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Suitability Evaluation of Rural Settlements Based on Accessibility of Production and Living: A Case Study of Tingzu Town in Hubei Province of China

LIU Yaolin[1, 2], YE Qingqing[1], LI Jiwei[1], KONG Xuesong[1], JIAO Limin[1]

(1. *School of Resource and Environment Science*, *Wuhan University*, *Wuhan* 430079, *China*; 2. *Key Laboratory of Geographic Information System*, *Ministry of Education*, *Wuhan University*, *Wuhan* 430079, *China*)

Abstract: Rural settlements are the main carriers of agriculture, rural areas and farmers; thus, optimizing the production and living space of rural settlements is highly significant to rural development. Taking the effective allocation of resources as the starting point, a suitability evaluation system of rural settlements, based on accessibility of production and living, was proposed in this study to provide scientific basis for the optimization of production and living space. The accessibility of production and living was measured by an improved two-step floating catchment area method, which considered proximity and availability based on the inclination of rural residents. The suitability evaluation system consisted of traditional suitability evaluation and newly proposed limiting factor identification based on the loss score proportion of suitability. Tingzu Town of Hubei Province, China, was chosen as the case study area. Based on the results of the suitability evaluation system, corresponding suggestions on rural land consolidation, industry division, as well as the layout of health care and education facilities were proposed to optimize the production and living space of rural settlements in Tingzu Town. It is found that the suitability evaluation based on accessibility of production and living is more scientific and accurate than the traditional ones which significantly overestimate production and living convenience. Moreover, the limiting factor identification can help us put forward suggestions according to local conditions and bring about the highly targeted optimization of production and living space of rural settlements.

Keywords: rural settlements; suitability evaluation; accessibility of production and living; two-step floating catchment area (2SFCA) method; limiting factor identification; Tingzu Town

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1 Introduction

At the turn of the new millennium, China entered an important development period for promoting industries to support agriculture and cities to support villages (Long *et al*., 2011). Moreover, agriculture, rural areas and farmers have become critical problems in China′s social and economic development (Zhou *et al*., 2013). Rural settlements are the main carriers of agriculture, rural areas and farmers; thus, optimizing the production and living space of rural settlements is significant to address the aforementioned three rural issues (Qiao *et al*., 2008; Cheng *et al*., 2013). However, the scientific construction of rural settlements has not been taken seriously because of the traditional dual-track structure of rural-urban development. At present, disordered layout,

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Corresponding author: LIU Yaolin. E-mail: yaolin610@163.com

poorly designed infrastructure, and inequality in public services characterize the present construction, which in turn have led to inconvenient production and living space (Qu *et al*., 2010). Moreover, with the acceleration of urbanization and industrialization, the area of rural settlements has continued to expand in spite of a decreasing rural population (Long *et al*., 2012). The farmland has constantly decreased because of urban-rural construction land expansion (Long *et al*., 2009; Liu *et al*., 2010a; Tan *et al*., 2011). These conditions are not in accordance with the basic national condition of 'more people and less land', which could lead to food security problems. Therefore, conducting the consolidation and planning of rural settlements, optimizing the production and living space, and rationally allocating the infrastructure and public services for rural development are very important measures that should be immediately implemented in China. However, the suitability of rural settlements must first be evaluated and analyzed prior to the implementation of these measures.

Rural settlements are production and living places for rural residents (Ma *et al*., 2013), of which the suitability is mainly determined through the performance of production and living functions. The performance depends on not only natural factors (e.g., slope, distance to water and geological hazard influence), but also more importantly the effective allocation of production and living resources. This allocation should be reflected and measured by the demand-supply matching degree between settlement demands and production and living resources. On the one hand, the layout of rural settlements should consider the proximity to surrounding production and living resources to minimize the travel costs of rural residents. On the other hand, the surrounding production and living resources should meet settlement demands to ensure the effectiveness of the production and living functions (Sun *et al.*, 2011). Therefore, the suitability of rural settlements should be evaluated in consideration of natural factors as well as the space and quantity matching between settlement demands and resources to identify whether the status layout of rural settlements facilitates the performance of the production and living functions. The results of the suitability evaluation can effectively guide the optimization of production and living space, thus giving full play to the production and living functions of rural settlements.

Previous studies on land suitability evaluation mainly focused on agricultural land (Cools *et al*., 2003; Reshmidevi *et al*., 2009; Liu *et al*., 2010b; Rodriguez-Gallego *et al*., 2012; Xu Y Y *et al*., 2012; Akinci *et al*., 2013; Feizizadeh and Blaschke, 2013) and not on construction land. Moreover, studies on the suitability evaluation of construction land primarily involved urban suitability assessment as well as site suitability analysis (Dai *et al*., 2001; Dong *et al*., 2008; Charabi and Gastli, 2011; Xu Y Y *et al*., 2012), and not rural settlement suitability. However, because of the national macro-control tendency, hierarchical planning is the main form employed in China to optimize rural settlements. Therefore, the macro-scale suitability evaluation of rural settlements is relatively common. In the evaluation method, previous studies mainly employed the multi-factorial comprehensive evaluation method (Xu Baowen *et al*., 2012), niche suitability (Qin *et al*., 2012), pressure model (Shuang *et al*., 2013), minimum cumulative resistance model (Wu *et al*., 2013) and matter-element model (Gong *et al*., 2012). The multifactorial comprehensive evaluation method is most widely applied, which is also employed in this study. In the evaluation index system, elevation, slope, distance to water and geological hazard influence were often selected to represent natural factors (Guo *et al*., 2012; Kong *et al*., 2012). The respective area proportions of agricultural and nonagricultural land, as well as distance to these lands, were also selected as factors that represented production conditions (Qu *et al*., 2010). The size of settlements, area proportions of the service facility land, and distance to town were selected to represent living factors (Qin *et al*., 2012). However, only the distance or area proportion indexes are not enough to reflect the demand-supply matching, and the integration of space and quantity has been neglected, leading to deviation results. In the evaluation system, the suitability evaluation was conducted merely by classifying suitability; however, an in-depth analysis on the factors that promote or limit suitability was often neglected. The corresponding suggestions may not be implemented because of such limitations; thus, providing effective guidance on optimizing the production and living space of rural settlements become difficult. In this light, the current study establishes the evaluation index system based on accessibility of production and living, measured by the improved two-step floating catchment area method

(2SFCA). This method overcomes the shortcomings of previous methods, which do not consider the matching degree between settlement demands and surrounding resources. Moreover, this study proposes the limiting factor identification based on the loss score proportion of suitability. The suitability evaluation and the limiting factor identification make up the suitability evaluation system of rural settlements, which is then used to propose the corresponding suggestions on optimizing the production and living space of rural settlements.

Accessibility refers to the relative ease with which the locations of activities, such as work, shopping and health care, can be reached from a given location (Luo and Wang, 2003). Accessibility can be classified into four categories, namely, potential spatial access, potential aspatial access, revealed spatial access and revealed aspatial access (Khan, 1992). This study adopts potential spatial accessibility, which consists of two components: proximity and availability (McGrail and Humphreys, 2009). The former refers to the distance or time between population and providers, and the latter involves either the capacity of providers or the size of population in a certain area. The traditional approaches to measure spatial accessibility, such as distance or time to the nearest service and population-to-provider ratios, only capture one aspect of accessibility. In comparison, the gravity model and the 2SFCA method consider both aspects of accessibility, thereby reflecting the demand-supply matching between population and providers. The 2SFCA method was proposed by Luo and Wang in 2003, which is based on the spatial decomposition method of Radke and Mu (Radke and Mu, 2000). The method has been proven to be a special case of the gravity-based method, but is simpler and easier to interpret (Luo and Wang, 2003). Since its introduction, the 2SFCA method has been applied in a wide variety of situations, including health care, employment and education, and has produced excellent outcomes. However, the method has two shortcomings. First, it does not differentiate distance impedance within the catchment, and second, the method is a dichotomous measure. Several studies have attempted to address these shortcomings (Wang, 2012). Some scholars introduced continuous distance decay functions, such as the kernel density, Gaussian, inverse power and exponential functions (Dai, 2010; Schuurman *et al*., 2010; Dai and Wang, 2011; Langford *et al*., 2012), whereas others employed discrete distance decay functions, including the multiple discrete and three-zone hybrid to improve the method (Luo and Qi, 2009; Shi *et al*., 2012; Wan *et al*., 2012a). However, empirical evidence that can guide the choice of one decay function over another has remained minimal (McGrail, 2012). Determining the distance decay function should be based on the inclination of residents. Therefore, the Gaussian function based on the inclination of rural residents is introduced in the current study to transform the 2SFCA method into a more scientific method.

This study builds a suitability evaluation system of rural settlements based on accessibility of production and living, which is composed of suitability evaluation and limiting factor identification. The specific aims of this study are: 1) to put forward an improved 2SFCA method using the Gaussian function based on the inclination of rural residents and make it to be a more scientific tool to measure accessibility of production and living; 2) to evaluate the suitability of rural settlements based on accessibility of production and living through a comprehensive evaluation method; 3) to identify the limiting factors of each evaluation unit using the loss score proportion of suitability; and 4) to propose corresponding suggestions and regional spatial optimization modes on the production and living space of rural settlements.

2 Materials and Methods

2.1 Study area

Tingzu Town is located in the eastern part of Hubei Province, China. It has one street and 19 villages, with an area of 7625.11 ha. Tingzu is located in a hilly region and has ample mineral resources. With the rapid development of society and economy as well as the process of rapid urbanization, this town has entered the stage of promoting industries to support agriculture and cities to support villages. Based on these conditions, optimizing the production and living space in this area has become the main problem of rural development. In 2012, the overall rural population of Tingzu was approximately 52 000, containing 7002 agricultural laborers and 14 505 nonagricultural laborers. The rural settlements, farmland as well as urban and mine land occupied 779.92, 2554.79 and 167.59 ha, respectively. Employment opportunities are mainly distributed in the urban and mine lands. This region has one hospital in the town, one clinic in each village, and 16 schools scattered throughout the whole area (Fig. 1).

2.2 Data source

The suitability evaluation index system of rural settlements in this study shows that the data include natural conditions and accessibility of production and living. The slope was obtained from 30 m ASTER GDEM. The distance to water is the Euclidean distance to lake and river. The geological hazard influence was obtained from the prevention plan of geological hazard with 0.3, 0.6 and 0.9 assigned values based on the influence degrees. Accessibility of production and living includes three aspects: demand, supply and time cost (Table 1). Land use data and traffic data were obtained from land use database of Tingzu in 2012. Population data, including agricultural labors, nonagricultural labors and pupils at village level, were collected from the annual report of rural economic statistics; data on the total population at patch level were obtained from spot investigation. The data on employment opportunities were obtained from the industrial and commercial sector based on the Second Economic Survey of Nation, with job distribution partly confirmed by spot investigation. Health care and education data were obtained from spot investigation.

The evaluation unit in the study is a grid with a size of 50 m × 50 m. The population data, including agricultural labors, nonagricultural labors and pupils at patch level, are difficult to obtain. This study assumed that the distributions of the three kinds of population are similar to that of the total population. Therefore, the three kinds of population at patch level are obtained by multiplying the population of each kind at village level by the percentage of each patch population.

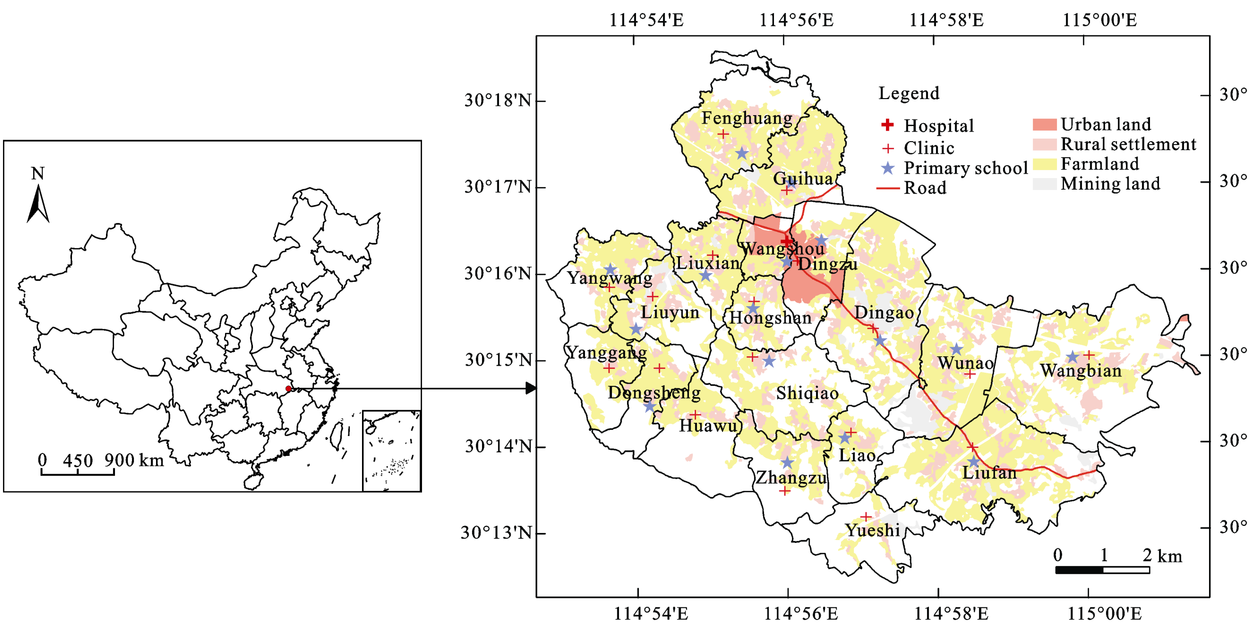

Fig. 1 Location, land use, production and living facilities of study area

Table 1 Data source of accessibility of production and living

Index		Demand	Supply	Time cost
Production	Tillage	Number of agricultural labors at village level; distribution of population at patch level	Area and distribution of farmland	Land use data and traffic data
	Nonagricultural employment	Number of nonagricultural labors at village level; distribution of population at patch level	Number and distribution of employment opportunities	
Living	Health care	Distribution of population at patch level	Number of doctors in each hospital or clinic; distribution of each hospital or clinic	
	Education	Number of pupils at village level; distribution of population at patch level	Number of teachers in each school; distribution of each school	

2.3 Methods

2.3.1 Suitability evaluation system of rural settlements

In this study, the suitability evaluation of rural settlements is a land evaluation system that is used to assess and classify the given land units according to the suitability degree and limitation classes for the given land use of rural settlements. In contrast to agricultural land, the suitability evaluation of rural settlements considers more social and economic conditions, especially the production and living conditions, than natural conditions. Thus, this study establishes the suitability evaluation system of rural settlements based on accessibility of production and living. Here, the suitability evaluation of rural settlements includes five procedures: determining the evaluation units, establishing the evaluation index system, determining the index weights, evaluating suitability, and identifying the limiting factors.

(1) Determining evaluation units

The land evaluation unit is a homogeneous land parcel with similar characteristics, which can be determined using the parcel, grid or overlay methods. The grid method is used in the present study. The evaluation unit with a size of 50 m × 50 m is established according to the characteristics of the evaluation method and rural settlement patches.

(2) Establishing evaluation index system

The study introduces the accessibility indexes, measured by the 2SFCA method, as a substitute to the traditional indexes including distance and area proportion indexes. These accessibility indexes, which are more scientific, consider both proximity and availability, thus reflecting the space and quantity matching between settlement demands and surrounding resources. For accessibility of production, tillage and nonagricultural employment are selected. For accessibility of living, health care and education, as the basic rural public service facilities, are selected. For natural conditions, three frequently-used indexes including slope, distance to water and geological hazard influence are selected based on principal factor and correlation analysis. Then, the suitability evaluation index system of rural settlements based on accessibility of production and living is established (Table 2).

Table 2 Suitability evaluation index system of rural settlements based on accessibility of production and living

Objective	Criteria	Factor	Definition	Weight	Correlation	Method
Suitability of rural settlements	Nature	Slope	Natural background factors affecting daily lives of rural residents	0.087	Negative	Derived from DEM
		Distance to water		0.109		Euclidean distance
		Geological hazard influence		0.137		Prevention plan of geological hazard
	Production	Accessibility of tillage	Access to farmland for agricultural labors	0.111	Positive	2SFCA
		Accessibility of nonagricultural employment	Access to a workplace for nonagricultural labors	0.222		
	Living	Accessibility of health care	Access to health care for rural residents	0.167		
		Accessibility of education	Access to school for pupils	0.167		

(3) Determining index weights

The analytic hierarchy process, which is a multi-criteria decision-making approach introduced by Saaty (Saaty, 1977; Saaty and Vargas, 1980), is employed to determine the index weights (Dai *et al.*, 2001; Akinci *et al.*, 2013; Yi and Wang, 2013). This method is generally used in the comprehensive evaluation of decision-making problems. By establishing the comparison matrix, calculating the weight vector, and certifying the consistency of the judgment matrix, the index weights are finally determined (Table 2).

(4) Evaluating suitability

A comprehensive evaluation method is employed to evaluate the suitability of rural settlements. Suitability is divided into five classes, namely, most suitable, highly suitable, moderately suitable, lowly suitable, and less suitable. These are based on the natural breaks method. The formulas of the comprehensive evaluation method are given by:

$$F_{ij} = \begin{cases} (f_{ij} - f_{\min})/(f_{\max} - f_{\min}) & \text{positive} \\ (f_{\max} - f_{ij})/(f_{\max} - f_{\min}) & \text{negative} \end{cases} \quad (1)$$

$$S_i = \sum_{j=1}^{n} F_{ij} W_j \tag{2}$$

where f_{ij} is the value of index j in the unit i; $f_{\max}$ is the maximal value of index j; $f_{\min}$ is the minimal value of index j; F_{ij} is the standardized value of f_{ij}; S_i is the suitability of the unit i and W_j is the weight of index j.

(5) Identifying the limiting factors

Limiting factor identification, which is different from suitability evaluation because the latter compares all evaluation units, is used to analyze which factors limit the suitability of a given unit. The identification result can guide us to specifically improve suitability. The limiting factors are identified by measuring the loss score proportion of suitability. The main procedures of this step are stated below.

The first step is to calculate the loss score of suitability using

$$L_{ij} = (1 - F_{ij}) W_j \tag{3}$$

The second step is to calculate the loss score proportion of suitability using

$$P_{ij} = L_{ij} / \sum_{j=1}^{n} L_{ij} \tag{4}$$

where L_{ij} is the loss score value of suitability of index j in the unit i and P_{ij} is the loss score proportion of suitability of index j in the unit i.

The third step is to identify limiting factors through selecting indexes with loss score proportions of suitability values exceeding a given threshold. The threshold of loss score proportion of suitability is determined to be 23% in this study through a series of experiments and analysis.

2.3.2 Evaluating accessibility of production and living

(1) 2SFCA method

Searching each provider and population demand is required in the 2SFCA method. For each provider location j, all population locations k within a threshold distance from location j (i.e., catchment area j) must first be searched, and then the population-to-provider ratio R_j must be computed. For each population demand location i, all provider location j within a threshold distance from location i (i.e., catchment area i) must then be searched. Subsequently, the population-to-provider ratio R_j must be summarized (Luo and Wang, 2003; Wang and Luo, 2005). Here, providers are labeled as a, b and c. Population demand is 1 to 15 (Fig. 2). The catchment area for provider a has eight residents, and thus its population-to-provider ratio R_a is 1/8. Similarly, the population-to-provider ratio for catchment b (R_b) is 1/4. The resident 4 is located in an area overlapped by catchment areas a and b, and therefore its accessibility (R) is 3/8, the sum of the catchment a ratio and the catchment b ratio.

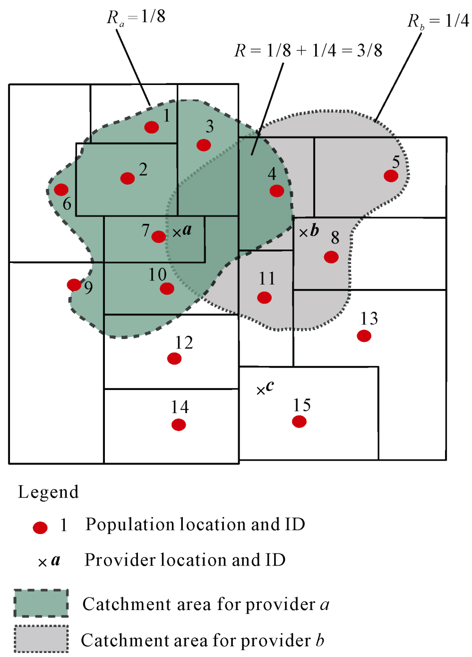

Fig. 2 2SFCA method. Luo and Wang, 2003

Previous studies introduced the distance decay function in the 2SFCA method to compensate for the two demerits (i.e., the lack of distance impedance within the catchment and it being a dichotomous measure). The specific form is given by

$$R_j = S_j / \sum D_k f(t_{kj}) \tag{5}$$

$$A_i^F = \sum R_j = \sum (S_j f(t_{ij}) / \sum D_k f(t_{kj})) \tag{6}$$

where t_{kj} is the time cost between k and j; t_{ij} is the time cost between i and j; D_k is the population count of location k that lies within the catchment area; S_j is a measure of the provider for location j; $f(t)$ is the distance decay function; R_j is the service population-to-provider ratio; and A_i^F is the accessibility for population demand in location i.

(2) Distance decay function

The difficulty in determining the distance decay function with common forms (e.g., kernel density, Gaussian, inverse power, and the exponential functions) is a shortcoming of the 2SFCA method. Although the widely used Gaussian function is relatively reasonable, determining the parameters has no scientific basis, which has been subjectively assumed in previous studies. Therefore, an improved Gaussian function based on the inclination of rural residents is proposed in the present study. The approach provides a new idea for the parameter determination of distance decay function and can transform 2SFCA into a more scientific method.

According to the economic man hypothesis, residents who accept high travel costs are generally willing to accept low travel costs as well. Therefore, the accumulated resident percentages of acceptable travel time costs are used as the basis of the distance decay function parameters. Information on the inclination of rural residents was acquired using questionnaires and in-depth interviews. These methods mainly help identify the longest acceptable travel time spent by rural residents for their production and living activities through setting options (10, 20, 30 and >30 min) as needed. The investigation was conducted in December 2013. A total of 625 valid questionnaires were obtained (Table 3). With regard to tillage accessibility, the proportions of rural residents that could accept the farmland access within 10, 20 and 30 min are 100%, 59% and 20.60%, respectively, which are used as the three key points of the distance decay function. Based on previous research (Shi *et al*., 2012; Wan *et al*., 2012b), the improved Gaussian function is used to construct a piecewise distance decay function, which is given by:

$$f(t)=\begin{cases} 1 & t<10 \\ a\mathrm{e}^{-(t-b)^2/c} & t\geq 10 \end{cases} \tag{7}$$

where $f(t)$ is the distance decay function, and t is the time cost. Meanwhile, a, b and c are parameters of the improved Gaussian function.

(3) Time cost

The time cost is employed to measure the distance between provider and population locations. Drawing from previous studies and on spot investigation, travel speeds are determined (Table 4) based on the assumption that the travel mode of tillage is walking, while others use vehicles. The travel time costs of production and living are then calculated using the cost distance module of ArcGIS 10.1.

Table 3 Parameters for improved Gaussian distance decay function

Index		Longest acceptable travel time	Proportion of rural resident (%)	Key point $(t, f(t))$	Parameter	
Production	Tillage	10	12.66	(10, 1.0000)	a	1.07
		20	28.34	(20, 0.5900)	b	4.94
		30	38.40	(30, 0.2060)	c	381.23
		>30	20.60	–	–	–
	Nonagricultural employment	10	9.63	(10, 1.0000)	a	1.05
		20	22.17	(20, 0.6820)	b	5.10
		30	36.60	(30, 0.3160)	c	517.38
		>30	31.60	–	–	–
Living	Health care and education	10	12.39	(10, 1.0000)	a	1.10
		20	41.21	(20, 0.4640)	b	4.99
		30	36.40	(30, 0.1000)	c	260.81
		>30	10.00	–	–	–

Table 4 Travel speed of different land use for production and living of rural resident

Land use	Tillage (km/h)	Nonagricultural employment and living (km/h)
County road	6	20
Construction land, township road and country road	5	15
Farmland, garden land and facility agricultural land	4	4
Forest, grassland and natural reservation land	3	3
Others	0	0

3 Results

3.1 Accessibility measurement

The accessibility measured by the improved 2SFCA method is the foundation of this study. The accessibility of tillage, nonagricultural employment, health care and education in Tingzu are shown in Fig. 3. In the production aspect, the accessibility spatial distribution of tillage and nonagricultural employment has a complementary characteristic. The high accessibility distribution of tillage and low accessibility distribution of nonagricultural employment is mainly located in the southwest hilly region and in parts of the eastern plains, whereas the high accessibility of nonagricultural employment and low accessibility of tillage are mainly concentrated around the town and along the county road. Furthermore, the accessibility of nonagricultural employment around the town and along the county road is superior compared with those of others because of the agglomeration and circulation functions of the town and county road. The accessibility of tillage in this region is inferior compared with others because of its high population pressure. Conversely, the accessibility of nonagricultural employment in the southwest hilly region and parts of the eastern plains is lower than others due to the lack of driving force from development centers and infrastructure. The accessibility of tillage in this region is higher than others because of its low population pressure. With regard to accessibility of living, accessibility of health care has significant disparities. High accessibility of health care is mainly clustered around the town, whereas low accessibility is distributed throughout the eastern and southern parts of the study area. Accessibility of education shows an equilibrium distribution. The high accessibility area of education is located in Wunao and Liufan in the southeast, whereas the low accessibility area is partly distributed around the town and in the southern hilly area. The difference in health care facility conditions between the town and villages, as evidenced by such conditions as a clinic with bad service in each village and a hospital with good service in the town, leads to the significant disparities in accessibility of health care. The area around the town, especially Fenghuang and Guihua, has low accessibility in terms of education because of its large population. Low accessibility of education is also observed in some local southern areas because of the lack of educational resources and relatively inconvenient traffic.

3.2 Suitability evaluation of rural settlements

The spatial distribution of suitability is similar to accessibility of nonagricultural employment (Fig. 4a). The 'most suitable' and 'highly suitable' classes, which are mainly located around the town and along the county road, occupy 158.64 and 160.29 ha, accounting for 20.34% and 20.55% of the total rural settlement area, respectively. In these areas, rural land consolidation should be conducted through internal integration and exploration to promote the concentration of population and resources in the central villages. Furthermore, the 'lowly suitable' and 'less suitable' classes, which are mainly concentrated in the southwest hilly region and partly scattered over the northern and northeastern plains, occupy 159.30 and 61.94 ha, respectively, accounting for 20.43% and 7.94% of the total rural settlement area. In this region, concentrating population and resources in the central basic villages with high suitability as well as increasing infrastructure and public service investments should be promoted to ensure equality of public services. In addition, the 'moderately suitable' class, which is scattered over the northern and eastern plains as well as western hilly region, occupies 239.74 ha accounting for 30.74% of the total rural settlement area. In this area, some of the previously proposed measures can be promoted according to the given conditions.

The kriging interpolation of suitability reveals that most of the plains have high suitability. Conversely, suitability in the southwest hilly region is widely low and gradually decreases with the increase in time cost to the town and county road (Fig. 4b). The scatter diagrams demonstrate that suitability has negative correlations with elevation and slope, specifically with the latter having a correlation coefficient of –0.49 (Figs. 4c–4d). Significant negative correlations with the time cost to the town and county road are also demonstrated, specifically with the time cost to the county road, which has a correlation coefficient of –0.69 (Figs. 4e–4f). These findings reveal that natural factors, including elevation and slope, affect the overall distribution of suitability to some extent, and the construction of high-level roads and sub-centers can significantly improve the settlement suitability of local regions. In addition, a few rural settlements in the eastern area have high suitabilities and high time costs to the town. These rural settlements can

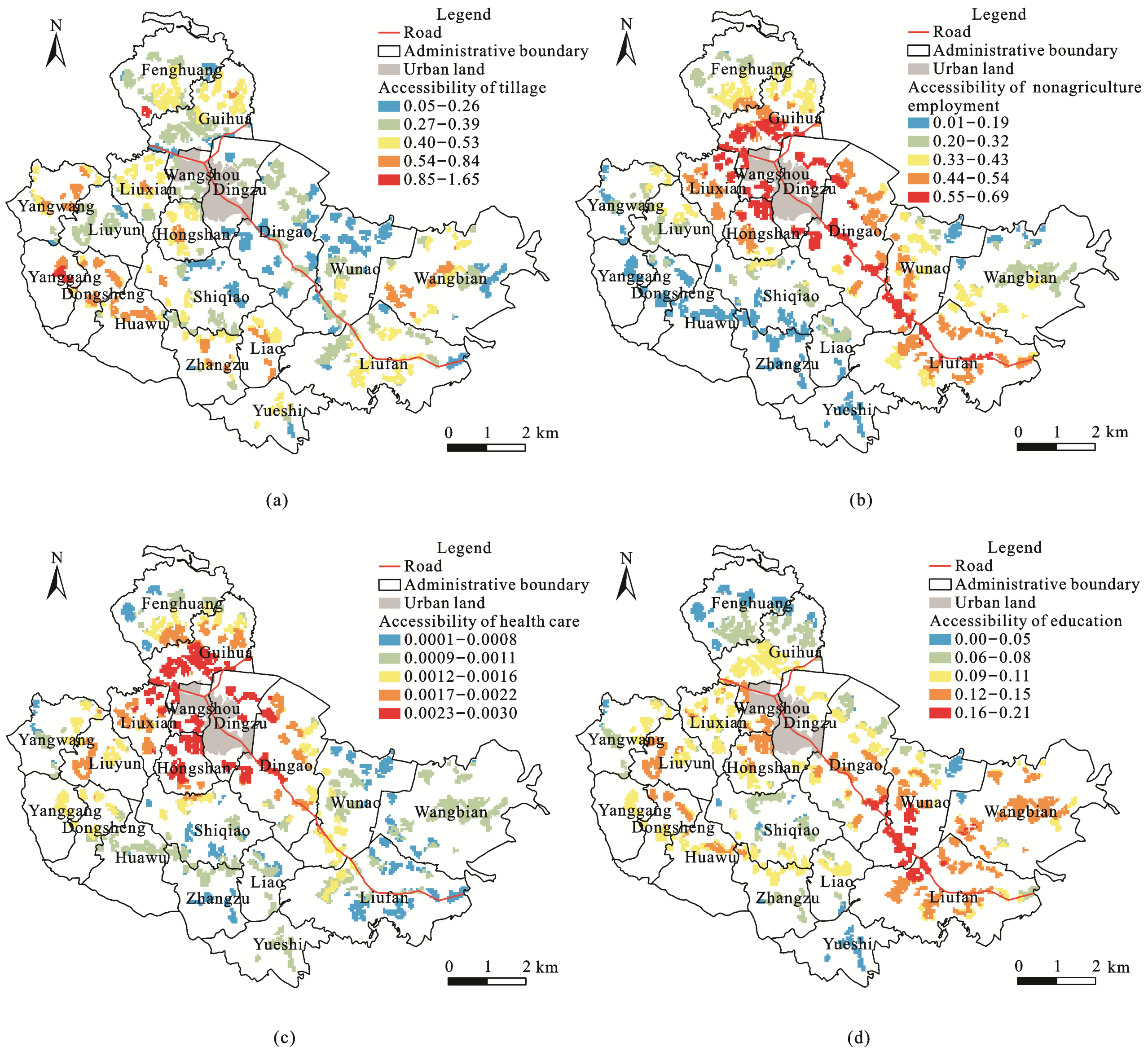

Fig. 3 Accessibility of production and living: (a) tillage; (b) nonagricultural employment; (c) health care; and (d) education

be developed as a sub-center to promote the development of the eastern area.

3.3 Limiting factor identification

The distributions of limiting factors in the case of Tingzu are shown in Figs. 5a–5e. An area measuring 214.36 ha, which accounts for 27.49% of the total rural settlement area, has been identified as the area that is limited by tillage. This consists of a highly limited area located around the town and a lowly limited area along the county road. An area measuring 301.23 ha (38.62%) has been identified as the area that is limited by nonagricultural employment. This consists of a highly limited area located in the southwest hilly region and a lowly limited area located in parts of northern and eastern plains. In contrast to the living aspect, tillage is an alternative to nonagricultural employment and vice versa because both are income sources of the rural residents. According to the comparative advantage theory, the development of competitive industries should be prioritized based on regional characteristics to maximize the total benefit. Therefore, based on accessibility and the limiting factor of production, the process of industrialization and urbanization should be accelerated around the town and along the county road to promote population concentration and industrial transformation. Moreover, characteristic agriculture and tourism agriculture should be developed in the southwest hilly region to improve the income of farmers. An area concentrated in the eastern plain measuring 258.22 ha, which accounts for 33.11% of the total rural settlement area, has been identified as the area limited by health care. An area of 257.65 ha (33.04%), located around the town and in the northern plain, has been identified as the area that education limits. Therefore, increasing the health care provision is necessary to improve the health care in the southeast, and increasing educational resource investments around the town is necessary to relieve the pressure of insufficient educational resources from excessive population. An area of 66.93 ha distributed in the middle

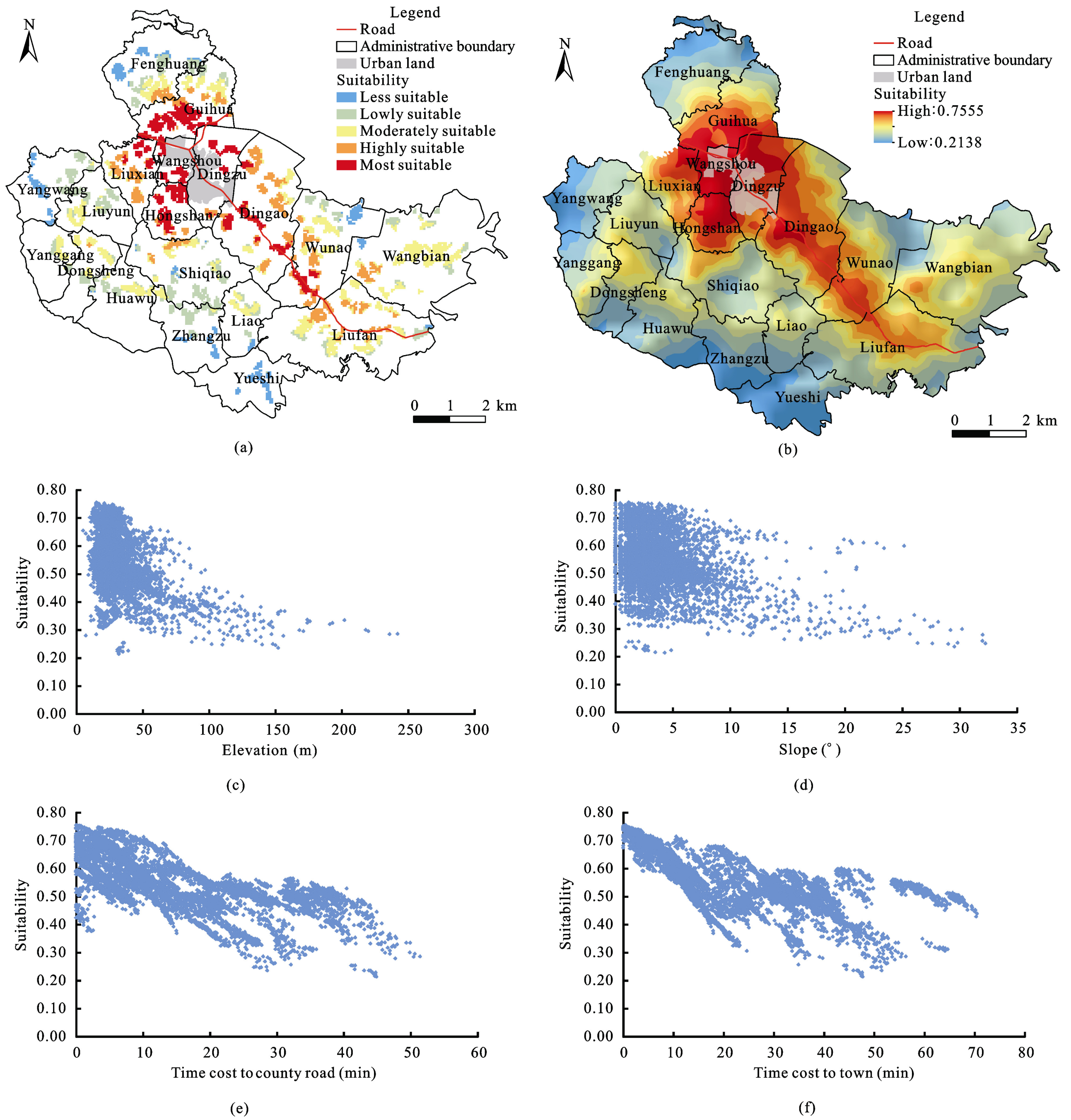

Fig. 4 Suitability evaluation and analysis: (a) rural settlement suitability; (b) kriging interpolation of rural settlement suitability; (c) relationship between suitability and elevation; (d) relationship between suitability and slope; (e) relationship between suitability and time cost to county road; and (f) relationship between suitability and time cost to town

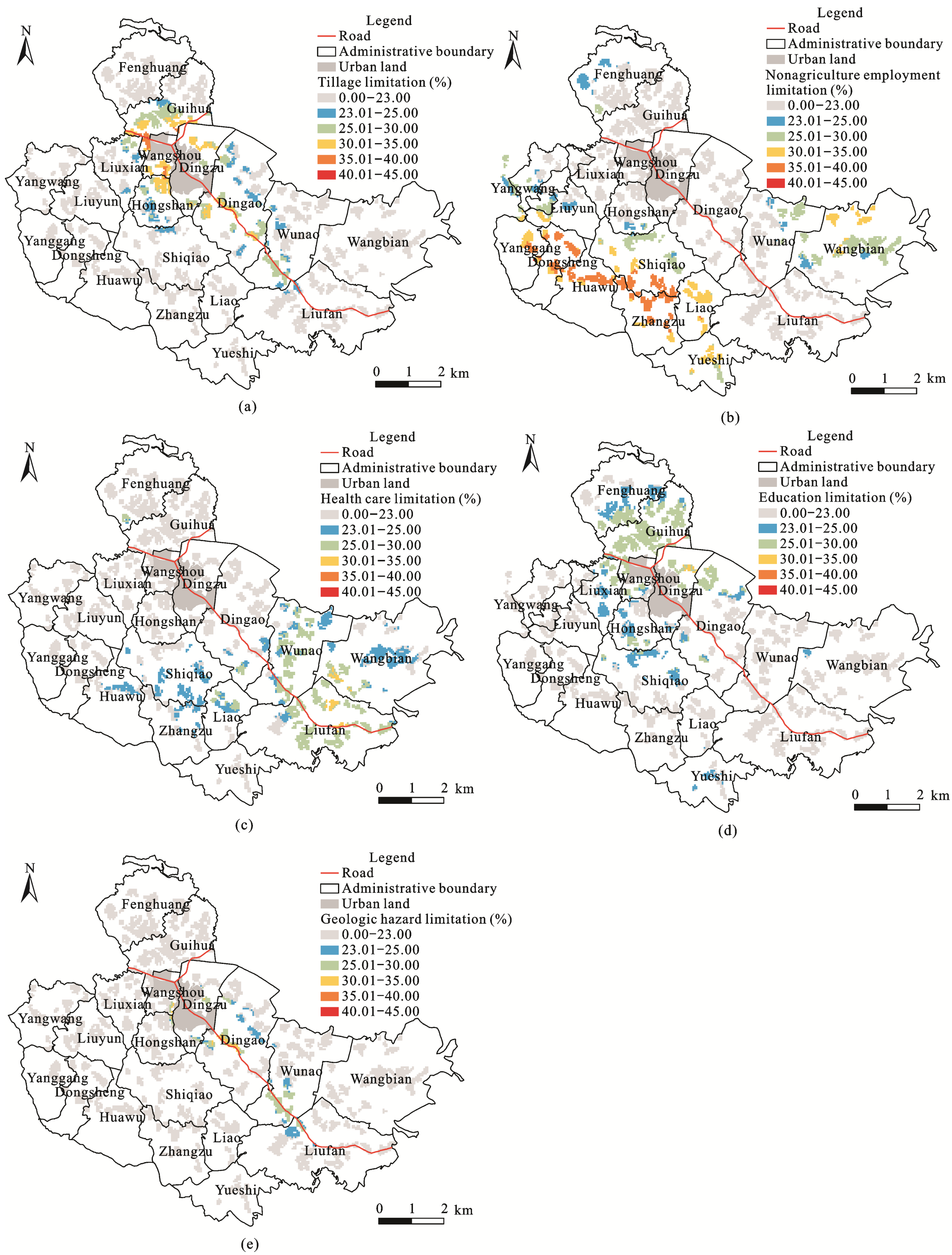

Fig. 5 Limiting factor identification: (a) tillage; (b) nonagricultural employment; (c) health care; (d) education; (e) geologic hazard

areas with ample mineral resources, which accounts for 8.58% of the total rural settlement area, has been identified as the area that is limited by geological hazards. This area has a high population concentration and is a key development area. Thus, geological disaster monitoring efforts should be increased and different kinds of engineering measures should be implemented in this area to eliminate security risks in the future.

4 Discussion

The effectiveness of resource allocation, measured by the demand-supply matching degree, is taken as the starting point of the suitability evaluation system in the study to assess the performance of the production and living functions of rural settlements. Moreover, the 'short plank' of the production and living space is identified through comparing the matching degree of different factors to propose corresponding support for decision-making regarding the optimization of production and living space of rural settlements. These two tasks are realized by introducing accessibility of production and living as well as limiting factor identification.

The traditional suitability evaluation of rural settlements introduces proximity measures, such as distance and time cost, when production and living convenience of rural settlements is considered (Qu *et al*., 2010; Qin *et al*., 2012). However, accessibility of production and living measured by the improved 2SFCA method, not only considers the proximity measured by the improved Gaussian distance decay function based on the inclination of rural residents, but also considers the availability which reflects whether the surrounding production and living resources meet the settlement demands. Tingzu was chosen as the case study area to reveal the relationship between accessibility and time cost to the nearest elements (Fig. 6). In general, accessibility and time cost have a negative nonlinear correlation, and the traditional measure of time cost significantly overestimates production and living convenience compared with accessibility. Specifically, the time cost to the nearest production elements tends to be lower than the living ones, which is caused by more number and wider distribution of production elements as well as the disadvantage of time cost measure that only considers the nearest elements. This result shows the overestimation of traditional measures to some extent. In addition, the low time costs to the four elements correspond to large ranges of accessibility, especially for nonagricultural employment and living elements. This is because accessibility considers availability. The result means that low time costs can not be equated with production and living convenience of rural settlements, which should consider whether the surrounding production and living resources meet the settlement demands. Furthermore, the accessibility ranges of four elements tend to be small when time costs gradually increase, indicating that the function of availability at low time costs is stronger than that at high time costs. This result is produced by the distance decay function based on the inclination of rural residents. Therefore, compared with traditional measures, the accessibility measure introduced in this study can properly interpret the space and quality matching degree between settlement demands and surrounding production and living resources. This is also a good measurement of the effectiveness of resource allocation as well as production and living convenience of rural settlements, thus making the suitability evaluation of rural settlements more scientific and accurate.

The traditional optimization methods of rural settlement layout mainly rely on the suitability degree to directly decide which settlements should be constructed, extended, reserved or moved. However, the suitability degree may come from the extreme values of one or a few factors, whereas most of the other factors are moderate. Thus, this is unilateral when making layout optimization decisions on rural settlements simply according to suitability. Moreover, these extreme factors may just be the key points that require improvement in optimizing the production and living space of rural settlements, whereas the traditional method may directly ignore. The limiting factor identification based on the loss score proportion of suitability proposed in the study overcomes these shortcomings. Taking Tingzu as an example, five limiting factors are identified. Multi-factors may limit the suitability of one evaluation unit and 17 combination types of limiting factors are identified. On this basis, considering the results of suitability evaluation and analysis, three kinds of regional spatial optimization modes are designed for rural settlements in Tingzu: 1) the central and northern plain mode, which is the important development area of population urbanization and industrial-agricultural modernization; 2) the southwestern hilly mode, which is a professional

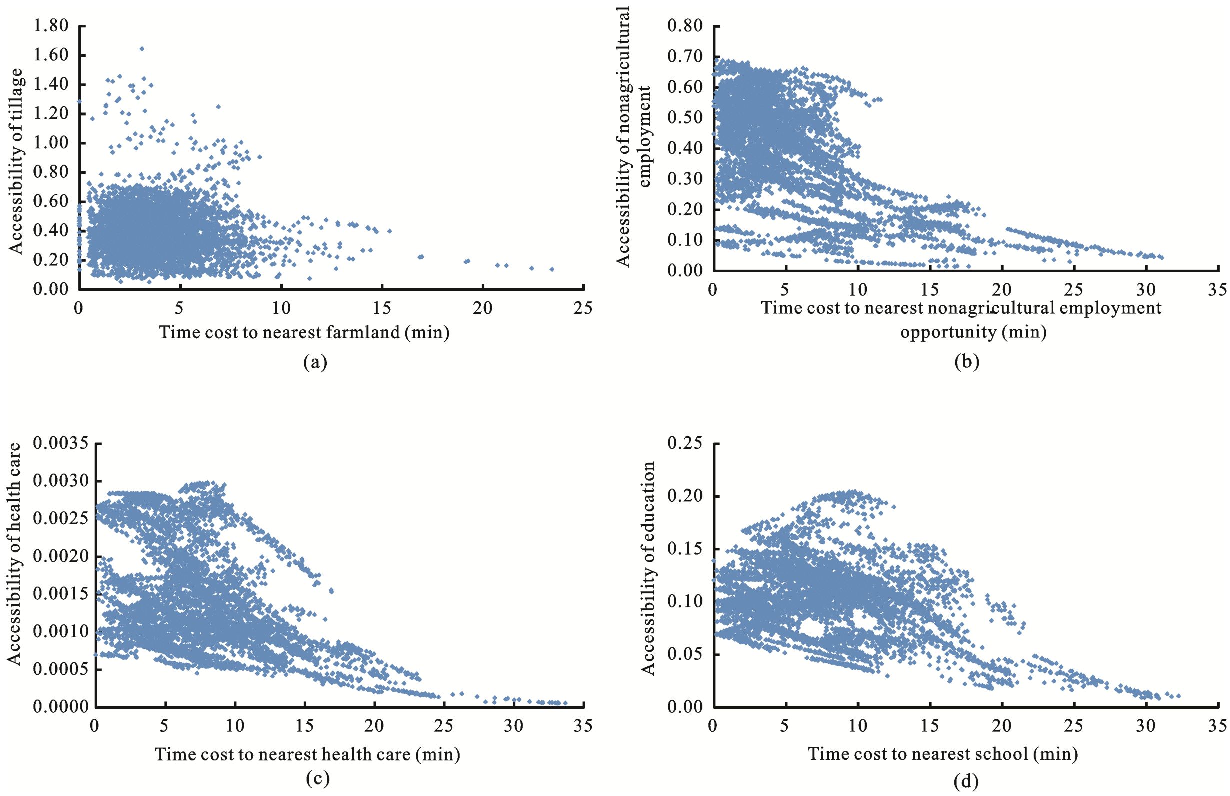

Fig. 6 Relationship between accessibility of production and living and time cost to the nearest elements: (a) tillage; (b) nonagricultural employment; (c) health care; and (d) education

development mode characterized by central village construction, characteristic agriculture development, as well as infrastructure investments; and 3) the eastern plain mode, which is a mixed development mode characterized by construction of the sub-center and central villages, balanced development of industry and agriculture, as well as optimization of public service facilities. Thus, there is no doubt that the optimization of the production and living space of rural settlements based on the three modes can be more highly targeted. This is what the traditional suitability evaluation cannot achieve.

Despite the superior performance of the suitability evaluation system, this study has several limitations. First, the incomplete data, particularly the lack of data on the areas around the study area, affected the evaluation accuracy, as the edge effect has shown. This study partially considered basic public service facilities, health care and education, because the other facilities lacked data. Some patch-level data, which were derived from village-level data, have also been used. Nevertheless, the main purpose of the study is to propose a new suitability evaluation system for rural settlements, and the case study has effectively shown its practicability and advantages. Thus, the absence of some data is relatively unimportant. Moreover, some methods used in this study, for example, weight determination and limiting factor identification can be improved. Determining the factor weights has an important effect on the evaluation results; thus, analyzing the change of suitability with varying weights is necessary. Furthermore, limiting factors have been identified based on the loss score proportion of suitability, which is a relative standard. Other standards can also be proposed and tested.

5 Conclusions

In China, the current problems of rural settlements are unreasonable land use due to the rural settlement hollowing, and disordered layout, poorly designed infrastructure and inequality in public services due to the lack of rural settlement planning. Therefore, conducting the consolidation and planning of rural settlements is necessary, and evaluating the suitability of rural settlements becomes critical.

In this study, a suitability evaluation system of rural settlements, based on accessibility of production and living, was proposed, which was composed of suitability evaluation and limiting factor identification. Suitability was evaluated using a comprehensive evaluation method, which considered the natural conditions and accessibility of production and living. The accessibility was measured by the improved 2SFCA method based on the inclination of rural residents. Limiting factors were identified through the loss score proportion of suitability. Based on the suitability evaluation and analysis of Tingzu, some corresponding suggestions on rural land consolidation, population concentration, as well as the construction of high-level roads and sub-centers were proposed. And corresponding suggestions on the regional industry division, as well as the layout of health care and education facilities were proposed based on limiting factor identification. Moreover, three regional spatial optimization modes were designed to make the optimization of production and living space of rural settlements more highly targeted.

With the objective of making the production and living space of rural settlements more convenient, this study proposes the effective allocation of resources as the starting point to conduct the suitability evaluation of rural settlements. In comparison with previous suitability evaluations, accessibility of production and living measured by the improved 2SFCA method, which considers both proximity and availability, is introduced. This measure, as an alternative to the traditional proximity indexes which generally consider only the nearest elements and significantly overestimate production and living convenience, can make the suitability evaluation of rural settlements more scientific and accurate. The proposed limiting factor identification, which overcomes the shortcomings of previous methods that only consider the suitability degree when deciding the layout of rural settlements, can help us generate effective suggestions according to local conditions. As a whole, the study has made some beneficial attempts on the suitability evaluation of rural settlements from two perspectives: effective resource allocation and differentiated planning, which yielded excellent results. Moreover, this study has great practical significance for the consolidation of rural settlements and new countryside building and may bring some enlightenment to future studies and practice.

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