Province

Century disaster	BC 1	BC2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	A/R	Avg.
Flood	14	13	9	29	14	0	0	3	18	25	11	39	22	11	25	69	57	84	81	68	86	39	717	33.4
Drought	7	0	29	42	16	3	1	3	7	7	17	50	60	13	35	49	30	72	79	56	63	33	672	32.3

The influencing factors of traditional villages' spatial distribution along the Yellow River

Natural environmental factors

River channel changes and construction of water conservancy facilities Based on the changes to the course of the Yellow River and the construction of water conservancy facilities, we can see that the Yellow River has moved abruptly with Zhengzhou as the apex on many occasions, affecting both the south and the north of the area. It has also frequently overflowed and diverted downstream. Statistics show that between the first century BC and the twentieth century, the southern part of the Yellow River Basin suffered an average of 33.4 floods and 32.3 droughts per year (Table 2) [54], posing a significant threat to people's lives. Since the process of regulating rivers and watercourses and damming them for irrigation began in ancient times, Chinese dynasties have carried out a series of water conservancy construction projects around the Yellow River to avoid floods. In the tenth year of King Hui of Wei Dynasty (360 BC), engineers built the Hong Gou Canal connecting the current water courses in the middle part of China. During the Western Han Dynasty (202 BC-8 AD), with the increase of population and the intensification of human activities, the tributaries in the lower reaches of the Yellow River had already become known as "muddy water" [55], and in the Eastern Han Dynasty (25–220 AD), the Luoshui River, a secondary tributary of the Yellow River, was diverted to solve the demand for water and improve shipping problems in the capital. Meanwhile, the water transportation channels were also improved by river control projects such as building an embankment along the Yellow River that stretched for more than 1000 miles. During the Wei and Jin Dynasties (224–420 AD), due to the difficulty of navigation in the middle reaches of the Yellow River, the emperor ordered water transport in the middle and lower reaches of the Yellow River to be made more convenient by digging away mountains and dredging river channels. In the Sui-Tang Dynasty and the Five Dynasties (581–960 AD), the third-level tributary Qi River was opened, and aqueducts and canals were dug, forming a nationwide water transport system centered on Luoyang and connecting the four major water systems of the Yangtze, Huaihe, Yellow and Qiantang rivers, with a total length of more than 2500 km. During this period the ecological environment also began to deteriorate sharply, and the sand content of the Yellow River increased year by year, causing siltation and changes to the river course. After generations of dredging, there is a section of the river that is still in use after more than 1300 years. During the Song Dynasty the Luoshui, a secondary tributary of the Yellow River, was diverted into the capital's water system, reducing sediment accumulation in the lower reaches of the Yellow River. In the Qing Dynasty, sand was cleared from the converging flow as flood control management and construction reached a more mature stage.

Early land development was concentrated in the middle reaches of the Yellow River, but with connections opened between the Yellow River system in Henan Province and other water systems outside the province, the water conservancy construction became more focused on disaster prevention and the water transportation of grain. Human activity interacted with the surrounding environment of the Yellow River, which had a profound impact on the development of villages, and the center gradually moved from the middle reaches of the Yellow River to the plains downstream. Due to the accumulation of silt and sand and the unpredictable relationship between water and sand in the Yellow River, a water system network with strong flood regulation and storage capacity was formed in the northern part of the middle reaches of the Yellow River in order to make use of the Yellow River's water sources and improve the land by forming a complex system of irrigation. Irrigation processes and land cultivation conditions in this area were fairly uniform, and a small number of villages with a common layout appeared. In the downstream areas, people lacked systematic flood prevention and irrigation methods at that time, and mainly used dikes as safety barriers against flooding, However, this resulted in a lack of external water sources for crops as well as serious sedimentation, although soil improvement methods and technologies were later developed. The natural environment of the plain was improved, and the population gradually migrated from the mountainous areas, where they lived to avoid the floods, to the lowlands where the protection measures and production conditions had improved. Here, they formed a variety of settlement types such as mountain settlements, hilly settlements, alluvial fan settlements and plain settlements, developing the basic pattern of village distribution in the southern section of the Yellow River Basin.

In short, the maturing technologies of river management, embankment construction, canal excavation and sand reduction provided excellent development opportunities for the villages in the middle and lower reaches of the Yellow River. Meanwhile, the construction of irrigation ditches solved the irrigation and drainage problems for villages in the lower reaches of the Yellow River, which was a necessary prerequisite for the development of villages in this area.

Elevation and village water distance

Based on to the elevation, the terrain can be divided into three categories: plains (< 200 m), hills (200–500 m) and mountains (> 500 m). Through ArcGIS, the elevation and slope of each village were obtained, and the Euclidean distance tool was used to measure the distances of the villages from water. It was statistically proved that 72.3% of the villages have a slope of less than 10 degrees and an average slope of 6.5 degrees; 55 of the villages are located in hilly areas, accounting for 46.2% of the total, and the average distance from the river was 12.5 km, mainly distributed in the Funiu Mountain area in Luoyang. 38 of the villages (31.9% of the total) are located in the mountains, at an average distance of 22.3 km from the river. These villages are mainly distributed in Xiaoshan and Xiong'er Mountains in Sanmenxia, with a small number in the Funiu and Songshan Mountains. 26 villages (21.8% of the total) are located in the plain, with an average distance from the river of 4.4 km. These villages are mainly distributed in the downstream area. Analysis of village distances to water by 5 km, 10 km, and 20 km intervals

Table 3 Traditional villages at different elevations and distances to water

Distance between village and water			Altitude				
Range (km)	Quantity (village)	Percentage (%)	Range (m)	Type	Quantity (village)	Percentage (%)	Average distance between village and water (km)
< 5	58	48.7	< 200	Plain	26	21.8	4.4
5–10	21	17.6	200–500	Hill	55	46.2	12.5
> 10	40	33.6	> 500	Mountain	38	31.9	22.3

shows that 48.7% of traditional villages are distributed within 5 km, 17.6% are distributed within 10 km, and 33.6% are distributed beyond 10 km (Table 3).

Sanmenxia City lies at roughly 377 m above sea level, making it the highest city in Henan. The Yellow River enters the territory of Henan Province from Lingbao, with a fast flow and a large drop, and traditional villages are mostly located in mountainous areas and farther from the water. Safety and disaster avoidance are the main considerations in locating villages here. After the Yellow River enters the Funiu Mountains, the hilly area of Luoyang, the speed of water slows down, and the average distance between villages and water is much closer. Villages are mostly distributed in the relatively flat terrain, which is more conducive to production and life. Most of the villages in the lower plains are distributed in areas on the north side of the Yellow River where there were more mature irrigation systems, and the distance to water is also close here. Statistics show a strong correlation between village site selection, proximity to water and topography.

By analyzing the average elevation, the average distance from rivers and changes in the number of villages in each period (Fig. 5), it was found that the trend of village development is consistent with changing trends of elevation and distances from water in most periods. During the Ming Dynasty, engineering and irrigation technology were greatly improved, and the number of villages in low mountainous areas and lower plains increased accordingly, with 11 traditional villages in Sanmenxia area lying at an average distance of 36 km from the river, and 8 villages in the plain area with an average elevation of 74 m, which had a greater impact on the total average value of distance from water. During the Qing Dynasty and the modern times, the number of traditional villages in the middle and low mountainous areas in Luoyang increased further. Because they were closer to second- and third-level tributaries, the average distance from village to water was 4.2 km, and as elevation increased, the average distance from the villages to water decreased.

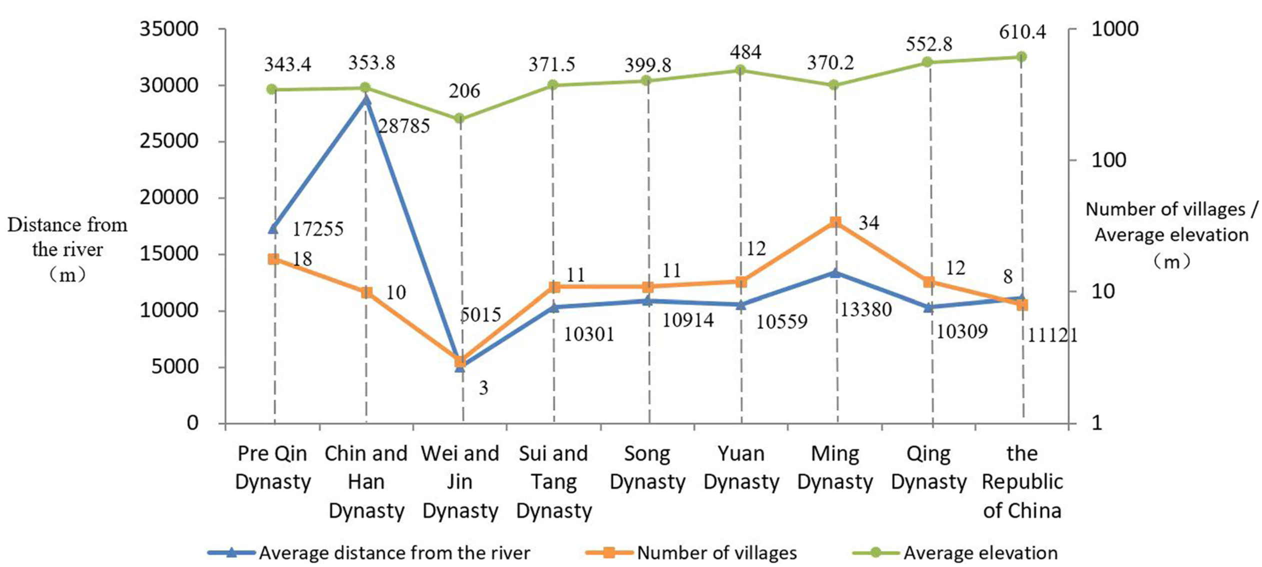

Fig. 5 Number of traditional villages with different elevations and village water distances

Climatic factors

The historical climate data for the Yellow River Basin shows a cyclical succession of warm humidity and cool dryness. The climate from the early Western Zhou Dynasty to the end of the Western Han Dynasty was warm, with temperatures roughly the same as the northern part of the modern mid-temperate zone, and average annual temperature were 2–4 °C lower than today, which was more suitable for crop growth and human development. This was conducive to the development of human civilization dominated by dry-weather farming. After the Western Han Dynasty, the Eastern Han Dynasty, Wei, Jin, Southern and Northern Dynasties were marked by a second cold period in China, which was extremely unfavorable to life and agriculture in the Yellow River Basin and had a great impact on the development of villages. The climate warmed up during the Tang dynasty and early years of the Northern Song dynasty, while colder weather dominated after the Song dynasty. The middle and high latitudes of the Yellow River basin were greatly affected by this climatic fluctuation, the agroecological environment was damaged and the Yellow River flooded frequently. The four great natural downstream migrations of the Yellow River all occurred in the early or late period of warm phases of cyclical climatic fluctuations [56].

Social and human factors

Politics and culture

The middle and lower reaches of the Yellow River, where Luoyang, Zhengzhou, Kaifeng in Henan Province are situated today were key areas chosen for China's ancient capital, but they were also the most damaged areas. During the Wei, Jin, Sui, Tang, Song, and Yuan dynasties, when locations of the capital were settled for longer periods, nearby villages developed more slowly. However, at other times, especially during the Wei and Jin dynasties, the country was in a state of long-term division, and few villages remained.

Politics and culture are inextricably linked. The Yellow River Basin in Henan Province can be divided into the Heluo Cultural Area (Sanmenxia, Luoyang, etc.) in the west, the Henei Cultural Area (Jiyuan, Xinxiang, Jiaozuo, Puyang, etc.) in the north and the Songyue Cultural Area (Zhengzhou, etc.) in the middle part of Henan [15]. We can see from the kernel density analysis (Fig. 2) that the Heluo Cultural Area is also an area in which traditional villages were concentrated. In ancient China, the ideal model of human settlement was fronting water with hills to the back and based on the premise of avoiding floods and other natural disasters, urban planning and village site selection were considered on a large scale, forming a cultural landscape that had a great impact on village site selection. Most villages in the middle and lower reaches of the Yellow River follow the model of "mountains and surrounding hills", and are located at the bend of the river, the hilly areas on the plain, and high land near the river [57]. Therefore, the villages of the Songyue Cultural Area developed more rapidly in the pre-Qin period, and most of the later villages revolved around the Heluo Cultural Area.

The formation and development of traditional villages is closely related to population levels, which to a great extent reflects the economic situation at that time. The population numbers of Henan Province in the Western Han Dynasty (2 AD), the Western Jin Dynasty (280 AD), the Tang Dynasty (740 AD), the Song Dynasty (1102 AD), the Ming Dynasty (1578 AD) and the Qing Dynasty (1911 AD) [31] was analyzed, and it was found that increases

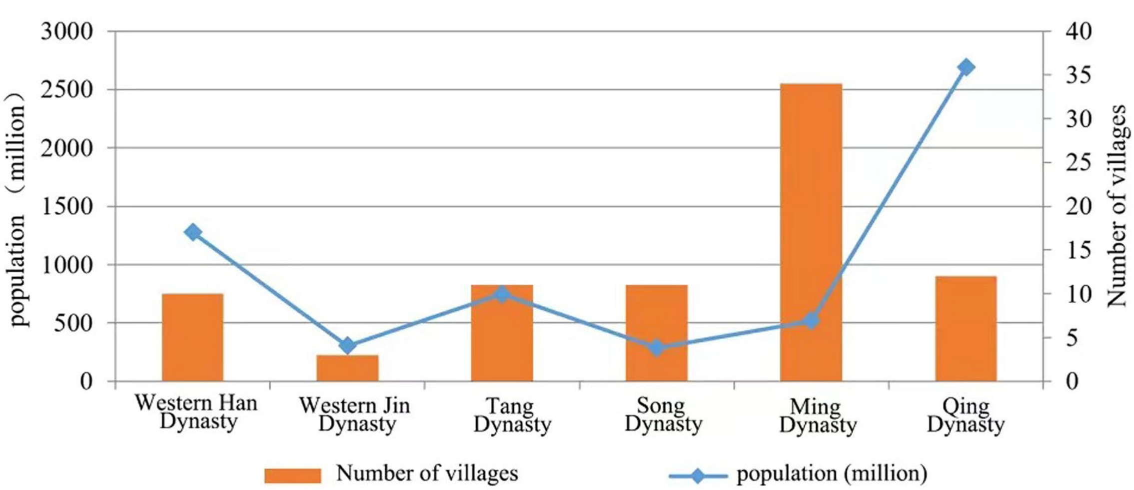

Fig. 6 Relationship between the population size of traditional villages along the Yellow River in Henan during different historical periods

and loss of population was basically consistent with the rise and fall of traditional villages along the Yellow River Basin in Henan (Fig. 6). The Western Han Dynasty represented one of the fastest growth periods of Henan's population in history and was also a period of vigorous village development. From the Wei and Jin dynasties to the Sui, Tang, Song and Yuan dynasties, there were many wars in the central plains area, which represented not only a period of population decrease, but also a period of shrinking and slow recovery of traditional village development. The population gradually increased once more during the Ming Dynasty, and due to improvements in technology, the land became more developed, and the growth period of villages entered its heyday. Although the Qing Dynasty was a period of rapid growth of population in Henan, the number of people in the area meant that the population density rose from 19.2 people/km^2 in the Hongwu period of the Ming Dynasty to 127 people/km^2 during the Jiaqing period of the Qing Dynasty, representing a seven-fold increase [58]. The number of villages did not increase significantly, however, and a period of saturation of village development began. In addition, after the Song Dynasty, land development in the lower plains was intensified, while the great migration in the Ming Dynasty was also an important reason for the proliferation of villages in the later period.

Distance from the central city

The farther the distance from the central cities of the province, the more conducive it was to the formation and protection of traditional villages [59]. Seven prefecture-level cities in the study area were selected as the central cities of surrounding traditional villages, and the distance between the cities and the villages under their jurisdiction was measured using the Euclidean Distance Tool in ArcGIS. It was found that 18 (15.1%) traditional villages were within 20 km of the central city, 91 (76.5%) were distributed within 20–100 km, and 10 (8.4%) were distributed 100 km or more from the city. Since most of the traditional villages along the Yellow River in Henan are far from the central cities and less affected by modern civilization and urbanization, the later development and construction in these the villages is low, and the style of the villages has remained relatively intact.

Discussion

Great rivers fed the earliest forms of agriculture in China through periodic flooding and locally appropriate irrigation, giving birth to a social division of labor, natural production techniques and cultural formations that were adapted to the river. Most of today's rivers have fixed channels after multiple floods and changes in course, and the evolution and development of traditional villages has to a certain extent been a process of co-evolution with water, showing basin-based distribution characteristics that are completely different from ordinary villages that are the result of historical development. Through the study of the spatiotemporal evolution of traditional villages in the Yellow River Basin in Henan Province, we can draw the following conclusions.

(1) There are 119 traditional villages along the Yellow River in Henan, 93 of which are located in the middle mountain area, accounting for 78.2%, and 26 in the downstream alluvial plain, accounting for 21.8%. The formation of these traditional villages has experienced a historical track of growth, contraction, growth and prosperity and stability, which is generally representative of the temporal characteristics of long-term concentration in the middle reaches and divergence to the lower reaches of the Yellow River in the peak saturation period.

(2) Through the reconstruction of rivers in important periods, we discovered that in the early stable period of the Yellow River Basin, human settlements were mostly located on tablelands formed by erosion in the middle reaches of the catchment and on alluvial plains with fertile soil in the lower reaches. In more unstable periods, which were marked by changes to the river basin, humans responded to flood disasters through a series of water conservation projects such as digging canals, connecting water systems and building dikes. During this period, villages in the middle reaches of the river basin were mostly located in the middle and low mountainous areas at higher altitudes and farther from water, while systematic irrigation areas were formed in the downstream areas, which greatly promoted the emergence and development of villages in those irrigated areas. Meanwhile, the growth of engineering technology meant that agricultural development in the midstream mountainous areas was gradually intensified.

(3) The traditional villages along the Yellow River in Henan showed the characteristics of a typical clustering distribution. The areas with high kernel density are distributed in the middle reaches of the Yellow River and are laid out in bands along the second-and-third-level tributaries of the Yellow River, forming a dense area of traditional villages. The center coordinate moves between 111.92°E, 34.60°N and 112.64°E, 34.83°N, with an east–west span of about 0.7° and a north–south span of about 0.2°, showing a migratory trend from southeast to northwest. The distribution shows the characteristics of an east-northeast to west-southwest distribution.

(4) In terms of influencing factors, the spatiotemporal evolution of the relationship between villages and their distance to water is closely related to climatic fluctuations, changes in channel, water conservancy projects and social and cultural factors. Natural environmental factors have a significant impact on the evolution of the area's spatial distribution. 55 of the villages are located in hilly areas, accounting for 46.2% of the total, and the average distance from these villages to the river was 12.5 km. 38 of the villages (31.9% of the total) are located in the mountains, at an average distance of 22.3 km from the river. 26 villages (21.8% of the total) are located in the plain, with an average distance from the river of 4.4 km. This indicates that the lower the altitude, the greater the hydrophilicity. Meanwhile, 84.9% of traditional villages are located more than 20 km from the central city, indicating that the lower the degree of urbanization, the more conducive that is to the protection of villages.

Before the Western Han Dynasty, most of the villages were located on the tableland formed by the alluvial Yellow River and the plain of the Yiluo River Basin. The development of villages was constricted by the climate and war during the Wei and Jin Dynasties. From the Sui and Tang dynasties to the Northern Song Dynasty, the climate was mild, and the channel of the Yellow River remained stable, but the development of villages was greatly affected by politics and war. During the Song and Yuan dynasties, the channel was more changeable, the climate became colder, and the development of villages slowed down. From the Ming and Qing dynasties to modern times, engineering technology, migration and safety needs were the main factors affecting the evolution of villages, and the number of villages rose significantly as villages in both the lower reaches of the Yellow River and the mountainous areas developed.

Conclusion

This paper has attempted to recreate the channels of the Yellow River and some of its more important tributaries through a literature review and research. From the research, the study constructed a research base map of traditional villages during different historical periods in the Yellow River Basin in Henan, China, in order to study the distribution of villages in terms of historical geography. Based on this, the spatiotemporal evolution of traditional villages in the basin was explored, and the study found that influencing factors on village development represent a complex system resulting from the combined action of multiple factors. As well as topography, elevation, altitude and culture, the adaptive development of society to nature has also greatly affected the distribution and evolution of villages.

It should be noted that in mapping village distribution over different historical periods, this study only provides a relative indication of location, as the boundaries of rivers cannot be accurately defined historically. In terms of the accuracy of village age, there is a lack of written materials for some of the villages due to their long histories, serious damage, time and other factors. Although sites have been verified through field visits, errors may still exist. However, these errors have little overall impact on the spatiotemporal evolution characteristics of traditional villages shown in this paper.

Author contributions

FY and WH introduced the research background and significance and searched the relevant literature. MZ and KD collected and collated relevant data. WH, LJ and HY constructed the pictures and tables. FY and MZ analyzed the temporal and spatial evolution characteristics of traditional villages in the middle and lower reaches of the Yellow River in Henan Province. FY and WH analyzed the influencing factors of the spatial and temporal evolution of traditional villages in the middle and lower reaches of the Yellow River in Henan Province. All authors read and approved the final manuscript.

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Availability of data and materials

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

Declarations

Competing interests

The authors declare that they have no competing interests.

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