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Study on spatial form evolution of traditional villages in Jiuguan under the influence of historic transportation network

Zurui Lin^{1*}, Yuan Liang¹ and Xiaohui Liu¹

Abstract

Traditional villages are China's cultural heritage resources; they carry rich historical and cultural information and have important historical significance and cultural value. Studying their spatial forms can suggest new ideas for the protection of traditional villages. The spatial configuration of traditional villages is shaped by a complex interplay of natural geography, socio-economic factors, transportation infrastructure, and essential facilities. Various developmental scenarios lead to diverse spatial development patterns, each demonstrating unique dynamic characteristics throughout its evolution. This article focuses on the exploration of the spatial morphology of Jiuguan Village, located along the Jingxing Ancient Post Road. By using kernel density analysis, space syntax, spatial form index, and so on, the spatial form of Jiuguan Village was studied from three aspects: public facilities clustering degree, road system, and spatial form index. Through a hierarchical approach involving points, lines, and planes, our study unveils the multifaceted influence of transportation factors on the village's historical development and its dynamic adaptive attributes within the context of traditional village spatial morphology. The results indicated that the location advantage of traffic is the driving force behind land expansion. Secondly, the areas with high traffic accessibility tend to be public spaces in villages. Third, the change in the transportation market will lead to a change in village land use functions. Finally, the renewal of transportation modes will change the spatial scale of the village. This research offers a deeper comprehension of the historical context surrounding traditional villages and provides a scientifically guided framework for heritage preservation and sustainable village development.

Keywords External transportation, Traditional villages, Spatial form, Transformation

Introduction

As of 2023, China has listed 8,156 villages of significant conservation value in the Chinese Traditional Village Directory (<https://www.mohurd.gov.cn/gongkai/zhengce/zhengcefilelib/202303/20230320770845.html>). Traditional villages play a pivotal role as custodians of Chinese cultural heritage, encapsulating the essence of rural cultural heritage amid the backdrop of rural revitalization.

Nevertheless, as the urban–rural divide continues to expand, the disappearance of these traditional villages has emerged as a pressing concern [1]. Consequently, safeguarding and passing down the legacy of traditional villages has taken center stage in contemporary academic discussions [2, 3]. In the preservation and redesign of traditional villages, it is essential to firmly grasp the evolutionary patterns of these villages and explore their spatial characteristics [4, 5]. This is vital for gaining precise insights into the developmental paradigms of these villages. The advancement of transportation has wielded a profound influence on both the economic landscape and the spatial structure of these communities, reshaping the course of their spatial evolution. Investigating the spatial

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configurations across various historical epochs is aimed at deciphering the dynamic interplay between villages and the progression of transportation networks.

Currently, research on the spatial configuration of traditional villages is primarily approached from two perspectives: geography and architecture [4]. Geographical research mainly focuses on the spatial characteristics and influencing factors of traditional villages [6], village hollowing [7], and morphological evolution [8]. Some scholars have used quantitative spatial morphology indices for rural settlements to analyze the spatial morphological evolution of Tunpu villages, offering new insights into the renewal and preservation of such settlements [9]. Other scholars utilized spatial syntax theory to delve into elements such as integration, connectivity, and choice within village streets and lanes, thus uncovering the intricate connections between village thoroughfares, public activity hubs, and historical environmental elements [10]. From an architectural vantage point, research centers on elements such as building orientation [11], building arrangement [12], and the texture of the village [13]. Some scholars described the morphological changes of settlements by calculating the aspect ratio of the bounding rectangles of settlement boundary shapes for different years, building density, courtyard space ratio, fractal dimension index, and shape analysis index, thereby providing a scientific and accurate quantitative description of settlement morphology [14]. This approach offers a scientific and precise quantitative representation of settlement morphology, thus serving as a valuable reference for the preservation, expansion, and strategic planning of rural settlements.

In the contemporary academic landscape, scholarly inquiries into the influence of transportation on the spatial configuration of traditional villages predominantly center around the examination of spatial morphological evolution, spatial morphological characteristics, and spatial structural layouts. This research can be broadly classified into qualitative and quantitative investigations. Some scholars used methodologies such as literature analysis and field investigations to conduct qualitative inquiries into traditional villages situated along historic post roads. Some scholar undertook a research endeavor focused on traditional villages situated along the Jingxing Ancient Post Road. They delved into the historical perspective of the Jin merchants' "Pingding Gang" and its influence [15]. Several scholars have used quantitative analytical techniques, including ArcGIS, SPSS statistical analysis, and spatial syntax, to investigate the correlation between contemporary transportation and the spatial organization of small towns and rural settlements [16, 17].

Although there has been some research on the impact of village morphology on spatial distribution and

structural layout [5, 6], there is relatively limited research on the relevant aspects of settlement spatial morphological evolution from a dynamic transportation perspective. Firstly, in academia, there has been an emphasis on studies constrained to specific time periods or transportation routes, with relatively few detailed examinations of the impact of external transportation changes on the developmental and evolutionary relationships of villages at larger temporal and spatial scales [17]. This fragmented approach has resulted in a discontinuity and a lack of comprehensiveness in our understanding of the historical development of village morphology. Secondly, most scholars primarily rely on methods like field investigations and literature reviews to conduct qualitative research on specific characteristics of settlements. While the results obtained are relatively precise, they do not provide a comprehensive assessment of the evolution of village spatial morphology, which can lead to a lack of objectivity in their arguments.

This study takes Jiuguan Village as the research object. According to the time order, the village development process is divided into 5 periods, and the concentration degree of public facilities, road system, and spatial form index of each period are studied so as to conduct a comprehensive and systematic analysis of the evolution of the spatial form of the village. Next, the second section describes the research area and research methods. The third section describes the research results. The fourth section is a systematic discussion, and the fifth section is a summary.

Materials and methods

Study area: Jiuguan village

Jiuguan Village is located to the east of Yangquan City in Shanxi Province, in the northeastern part of Pingding County. It occupies a central position within the Taihang Mountains, near the border that separates Shanxi and Hebei provinces. This locality falls under the jurisdiction of Niangziguan Town, as indicated in Fig. 1. Renowned for its challenging terrain, the Jiuguan Village has earned its reputation as a strategic pass of great historical significance. It functions as a crucial gateway, facilitating the connection between Shanxi and Hebei provinces, and it has played a pivotal role as a vital transportation route, particularly on the road leading to Beijing.

Consequently, this area has been the subject of historical contention and remains of substantial historical import. Historical records in the "*Pingding State Annals*" and the "*Book of Han*" reveal that the establishment of the Jiuguan Village can be traced back to the Warring States period, spanning over two millennia ago. Jiuguan Village is nestled within a valley that lies between two mountains (Fig. 2). This strategic geographical positioning provides

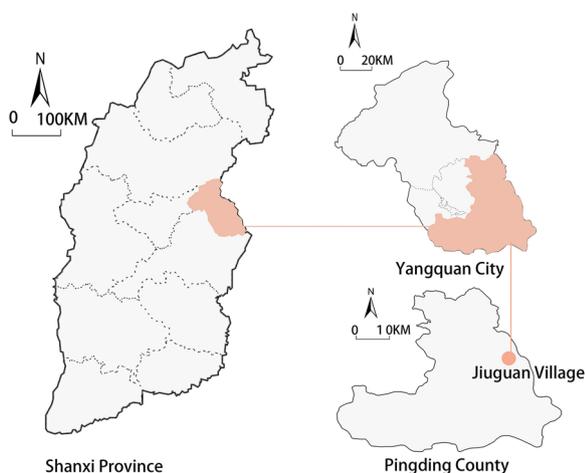


Fig. 1 Geographical location of Jiuguan Village. Source: author

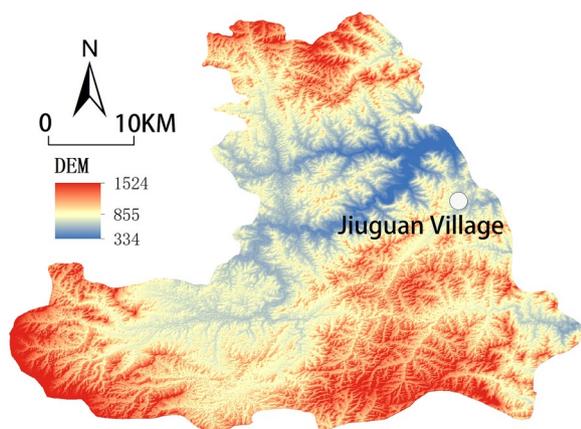


Fig. 2 Elevation analysis map of Pingding County. Source: author

a natural advantage in terms of defensibility, rendering it an exemplary example of the traditional villages along the Jingxing Ancient Post Road. To this day, the village has preserved a significant number of ancient buildings dating back to the Ming and Qing dynasties and has well-preserved its own cultural and spatial morphology. In contemporary times, National Route 307 and Taijiu Expressway were officially opened to traffic, transportation has become extremely convenient. Coupled with the local abundance of mineral resources, the transportation and logistics industry in Jiuguan Village has flourished. In addition, in 2019, Jiuguan Village was designated as a National Traditional Village of China, effectively uncovering its rich historical, cultural, and aesthetic values. Its convenient transportation, connectivity, and the simple and honest nature of its people have attracted numerous archaeologists, university scholars, investors, and domestic and foreign tourists. To address the diverse needs of these stakeholders and enhance the quality of life for its

residents, Jiuguan Village has experienced remarkable growth in its modern transportation infrastructure. The introduction of large-scale mechanized equipment and the construction of transportation hubs are progressing rapidly, offering an opportunity to stimulate economic growth and foster tourism.

Data source and use

The research area is situated within the Taihang Mountains region of China, and the field survey for this study took place in July 2023. The on-site visits were carried out to ensure the data’s comprehensiveness and accuracy. The required data for this study were sourced from websites, literature, historical records, relevant government agencies such as the government of Niangziguan Town and the village committee of Jiuguan Village, as well as direct observations and mapping during fieldwork. The necessary data for this research includes village administrative boundaries, satellite imagery, digital elevation model data, village locations, characteristics of public service facilities, construction eras, road network structure, and road widths.

The source and descriptions of the spatial data used in this study are shown in Table 1. The satellite image data used in this paper is from Wemap, with an accuracy of 18 and a shooting date of September 21, 2022, which is convenient for adding vector data such as building outlines and POIs in the study area at a later stage. The land use map used in this paper comes from "the Protection and Development Plan of the Traditional Village of Jiuguan Village," provided by the Niangziguan Town government. Village-level administrative boundaries and road data were provided by Niangziguan Town, Pingding County. The number of public service facilities produced in different historical periods comes from the traditional Chinese village archives and field research provided by the village committee of Jiuguan Village. The digital elevation model data comes from the geospatial data cloud (<http://www.gscloud.cn/>) (accessed on November 10, 2019). In addition, the results of the field survey visit and shooting in July 2023 supplemented and corrected the data to ensure the consistency and validity of the data.

Research method

The method of map data analysis

We acquired satellite imagery of the villages utilizing WeMap and combined this with data obtained through field research. Subsequently, CAD software was employed to process the satellite imagery, enabling the creation of detailed representations of the villages. This process included delineating village boundaries, road network systems, and building profiles. The data generated in CAD was then imported into ArcGIS, where additional

Table 1 Data source and uses

Data	Data source	Data use
Satellite Imagery	WeMap	Facilitates the addition of vector data such as building outlines and the location of public facilities within the research area
Land- use map	Jiuguan Village Traditional Village Protection and Development Plan	Defining the boundaries of the research area
Digital Elevation Model	Geospatial data cloud http://www.gscloud.cn/ (accessed on 10 November 2019)	Determining the spatial relationships of the villages
POI Data	WeMap and interview results	Facilitates the analysis of public facility aggregation

attributes, such as the number of stories, construction era, and function, were assigned to individual buildings. This comprehensive dataset facilitated a thorough analysis of village structures, encompassing visual assessments of building density and the timelines of construction. These analyses were conducted with the primary aim of ascertaining the direction and patterns of village expansion.

Kernel density analysis

Kernel density analysis is a technique that employs individual feature points distributed across a spatial region as reference centers [18]. By utilizing a designated radius, this technique defines a specific range and employs a kernel function to generate a spatial density surface. Kernel density analysis serves as a valuable tool for offering an intuitive depiction of the density and clustering of point features within a given space, particularly with regard to the spatial distribution of public service facilities. The calculation formula for kernel density analysis is as follows:

$$D(x_i, y_i) = \frac{1}{ur} \sum_{i=1}^u k\left(\frac{d}{r}\right) \tag{1}$$

In the equation, $D(x_i, y_i)$ is the kernel density of points; r is the threshold for distance decay; u is the number of features where the distance between them and the current point is less than or equal to (x_i, y_i) ; k is the spatial weighting function; and d is the Euclidean distance between the current point and (x_i, y_i) .

Spatial syntax

In the 1970s, British scholar Bill Hillier introduced spatial syntax, which is essentially a quantitative spatial analysis method for studying spatial configuration relationships. Spatial syntax simplifies complex urban spaces and buildings into new linguistic patterns for description. Buildings or other spatial elements are treated as points, and the paths connecting these elements are seen as lines [19]. Quantitative analysis of the topological relationships formed by these points and lines is used to express

the internal characteristics of space. This study primarily uses "integration" and "choice" as syntax variables.

Integration: Integration typically refers to the degree of aggregation or dispersion in a specific area and is one of the most commonly used and important variables in spatial syntax. It represents the convenience of transportation and strong accessibility within a certain area, making it easier for pedestrian flows to aggregate, which results in greater centrality. Its formula is as follows:

$$I_{nt} = \frac{2(D_a - 1)}{a - 2} \tag{2}$$

In the equation, I_{nt} represents integration, a is the total number of axial lines or nodes, and D_a is the average depth value.

Choice: Choice represents the frequency with which the shortest topological distance between two nodes passes through a particular area in space. It examines the advantage of a spatial unit as the shortest travel path and reflects the likelihood of space being traversed. Locations with higher choice values can attract more pedestrian or vehicular traffic and have a greater likelihood of being traversed by such traffic [20].

Spatial morphology index method

Drawing inspiration from the fractal dimension index in landscape ecology and based on Pu Xincheng's "Quantitative Study of Traditional Rural Settlements' Planar Morphology", and considering the specific circumstances of Jiuguan Village, the study involved processing historical satellite imagery (Source from Wemap, a shooting date of September 21, 2022) to create overall outlines of the settlement's buildings and its boundaries [21]. Based on the longitudinal calculation of the change of time axis, the dynamic changes of settlement scale and settlement form are quantified so as to analyze the development process and the dynamic change trend of village settlement form.

Length-to-width ratio (λ): the ratio of the long axis to the short axis of the minimum bounding rectangle or arc

Table 2 Correspondence between λ values and village morphology

λ values	Settlements category
$\lambda < 1.5$	Cluster settlements
$1.5 < \lambda < 2$	Indicates a compact village morphology with a tendency towards elongation
$\lambda > 2$	Indicates an elongated village morphology

Table 3 Classification of village forms based on λ value and weighted shape index S

S values	λ values	Settlements category
$S \geq 2$	$\lambda < 1.5$	Finger-like settlements with cluster tendency
	$1.5 \leq \lambda < 2$	Finger-like settlements without obvious tendency
	$\lambda \geq 2$	Finger-like settlements with band tendency
$S < 2$	$\lambda < 1.5$	Cluster settlements
	$1.5 \leq \lambda < 2$	Cluster settlements with band tendency
	$\lambda \geq 2$	Band settlements

of the village boundary, reflecting the elongation of the boundary shape of the village. Different ranges of λ values correspond to different village morphologies, as shown in Table 2 [4, 22]. Shape Analysis Index (S): A quantified landscape index is used in landscape ecology, usually using a specific mathematical transformation of the ratio of the side length to the area of a graphic patch. Based on Pu's method [22], a shape index $S=2$ is set as the critical value for a weighted analysis of the aspect ratio and shape index, as shown in Table 3. S reflects the complexity of the village's boundaries [11]. The formula for the shape analysis index S is as follows:

$$S = \frac{P}{(1.5\lambda - \sqrt{\lambda} + 1.5)} \sqrt{\frac{\lambda}{A\pi}}, \tag{3}$$

In the formula, S refers to the shape index of the settlement boundary, P is the perimeter of the settlement boundary, A is the area of the settlement, and λ is the aspect ratio of the minimum outer rectangle of the boundary.

Results and analysis

Morphological multinetwork construction of villages under changes in external transportation

Analysis of public facility aggregation

Before 1949, the data on public service facilities in Jiuguan Village primarily came from the "Traditional Village Archives of Jiuguan Village," provided by the village committee of Jiuguan Village, and oral accounts from villagers. The data on newly added public service facilities

after 1949 mainly comes from satellite imagery and on-site surveys. First, satellite imagery of Jiuguan Village was obtained using WeMap. CAD software was used to draw the current village road and building conditions. Combining the results of on-site surveys and POI data obtained from WeMap (Fig. 3), public service facilities in Jiuguan Ancient Village were categorized into five periods: pre-Ming and Qing dynasties (before 1368), Ming and Qing dynasties (1368–1912), the Republican era (1912–1949), post-1949 until the year 2000, and from 2000 to the present. From a functional perspective, these facilities were divided into six categories: defense facilities, commercial facilities, ritual facilities, cultural facilities, transportation service facilities, and life service facilities. By overlaying time and public facility categories (Table 4), a detailed analysis of the evolution of village public facilities was conducted. Finally, using ArcGIS spatial analysis tools, a public facility kernel density analysis was performed to generate density images.

Before 1368, Jiuguan Village was still in a developmental stage. During the Qin Dynasty (221–207 BC), China constructed an extensive network of roads radiating from Xianyang to various parts of the country. Jiuguan Village was situated on the Qinhuang Post Road, one of the "Eight Passes of Taihang," and served as a critical military and administrative route for the exchange of military information, government documents, imperial edicts, and the passage of officials between the provinces of Shanxi and Hebei. Influenced by continuous warfare, the ancestors of Jiuguan Village, out of safety considerations, chose locations near the mountains as a shield. Generations of soldiers and their families resided near the passes. Therefore, before the Ming dynasty, the public facilities in Jiuguan Village primarily served military and political purposes. They were scattered along the ancient post road near the mountain passes and included inspection division¹ and garrisons.² Additionally, relay stations and beacon towers (Fig. 4a) were established to provide resting places and supplies for officials traveling to and from the area. This village, where both military and farming activities coexisted, possessed strong defensive capabilities.

Between 1368 and 1912, national stability and the "Kai Zhong Zhi" policy promoted the prosperity and development of Jin merchants. As a result, the political and military functions of the village gradually weakened, while its economic functions strengthened. The public spaces in the village began to shift from serving military

¹ Inspection division: an administrative institution responsible for maintaining law and order at local passes, first appearing during the Yuan Dynasty but now unfamiliar to modern people.

² Garrisons: soldiers who patrolled and delivered official documents.

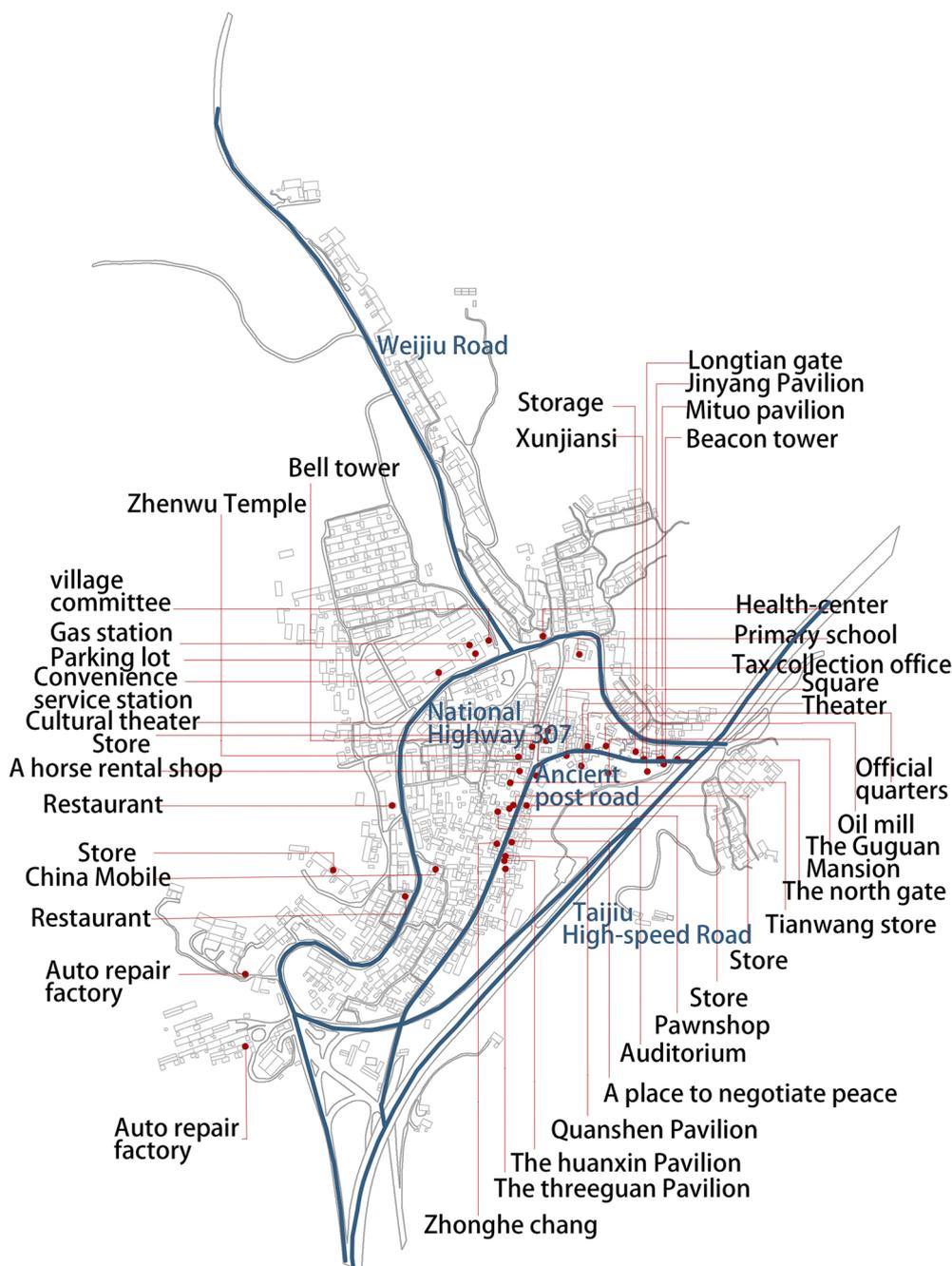


Fig. 3 POI points. Source: author

purposes to meeting the demands of commerce. Along the post road, numerous shops lined the streets, creating commercial zones where people congregated. These areas primarily served as places for Jin merchant travelers to eat and stay overnight, including locations like West Store, East Store, Tianyu Store, and West Tower, as well as official residences and ancient theaters (Fig. 4b). The growth of the commercial economy along the Qinhuang

Post Road led to the development of public spaces within the village, making it highly open to external trade.

Between 1912 and 1949, China experienced significant social upheaval and transitions. The whole of China was in a state of chaos among warlords and invasion by foreign enemies. Jiuguan Village was affected by the chaos of warlord conflicts and the occupation by Japanese forces. Consequently, the post road once again played a

Table 4 Summary of POI data statistics

Period	Public facilities	Increased quantity	Function type	Location	Data source
Before 1368	Beacon tower; Inspection division, etc	5	Defensive Facilities; Religious Facilities	The ancient post road	The traditional Chinese village archives and villagers oral
1368–1912	Pawnshop; Jinyang Pavilion; Oil mill, etc	18	Commercial facility; Cultural facilities	The ancient post road	The traditional Chinese village archives and villagers oral
1912–1949	Primary school of the Republic of China; Temple; Auditorium, etc	4	Defensive Facilities; Religious Facilities; Commercial facilities	The ancient post road	The traditional Chinese village archives and villagers oral
1949–2000	Catering; Shop; School; Health center; Village committee; Theater, etc	4	Living service facilities; Commercial facilities; Cultural facilities	Modern transportation	Interview and investigation
After 2000	Communication service; Gas station; Auto repair shop, etc	9	Transportation service facilities; Living service facilities; Commercial facilities	Modern transportation	Wemap and field research

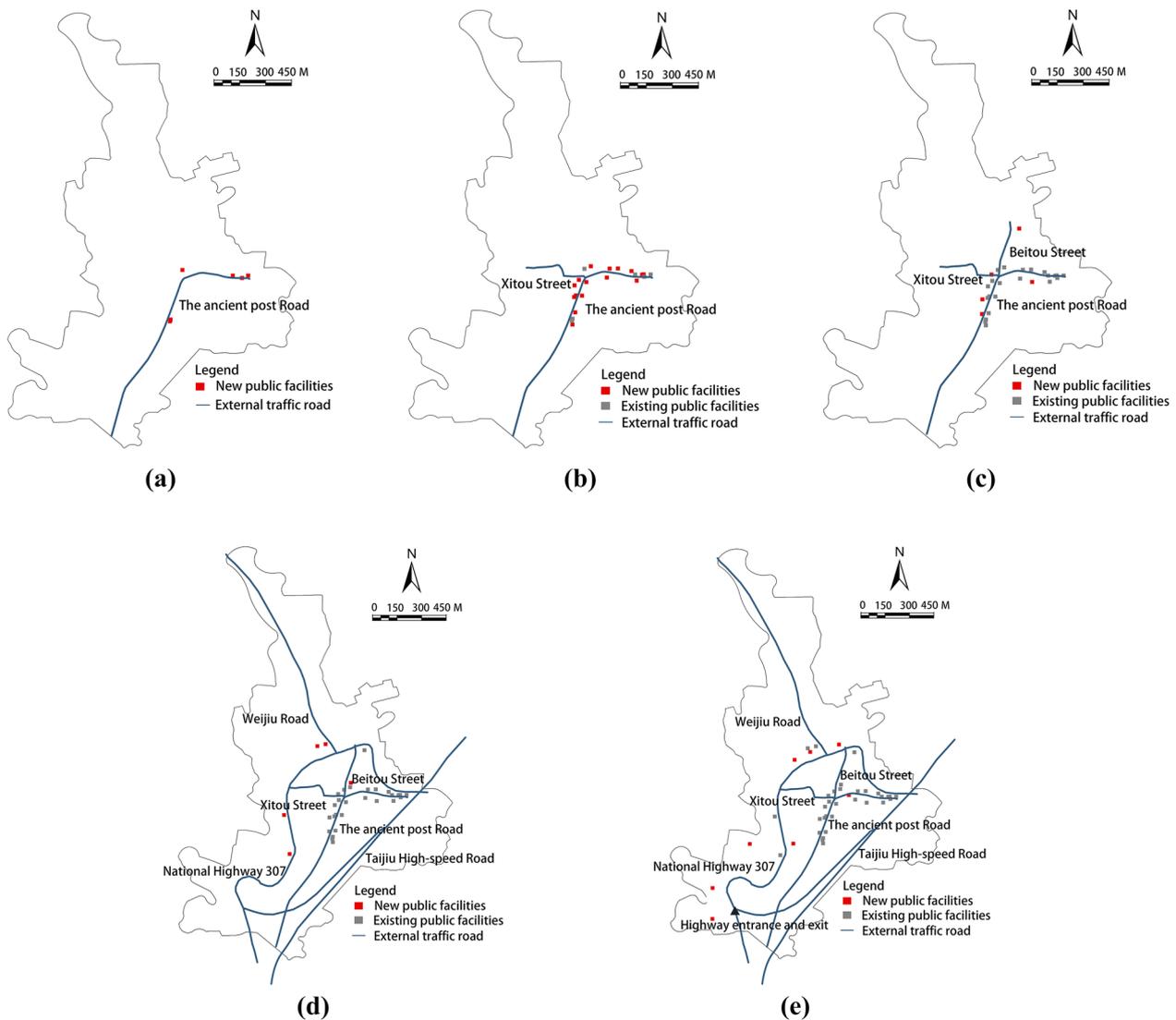


Fig. 4 . The relationship between the distribution of public facilities and external traffic in different periods. **a** Before 1368; **b** 1368-1912; **c** 1912-1949; **d** 1949-2000; **e** After 2000. Source: author

military role as a marching route. With the decline of Jin merchants and the traditional functions of the ancient road, the previous commercial functions began to wane, although some remnants remained. Thus, during this period, the village served mixed functions in defense and commerce. During Xishan Yan's governance of Shanxi Province (1912–1949), the region implemented a "village-based political model".³ This model played a significant role in maintaining relative prosperity and peace in the region. Despite the impact of various wars along the ancient postal routes in Jiuguan Village, the villagers, driven by a desire to improve their living conditions, continued to develop the village. During this period, cultural facilities were constructed within the village, including a meeting hall and a school from the early years of the Republic of China (Fig. 4c).

Between 1949 and 2000, as military and commercial functions along the ancient postal routes gradually disappeared, the village's traditional layout centered around these routes weakened. Due to the convenience of transportation, new development areas in Jiuguan Village were extended along the transport routes. To expand their sources of income, the villagers developed a "roadside economy" by establishing businesses such as restaurants, convenience stores, gas stations, and automobile repair shops (Fig. 4d). As a result, the ancient postal route's commercial street lost its former prominence, and most of the regular markets and small businesses relocated to both sides of the 307 National Road.

After 2000, in response to the national initiatives for beautiful rural areas and the preservation of traditional villages, the village's infrastructure improved further. The village witnessed the development of more life service facilities and cultural amenities, including China Mobile, the Jiuguan Convenience Service Station, and a cultural square (Fig. 4e). As a result, the villagers' quality of life gradually improved, leading to higher satisfaction levels.

As shown in Fig. 5, the density of public service facilities in Jiuguan Village is relatively small, ranging from 0 to 0.002. The spatial distribution follows a pattern of "one core, one zone, and multiple nodes." Specifically, the "core" is primarily situated at the intersection of Weijiu Road and National Highway 307. After 1949, with the development of external transportation in Jiuguan

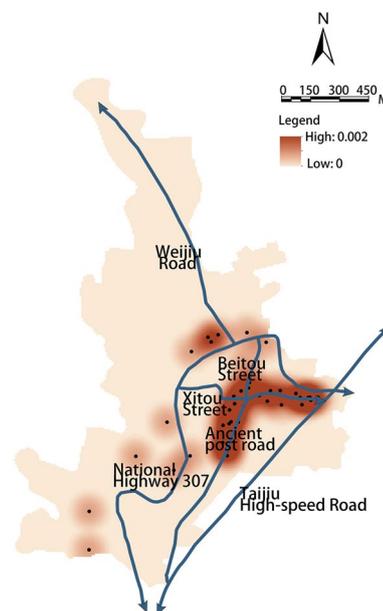


Fig. 5 Nuclear density analysis of public service facilities. Source: author

Village, the transformation of the village's socioeconomic structure was triggered. The social structure, previously based on blood ties and geographical proximity, was reorganized. The "zone" refers to the spiritual belief space formed by the gradual expansion to the west and north along the ancient post road as the skeleton. "Multiple nodes" refers to the public service spaces such as gas stations, auto repair departments, parking lots, and Jiuguan convenience service stations formed along National Highway 307 as a skeleton scattered to serve the needs of traffic development. In summary, the primary public spaces in Jiuguan Village shifted from the "religious and belief-related spaces" along the postal route towards the "comprehensive service spaces" along the National Highway 307. These spaces have grown in size, increased in comprehensiveness, and expanded their range of services. However, no matter which development period the village is in or how the scale and attributes of public space change, the main public space is located near the external traffic, such as the Quanshen Pavilion and village committee. The reason is that in order to equalize public services, public space needs to have good accessibility, and the higher the level, the higher the requirement for accessibility.

Road analysis

According to the existing data, the history of the change in external transportation in Jiuguan Village is summarized. Before 1949, the ancient post road, as the main external traffic of the old pass, assumed different

³ Village-based Political Model: This model included the establishment of "compiled villages," with each compiled village managing a hundred households, led by a village head and vice head with a village public office. Additional village-level organizations included dispute settlement meetings, supervisory meetings, and village citizen assemblies, as well as the formation of defense squads comprised of eligible men. A village code of conduct, known as the "village constitution" in Yan Xishan's terms, was established to govern village politics. Shanxi Province has established over 40,000 compiled villages.

Table 5 Schematic diagram of external traffic expansion after 1949

Year	1956	1973	1996
Type of external transportation	Access-type	Penetrating-type	Circumferential-type
Road pattern			

functions in different historical periods. Before 1368, it played a crucial role in defense and military functions. Between 1368 and 1912, it transformed into a commercial route, emphasizing trade and economic activities. Between 1912 and 1949, the military role was re-played, and the function of combining military and commerce was formed. After 1949, Shanxi’s transportation infrastructure development started in a relatively backward and closed state and gradually transitioned towards open and modern road networks. This marked a new phase in the modernization of Shanxi’s road infrastructure. As shown in Table 3, the main external transportation phases for Jiuguan Village after 1949 can be divided into three stages: 1) In 1956, WeiJiu Road from Jiuguan Village to Niangziguan Town was completed and opened to traffic, which integrated Jiuguan Village into the modern transportation network of Shanxi Province and strengthened the connection between Jiuguan Village and the surrounding villages and towns. 2) In 1973, National Highway 307 in Pingding County was completed and opened to traffic. During the 1970s and 1980s, due to the increased transportation of coal, minerals, and other goods in Shanxi, traffic congestion became a severe issue. The construction of the National Road provided favorable conditions for resource transportation in Jiuguan Village and opened up a vast market for its transportation and logistics industry. In the 1990s, Shanxi initiated the construction of expressways, and in 1996, the Taijiu Expressway, the first expressway in Shanxi, was opened. It extended from the provincial capital, Taiyuan, to Jiuguan at the provincial border. The construction of the Taijiu Expressway contributed significantly to the economic development of Jiuguan Village, serving not only as its primary external transportation route but also as a vital transportation artery in the Yangquan area, particularly for the transport of coal from the Jinzhong area (Table 5).

In the morphological theory of Conzenian, the street system serves as the most stable form, providing the backbone and support for organizing the entire spatial growth of a village. It not only carries out the transportation function but also effectively reflects the relationship between the spatial form, production, livelihood, and cultural heritage of the village. The author employed spatial syntax theory to construct a model of the village road network. Initially, satellite images of Jiuguan Village were obtained through WeMap, and current road networks were drawn using CAD software. To enhance the tolerance of the axis model, an extended section of the road network was processed, resulting in the axis model of Jiuguan Village. This model served as the foundational data for research using Depthmap software.

In spatial syntax analysis, integration refers to the average distance from one axis to other axes, reflecting the degree of local spatial aggregation or dispersion with respect to other spaces. Higher integration indicates stronger accessibility, higher centrality, and increased spatial vitality. Warmer colors in the axis lines represent higher integration, which implies greater accessibility and centrality. In Fig. 6, there are two segments of high integration in Jiuguan Village, which include the village’s major transportation arteries: the National Highway 307 and the Qinhuang Post Road. These roads are essential transportation routes for the village. Before 1949, most villagers settled on both sides of the post road, and with the continuous development of The Times, the roads in the village expanded outward with the post road as the framework. After 1949, with the ongoing improvement of modern transportation, the road network within the village continued to expand along both sides of National Highway 307. Although the Taijiu expressway is modern traffic, its closure inhibits the village’s eastward development and eventually forms a fishbone-shaped road system. Whether it’s the Qinhuang Post Road or the

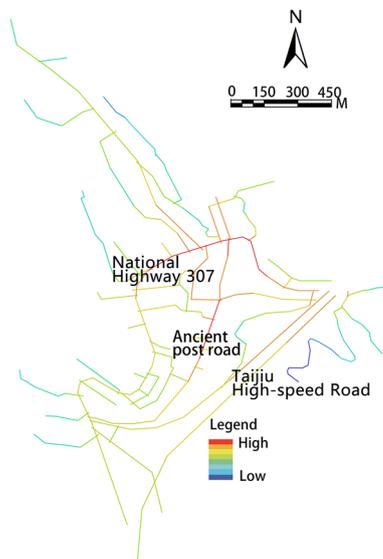


Fig. 6 Integration analysis of Jiuguan Village. Source: author

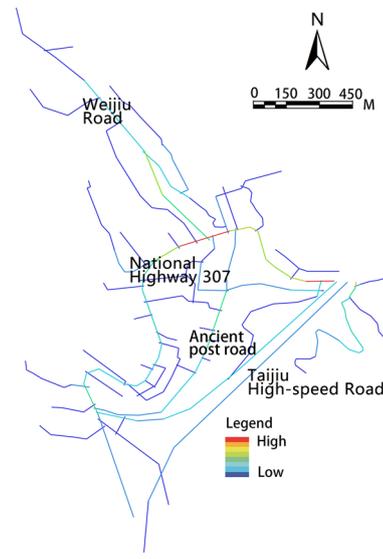


Fig. 7 Choice analysis of Jiuguan Village. Source: author

National Road, these routes are not only essential for entering and leaving the ancient village but also serve as primary transportation links connecting the surrounding villages and towns.

Spatial selectivity reflects an indicator of spatial permeability within a certain range, typically indicating the likelihood of being traversed. A higher value indicates better location and transportation conditions, making the area more attractive to pedestrian flow and thus facilitating the congregation of people [23]. From Fig. 7, it is evident that the overall spatial selectivity in Jiuguan Village is relatively low. The fact that the 307 National Road exhibits the highest selectivity underscores that it has become the most frequently used road by the villagers. In turn, this emphasizes the influence of modern transportation changes on the daily lives of the villagers. Combined with the above analysis of public facilities, it once again confirms the demonstration that external traffic has certain guidance for village development.

Spatial form analysis

In this paper, an analysis of floor area ratio and village boundary morphology for the various historical periods of Jiuguan Village was conducted. Based on the temporal development sequence, the dynamic and diachronic changes in settlement morphology are analyzed quantitatively. The author imported the building outline with attributes drawn by CAD and village roads into Arc GIS software to draw the distribution of buildings in Jiuguan Village and calculated the density and floor area ratio of village buildings by using the digital analysis technology of GIS software. Thus, the evolution of the external shape

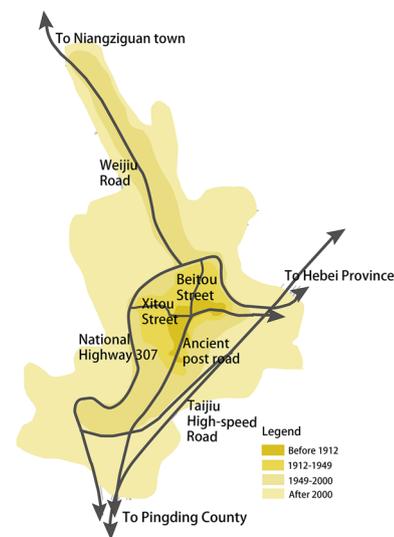


Fig. 8 Village expansion situations. Source: author

profile and floor area ratio distribution of Jiuguan Village under the influence of external traffic changes is obtained (Figs. 8, 9).

A single characteristic value cannot accurately define the morphology of a village; only a simple change rule can be obtained. Therefore, in addition to calculating the distribution of the floor area ratio, this paper combines common landscape analysis indices such as length-to-width ratio and shape analysis index to accurately determine the morphological characteristics of the village.

Due to the lack of ancient maps, this study relied on field visits and information provided by villagers to

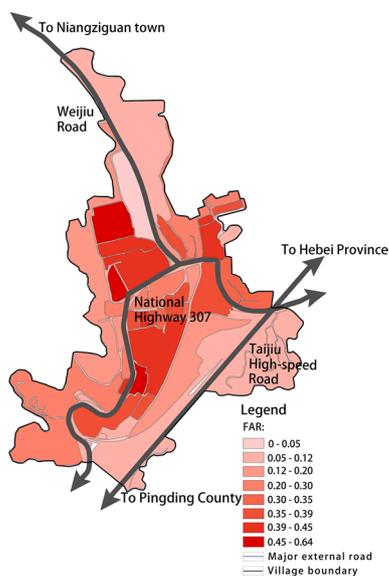


Fig. 9 Analysis of floor area ratio. Source: author

estimate the historical locations and outlines of the buildings from different historical periods. First, the historical image maps were vectorized using CAD software, creating a precise dataset for the study. Starting from the corner vertices of the individual buildings at the outer edge of the settlement, non-crossing lines were drawn sequentially along each base point to form closed shapes. The minimum bounding geometry tool in ArcGIS spatial analysis software was then used to obtain the minimum bounding rectangle, which allowed for the calculation of the λ data. This λ data was then used in the formula for calculating the settlement boundary shape index S .

From Fig. 10 and Table 6, comparing the overall boundary shape and scale, it can be observed that S is on an upward trend throughout the study period, indicating an increasing complexity in the settlement's shape. It can be observed that S is on an upward trend throughout the study period, indicating an increasing complexity in the settlement's shape. Before 1949, the area around Jiuguan

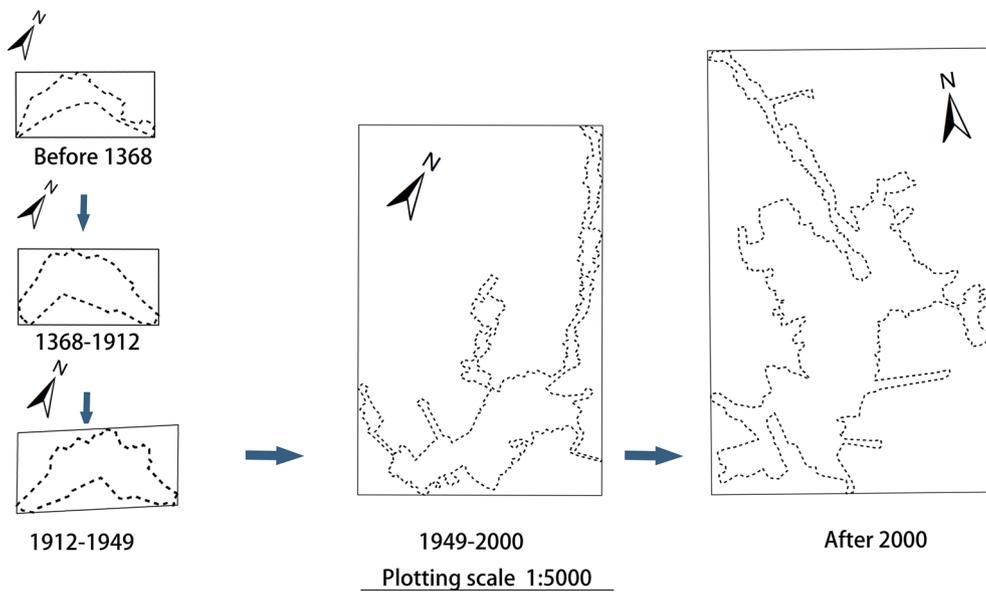


Fig. 10 Evolution of Boundary Morphology of Jiuguan Village. Source: author

Table 6 Spatial quantification data of Jiuguan Village

Period	Settlement scale(ha)	λ values	S values	Settlements category	Reason
Before 1368	0.627	2.104	0.5936	Band settlements	Military
1368 -1912	1.327	1.839	1.377	Cluster settlements with band tendency	Commerce
1912–1949	1.429	1.177	1.685	Cluster settlements	Military
1949–2000	7.983	1.531	4.972	Finger-like settlements without obvious tendency	Transport
After 2000	18.7331	1.560	4.314	Finger-like settlements without obvious tendency	Transport

Village was characterized by mountainous terrain and gullies. Influenced by the Ancient Post Road, the village primarily served military functions, with residents scattered in the vicinity of the post road. The original settlement had a relatively small volume, and the buildings were naturally and randomly distributed in a strip along the ancient post road. In 1368–1912, influenced by commerce and trade, the village expanded westward, and the village's morphology extended to the north and south of the original strip, forming a morphology with a tendency towards a compact village. In 1919–1949, the Japanese expanded the roads to the north and built Beitou Street. The villagers arranged residences along both sides of Beitou Street, and the village's morphology took on a compact form. Since 1949, with the construction of the road through the village, the settlement scale of Jiuguan Village has been continuously expanded, and the external communication system of the village has been continuously improved. The economic value of the land along the line has become prominent, shifting from land fertility to land rent gradients based on transportation location. External transportation became a key factor in the contemporary evolution of Jiuguan Village. Under the influence of the road network, the village expanded in multiple directions, forming a planar morphology that extended in a radial pattern along the transportation lines.

Stage characteristics of village spatial morphological evolution under the influence of external transportation changes

From the summary above, it is evident that before 1368, the Qinhuang Post Road had a significant military and defensive role and functioned as a route for war-related migration. Along this route, a military defense system was established, which led to the development of villages primarily focused on military service. The village's buildings exhibited a dispersed and nucleated "inverted L" pattern along the Post Road on the flat terrain, indicating the military and closed nature of the village's development. During 1368–1912, a period of peace and prosperity, the village transitioned from a military-oriented structure to a commercial one. The village expanded westward along "Koupo Street" to form "Xitou Street", and the whole village developed into a linear cluster pattern of "J". The Post Road was bustling with the continuous movement of merchant caravans. Villagers, particularly traders, constructed buildings and courtyards on a large scale to meet commercial needs. Courtyards within the village were developed to have a "shop in the front and residence in the back" layout. Therefore, the scale of the village continues to expand, and the development of the village is characterized by trade and openness. From 1912 to 1949,

the village was affected by internal and external wars, the decline of commerce and trade, and the innovation of transportation technology. At that time, the village was mainly extended outward by Post Road, and the folk houses were in the form of planar cluster housing, showing the characteristics of inclusiveness and curvature. Since 1949, with the diminishing military, commercial, and historical functions of the Qinhuang Post Road and the resulting decline in historical significance, the influence of the ancient road on the village's spatial form has been reduced. During this period, the impact of the route on the village's development waned, and newly constructed areas in the village were situated closer to modern transportation networks. The overall layout of the village exhibited an open and expansive character, resulting in significant changes in the village's spatial structure. Figure 11 reflects the change process of village construction space according to the passage of time.

Discussion

Traditional culture is the spiritual connotation of traditional village form [24]. Influenced by Confucianism and ritualistic thought, villages maintain a reverence for nature in their construction practices, such as the location and orientation of houses. This aspect is also true for Jiuguan Village. In a new development stage, the village spatial system needs to integrate different spatial elements, so as to be reorganized [25]. Currently, research on the spatial form of traditional villages often focuses on specific factors or uses a single method to study morphological evolution [26]. However, they overlook the formation mechanism behind the spatial change of villages [19]. There are also studies on the impact of land use on village landscape patterns. Yet, guiding village planning and design from a macro perspective remains a challenge. This paper expands the dimensions of research on the spatial evolution of traditional villages by using a combination of qualitative and quantitative methods. It analyzes the morphological evolution of traditional villages comprehensively and systematically, focusing on three aspects: public facilities, road systems, and spatial forms, at three different scales of analysis: point, line, and plane. It uncovers the underlying patterns behind the spatial morphological changes, providing valuable insights into the spatial evolution of small-scale settlements [21]. Moreover, the research can provide scientific and practical guidance for the protection and planning of traditional villages. We analyzed the spatial form of village from three perspectives: public facilities, streets and layout patterns. There are indeed various other perspectives to explore when researching the spatial morphology of traditional villages [27, 28], such as architectural styles, colors, landscape patterns, and more. Additionally, we

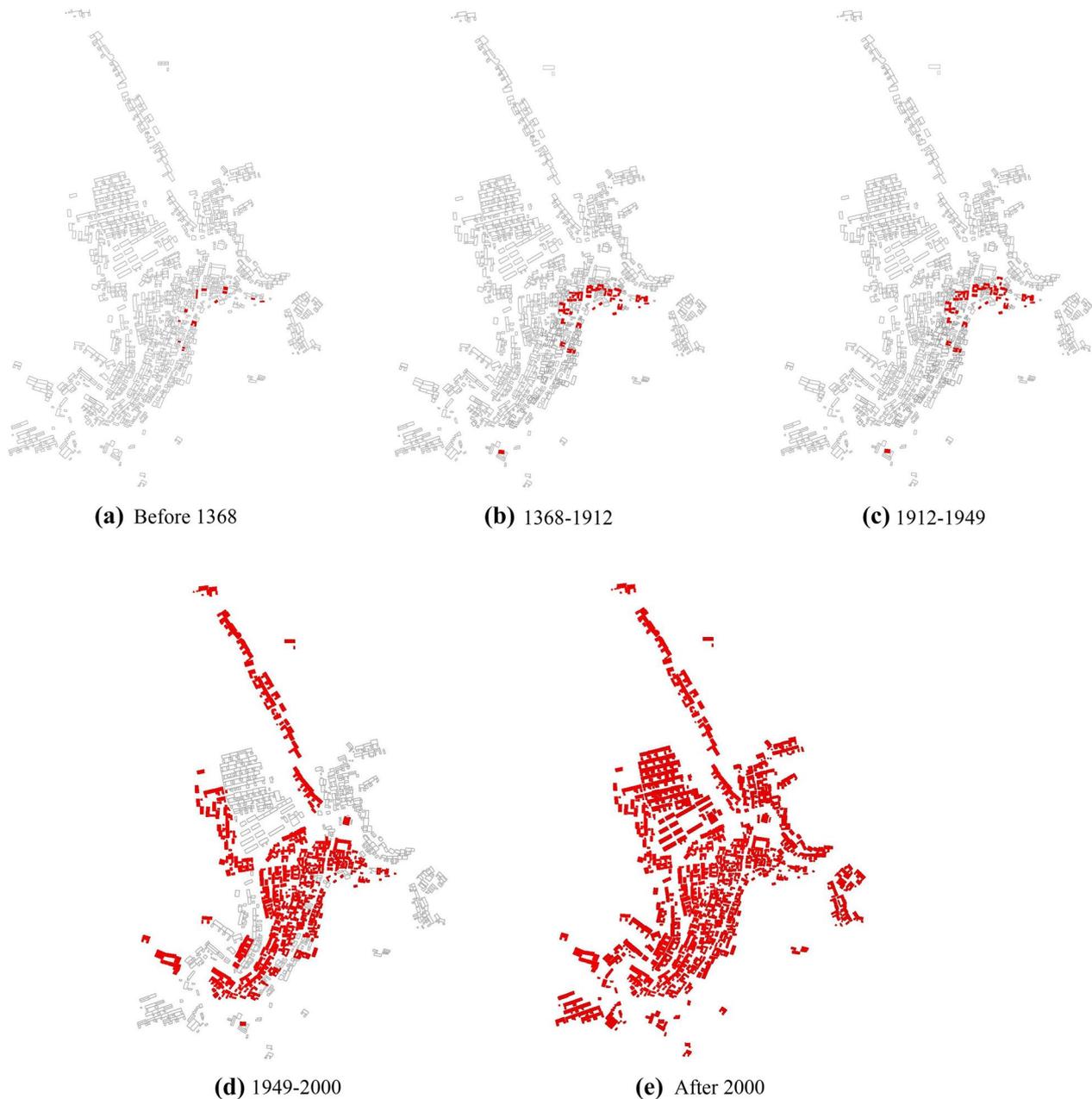


Fig. 11 Village construction expansion form. Source: Author

only chose one village as our research subject, and we did not compare different village morphologies in terms of geographical, economic, or cultural aspects [29]. Therefore, this study has its limitations. In future research, we plan to include a wider variety of village types and increase the number of villages to provide a more comprehensive analysis.

Transportation plays a crucial role in shaping the spatial form and internal structure of settlements, and the

improvement of transportation conditions can enhance regional accessibility, thereby positively impacting land and housing values [30–33]. However, it may simultaneously disrupt the spatial layout and the overall appearance of traditional villages. In the planning and design of traditional village preservation, it is essential to consider the impact of modern transportation on traditional villages to avoid compromising their traditional street and lane patterns. Most scholars, both domestically and

internationally, have focused on historical ancient roads, using a static perspective to analyze the spatial forms of surrounding traditional villages. However, under the influence of transportation changes, the evolution of spatial forms in traditional villages exhibits certain patterns and dynamic characteristics, which have been insufficiently explored in existing research. This paper, therefore, examines the spatial evolution characteristics of Jiuguan Village, contributing theoretical significance to the preservation of traditional Shanxi merchant styles, the realization of rural revitalization strategies, and achieving sustainable development. However, we have not put forward specific protection strategies. In the follow-up research, we will increase the strategic research on village protection and development, which has realized the practical significance of this research.

Conclusion

Taking Jiuguan Ancient Village as an example, this paper takes a long-term, dynamic, and developmental perspective to clarify the history of changes in external transportation. It uses methods such as kernel density analysis, spatial syntax analysis, and spatial morphology indices. The study examines the historical trajectory and morphological characteristics of the village's spatial form, from ancient times to the present, by focusing on three aspects: the aggregation of public facilities, the road system, and spatial morphology indicators. The following conclusions are drawn:

- (1) The transportation and location conditions serve as the fundamental driving force for the outward expansion of land [34]. To accommodate the development of an export-oriented economy, the village's construction has gradually extended from being along the ancient road to spreading along the directions of external transportation, exhibiting a clear orientation towards external transportation.
- (2) Accessibility is the guiding force for the aggregation of public facilities in Jiuguan Village. The gathering place of public facilities is usually the activity space for villagers' daily communication [35]. Compared with other plots, the plots along the traffic line have the highest accessibility and publicity, have a large human flow, and are the most frequent areas for village activities, thus playing a significant role as public spaces.
- (3) Transportation market demand is the external driving force for the diversification of land use functions in Jiuguan Village. Under the influence of military defense and trade, the ancient Qinhuang Post Road played a crucial role. In modern society, Jiuguan Village experienced rapid growth in the secondary

sector due to its abundant mineral resources, leading to the development of the transportation and logistics industry. This led to the emergence of various commercial and service land uses, resulting in the continuous enrichment of land use functions in the village.

- (4) The innovation of transportation modes is an important driving force of spatial scale change in Jiuguan Village. The upgrading of road infrastructure and the improvement in accessibility accompanying transportation innovations have played a crucial role in driving the changes in spatial scale in Jiuguan Village [36]. Spatial scale is an important indicator for evaluating land parcel forms.

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Author contributions

Conceptualization, ZL and XH; methodology, YL and ZL; software, YL; writing—original draft preparation, YL; writing—review and editing, ZL and XH. All authors have read and agreed to the published version of the manuscript.

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Data availability

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request. The data analysis in this study can be obtained from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

All participants provided written informed consent before taking part in the study. They were informed about the purpose, procedures, risks, and benefits of the research.

Consent for publication

Written informed consent for publication of the participants' data was obtained from all participants.

Competing interests

The authors declare no competing interests.

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