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# Quality Analysis on Spatial Planning Pattern of Rural Area in Southern Shaanxi, China

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**Abstract:** There have been many studies that have only focused on factors affecting the spatial distribution of rural settlements, without paying attention to their function and scale. China's mountainous rural area has many problems, such as a fragile ecological environment, poor infrastructure and limited public service facilities. As a result, mountainous rural settlements demonstrate a disorderly and scattered layout. This research takes southern Shaanxi as its research area and uses quantitative and qualitative analysis to analyze the field survey data, revealing the spatial format of rural settlements and its influencing factors. The research results show that: (1) The spatial structure of mountainous settlements can be summarized as falling into three types—agglomeration type, belt type, and dispersion type. The individual settlements are discrete, and the spatial structure of the settlement groups exhibits small-scale clustering in a large area. (2) The influencing factors of spatial structure are ranked thus—geomorphological conditions > population quantity > land use scale. (3) The number of settlements in the study area is constantly decreasing, and their boundaries are gradually shrinking, showing randomly distributed characteristics. (4) A radius of 284.12 m can be used as a measure of the development scope of the village to control the scope of settlement construction. The objective of the research is to classify the spatial structure and propose the most optimal spatial mode in mountainous rural areas.

**Keywords:** southern Shaanxi; rural settlement; spatial development; GIS



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## 1. Introduction

China is a primarily agricultural country, but its town planning is basically dictated by the needs of the primary industry in that area. However, with the development of urbanization and the improvement of industrialization in China, the manpower needed to maintain comprehensive development has caused the population to rapidly inflow to urban areas from surrounding suburban and township areas. This phenomenon dramatically affects urban–rural duality, resulting in massive problems in rural areas, such as the hollowing out of villages, the polluting of natural environments, weakened agricultural activities, the enclosure and restriction of agricultural land, and so on [1,2]. In order to address this problem, the Chinese government has initiated many strategies, such as the transformation of urban and rural development, the new urbanization, and urban revitalization [3,4]. The effective planning and development of rural areas depend on a detailed analysis of the spatial evolution of rural settlements. The impact of urbanization on agriculture is mainly reflected in the migration of rural populations to cities. A large number of farmers have left agriculture, causing increased abandonment of farmland. As a result, China's grain import rate is gradually rising, making China's long-term food security a problem. From the perspective of economic structural changes, urbanization is a process of gradual transformation from agricultural activities to non-agricultural activities and the updating of industrial structure. In China, urbanization has a major impact on agricultural development. Theoretically, the process of population migration has played a role in promoting and restricting agricultural development. In accordance with the scale of rural development, we will address the problems of limited rural economic development, population reduction and inadequate infrastructure. A reasonable optimization of the spatial structure of villages is the basis of improving the rural living environment in China. Some successful examples show how rural problems have been addressed in developed countries [5]. During the process of exploring ways to address these problems, academics pay more attention to the details of rural education, farmer behavior, agricultural science and technology, food security, and rural structure, and study the broader landscape climate and environment of rural areas [6–8].

Western scholars' early studies on rural settlements focused on their origins and types. Research on the evolution of rural settlements was initiated at the beginning of the 20th century, via qualitative description and statistical analysis of the formation, development, and distribution of rural settlements. The research mainly analyzed the rural spatial structure regarding agricultural geography and rural settlement geography [9]. At the end of the 1990s, analysis of the development of rural settlements revealed the mechanisms of spatial evolution [10]. The main influence mechanism of urbanization is the conversion of rural settlements into urban areas and changes in land use around cities [11,12]. Furthermore, these researchers comprehensively analyzed the rural history and development status of both developing and developed countries. They also introduced the theory of landscape ecology and proposed the concepts of continuous suburban settlement groups and the outer suburban area model. With regard to the spatial structure and distribution characteristics of rural settlements, the researchers focused on the rural settlement system and its internal space, using the central place theory, diffusion theory, and location theory [13]. The concept of rural settlement, always mentioned in the above-referenced studies in terms of planning and activities, refers to the phenomenon, processes, and form of concentrated residence in a certain area by people who are closely related to agricultural production on a certain scale [14]. It is the place of habitation, production, and living for rural people; they are the settlements of rural regional space whose formation and development evolution were affected profoundly by natural conditions, rural society, the economy, culture, and national policy and planning [15–19]. Rural settlements are an important social unit in the city, reflecting the connections between man and the land, historical background, and sociopolitical relationships.

In the process of urban and rural development, the increasing scale of rural settlements in China is driven by necessary construction. Especially in China, due to rapid urbanization, there has been a rapid population migration from rural areas to cities, which has prompted research on the development and functions of rural settlements and motivated the transformation of the industrial structure of rural settlements [20]. Zheng et.al. analyzed the spatial features of the rural settlements from multiple aspects and divided the spatial mode of the areas researched into 4 different developing types [21]. Spatial structure and its optimization provide a research direction for rural sustainable development [22–24]. Wang et al. introduced the concept of "third space" and conflicts of value and proposed a series of countermeasures of regional expression, given the inherent features of rural settlements [25]. Aubrecht et al. introduced the novel URBAN geospatial modeling approach, identifying urban-rural patterns that can connect all the population with the inhabitable areas [26,27]. Li et al. suggested that ecological land in rural settlements is significantly spatially different in China's central plains; elevation is the most important independent factor in controlling ecological land structure. Lu et al. obtained a spatial optimization scheme of rural settlements, based on social dominance theory and central place theory, through spatial cluster analysis. The early research on rural settlement in China mainly focused on location, formation, spatial distribution, evolution, landscape, and the relationship between rural settlement and natural conditions [28,29]. In recent years, the study of rural settlements began to use quantitative comprehensive analysis methods, including remote sensing image technology, GIS spatial analysis, and the landscape pattern index [30,31]. Most of these studies are related to land changes, and seldom use simulation or prediction methods to study rural development trends. Theories and practices of environmental and spatial improvements in rural areas by Chinese scholars are constantly developed and improved. However, there are very few studies that have focused on rural settlements in mountainous areas with a fragile ecological environment. This study shows that an appropriate development model is essential to assess the future development of the village in general.

The spatial structure of rural communities involves optimizing the layout of rural development. This has become an important part of creating a livable and appropriate living space. The classification of rural structure can optimize the spatial structure of rural planning and prompt better practice in general development. Taking Southern Shaanxi as an example, this research proposes a relationship between the influencing factors and components of development, based on an analysis of spatial characteristics such as the spatial distribution, shape, and scale of the inner layers in rural settlements. Through research on and analysis of the rural settlement space in southern Shaanxi, a development strategy is put forward to form a regional sustainable development plan.

## 2. Materials and Methods

### *2.1. Study Area*

Southern Shaanxi, a south zone of Shaanxi Province between the south of Qinling mountain and the north of Daba mountain, has numerous basins and valleys, as shown in Figure 1. This region is located in a climatic zone with hot summers and cold winters. The residents' various lifestyles were adapted to the special climate of this region [32–34]. Those residents were also affected by the area's multi-ethnic culture, which was a melting pot of Qin culture, Ba culture, Chu culture, and Shu culture. Spatial characteristics are the external expression of space development patterns, which are supported by certain cultures and climates in a particular area [35,36]. The southern Shaanxi region covers an area of 69,500 square kilometers and has a population of about 8.87 million, with an altitude averaging below 2087 m. Thus, the diverse and numerous villages in Southern Shaanxi are widely distributed. The abundant village samples in this area provide valuable material for this research into spatial structure.


**Figure 1.** Location map of Southern Shaanxi.

### 2.2. Method

#### 2.2.1. Field Research

Through field investigation, more intuitive data can be obtained, which is of great value for this research on the spatial structure of villages in southern Shaanxi. The research team conducted field investigations in 12 districts and counties in southern Shaanxi, from September 2017 to December 2020. The authors selected 26 national historical and cultural villages as the research objects, as shown in Figure 2. The concept behind these national and historical cities is that of ancient villages, containing much historical information and a rich cultural landscape; they form China's material cultural heritage. The content of the basic research data is created by surveying paper and text descriptions, completed by our predecessors in various relevant fields. We then surveyed and mapped the streets, buildings, and landscapes of the village. Combined with the feedback from our questionnaire and residents' interview records, this article tracks and analyzes the impact of natural and human factors on the spatial structure of the village. This research analogizes and summarizes the settlement layout, street size, courtyard shape, functional space, and other components of traditional villages in southern Shaanxi. It extracts the representative spatial structure components and analyzes the strength of interactions between spatial structure components and influencing factors such as nature, humanity, and society.

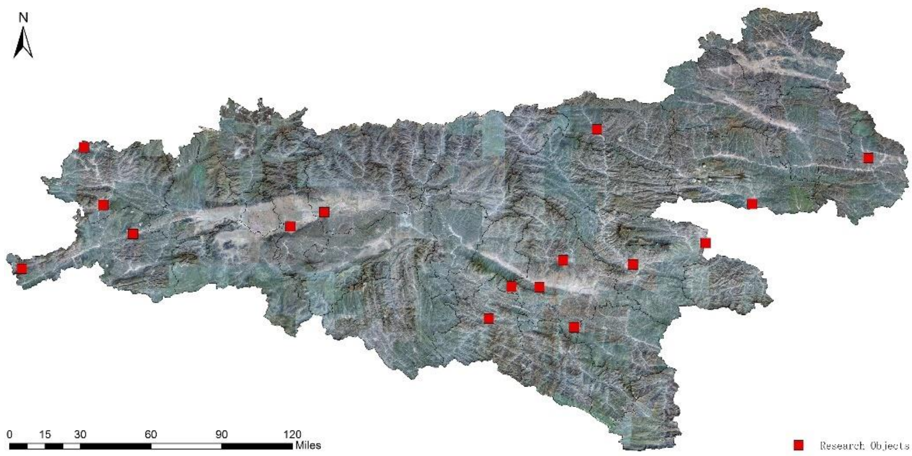



**Figure 2.** Rural settlements, selected via field research.

#### 2.2.2. AHP

There are many elements to the village's spatial structure, and the importance of each element to the spatial structure is different. Each artificial and natural factor has different degrees of influence on each component. To ensure that the discussion is systematic, this research uses the analytical hierarchy process (AHP) to create a logical research framework, separately listing the constituent components of a village's spatial structure and its influencing factors [37,38].

The study sorts out the constituent components and influencing factors of the general village spatial structure. The research objects are decomposed into components, according to the principles of urban and rural planning and other related interdisciplinary subjects. Then the researchers compare each component or factor with others at the same level. From Table 1, we can see that the comparison standard adopts the nine-level evaluation scale proposed by Saaty (1980), which quantifies the decision-maker's preference judgment via AHP. To improve the effectiveness of this comparison of components or factors, the researchers conducted multiple inquiries and exchanges with experts, following the Delphi method [29]. The questionnaire was distributed to 64 scholars who have researched related topics in southern Shaanxi. The content of the questionnaire was formulated based on previous literature on data collection, survey results, and technical information analysis.

The scholars who received the questionnaire evaluated the importance of components or factors, according to the evaluation criteria shown in Table 1.

**Table 1.** The nine-point intensity scale of importance and its description. Source: Saaty (1980).

| Intensity of Importance | Definition | Content |
|---|---|---|
| 1 | Equally important | Both elements are of equal importance. |
| 3 | Moderately more important | One element is slightly more important than the other. |
| 5 | Strongly more important | Judging by experience, there is a strong preference for a certain element. |
| 7 | Very strongly more important | The responder is very inclined toward a certain element. |
| 9 | Extremely more important | There is evidence that an element is very important when comparing two elements. One element is significantly stronger than the other element can control. |
| 2, 4, 6, 8 | Intermediate values | Used for compromises between the above criteria. |

Then, we calculated the weight of elements and factors for each feedback questionnaire and verified its consistency. The importance of each component or factor was set in turn as $A_1, A_2, \ldots, A_i, \ldots, A_j, \ldots, A_n$. The comparison result of the two elements' factors is expressed by the formula:

$$a_{ij} = \frac{A_i}{A_j} \tag{1}$$

In the case where $n$ components or factors are compared in pairs, we need to create a working model, as in Table 2. The calculation and verification processes are shown in Figure 3.

To use a mathematical method for calculations, the data in the table needs to be converted into a matrix:

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1i} & \cdots & a_{1j} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2i} & \cdots & a_{2j} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots & & \vdots & & \vdots \\ a_{i1} & a_{i2} & \cdots & 1 & \cdots & a_{ij} & \cdots & a_{in} \\ \vdots & \vdots & & \vdots & \ddots & \vdots & & \vdots \\ a_{j1} & a_{j2} & \cdots & a_{ji} & \cdots & 1 & \cdots & a_{jn} \\ \vdots & \vdots & & \vdots & & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{ni} & \cdots & a_{nj} & \cdots & 1 \end{bmatrix} = \left(a_{ij}\right)_{n\times n} \tag{2}$$

R.I. is the random consistency index, the specific values for which are shown in Table 3. For the consistency ratio, when C.R. = 0, matrix A can be called a complete consistency matrix; when C.R. < 0.1, matrix A can be called a satisfactory consistency matrix; when C.R. > 0.1, matrix A does not have consistency.

**Table 2.** Pair-wise comparison matrix(aggregated using the geometric mean).

| | $A_1$ | $A_2$ | … | $A_i$ | … | $A_j$ | … | $A_n$ |
|---|---|---|---|---|---|---|---|---|
| $A_1$ | 1 | $a_{12}$ | … | $a_{1i}$ | … | $a_{1i}$ | … | $a_{1n}$ |
| $A_2$ | $a_{21}$ | 1 | … | $a_{2i}$ | … | $a_{2j}$ | … | $a_{2n}$ |
| … | … | … | … | … | | … | | … |
| $A_i$ | $a_{i1}$ | $a_{i2}$ | … | 1 | … | $a_{ij}$ | … | $a_{in}$ |
| … | … | … | | … | … | … | | … |
| $A_j$ | $a_{j1}$ | $a_{j2}$ | … | $a_{ji}$ | … | 1 | … | $a_{jn}$ |
| … | … | … | | … | | … | … | … |
| $A_n$ | $a_{n1}$ | $a_{12}$ | … | $a_{ni}$ | … | $a_{nj}$ | … | 1 |

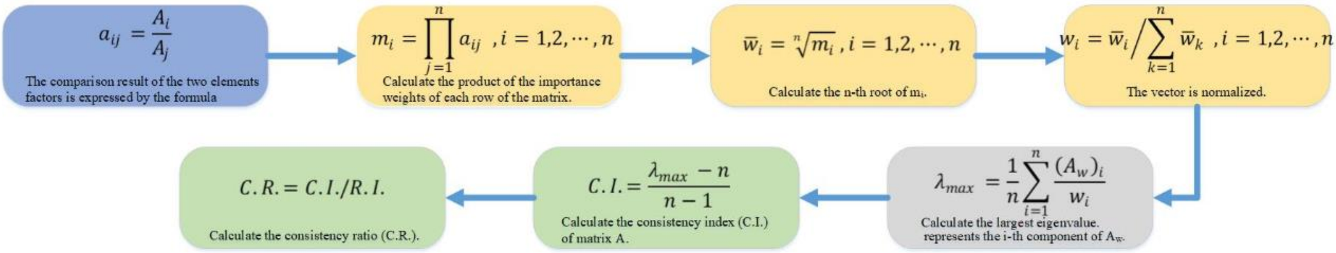



**Figure 3.** The calculation and verification processes.

**Table 3.** Random Consistency Index.

| n | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R.I. | 0.58 | 0.89 | 1.12 | 1.24 | 1.32 | 1.41 | 1.46 | 1.49 | 1.52 | 1.54 | 1.56 | 1.58 | 1.59 |

According to the consistency result, scholars were asked to modify their questionnaires. This research collected questionnaires and feedback, based on the Delphi method. Finally, the study integrated the weight calculation results of the questionnaires that met the requirements of consistency, to find the weighted average of each component and factor. According to the weighting result, the degrees of importance of the components and the factors are arranged in hierarchical order.

2.2.3. GIS

Based on the mapping achieved by GIS, this research applied spatial interpolation, spatial autocorrelation, and network analysis methods to quantitatively analyze the space occupied by the villages [39–41].

Table 4 shows the calculation process and formulae of the three indicators. By comparing the radiation radius of each village and the distances between each one, this difference can be used to optimize the space occupied by the village and achieve an efficient operation mode of village–village intercommunication.

**Table 4.** The industry types and spatial forms of rural settlements in southern Shaanxi.

| Calculate Indicators | Spatial Autocorrelation | Spatial Interpolation | Spatial Metric |
|---|---|---|---|
| | By considering the location of points and the attributes of their changes, spatial autocorrelation measures the correlation between the values of various variables according to the spatial distribution status. Moran's Index is used to measure the spatial correlations of each residential area. | Spatial interpolation is often used to convert measured data at discrete points into continuous data surfaces, for comparison with the distribution patterns of spatial phenomena, to ensure the accuracy of the imaging of geographic data. The inverse distance weight (IDW) value is used in the calculation process. | As a crucial parameter of space, distance is an important research variable for optimizing the regional layout. The position of the centroid point is set as being in the population distribution center rather than the geometric center of the space. |
| Equation | $I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} W_{ij}(x_i-\bar{x})(x_j-\bar{x})}{S^2\sum_{i=1}^{n}\sum_{j=1}^{m} W_{ij}}$ (3)<br>$E(I) = \frac{-1}{n-1}$ (4) | $\hat{Z}(x_0) = \sum_{i=1}^{n} \lambda_i \cdot z(x_i)$, $\sum_{i=1}^{n} \lambda_i = 1$ (5)<br>$\hat{Z}(x_j) = \sum_{i=1}^{n} \lambda_i \cdot z(x_i) \cdot \frac{d_{ij}^{-r}}{\sum_{i=1}^{n} d_{ij}^{-r}}$ (6)<br>$\hat{Z}(x_0) = \frac{1}{n}\sum_{i=1}^{n} z(x_i)$ (7) | $X_G = \frac{\sum_i W_i X_i}{\sum_i W_i}$, $Y_G = \frac{\sum_i W_i Y_i}{\sum_i W_i}$ (8)<br>$d = \sqrt{(X_i - X_j)^2 + (Y_i - Y_j)^2}$ (9) |

**Table 4.** *Cont.*

| Calculate Indicators | Spatial Autocorrelation | Spatial Interpolation | Spatial Metric |
|---|---|---|---|
| Explanation of the formula | In Equation (3), $C$ is the value at point $i$, $x_j$ is the value of point $j$ adjacent to point $i$. $W_{ij}$ is the coefficient, $n$ is the number of points, and $S^2$ is the variance of the value of $x$ and its average value $\overline{x}$. The coefficient $W_{ij}$ is the weight used to measure the spatial autocorrelation and is defined as the reciprocal $(1/d_{ij})$ of the distance $(d)$ between point $i$ and point $j$ in this study. In Equation (4), when the number of points is large, the value of E(I) is close to 0. | In Equation (5), the weight coefficient is calculated by the function $\varnothing(d(x, x_i))$, and it is required that when $d \to 0$ is $\varnothing(d)$, we generally take the reciprocal or negative exponents $d^{-r}$, $e^{-d}$ and $e^{-d^2}$. In Equations (6) and (7), $x_j$ is an unknown elevation point, and $x_i$ is a known elevation data point. The calculation result often shows a malformed distribution pattern, in which the outlier data is significantly higher than the surrounding data points. | In Equation (8), $W_i$ is the weight of the $i$-th discrete target, and $X_i$, $Y_i$ is the coordinate of the $i$-th discrete target. Equation (9) is the Euclidean distance by which we can calculate the distance between adjacent villages. |

## 3. Results

### *3.1. The Overall Review of Rural Settlements*

Southern Shaanxi is in the south part of Shaanxi Province, between the north of Qin Mountain and the south of Daba mountain [31]. The region has many small basins and valleys. It is a multi-ethnic intersection zone for the Qin culture, Ba culture, Chu culture, and Shu culture. The area has the climate characteristics of both hot summer and cold winter regions, as well as cold regions. It is hot and humid in summer, and cold and wet in winter, encompassing a variety of living styles under special climatic conditions. The area is ethnically diverse and is rich in cultural deposits. Southern Shaanxi has many villages, and the spatial distribution of this area is diverse. Spatial characteristics are the external expression of space development patterns, which are supported by certain industries and facilities in this area [32]. The spatial characteristics of rural settlements can be expressed from many aspects, including the distribution and structure of settlements, the spatial representation of the scale, and the shape of settlements on the micro-scale.

#### 3.1.1. Spatial Structure

The distribution of rural settlements in southern Shaanxi is affected by topography and its traditional agricultural economy. The poor infrastructure and traffic conditions restricted the formation of large-scale settlements [23]. Although the surrounding settlements are spatially close to each other, the relationships between settlements is weak, which leads to a non-typical spatial structure of settlements. According to the survey data given in Table 2, the average size of the settlement groups is relatively small. The large-scale clusters are distributed along the gully regions, most of which contain only 3–5 settlements, with an average population of 350 people and an average cultivated land area of 466 hm$^2$. The internal structure of rural settlements is a feature of the spatial layout of the various components within the settlement. This involves both the spatial form and the spatial mode.

1. Spatial Form

With its complex topographical environment, backward social and economic development, and profound traditional cultural influence, the spatial structure of rural settlements in southern Shaanxi is complicated. According to the structural characteristics of the settlement space, spatial form is classified into agglomeration type, belt type, and dispersion type. Table 5 shows the industry types and spatial forms of rural settlements, and the corresponding classification basis.

**Table 5.** The industry types and spatial forms of rural settlements in southern Shaanxi.

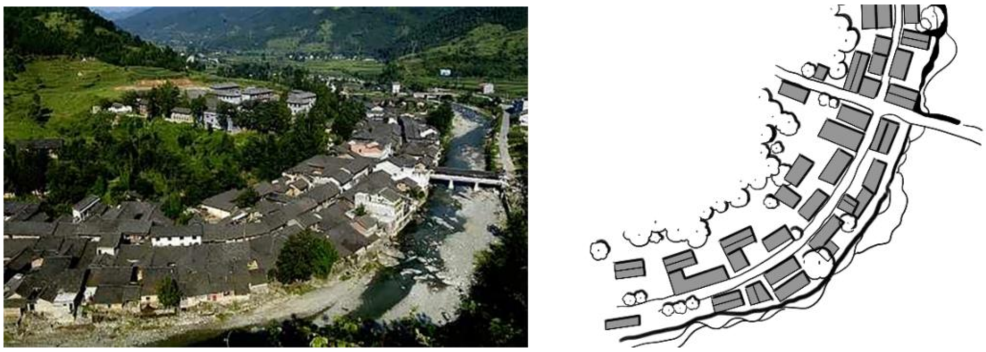
| Spatial Structure Type | Industry Type | Classification Basis | | |
|---|---|---|---|---|
| | | **Dominant Reason** | **Characteristics of Distribution** | **Morphological Characteristics** |
| Agglomeration type | Industrial cluster | Industry factor | Found along the edge of the tourist area, in the industrial area | Group |
| Belt type | Traffic service | Traffic factor | Found with the road traffic | Linear |
| Dispersion type | Traditional agriculture | Natural factor | Widely distributed in hilly mountains | Point shape |

An agglomerated spatial structure is a centrally arranged layout, in the form of a group, square, or polygonal geometry. From Figure 4, we can see that, according to density, it is divided into either a compact agglomeration or a loose agglomeration. The compact agglomeration type is distributed either in the ditch and river valley or on land where the terrain is relatively flat. The compact agglomeration type of settlement has the characteristics of a large-scale, high-clustering area, with a vertical and horizontal road network, a relatively regular spatial pattern, a perfectly functioning layout, and a clear boundary. An agglomeration-type settlement mainly relies on tourism and industrial development. The centralized space format can guarantee the successful operation and management of tourism and industry.

(**a**) (**b**)

**Figure 4.** Agglomeration-type settlement spatial structures. (**a**) Photographed example of a settlement form. (**b**) Schematic representation of the settlement form.

The belt-type settlement is distributed in the valley or the flat land between the two mountains. From Figure 5, we can see that the belt-type settlement in the example is distributed along a river, a valley, and a road to form a strip-shaped spatial pattern. In the expansion zone, the settlement's density and scale are large, and the pattern of roads is relatively regular. In narrower locations, the settlements are arranged in a point or line shape, and the pattern of roads is irregular. The local industry relies on small-scale logistics, business service facilities, auto parts, and traditional agriculture to form a community centered around important transportation routes.



(a) (b)

**Figure 5.** Belt-type settlement spatial structures. (**a**) Photographic example of belt-type settlement form. (**b**) Schematic representation of the belt-type settlement form.

Dispersion-type settlements are distributed in the hilly and mountainous areas and are mostly naturally distributed. From Figure 6, we can see that in our example, according to the characteristics of the geomorphology, the settlement forms a rich and diverse geographical distribution and spatial form, showing a spatial structure with a scattered distribution of three or five household groups or a single household group. The small settlement groups are mainly distributed in low hilly areas. The distance between groups is greatly affected by rivers, roads, and terrain. The dispersion type of settlement is widely distributed in the hilly mountainous area, with the distinguishing features of a small scale, loose spatial structure, an unclear road network, and a blurred boundary. The scattered settlement points are mainly distributed in mountainous areas and some hilly areas, with narrow and tortuous streets and large distances between buildings. Dispersion settlements mainly rely on traditional agriculture and planting. With the surrounding mountain and water resources, this creates a unique spatial form of settlement.

(a) (b)

**Figure 6.** Dispersion-type settlement—spatial form. (**a**) Photographic example of a dispersion-type settlement form. (**b**) Schematic representation of the dispersed settlement form.

2. Spatial Mode

Through the team's extensive investigation in southern Shaanxi, it was established that the centralized settlement's spatial form is the most common type. In the narrowest sense, the settlement space is composed of basic components, including homesteads, public buildings, roads, and open spaces. This is a multi-functional activity space for living, usually with a center. Table 6 shows the modes of the spatial structure of rural settlements in southern Shaanxi. The spatial structures of settlements in different regions show great differences. The spatial structure of rural settlements in southern Shaanxi could be summarized as either the river valley mode or the mountainous ladder-shaped scattered settlement mode.

**Table 6.** Modes of the spatial structure of rural settlements in southern Shaanxi.

| Mode | Distribution Area | Spatial Layout Characteristics |
|---|---|---|
| River valley mode | River valley | The residential buildings are arranged in a checkerboard mode with streets and lanes acting as the skeleton. The structure density is high and the settlement boundary is obvious. The main roadway of the settlement is not only the main passage of the internal traffic of the settlement but also plays a controlling role in the formation and development of the settlement's spatial mode. |
| The mountainous ladder-shaped scattered settlement mode | Hilly mountains | The residential buildings are distributed in narrow platforms at different heights, presenting a ladder-shaped scattered mode. The number of dwellings in each platform is determined by the width of the area. The looseness of the spatial structure of the settlement is affected by topography and socioeconomic characteristics. |

#### 3.1.2. Spatial Distribution

The rural settlements in southern Shaanxi are characterized by small-scale, low-density areas with uneven distribution, decreasing along with the dendritic water system, presenting the characteristics of distribution facing toward the sun, along the road, and along the valley. There are three spatial distribution types, including uniform distribution, concentrated distribution, and random distribution. In terms of the geometric characteristics of the settlements' planning layout, they can be classified into three different types, these being aggregation-type, belt-type, and dispersion-type. According to the geomorphologic environment, the settlement can be divided into hilly settlements and gully settlements. The hilly settlements tend to collect around the land, water, and solar sources. Due to the limitation of available construction land, most of the settlements are in the form of stairs or clusters. The density and scale of the settlements are small. The gully-type settlements tend to water and road sources, facing the valleys. They are distributed along the valleys and rivers. Due to the good construction conditions, the density and scale of the settlements are large.

### *3.2. The Components and Factors of Space Structure*

#### 3.2.1. The Components of Spatial Structure

Under different cultural backgrounds and development levels, the components of the spatial structure of rural settlements are also different.

**Land use scale.** The indicators of rural settlement land, such as length, area, etc., are important factors that determine the external and other correlations of the settlement space. The scale and location of the productive and residential land areas of the settlements have changed rapidly due to population levels, the development of the industry, and the relocation of immigrants to alleviate poverty. **Population.** Population growth will lead to increased housing demand and construction, which will inevitably result in a change of village spatial structure, shape, and area. **Adjacent distance.** The spatial distribution of rural settlements can be revealed by analyzing the distances between settlements. **Settlement core**. In the development of villages and towns, traditional settlements along the river are originally single-core, centered around the water. Due to population growth, highway construction, and the reduced importance of rivers, some residential houses began to migrate to both sides of the highway, gradually forming double-core settlements. **Building group.** The behavior and purpose between groups are the reason for the formation of the settlement's spatial structure. The relationship between the building groups has gradually changed from the consanguinity building mode, based on private land, to independent dwellings. **Courtyard unit.** The size of courtyards and their length-to-width ratio influence the spatial form and structure of settlements. The courtyard is the smallest unit of settlements, and the changes in the structure of the settlement are ultimately reflected in the changes in the organization of the courtyard. **Street scale.** The width and density of the streets affect the aggregation degree of the settlement's spatial structure. **Production**

**space.** The agglomeration brought by industrialization, the elimination of the closeness of space, and the various choices of villagers regarding the life of the settlement guide the changes of settlement morphologies into demonstrating the structural characteristics of linear networks. **Development boundary.** The development boundary of the settlement determines the size and shape of the settlement. It can effectively direct the gathering of population, land, and industry within the settlement.

#### 3.2.2. The Factors of Spatial Structure

The spatial structure of rural settlements demonstrates internal organization and other external influences. As the inherent basic attributes of settlements, their components are independent of each other in space and are connected in proportion to form a stable structural system that largely determines the spatial form. The influencing factors are the external conditions that determine the spatial form, such as the natural environment and human environment. The unique spatial characteristics of each settlement are formed by the same components under different influencing factors.

1. Natural Factors

Natural factors are the basis of the formation and development of rural settlements' spatial structure; they affect and control the spatial distribution pattern of settlements, to a great extent. In each case, the natural geographical environment and the settlement's spatial structure influence and restrict each other. **Terrain conditions**. The terrain has a great influence on the land scale, adjacent distance, building group, and street space of rural settlements. The terrain in Southern Shaanxi greatly limits the agglomeration and expansion of building groups, leading to a scattered distribution and small scale of building groups. **Water source.** Due to the farming radius and production needs, the settlement production space is generally located 1–2 km away from the water source in this region. **Altitude and slope**. Southern Shaanxi is located in the range of elevation from 1000 to 1500 m and slopes of 5–15 degrees; the degree of agglomeration and the size of the production space show a significant negative correlation with elevation and slope. **Climate and soil.** The climate of the valleys in southern Shaanxi is humid and mild. The climate of hilly and mountainous areas changes most obviously according to elevation.

2. Humanities and Social Factors

With many immigration activities in history, southern Shaanxi has gradually formed a unique cultural environment. The research involved four factors, these being economic factors, cultural factors, traffic factors, policy factors.

#### 3.2.3. The Relationship between the Components and Factors

The researchers used the method of AHP to classify the influencing components of the spatial structure. Then, the expert scored those components, synthesized the experience, and made a subjective judgment to analyze and estimate the influencing value of spatial structure, as shown in Figure 7. After many rounds of consultation, feedback, and adjustment, the impact index value was finally determined. In the evaluation of the influence degree index, the proportional scale of the quartile is used, which means that 5 is the main influence, 3 is a comparative main influence, 1 is a smaller influence, and 4 and 2 are the intermediate values of the above evaluation values.

As shown in Table 7, we found that the influence degree of geomorphological conditions is 33.4, making it the main influencing factor. The influence degrees of land-use scale and population quantity are 27.6 and 27.7, making them key factors. Through detailed comparative analysis and collation of the data, the factors of the courtyard unit and street scale, which have little influence, were eliminated. Besides these, other less important components are left out. Then, the relationship index between the constituent components of structural characteristics and the influencing factors can finally be determined. This study could then further extract important components to serve as the basis of a spatial structure model of rural settlements in southern Shaanxi.

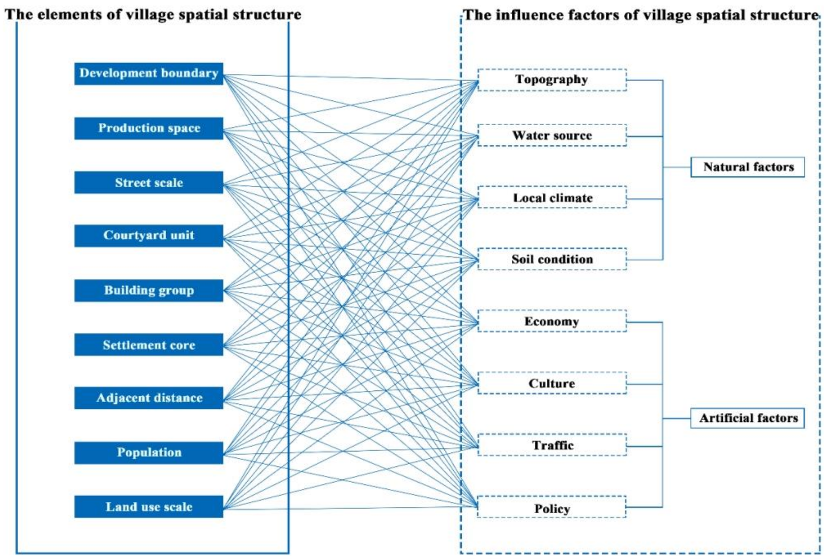



**Figure 7.** The relationship between the components and factors.

**Table 7.** Relationship between the constituent components of structural characteristics and the influencing factors.

| Component Influencing Factor | Land Use Scale | Population | Adjacent Distance | Settlement Core | Building Group | Courtyard Unit | Street Scale | Production Space | Development Boundary | Degree of Influence |
|---|---|---|---|---|---|---|---|---|---|---|
| **Terrain conditions** | 4.6 | 3.8 | 3.7 | 3.3 | 3.7 | 3.3 | 3.6 | 3.2 | 4.2 | **33.4** |
| **Water source factor** | 3.5 | 3.7 | 2.6 | 3.2 | 2.6 | 2.1 | 2.0 | 3.2 | 2.8 | 25.7 |
| **Altitude and slope** | 3.2 | 3.1 | 3.3 | 3.1 | 2.7 | 2.4 | 3.0 | 3.1 | 3.1 | 27.0 |
| **Climate and soil** | 3.1 | 3.3 | 2.5 | 2.7 | 2.6 | 2.3 | 2.4 | 2.7 | 2.5 | 24.1 |
| **Economic factor** | 3.8 | 4.1 | 3.1 | 3.6 | 2.7 | 2.9 | 2.3 | 3.6 | 3.2 | 29.3 |
| **Cultural factor** | 2.2 | 2.6 | 2.5 | 3.5 | 3.2 | 3.0 | 2.9 | 2.2 | 2.2 | 24.3 |
| **Traffic factor** | 3.9 | 3.9 | 3.9 | 3.8 | 3.3 | 2.6 | 3.0 | 3.4 | 3.6 | 31.4 |
| **Policy factor** | 3.3 | 3.2 | 2.7 | 2.8 | 2.9 | 2.0 | 2.6 | 2.7 | 3.3 | 25.5 |
| **Degree of influence of each component** | 27.6 | **27.7** | 24.3 | 26.0 | 23.7 | 20.6 | 21.8 | 24.1 | 24.9 | |

### 3.3. The Influence of Components and Factors

Through the above research, the population and terrain were identified as quantitative indicators that strongly affect the spatial characteristics of rural settlements in Southern Shaanxi, which closely mirror the spatial density of rural settlements as a whole. For verification, the authors selected Pingli county, made up of several settlements that are located in Southern Shaanxi, as a research object. Based on the results of field research, this study deconstructed the spatial structure using geometry components, such as points, curves, and planes. This research demonstrated that the layout of these settlement's spatial structures can be identified as low-density clustered type, medium-density clustered type, high-density clustered type, Arc-banding type, and scattered type, as seen in Figure 8.

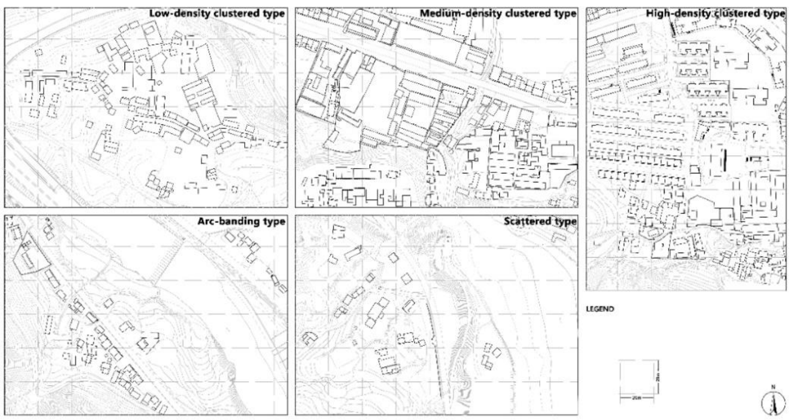



**Figure 8.** Spatial plan of rural settlements in Pingli County, Southern Shaanxi.

3.3.1. Population (Main Internal Components)

During the investigation process, the scientific research team members created statistics on the population of each settlement. Based on the dwellings and the corresponding population data, this research analyzes the population density of the 5 villages, which have equal planning space, as is clear in Figure 8.

As shown in Figure 9, the size of population points varies from settlement to settlement, which can be clearly distinguished from each other. To begin with, the population points of clustered-type settlements have a relatively large scale, compared with the other layout formats. Among them, the settlement with high-density clustered-type settlements has high-rise dwellings, resulting in greater population density located in this area because of the gradual implementation of rural revitalization policies. What is more, those denser population points in the settlement of the arc-banding type are densely arranged on both sides of the river. Besides this, the settlement of the scattered type is constituted by several residential points that have a certain density of population.

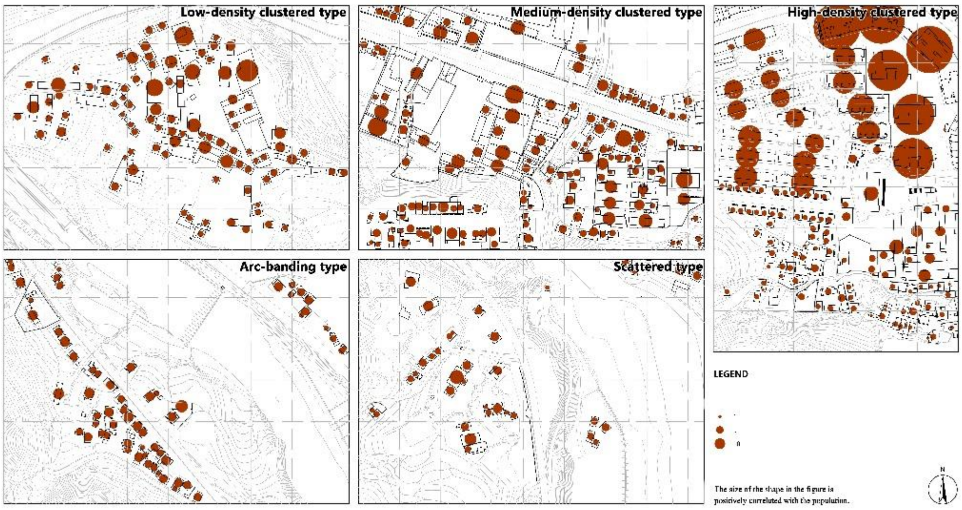



**Figure 9.** Distribution map of spatial population settlements.

To reveal the relationship between population and spatial structure in these rural settlements, Figure 10 shows the distances between population points by spatial autocorrelation. The result shows that the distribution forms are classified into two types—clustered and random. Observing the settlement of the cluster form, we find that Moran's index for the medium-density cluster type is 0.064653, which is much higher than its expected value, E(I), of −0.006536. Moran's index for the high-density cluster type is 4.782703, which is much higher than its expected value, E(I), of −0.008. Comparing both Moran's indexes, the high-density cluster type is much higher than the medium-density cluster type, which demonstrates that the population has a relatively strong relationship with the spatial structure, based on the constant measure distance, and the relationship is positively correlated. However, Moran's indexes for the other three spatial forms—high-density cluster type, Arc-banding type, and scattered type—display a random character. It is demonstrated that the spatial structure of the rural settlements in which the population does not reach a certain level does not have a strong relationship with their population level.

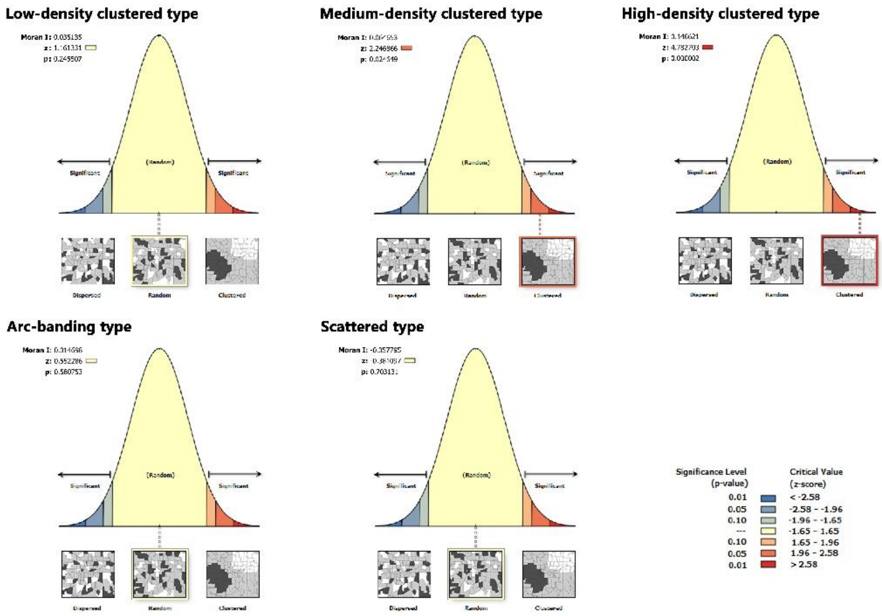



**Figure 10.** The distances of population points by spatial autocorrelation.

### 3.3.2. Terrain (Main External Factors)

As the factor with the highest weight, terrain visibly impacts the spatial structure of rural settlements, especially in these mountainous areas. Their location is limited by the terrain; therefore, most dwellings are laid out along the contour lines. The dwellings that are sited on contour lines are of the stilted building type, which is a mature architectural form of a traditional Chinese dwelling.

To accurately depict the relationship between spatial structure and terrain in these rural settlements, in Figure 11 we have shown generated schematic diagrams of the topography of these five rural settlements by spatial interpolation. The lowest altitude of this area is 420 m, which is the absolute elevation relative to the sea level of the Yellow Sea. As shown in these pictures, the height difference between adjacent contour lines is 5 m, which is close to the height of the first floor of local sloping-roof houses. Low-density communities are more restricted by the terrain. These houses adapt to the terrain as much as possible, and the long sides of the building are parallel or tangential to the contour. High-density communities are affected by urbanization, and construction activities frequently transform the local terrain. The artificial use of filling and excavation, independent pillars, elevating ground floor, and other means are employed to solve the structural problems of building in the mountains.

Further observation and analysis of the content shown in Figure 10, as the low-density form of the cluster layout, reveals that its architectural layout has both strip and dot layout forms. In the middle of the low-density cluster settlement, the buildings are evenly arranged along the topographic contour lines to form the main block of the settlement. On the north and south sides of the settlement, the buildings are distributed in irregular dots. Based on this, it is apparent that the complex spatial structure of the settlement has evolved from a simple combination of dots and lines, forming a variety of layout forms. It can be inferred that small-scale villages are more obviously affected by topography; when the village develops to a certain scale, the influence of topography begins to weaken.

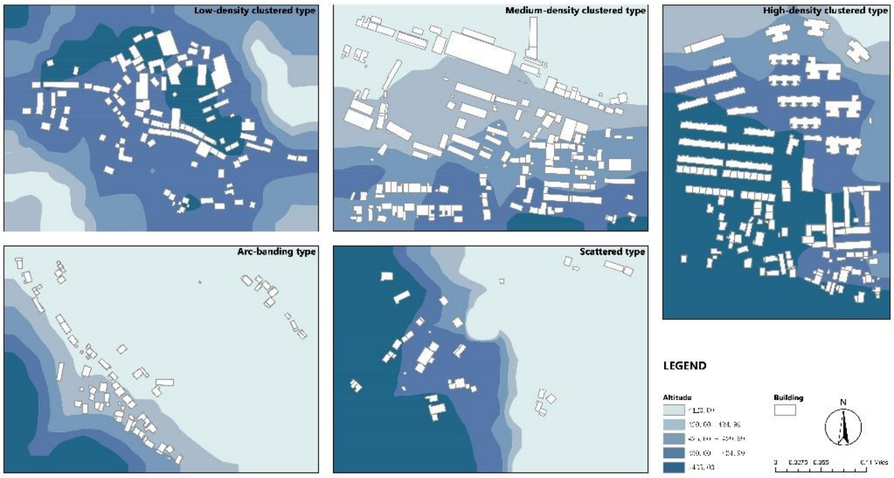



**Figure 11.** Generated schematic diagrams of the topography.

### *3.4. The Optimization of Spatial Structure*

Through the above research, it was established that population is a quantitative indicator that affects rural settlement space in southern Shaanxi. When its population size reaches a certain value, its Moran value is higher than the expected value, which can be positively correlated with the spatial concentration of rural settlements. With the increase in the size of the villages, the unfavorable factors of the terrain are gradually reduced by the influence of modern construction technology.

To facilitate the study of spatial issues, this study takes the population center of each village as the center of mass, in the establishment of the frame of reference. In image processing, measuring geographic distribution is used as a way to determine the center of mass of the village. Measuring geographic distribution is a commonly used spatial statistical method in ArcGIS. The data cluster can display the center of gravity of a certain characteristic of the vector data in the image, through the derivation and calculation of its central component. According to the distribution status of the population of each village, Figure 12 shows the population quality points of the rural settlements of eleven villages in in Pinli County.

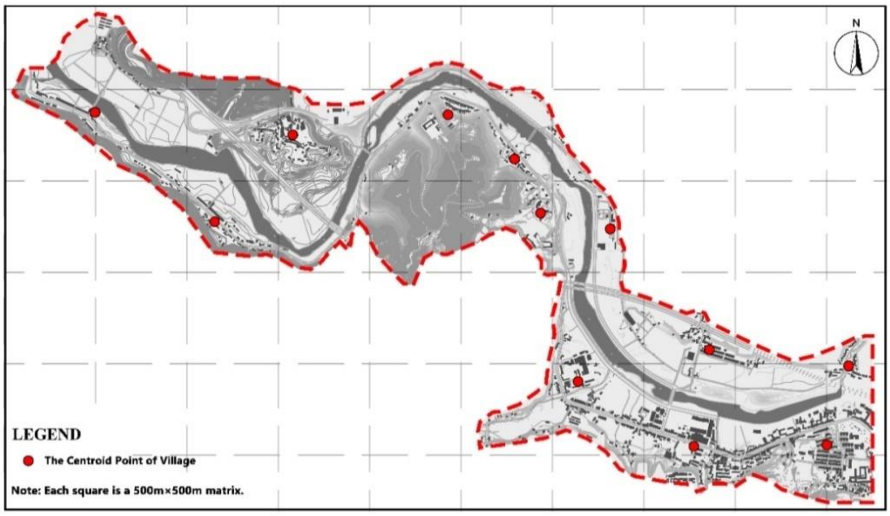



**Figure 12.** The population centers of rural settlements in Pinli County.

#### 3.4.1. Strengthening the Connections

Population growth contributes to the recovery and innovation of existing resources and the increase of new resources, rather than consuming resources. It is difficult to force a region to achieve population growth in a short period, but the unity and cooperation of people in a certain region can increase productivity and promote regional economic development. Strengthening the connections between communities can concentrate human resources, integrate the productivity of certain regional residents, accelerate the development of villages and towns, and shift the development of villages and towns from extensive development to intensive development.

Road traffic, network construction, emergency rescue, production, and transportation all need to consider the distance between each village and its neighboring locations. This research uses the spatial measurement method to draw the buffer zone of each village, using every 300 m as a base and using the population centroid as the starting point. As shown in Figure 13, in this area, the villages on the west side are far apart and begin to merge within a radius of 600 m; the villages in the middle gather closer and begin to merge within a radius of 300 m; the villages on the east side appear random. Western villages are laid out in a strip along the river, greatly extending their horizontal orientation, and some residential buildings are out of the scope of public services.

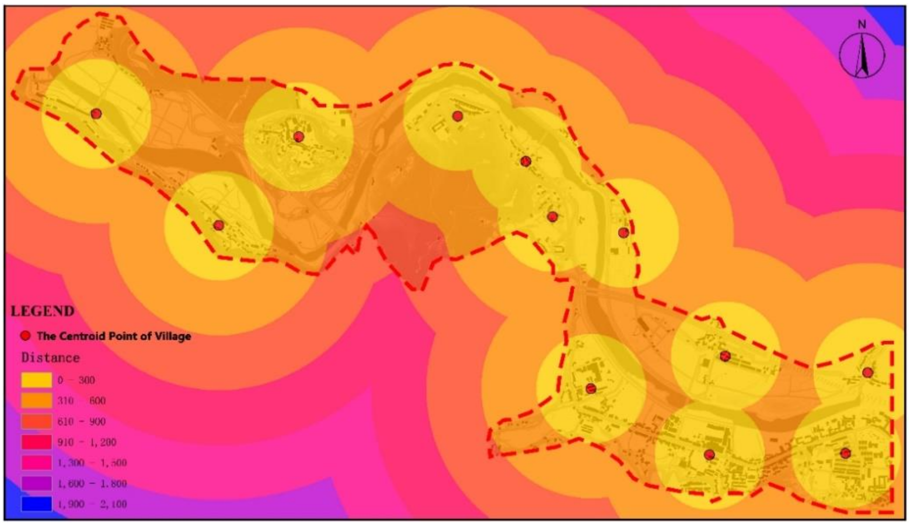



**Figure 13.** The buffer zones of villages.

The information in Figure 14 takes the population center point as the base point and uses the Euclidean distance method to measure the neighboring settlements of each village and the distances between them. The calculation results of the proximity index show that the population centers of villages 0 to 2 in the west are close to each other; the population centers of villages 3 to 6 in the middle are close to each other; in the east, villages 7, 8 and 11 are close to each other; and villages 9 and 10 are close to each other. The calculation results show that the maximum distance between the population centers of neighboring villages is 906.19 m, and the minimum distance is 336.01 m. In the area covered by this study, using 500 m as the threshold, it can be seen that there are few dwellings among villages at a distance of more than 500 m, and there are relatively densely situated buildings among villages at a distance of 300 m.

Due to the obstruction presented by the river, the enhancement of the connection between villages numbered 1 and 2 and the connection between numbers 8 and 11 have certain limitations. In the face of the above situation, a bridge and cableway can be built above the river, and the bridge can allow passing vehicles to connect the villages, to achieve the aim of village intercommunication. Those villages numbered 0 and 1 are affected by the topography of the canyon, and the road between the two villages is relatively long and narrow, thus being prone to congestion problems during the tourist season or in rescue and relief activities. Therefore, to ensure the safe development of the villages in this area, a hub service system can be built between the two villages, providing tourist service centers, public transportation stations, emergency dispatch centers, etc. Establishing spatial and informational connections can concentrate human resources and solve public resource allocation problems in many villages, such as elderly care, employment, education, and people's livelihoods.

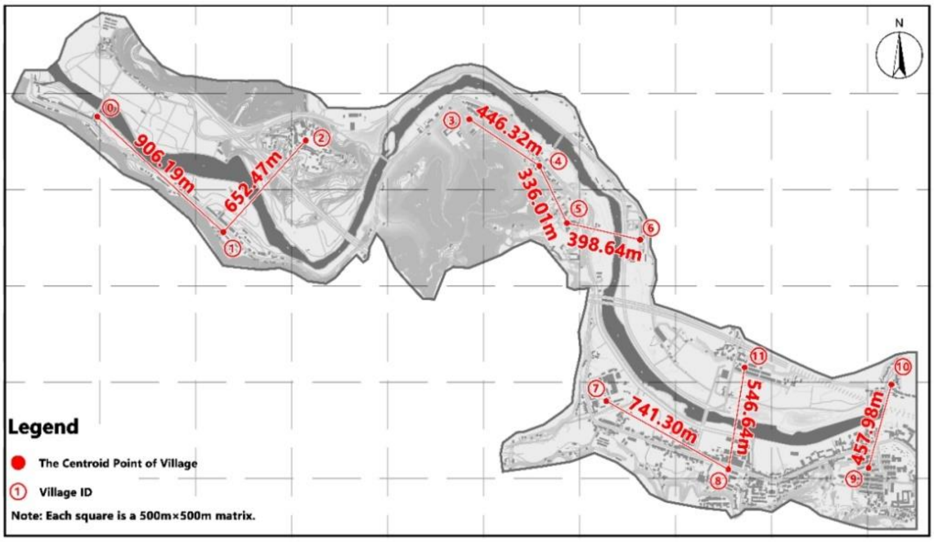



**Figure 14.** The distances between neighboring villages.

### 3.4.2. Controlling the Scale

The southern Shaanxi area has the characteristics of sensitive ecology, low density, small scale, and dense land use. The establishment of a comprehensive public service system in each village will generate huge economic costs, and the completed service facilities will not be able to operate at full capacity, resulting in a huge waste of manpower and material resources. If each village shares the same public service facilities according to its radiation range, then the villages in a certain area can obtain the most profitable intensive development. Controlling the scope of settlement construction is an important link in achieving sustainable rural development.

Based on the principle of "continuing regional spaces with mountain characteristics and promoting the moderate concentration of rural settlements", it is normally important to choose a natural village agglomeration development with a good foundation and improve the social and economic development conditions, as shown in Table 8. However, the villages in southern Shaanxi are affected by the population and terrain, which factors are difficult to apply to the service radius of public facilities listed in the table.

**Table 8.** Requirements for rural settlement public service facilities.

| Classification | Restriction Requirement |
| --- | --- |
| Primary school | Service radius: 420–1000 m<br>Maximum travel distance: 2 km<br>Population threshold: 1700 |
| kindergarten | Service radius: less than 800 m<br>Population threshold: 1500 |
| Tillage radius | Service radius: 1.5–2.5 km<br>Agricultural machinery transportation radius: 7 km |
| Medical Facility | Service radius: less than 800 m<br>Population threshold: 1600 |
| Commercial facility | Service radius: 400–800 m<br>Population threshold: 1300 |

This research takes the population center of the village as the center of the circle, analyzing the construction scope of the village based on the proximity index. The scale of rural settlement in southern Shaanxi is too small; the residential unit groups should be evenly distributed among agricultural and forestry land. From Table 9, using the ideal development radius and the maximum difference, it can be inferred that the ideal maximum development radius of settlements in this area is 538.81 m. No matter where the public service facilities are located at any point within the radius of the village, they can benefit the residents in the village, and the maximum development radius is more in line with the "economic threshold" of the settlement radius.

**Table 9.** Village construction radius calculation.

| Group | Distance between Adjacent Villages | Difference | Mean Radius | Ideal Value |
|---|---|---|---|---|
| 1 | $D_{01} = r_0 + r_1 = 906.19$ m<br>$D_{12} = r_1 + r_2 = 652.47$ m | $d_1 = 254.43$ m | $R_1 = 389.67$ m | |
| 2 | $D_{34} = r_3 + r_4 = 446.32$ m<br>$D_{45} = r_4 + r_5 = 336.01$ m<br>$D_{56} = r_5 + r_6 = 398.64$ m | $d_2 = 110.31$ m<br>$d_3 = 62.54$ m | $R_2 = 196.86$ m | $R \rightarrow 284.38$ m |
| 3 | $D_{78} = r_7 + r_8 = 741.30$ m<br>$D_{811} = r_8 + r_{11} = 546.64$ m | $d_4 = 194.66$ m | $R_3 = 321.99$ m | |
| 4 | $D_{910} = r_9 + r_{10} = 457.98$ m | | $R_4 = 228.99$ m | |

$D_{ab}$ represents the linear distance between the population centers of any two villages; $r_a$ represents the radiation radius of the construction scope of village a; d represents the numerical difference between adjacent indices.

Within the research scope of this area, based on the analysis results of the GIS above, a radius of 284.12 m can be used as a measure of the development scope of the village. When the village development radius is less than this value, the village can be merged with neighboring settlements to form a new village construction scope; when the village scope is larger than this value and does not exceed 389.67 m, the current development radius can be maintained for independent development; when the village scope is larger than 673.79 m, the residential houses beyond the village need to be relocated.

Based on the above numerical analysis, the development space range of settlements can be expressed algebraically, which is also applicable to the development standards of villages in other regions. Taking the population center of gravity as the center of the circle, and setting the radius of the confirmed development village as $r$, the following formula is given:

$$R < r \leq R + d \leq 1000m \tag{10}$$

In this formula, R is the ideal radius of the development range of the villages in the area, which is calculated by the average of the neighboring indexes between the villages; d is the difference in the development radius of the villages, which is the maximum difference of the neighboring indexes between the villages; 1000m is defined as the ideal value of the public service radius of mountain settlements in southern Shaanxi, and this value can be adjusted according to the actual local conditions.

This research uses the above formula to calculate the construction scope of each village within the scope of the case, as shown in Figure 15. Combined with the strategy of strengthening the connection, as proposed above, the construction radius between neighboring villages borders each other, forming their groups, and achieving an intensive mode of common development. In addition, the residential buildings near the line segment can be further optimized, according to the theoretical model of public service location (calculated according to the proximity index), to solve their production and living problems.

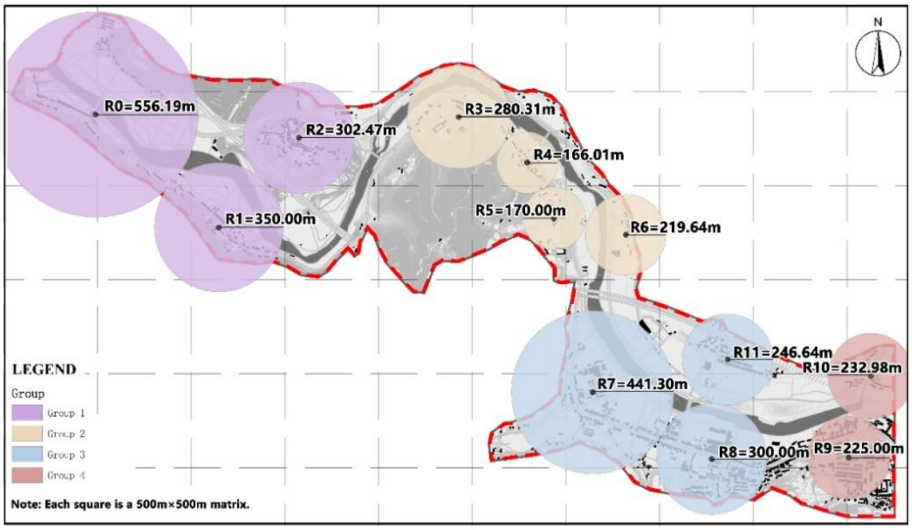



**Figure 15.** The construction scope of each village within the scope of the case study.

## 4. Discussion

China is a largely agricultural country, with a large rural population that is widely distributed in different regions. There are still many problems facing the study of rural settlements that need to be solved urgently. Southern Shaanxi is located in the central part of China, with rich topography, geomorphology, hydrology, and climate, which is more in line with the ideal zone of "Harmony between Man and Nature" found in traditional Chinese thought. Based on the results of this article, the following issues should be discussed.

The influencing factors put forward in this article are based on the results of surveys and interviews, and the important factors and components discussed are also based on the experiences of scholars in related disciplines, which are subjective. However, the factors and components proposed in this article have an impact on the spacing of rural settlements, and the relationships between them can be obtained through related qualitative or quantitative research.

Through an analysis of spatial autocorrelation, it is proposed that when the population gathers to a certain extent, the spatial arrangement of settlements forms a cluster. Being restricted by the number of samples and data statistics, the critical value for forming a cluster is difficult for us to calculate. The calculation result of this value may provide effective reference material to address the population control problem in future village development.

This research is relatively static. In the face of the challenges of today's world, many rural space issues need to be further deepened. For example, prevention of the spread of COVID-19, the popularization of 5G technology, and the development of China's infrastructure have far-reaching effects on settlement space and need to be further explored.

## 5. Conclusions

The distribution of rural settlements and the population in mountainous areas are relatively scattered in terms of geography. The expansion of settlements, the evolution of spatial structure and the formation of internal differences are closely related to the spatial differences of their natural conditions and those of the economic development conditions. Due to conflicts between humans and the land itself, settlements generally follow the traditional, natural economy model, with low productivity and obvious diffusion characteristics. Research into rural settlements' spatial structure should learn from the methods of analyzing modern urban spatial structure. The development of rural settlements and the evolution of their spatial structure can be studied from the perspectives of history, society, and economy, putting forward the hierarchical model of the spatial development of mountainous rural settlements. It is also possible to explore via quantitative methods the importance of various factors, their influence on the development of rural settlements, and the evolution of their spatial structure.

Under the conditions of complex terrain, construction requires land offering good prospects, which is often farmland. Therefore, the conflict between construction land and permanent farmland needs to be resolved in the planning stages. For urban and rural planning on complex terrain, the ecological protection "red line" needs to be maintained through legislation and administrative authority. The permanent, basic farmland "red line" protection needs to coordinate the conflicts caused by different formulation timelines. The core of the urban development boundary control line needs to ensure monitoring of the size of developments and the formulation of differentiated policies, both inside and outside the line.

(1) China's mountainous rural areas have a fragile ecological environment, simple economic activities, and poor infrastructure and public service facilities. Furthermore, mountainous rural settlements have disorderly development and a scattered layout. The most important problem facing the spatial planning of mountainous rural areas is to coordinate ecological protection and village development.
(2) The spatial structure of mountainous settlements can be summarized into three types, those of the agglomeration type, belt type, and dispersion type. The team conducted long-term visits and investigations in southern Shaanxi, and the results showed that 67.3% of the rural settlements in this area are located in the valleys; their spatial layout can be divided into the aggregation type, accounting for 13.6%, the belt type, accounting for 47.2%, and dispersion type, accounting for 39.2%. The modes of the spatial structure are represented as the river valley mode and the mountainous ladder-shaped scattered mode.
(3) The factors influencing rural settlement development are ranked as geomorphological conditions > population quantity > land use in southern Shaanxi. When the value of spatial autocorrelation of the population gets closer and closer to 1, the rural settlement space can form a state of aggregation. The smaller the population, the more obvious the influence of topography on the settlement space, and vice versa, where the settlement space is clustered together.
(4) The greatest resistance to the development of rural settlements and the optimization of their spatial structure in China lies in the lack of strong industrial support. Therefore, rural industrialization is the key factor in the development of rural settlements and the optimization of their spatial structure. The development of rural settlements in southern Shaanxi should strengthen the connection between the villages and control the construction scope of each settlement. The proximity index of the settlement within the scope is an important spatial measurement index, based on which the ideal radius (R) and maximum radius (R + d) of settlement construction can be inferred. Based on the analysis results of the GIS above, a radius of 284.12 m can be used as a measure of the development scope of the village. As a result, the focus of rural planning is to reconstruct the rural space and to guide the moderate concentration of rural population through the construction of central villages.

**Author Contributions:** Conceptualization, J.X. and M.Y.; methodology, Y.W.; software, M.Y.; validation, D.L. and Z.L.; formal analysis, M.Y.; investigation, M.Y. and Y.W.; resources, J.X.; data curation, Z.L.; writing—original draft preparation, J.X.; writing—review and editing, M.Y.; visualization, D.L.; supervision, J.X.; project administration, M.Y.; funding acquisition, J.X. All authors have read and agreed to the published version of the manuscript.

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