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Quantitative Study on the Evolution Trend and Driving Factors of Typical Rural Spatial Morphology in Southern Jiangsu Province, China

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Abstract: Due to rapid changes in urban and rural economic development, the Chinese landscape has been gradually transforming toward urbanization. Most Chinese rural villages face declining problems such as population loss, land use transformation, fragmentation and abandonment, resulting in big changes in the rural spatial morphology. To understand these urbanization challenges, this study established a multi-factor methodology and applied it to a case study of three selected typical villages in southern Jiangsu Province. From this analysis, the quantification of the rural spatial morphology and environmental status, from 2005 to 2016, was determined. The eight driving factors established considered the rural geological location, landform, and social economic status. To analyze the driving factors, a quantitative analysis using ArcGIS, Environment for Visualizing Images (ENVI), and Analytic Network Process (ANP) decision-making methods were used. The results revealed mechanisms between the changes to spatial morphology of rural villages in southern Jiangsu Province and their key driving factors. This study provides data support and a theoretical framework to guide future development and policy of rural villages of different types, which supports the sustainable development of Chinese rural villages.

Keywords: rural spatial morphology; evolution; driving factors; ArcGIS; ANP; southern Jiangsu province

1. Introduction

The rural ecosystem is a transient environment influenced by the evolution of nature and the social, economic and human activities that occur [1]. Due to urban development, the Chinese rural population declined from 73% in the 1990s to 60% in 2005 [2]. Despite this decline, by 2015, the Chinese rural population still accounted for 43% of the total population [3]. With increasing economic liberalism in China, the integration of economic policies has benefitted and changed both rural and urban areas [4]. The development has driven land-use changes [2,5–7] and rural-urban migration, influencing the rural spatial morphology [2,8]. Rural spatial morphology refers to the spatial organization amid the human-earth relationship. This considers both the tangible physical spatial form, such as geographical location, landform and the road and water systems, and the intangible social and economic form, such as village economy, culture, population, policy, etc. Combining these factors encapsulates the major driving entities that impact the evolution of rural spatial form. Moreover, an assessment of these factors can reflect the overall trend of the evolution of rural spatial form.

Historically, a single driving factor was used to assess the rural spatial morphology. For example, Lin [9] and Yan [10] used rural settlements to investigate aspects of natural driving forces and Guo et al. [11] generalized the rural spatial structure of Miyun County in Beijing, to investigate artificial driving forces. However, using a single driving factor to analyze rural spatial morphology has deficiencies [11], and therefore researchers transitioned to using multiple factors in assessments [12,13]. One of the earliest multi-factor studies was conducted in 1959, where Kovalev [14] used six factors that affected the rural spatial structure, including: social economic, technological economic, the size and density of population, the relationship among village inhabitants and their spatial combination, landform and location, plane modality. Also, Evans had presented a fundamental and scientific theory introduction of urban economics in year 1985 [15] and Skinner [16] extensively studied the Chengdu Plain and from his research proposed the concept of "market community", where the rural spatial structure was determined by the relationship between two factors, the transportation fee and agricultural productivity. Bedate conducted economic valuation of the cultural heritage with travel cost method in four cases studies in Spain, including a cultural artistic event, a village, a museum, and a cathedral [17].

Despite advancements in multi-factor analysis to assess impacts on rural spatial change, consistency within the scientific community varies, with different influencing factors and different analysis techniques emphasized. Bin [18] used quantitative analysis considering the natural environment, urban and traffic location and policy in rural villages of Guangzhou City for his assessment of rural spatial morphology. Wu [19] suggested that the economic, social structure evolution, urbanization, change in traditional views, and the impact of national policy in different periods, combined were the major driving factors in spatial morphology. Wu [18] suggested population be considered more fundamental or basic than an influential factor. Long et al. [20] focused on the spatiotemporal characteristics and internal mechanisms of China's rural areas and its effect on rural morphology. Wang et al. analyzed spatio-temporal characteristics of rural economic development in eastern coastal China, employing Gini coefficient index, Tsui-Wang index, and Theil index [21]. Shi et al. Liu et al. [22] administered surveys on rural land use at village scale to present how land-use change takes place in response to inhibitive institutional forces, such as lack of land ownership. Other researchers suggested migration, rural economic development, and urbanization were the primary forces driving the conversion from farmland to non-agricultural use in China [23–26]. Wang et al. applied the decoupling method for population and construction land use change in urban and rural settings and found that rural population decreased while the rural settlement land use increased, showing a strong negative decoupling [27]. Shi et al. studies the middle basin of the Heihe River in China by considering decoupling relationship between the spatiotemporal changes in rural settlement land and rural population [28]. Shui et al. selected a case study of China's Xinjin county in Chengdu city to conduct the analysis of the influencing factors on farmer's satisfaction and occupancy considering the policy of balance between urban and rural construction [29].

In recent years, interdisciplinary, multi-variable studies have been conducted to further analyze the impact of driving factors on rural spatial morphology evolution. Within these interdisciplinary studies, some of the most common quantitative analysis methods used include: Remote Sensing (RS), Geographic Information System (GIS), and Environment for Visualizing Images (ENVI) [30]. The study in [31] gave a methodological framework of taking data for the popular analysis through computer tools. Murgante and Danese took the Potenza municipality in Italy as a case study to investigate spatial morphology within more than twenty-year dataset and apply some spatial statistic techniques to define suitability with indices, such as, density, distance from infrastructures, spatial autocorrelations, intensity of events and contiguity belt [32]. Shi et al. [33] conducted a comparative analysis of the landscape patterns of rural settlements within eight villages in Yixing City and explored the mechanism of driving factors considering landscape ecology and GIS space analysis. Wu and Wang [34] utilized

RS, GIS techniques and analytic hierarchy process (AHP) method to set up the assessment indices of landscape resources around rural-urban regions in southern Jiangsu Province, China. Zhu et al. applied a Principal Component Analysis (PCA) and Grey Entropy measurement model to evaluate urban-rural coordination by considering the indices of economic, social security, public services, and environmental quality [35]. Liang and Peng used AHP to examine the success factors of autonomous landscape development in rural areas, covering 8 criteria and 28 sub-criteria [36]. Using GIS, Masot and Alonso analyzed the 25 years of European rural development policy through LEADER approach to reduce the differences between rural and urban areas, as well as to satisfy the basic needs of population [37]. Zareei [38] evaluated biogas potential and developed a model from livestock manures and rural wastes in Iran using GIS. Cano et al. [39] conducted a method for the inventory of traditional buildings based on a GIS in the rural development in Spain. Further, Swetnam [40] proposed a GIS-enabled method for extensive monitoring of a valued ecosystems service in rural Wales.

Most of the rural studies with GIS and other techniques focus on the analysis of land use management or rural landscape transformation. Few assess the quantitative impact of different driving factors on rural spatial morphology evolution. To investigate the impact of different factors on rural development, this study selected three cases of typical rural villages in southern Jiangsu Province, China, and selected eight driving factors in terms of the location, landform, and social economy, to analyze the spatial form of rural villages. The eight driving factors were explored in three rural village spatial morphologies and ArcGIS and ENVI were utilized for the quantitative analysis. Hypothetically, there are certain intrinsic relevance between the quantized grades of these driving factors and evolution trends of these villages. Finally, the Analytic Network Process (ANP) decision-making method was applied to provide a quantitative assessment of different types of rural villages. This study aims to achieve the following objectives:

(1) Apply eight driving factors to analyze the rural spatial morphology of three typical rural villages in a case study.
(2) Propose a novel framework for quantifying the impact of the eight driving factors on rural spatial morphology based on ArcGIS, ENVI, and ANP.
(3) Provide a baseline to help assess the decision making of development of different types of rural villages using the driving factors.
(4) Finally, provide predictive and analytical insights into the typical rural spatial morphology evolution trend.

2. Methodology

2.1. Explanation of the Driving Factors

To analyze the spatial morphology evolution of rural villages in the southern Jiangsu Province, three main rule levels were selected: the geographical location (B1), the landform (B2), and the social economy (B3) in Figure 1. Within each rule level (B1, B2, B3) a number of driving factors exist (C1-C8). The geographical location (B1), referring to the location of villages, includes: the distance to the urban (C1), the distance to the highway (C2), and the distance to the water system (C3). The landform (B2), referring to the form of land surface, includes: the land gradient (C4), the land exposure (C5), and the land type (C6). The social economy, referring to the nonmaterial level of rural areas, includes: the population density (C7) and the annual per capita net income (C8). The relationship between each rule level is shown in Figure 1. Observe in Figure 1 that the distance of the rural village to the urban center, road, and water systems, will influence the social economy of the rural areas. The population and income of the rural village becomes inversely proportional to the location of rural village to the natural and social resources. Meanwhile, the landform also impacts the social economy and the geographical location due to gradient and surface exposure variances (Figure 1). For example, a location closer to a water system or industrial system will have more influence on the landform [41].

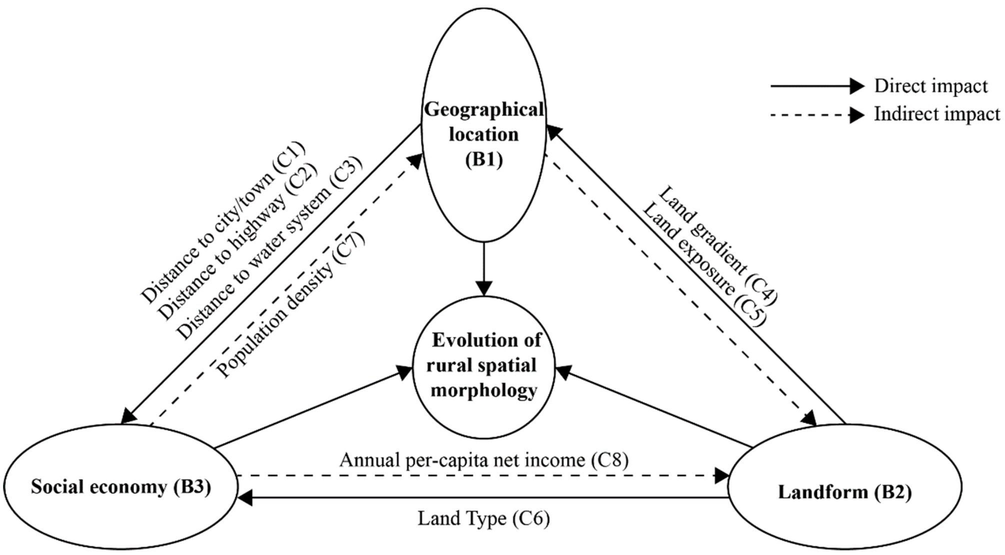

Figure 1. The relationship between rule levels in southern Jiangsu Province. (source: drawn by the authors).

2.1.1. Geographical Location

(1) The distance to the town (C1)

A grading system, Grade 1 to Grade 5, was applied according to the driving distance from the rural village to the town, as shown in Table 1.

Table 1. The grade standards of the distance to the town.

Drive Distance to the Town (km)	3–5	5–7	7–9	9–11	11–13
Grade	5	4	3	2	1

(2) The distance to the highway (C2)

If a national, provincial or county-level highway goes through or around the village, the industrial resources and the technical exchange surrounding and within the village can be effectively promoted, so that the development of the village can be improved. Table 2 provides the grading standards defined according to the distance between the rural village and the highway. Scoring was such that the shorter the distance, the higher the grade given.

Table 2. The grade standards of the distance to the highway.

Distance (m)	30	50	70	100	200
Grade	5	4	3	2	1

(3) The distance to the water system (C3)

In southern Jiangsu Province with a dense water network, the water system has an important impact on the early structure and form of rural villages. The grade standards and quantification steps are similar to those of the factor of distance to the highway, shown in Table 3.

Table 3. The grade standards of the distance to the water system.

Distance (m)	30	50	70	100	200
Grade	5	4	3	2	1

2.1.2. Landform

(1) Land gradient (C4)

The topography of the ground gradient plays a decisive role in the development pattern, building site and road construction, etc. of the rural villages. For this, the ground TIN elevation was used for the quantification. The gradients were divided into five grades according to the gradient scope, shown in Table 4.

Table 4. The grade standards of gradient scope.

Gradient (°)	0.00–1.43	1.43–5.71	5.71–24.89	24.89–84.29	>84.29
Grade	5	4	3	2	1

(2) Land exposure (C5)

Table 5 contains the standards for the grade attribute using the exposure map.

Table 5. The grade standards of exposure.

Exposure	Flat	South	Southeast/Southwest	East/North	Northeast/Northwest	North
Grade	5	4	3	2	1	0

(3) Land types (C6)

The different land utilization capabilities impact village development. Using Google imaging maps, the land of typical villages was classified into 5 types and Grade 1 to 5. Table 6 provides the standards for the grade attribute division for different land types.

Table 6. The grade standards of land types.

Land Type	Construction Land	Idle Land	Forest and Grassland	Land for Other Purposes	Arable Land
Grade	5	4	3	2	1

2.1.3. Social Economy

(1) Population density (C7)

Population density refers to the size of population inhabiting the land. The larger the village population, the bigger the development power and the higher the grade received. Table 7 provides the grade standards for the population density.

Table 7. The grade standards of village population density.

Population Density (People/hm^2)	0–2.4	2.4–4.8	4.8–7.2	7.2–9.6	9.6–12
Grade	1	2	3	4	5

(2) Annual per-capita net income (C8)

In addition to population density, the annual per-capita net income of the villagers can be taken as the appraisal index of village vitality. It is used as a judging standard of village development power. By generalizing and arranging the annual per-capita pure income data of 3 rural villages to be highlighted in the case study, we divide into 1–5 different grades according to the value size in Table 8.

Table 8. The grade dividing standard of annual per-capita pure income.

Annual Per-Capita Net Income (RMB 10,000)	1–1.6	1.6–2.2	2.2–2.8	2.8–3.4	3.4–4.0
Grade	1	2	3	4	5

2.2. ArcGIS and ENVI Platform

This study conducted a quantitative assessment on the rural spatial morphology evolution at two levels, physical space (geographical location and landform) and social economic. The ArcGIS technique was used to quantify the driving factors. ArcGIS is a computer system for entering, storing, inquiring about, analyzing and displaying geographical data. The spatial analysis tools involved included buffer area analysis, surface analysis, and reclassification and overlay analysis. The ENVI platform was also applied for the quantification of land types. It is one of the important analysis tools used for the quantification of evolution trend of rural spatial form.

2.3. Analytic Network Process (ANP)

To assess the impact of the eight driving factors on the rural spatial morphology evolution, a comprehensive analysis of these factors was conducted, and a multi-criteria decision-making framework established, to assess each driving factor. As shown in Figure 1, the rule levels for rural evolution studies influence each other. To accurately assess each rule level and driving factors at the sub-rule level, the Network Analysis (ANP) method was used. The ANP is a decision-making method adapting to non-independent hierarchical structures, proposed by Professor Saaty of the University of Pittsburgh in 1996 [42]. It obtains a weight of the various driving factors on rural evolution after considering the quantitative grade of each driving factor. Steps 1 and 4 summarize the ANP method applied to this study.

Step 1. Define the objective, rules, and network: the objective of this study was to assess the rural spatial morphology evolution in three typical villages and in each village, consider the three rule levels and eight driving factors. The network between objective, rule, and driving factors was shown in Figure 1.

Step 2. Define the unweighted supermatrix: when the network is set, we need to determine an unweighted matrix. Based on assessment scales, we can define a super-matrix (w_S) of all driving factors by comparing the two against one another. For example, Figure 2 shows $(B_1, B_2, \ldots, B_N)$ the series of rule levels, where N is the number of rule levels and $(c_{11}, c_{12}, \ldots, c_{1n1})$ the series of driving factors in rule level. Therefore, B_1, $(n1, n2, \ldots, nN)$ is the series of number of driving factors at the rule levels.

Step 3. Define the weighted supermatrix: Table 9 contains the assessment scales to compare each pair of driving factors. With this information and the unweighted matrix, the weighted supermatrix can be calculated. For example, taking rule level B_j, we can get the assessment matrix shown in Figure 3. We can then normalize the assessment matrix and get a weighted matrix to represent the relationship between driving factors.

$$W_S = \begin{array}{cc} & \begin{array}{ccccccccccc} & B_1 & & & B_2 & & & & B_N & \\ c_{11} & c_{12} & \cdots & c_{1(n1)} & c_{21} & c_{22} \cdots & c_{2(nN)} & \cdots & c_{N1} & c_{N2} \cdots & c_{N(nN)} \end{array} \\ \begin{array}{cc} B_1 & \begin{array}{c} c_{11} \\ c_{12} \\ \vdots \\ c_{1(n1)} \end{array} \\ B_2 & \begin{array}{c} c_{21} \\ c_{22} \\ \vdots \\ c_{2(n2)} \end{array} \\ \vdots & \vdots \\ B_N & \begin{array}{c} c_{N1} \\ c_{N2} \\ \vdots \\ c_{N(nN)} \end{array} \end{array} & \begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1N} \\ W_{21} & W_{22} & \cdots & W_{2N} \\ \vdots & \vdots & & \vdots \\ W_{N1} & W_{N2} & \cdots & W_{NN} \end{bmatrix} \end{array}$$

Figure 2. The unweighted supermatrix assessment.

Table 9. Assessment scales of each driving factor.

Scale	Description
1	The two driving factors have the same importance
3	One driving factor is slightly more important than the other one
5	One driving factor is obviously more important than the other one
7	One driving factor is strongly more important than the other one
9	One driving factor is extremely more important than the other one
2, 4, 6, 8	The importance between each of the above two scales

Note: The comparison between driving factor i and j is a_{ij}, then comparison between driving factor j and i is a_{ji}.

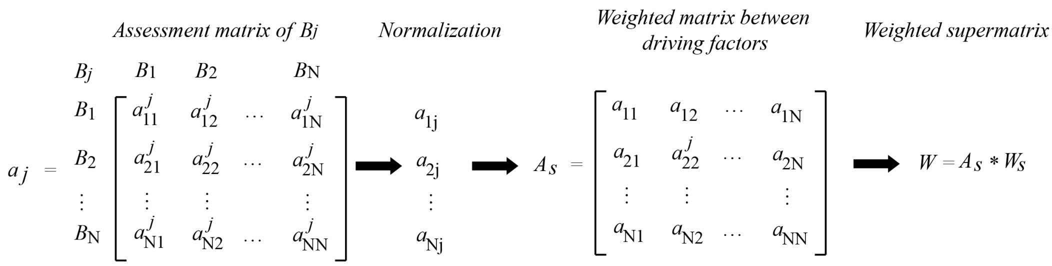

Figure 3. Overview of the weighted supermatrix.

Step 4: Calculate the weight of each driving factor. After step 3, we can calculate the weight of each driving factor as $[W_1, W_2, \ldots W_m]^T$, where m is the number of total driving factors. Finally, we can normalize the vector and get the impact of driving factors on rural spatial morphology evolution using Equation (1).

$$\overline{W_i} = \frac{W_i}{\sum_{j=1}^{m} W_j} \tag{1}$$

3. Case Study

Figure 4 shows the logic of the proposed framework in this study, and to validate the framework, this study selects three typical villages as a case study. Three cases of rural villages, located in the south of Jiangsu Province, were selected to assess the rural transformation. The southern Jiangsu Province is one of the most economically-developed regions in Jiangsu Province and China, shown in Figure 5. The region is a good representation of a typical case found in Chinese rural spatial morphology evolution. This study selected three different types of rural villages within the southern Jiangsu Province, namely, a suburb-radiation type, a resource-development type, and an integrated and independent type.

Data used included Yearbook reports provided by local governments, topographic information, coupled with Google map imagery. Specifically, geographical information, including AutoCAD maps and high-definition satellite imaging maps in different periods of the villages, were obtained from governmental departments. In addition, it was generally assumed that the topographic and mapping information was accurate, therefore, the emphasis of this paper is on completing the research objectives of defining a novel framework for quantifying the impact of the eight driving factors on rural spatial morphology based on ArcGIS, ENVI, and ANP and applying this to the case study, and providing a baseline to help assess decision making.

However, in addition to the data collection, informal site observations, recording and video shooting, and visits to the relevant administrative departments, were conducted as part of the data collection process. However, these trips were mainly used to provide a more complete assessment of the data, with the raw content not included in this paper.

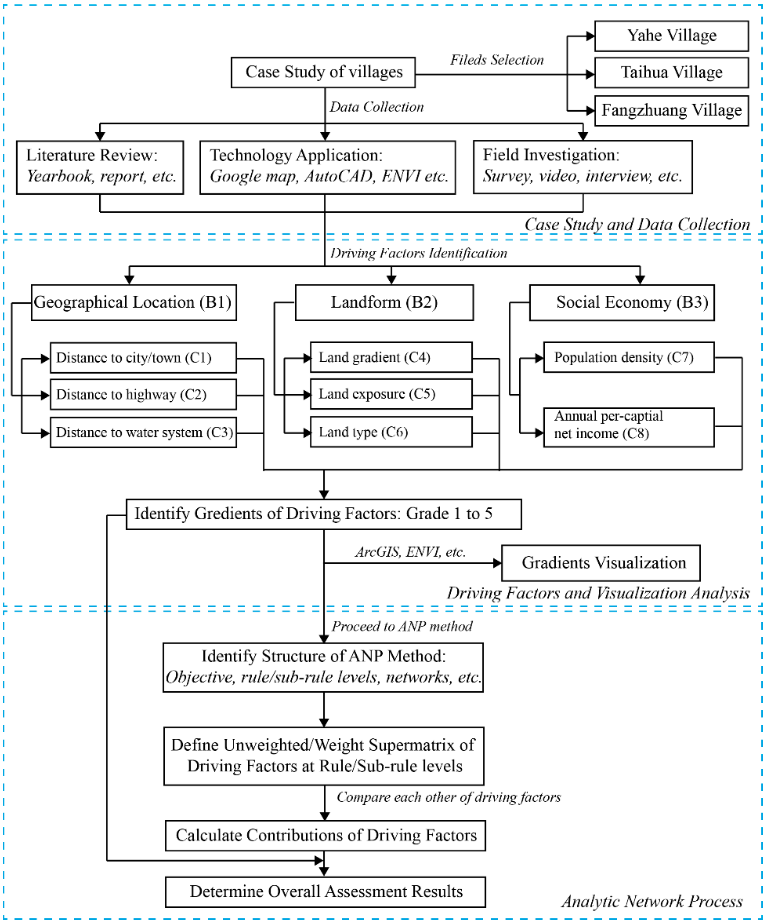

Figure 4. The logic of the proposed framework in this study.

Figure 5. The location of the Southern Jiangsu Region in East China.

3.1. *Villages of Suburb-Radiation Type*

Villages of suburb-radiation type are located near the nucleus of the town development and have a prominent location advantage. The convenient traffic, economic advantage, and job opportunity of the town can attract inhabitant migration from rural villages in search of improved economic opportunity. This negatively impacts the rural infrastructure and strength. Therefore, villages of suburb-radiation type assume a pro-economic development trend and toward densification.

Yahe Village is of suburb-radiation type and located by Niutang Town, the epicenter of the Wujin District of Changzhou City, shown in orange in Figure 6. Yahe Village has an area of 3.6 km^2 with 3215 official villagers and roughly 2500 inhabitants from other areas. In 2016, the annual per-capita net income was roughly RMB 26,800. The distance to Niutang Town is about 3.5 km by bus taking about 27 min. Driving a car the distance and time shortens to 3 km and 7 min.

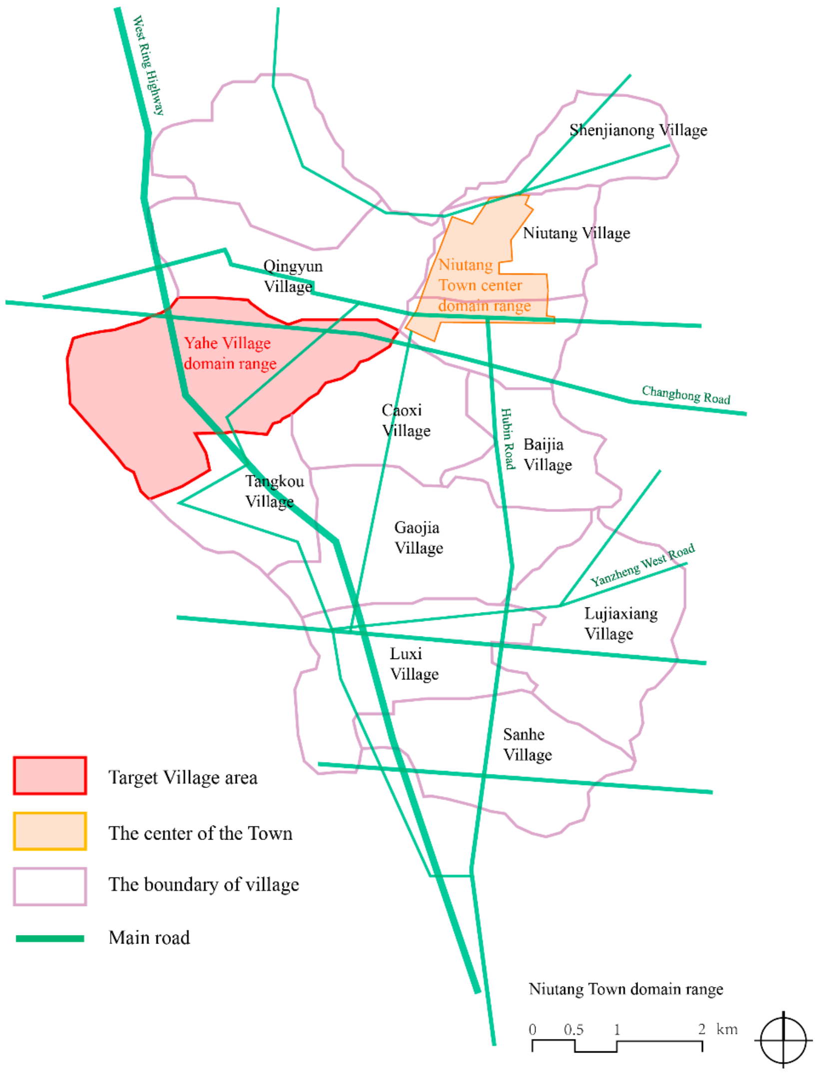

Figure 6. The area of Yahe Village.

3.2. *Villages of Resource-Development Type*

The villages of the resource-development type have unique resource and industrial advantages and limitations, providing more consistent morphology overtime. Generally, such areas have limited natural and industrial activities, only enough to promote self-supporting rural developments, rather than mighty or emerging industries, such as newly-discovered mineral resources, scientific and technological support. Therefore, the rural area is basically stable, with new construction activities limited to mostly upgrading or re-constructing original dwellings. The vitality, vigor and traditional landscape of the village can be maintained over time.

Taihua Village is located by Taihua Town, the center of which is orange (Figure 7), and includes the famous Taihua Mountains. It has an area of 18 km^2. Taihua region has the largest moso bamboo base in Jiangsu province, with bamboo forest covering about 7 km^2. Considering its unique natural landscape, limited technological resources and moso bamboo processing industry, Taihua Village can be categorized as a village of resource-development type.

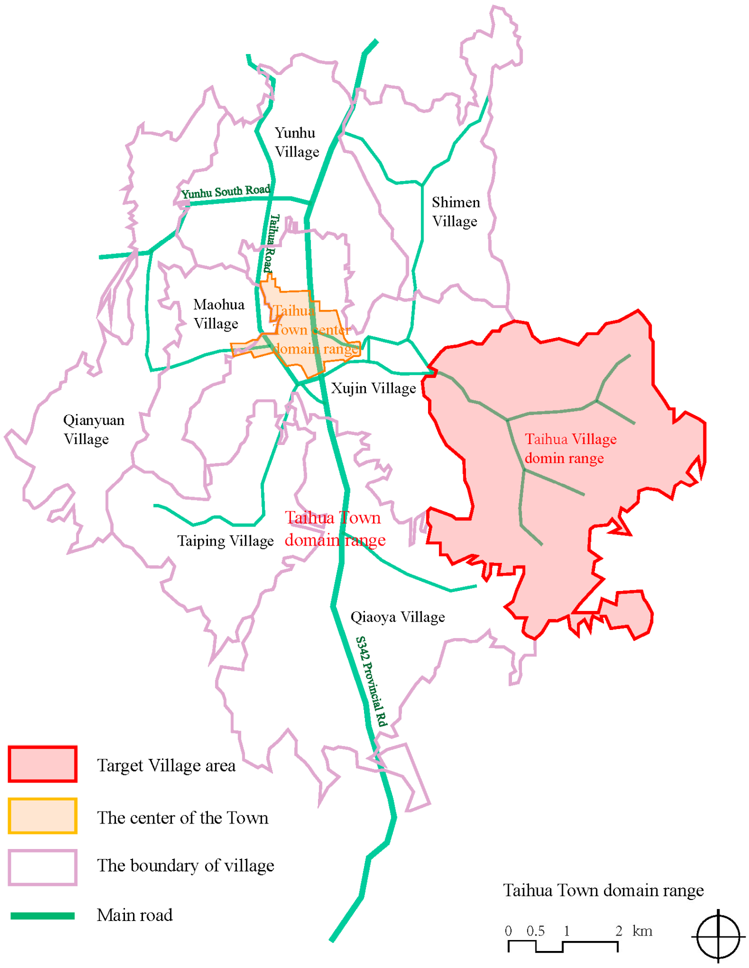

Figure 7. The area of Taihua Village.

3.3. *Villages of Integrated and Independent Type*

Villages of integrated and independent type are furthest away from the town, located beyond the radiation of town resources, and often require superior resource endowments to support their development. Villages of this type are often combined with traditional villages or towns, and have little to no new development.

Located in the northwest of Xushe Town, the center of which is orange in Figure 8, Fangzhuang Village has an area of 7 km^2 with annual per-capita income of RMB 11,678. Fangzhuang Village is the furthest away from the town, and does not have a large-scale township, but its unique history, humanistic landscape and distinctive local industry (e.g., mutton), enable the village to maintain some development.

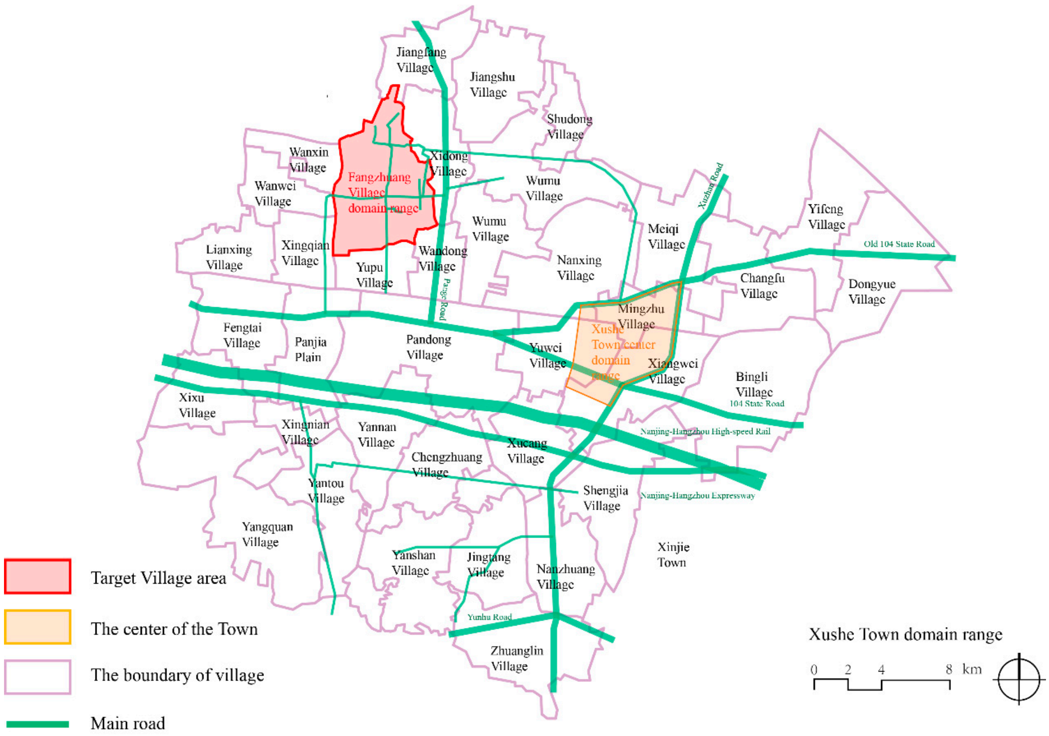

Figure 8. The area of Fangzhuang Village.

4. Results

4.1. The Results of Driving Factors

4.1.1. Geographical Location Factors

The geographical location has a vital impact on development. The factors of geographical location selected in the research include the distance from the village to the nearest town, highway and water system. Based on geographical data, a corresponding buffer area operation of the ArcGIS platform was conducted and the numerical grading to distances determined. The grades obtained matched intuition, confirming the advantages of various village locations based on this index.

(1) Distance to town

Towns have a certain radiation effect, such as social, economic attraction which is inversely proportional to distance, with a limited effective scope. Generally, a smaller village closer to a larger town would enjoy better development. The results show the grading of the three villages according to their distance to a neighboring town, Table 10. The grade of villages of suburb-radiation type (grade 5) and villages of resource-development (grade 4) were higher than that of the integrated and independent type (grade 3) indicating the villages of the first two types enjoy certain advantages due to the distance to a town. The results support intuition and were considered reasonable.

Table 10. Grade of villages based on distance to the town.

		Yahe Village	**Taihua Village**	**Fangzhuang Village**
Drive/bus	Distance (km)	3.0–3.5	3.9–8.7	12.0–12.7
	Time (min)	7–27	7–70	16–61
	Grade	5	4	3

Note: Bus distance and time include required walking distance and time.

(2) Distance to road

A village, which has less infrastructure and contacts with the outside, can be greatly influenced if a state highway, a provincial highway or a county-level highway runs through or around the village. The result of such resource access is an increase in the circulation of the industrial resources and the technical exchange with other villages. Vector drawings were coupled with the buffer area tool of ArcGIS to obtain the quantitative grade diagram of the research object for this index, aided by the distance grade standards already calculated. Figure 9 shows the results of the road buffer grade maps of the (a) Fangzhuang Village; (b) Taihua Village and (c) Yahe Village.

The results in Figure 9 show that nearly 50% of the Yahe village is within the effective radiation scope of main roads. At the level of this quantitative factor, the village enjoys obvious advantages, with an overall calculated grade of 5. Taihua Village, located in a mountainous region, had only one village-level highway through the village. With a small radiation scope, grade 1 resulted. There are two roads crossing the Fangzhuang Village, within portions of the radiation scope, an overall grade 4 was calculated.

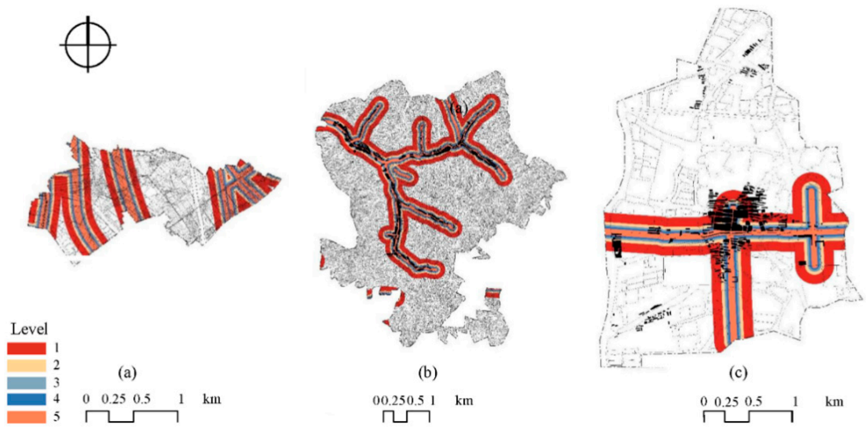

Figure 9. The grade diagram of road buffer areas: (**a**) Yahe Village; (**b**) Taihua Village; (**c**) Fangzhuang Village.

(3) Distance to water system

The southern Jiangsu Province has a dense water network. Water systems have a major impact on the early structure and formation of the village, the traffic mode, and landscape pattern of the region. Following the grade standards and quantitative steps used to calculate the distance to the highway, water system buffer grade maps of the three villages were calculated. The results are shown in Figure 10.

The Mengjin River and New Wuyi Canal run through the Yahe Village with a certain effective radiation scope. However, the village today does not enjoy big advantages from these rivers and was graded a 3. In the Taihua Village only one small water system runs through the village, with a small radiation scope, therefore was graded as 1. Fangzhuang Village has the densest water network (Figure 10c), with the entire village almost completely located within the effective radiation scope of the water systems. Therefore, this village enjoyed the biggest advantage for the three villages, being calculated at grade 5. The grades given and the map topography (Figure 10) are in good agreement.

To summarize, using quantitative comparison of the three factors related to geographical location, Yahe Village has a shorter distance to town, and is very close to roads, and received high grades due to these aspects; however, Yahe Village did not have a robust water system. Taihua Village preformed the worst regarding the distance to the roads and water systems receiving both a Grade 1. Fangzhuang Village had slight disadvantages in both the distance to the town and the distance to the road network; however, it enjoyed certain advantages in the distance to water systems, receiving the highest grade (grade 5).

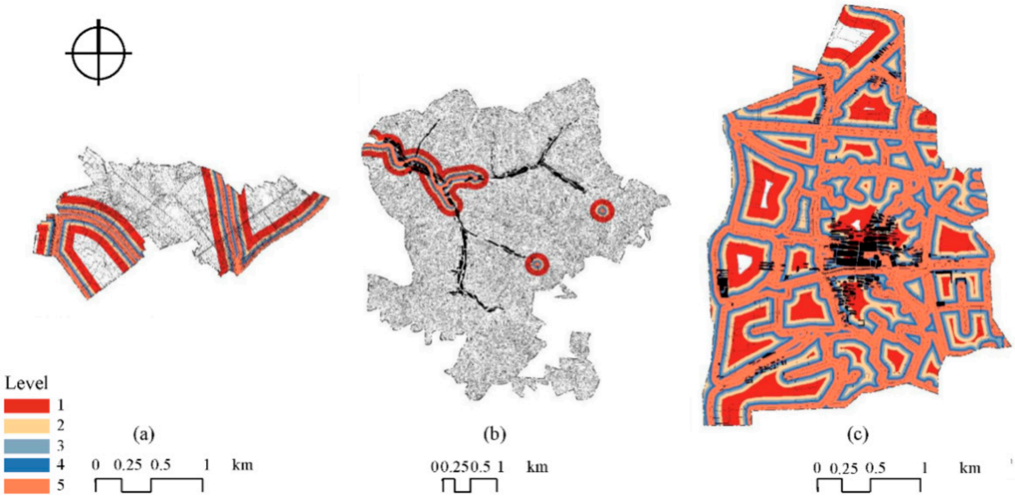

Figure 10. Grading maps of water system buffer areas: (**a**) Yahe Village; (**b**) Taihua Village; (**c**) Fangzhuang Village.

4.1.2. Landform Factors

Driving factors of landform include ground gradient, exposure and land type. As to the former two factors, DEM (digital elevation model) is commonly used as the data source for the quantification of the ground gradient and exposure, which can be downloaded from some websites, such as Geospatial Data Cloud. However, the research objects of this study were villages and the resolution of the data obtained from the website was too low to be analyzed. Thus, in this study, TIN data of 3 villages were generated within the ArcGIS platform by extracting contour lines or elevation points in CAD topographic maps. In addition, the ground gradient and exposure were then analyzed through the use of TIN surface analysis tool.

(1) Land gradient

Ground gradient of landform plays a decisive role in the development layout, architectural site selection and road planning of villages. We obtained their quantification using ground TIN elevation maps. With the gradient extraction tool of the TIN surface analysis tools of ArcGIS, we can obtain the gradient maps of the three villages, and divide them into five grades according to the gradient scope (see Figure 11).

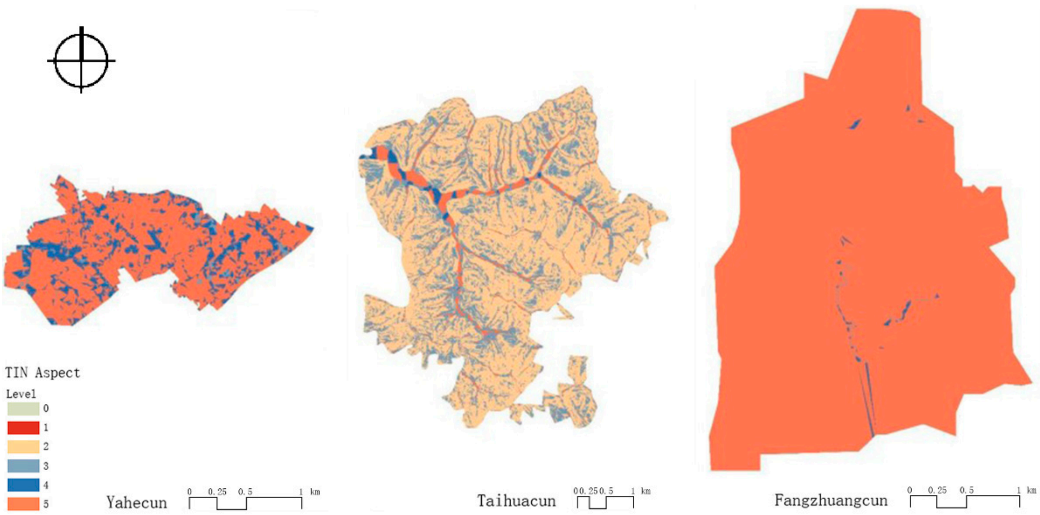

Figure 11. TIN gradient grade maps: (**a**) Yahe Village; (**b**) Taihua Village; (**c**) Fangzhuang Village.

Yahe Village of suburb-radiation type and Fangzhuang Village of integrated and independent type are both plain-based villages graded as 5. They have a small undulation of elevation. Taihua Village, of the resource development type, located in the mountain region, with a big elevation change was graded as 2.

(2) Land gradient

Just like ground gradient, we conducted quantitative grading to exposures with the exposure analysis tool and reclassification tool of the ArcGIS platform. According to the standards, we obtained the following TIN exposure grade maps.

In agreement with the TIN elevation maps, the Yahe Village type (grade 4) of suburb-radiation and Fangzhuang Village (grade 5) of integrated and independent type had small gradient undulations, enjoying obvious advantages of level ground. The mountainous Taihua Village calculated an overall area grade of 3 (Figure 12b).

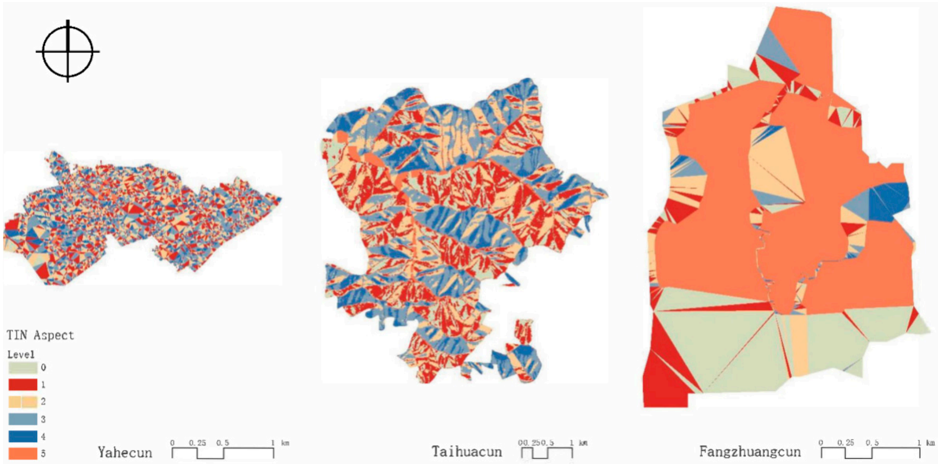

Figure 12. TIN exposure grade maps: (**a**) Yahe Village; (**b**) Taihua Village; (**c**) Fangzhuang Village.

(3) Land types

The difference of land use types also has a certain impact on rural development. Using Google image maps, the land type grading maps were determined in Figure 13.

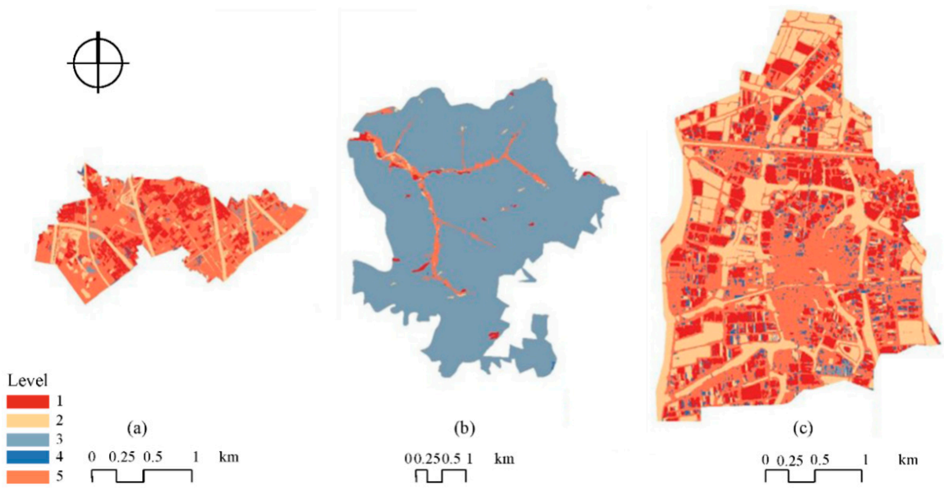

Figure 13. Land type grade maps: (**a**) Yahe Village; (**b**) Taihua Village; (**c**) Fangzhuang Village.

Yahe Village of suburb-radiation type and Fangzhuang Village of integrated and independent type have a big percentage of high-grade land types shown in red, sharing a big advantage at the level for this factor (Figure 13a,c). This is in agreement with the fact that most of both villages' area is construction land with grade 5. Meanwhile, Taihua Village, of resource development type, has a small distribution of high-level land types, shown in mostly blue color (Figure 13b). Most of it is forest and grass land and can be graded as 3.

As inferred by quantitative grades to the relevant factors of the landform of 3 typical villages: Yahe Village has a big advantage at the level of gradient and type of land, and does not have any advantage at the level of exposure. Located in a mountainous region, Taihua Village lies in a disadvantageous position at the level of three factors of landform. Located in a plain region, Fangzhuang Village has a high grade of gradient, exposure and land type in the village scope, with obvious advantage. Different factors have different representative forces on the spatial forms of villages. The process values of quantification result will be used in the subsequent operation of factor overlay analysis.

4.1.3. Social Economy Factors

Social economy is a nonmaterial-level factor in rural evolution, including population and annual income. Population density refers to the size of population which resides on the land of the unit area. Generally speaking, the larger the population density, the bigger the development power, and the higher the grade calculated. According to Table 7, we respectively obtained the following population density grades for the 3 typical villages studied. In addition to population density, the annual per-capita net income can also be taken as the assessment index of village vitality. We summarized and arranged the annual per-capita net income data of the 3 typical villages, and graded them accordingly, and divided them into 1-5 grades according to the value sizes (Tables 11 and 12).

Table 11. The grades of population density of the villages.

Village Name	Yahe Village	Taihua Village	Fangzhuang Village
Population (person)	4230	6290	4455
Village area (hm^2)	363	1813	688
Population density (person/hm^2)	11.65	3.47	6.48
Grade	5	2	3

Table 12. The grades of the annual per-capita net income.

Village Name	Yahe Village	Taihua Village	Fangzhuang Village
Income (RMB 10,000/person)	1.65	1.10	1.06
Grade	2	1	1

By grading 2 factors at the level of social economic form of the 3 typical villages, we drew the following conclusion: Yahe Village is located in the plain region, with obvious advantage in population density, and a small gap in annual per-capita pure income. Taihua Village does not have any advantage at the above-mentioned 2 levels. Fangzhuang Village, located in the plain region, has a moderate grade of population density, with certain advantage, and does not have any advantage in annual per-capita pure income.

4.2. The Assessment Results Using ANP

After analyzing the eight driving factors, this study applied the analytic network process as a decision-making baseline to assess the performance of the different driving factors on the rural evolution. Table 9 shows the assessment scales of each driving factor. This can be used in determining the importance of two driving factors at the rule level. Using the ANP method, this study calculated the results of assessment of different driving factors, as shown in Figure 14. In Figure 14, the weights of the impact of different driving factors can be found normalized using Equation (1).

The results showed that the driving factor C1, the distance from the rural village to urban or town center, had the highest percentage impact (20%, ranking 1). This is the most influential factor and plays an important role in rural development and evolution. The next ranking driving factor, the distance to the highway (C2, 7%, ranking 2), was performed similarly to the net income (C8, 6.9%, ranking 3). Thus, being closer to a major road provides convenient access to resources being received or exchanged. The factors such as distance to water systems (C3) and land type of rural (C6) village were performed similarly. The population density (C7) was unremarkable. The surface gradient (C4) and exposure of land (C5) had the lowest impact.

Driving factor	Raw	Normal	Ideal	Rank
C1	0.1016	0.2032	1	1
C2	0.0695	0.139	0.684	3
C3	0.0613	0.1226	0.6033	5
C4	0.0416	0.0832	0.4096	8
C5	0.0416	0.0832	0.4096	7
C6	0.064	0.1279	0.6296	4
C7	0.05	0.1	0.4919	6
C8	0.0705	0.1409	0.6937	2

Raw: the score of driving factor after supermatrix in ANP
Normal: the normalized weight of driving factor using Eq. 1 in rural transformation.
Ideal: the weight of other driving factor compared with C1
Rank: the rank of driving factor

Figure 14. Assessment results of different driving factors.

With the weights of different driving factors calculated (Figure 14), the final grades of the eight driving factors can be applied to the three cases of rural villages to observe a final result of the rural evolution of the regions. Figure 15 summarizes the grades of the eight driving factors in three rural villages. Equation (2) was used to calculate the final grade of three typical rural villages.

$$S = \sum_{i}^{n} \overline{W}_i * G_i \tag{2}$$

where $\overline{W}_i$ is the normalized weight of different driving factors and n is the number of driving factors. G_i is the grade of different driving factors.

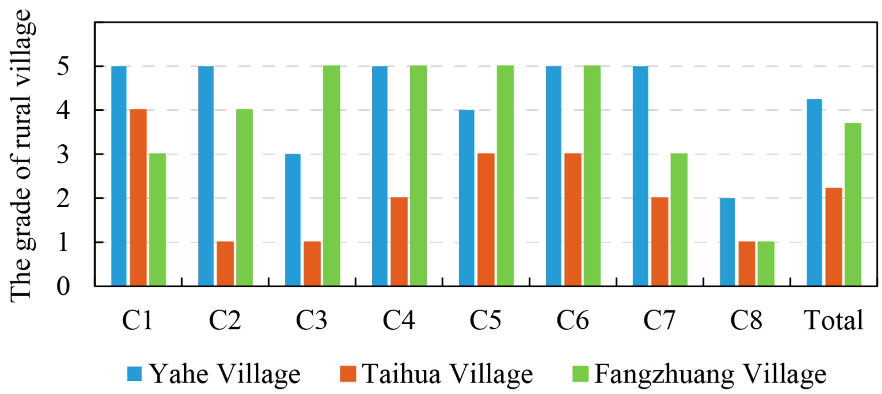

Figure 15. The assessment results of three typical rural villages.

The results presented in Figure 15 show the final grades or overall evaluation of three typical rural villages used in the case study. The average grade for Yahe Village was around 4.24, higher than the other two rural villages. This supports the fact that villages of suburb-radiation type have big development advantages, strong survivability and development potential. The total grade of Fangzhuang Village was about 3.69. An argument can be made that villages of integrated and independent type have certain development advantages, with results supporting the idea of certain financial or policy-based support warranted. The Taihua Village received the lowest grade, at around 2.21. This shows low development power, with governmental or outside support needed to contribute toward any human, material or financial resource development.

5. Discussion and Limitations

The sustainability of rural development is quite important in modernizing the agricultural and forestry sectors, protecting the environment and improving the quality of life [43]. China has hundreds of thousands of rural villages, which occupy more than half of all Chinese land (about 58%). Although China has a unique urban-rural relation, the development of rural villages always lies in a relatively disadvantageous position, impacting relevant data reserves. In the context of information technology, interdisciplinary research has been arousing more and more attention, further expanding technical and methodologic capabilities. This study quantitatively obtained the grade distribution diagram within the case study of three typical villages. Eight driving factors of three rural villages, in terms of geographical location, landform, and social economy of rural villages were obtained and accordingly conducted quantitative research on three rural villages with ArcGIS and ENVI. A decision-making method, ANP, was utilized to analyze the performance of different driving factors in rural spatial morphology evolution of the villages. The objective of this study was to investigate the correspondence between the rural spatial morphology through quantitative analysis and compare the performance of different village types. The techniques and methodology established in this study provide a baseline for future studies and can be used in influence policy makers. In the context of China's new urbanization, this study can compensate for the insufficiency of present study countryside. This study can be regarded as a kind of positive and beneficial exploration by extending the knowledge of ArcGIS spatial structure and ANP integrated multi-criteria decision-making process to quantitatively analyze and evaluate rural area. To summarize the results, this study suggests:

(1) The village of suburb radiation type is a rural mode in the effective radiation scope of the town, and the quantification to rural spatial structure indicates that it has a great development potential. The evolution trend of rural villages of this type usually performs as a growth type, indicating that most of the villages which are close to the urban system, having a strong potential of development and vitality;
(2) The village of resource development type is supported by characteristic industries, and the quantification to rural spatial structure, indicating certain developmental advantages. The trend of spatial form of villages of this type generally assumes a development mode of progression, and can maintain its own steady development under the support of supportive industries, and can moderately receive certain policy support;
(3) Villages of integrated and independent type do not have the same location advantage and industrial advantage as the above two types of villages. Most of them are based on the combination of several aggregated natural villages retained for the historical reason. The results from the quantification of this type indicate that: (a) social and economic forms show an obvious growth; and (b) material space forms show some stability. Any popularity in new rural growth maybe temporary and if not supported, becomes unsustainable. Considering the low grade calculated in the results, suitable economic or industrial recurrent support to maintain continuous and steady development of villages of this type is needed.

Despite the clear findings, there were some limitations when conducting this study. Firstly, the difficulty in obtaining historical data and the rapid development of Chinese urbanization makes it difficult for the diachronic evolution of spatial forms of rural villages. A longer period of data is required for more comprehensive studies of rural villages. Secondly, based on the Chinese household management system, the rural people who work and live for a long time in cities but whose household registration has not been transferred out of rural villages are still categorized in rural population. As a result, the population density generated according to the statements is on the high side, and cannot fully reflect the actual population density of rural villages. Meanwhile, due to the lack of net income of individual families, this study did not visualize spatially the information of factors c7 and c8. However, it is important to conduct such spatialized information in the future with a more detailed dataset. Additionally, indices could be included in future studies to research historical space forms of rural villages. Finally, although ArcGIS has obvious technical advantages in spatial data analysis, however, rural studies are more complex and if data collection and arrangement is lacking regarding to rural planning and construction, it becomes difficult to timely and effectively collect, arrange and renew the data based on the analysis of the ArcGIS analysis, e.g., income, population and digital elevation.

6. Conclusions

A framework and methodology was developed and applied to analyze the rural spatial morphology of the typical rural villages in China. Within the framework three levels were established (A) The Goal Level: to determine the evolution of the rural spatial morphology; (B) The Rule Level: geographical location (B1), landform (B2), and social economy (B3); and (C) the eight driving factors. The framework was applied to a case study with different types of villages, (1) the Yahe Village as suburb-radiation type; (2) the Taihua Village of the resource-development type; and (3) the Fangzhuang Village as integrated and independent type, providing a standard method for research results to be generally applied to other provinces and cities of China. Using the case study, we investigated the impact of the eight driving factors on the rural spatial morphology evolution. The quantification of each factor's impact on development provided insight into different performance levels of the driving factors. The decision-making method, analytic network process, further revealed that the distance from the rural village to city/town had the biggest impact on rural development compared to the other seven driving factors considered. By using a five-level grade system for each of the eight factors, we found that the Yahe Village had an average grade of 4.24/5, the highest of the three rural villages. These results suggest big development advantage for this village, with strong survivability, and justification to receive more support from different governmental department for development. The total grade for the Fangzhuang Village was about 3.69. The Taihua Village received the lowest grade of around 2.21. Villages with lower scores will require more attention and support for rural development and transformation, due to different limitations shown by the driving factor scores. This study developed a synthetic analysis framework for rural villages of different types. The findings provide insights into the transformation of rural villages along with their driving factors, which can inform China rural planning, management and construction during its current rapid urbanization process. The proposed framework can also provide a significant reference study of applying multiply driving factors with multi-year rural datasets when quantifying time-varying rural spatial morphology in the future.

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