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Study on spatial tropism distribution of rural settlements in the Loess Hilly and Gully Region based on natural factors and traffic accessibility

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ABSTRACT

The keys to realizing spatial restructuring in rural areas are the optimization of the spatial pattern of rural settlements and the integration of rural resources. Based on a 2015 Google Earth remote sensing image, this study employed kernel density estimation (KDE), the minimum cumulative resistance (MCR) method, and a logistic regression model to apply quantitative analysis to the spatial distribution characteristics and influencing factors of a rural area. The results revealed that the density of rural settlements is significantly spatially different in Baota District; the density core area in the district was located in the valley area with industrial agglomeration. Rural settlements in Baota District were located near the county seat and township seat, near a river, farmland and county-level road, on sunny slopes. Traffic accessibility to the townships had a greater impact on the spatial distribution of rural settlements than the traffic accessibility to the county. Thus, county-level road development plays a more important role in the optimization of town-village systems. Hence, we suggest constructing a complete transportation network system in the optimization of the town-village spatial pattern in the county, thereby improving the central service functions of towns to strengthen the spatial connection between townships and the central agglomeration effects of towns.

1. Introduction

Settlements are the basic units of rural areas because they reflect the connection between people and various elements, such as land, historical background, and sociopolitical relationships (Jones, 2010; Palmisano et al., 2016). Rural settlements are also the geographical space carrier of agricultural production, peasant life, and rural ecosystems (Long et al., 2014; Yang et al., 2015). Spatial patterns, evolutionary processes, and the influencing mechanisms of rural settlements have been the key issues for rural geography research.

In China, in 2008, there still existed $7.21x10^8$ rural residents, $1.92x10^4$ town governments, $1.51x10^4$ township governments, and $6.40x10^5$ village committees, which remain the primary form of human settlement in the country (Zhou et al., 2013; Tian et al., 2014). Alongside the rapid development of industrialization and urbanization, rural areas proliferated in China. However, due to the lack of rural development planning, serious problems existed in the process of rural development, such as rural population urbanization, population aging, environmental pollution, hollowed villages, and rural poverty (Long et al., 2009; Liu and Li, 2017a; Liu et al., 2017). Spatial structure optimization of rural settlements and a new village-town construction pattern are important for rural sustainable development (Liu et al., 2014). Therefore, a study on rural settlement spatial distribution, providing great insight into rural sustainable development, is imperative.

Previous studies of rural settlements cover a range of topics, from spatial patterns and types of rural settlements (Li et al., 2014; Chen et al., 2017), the spatial evolution and mechanisms of rural settlements (Long et al., 2009; Liu et al., 2010), functional differentiations of rural territory (Zhang et al., 2014; Liu, 2018), the optimization of rural settlements (Guan et al., 2013; Liu et al., 2014; Yang et al., 2016), to rural restructuring (Long et al., 2012, 2016; Woods, 2007). For example, using multiple time Landsat TM data, Tian et al. (2014) analyzed the distribution patterns of rural settlements and the driving factors of change in rural settlement in the Beijing metropolitan region. Yang et al. (2016) analyzed the spatial distribution of rural settlements in China and proposed four new village-town system patterns, such as 'central place distribution mode', 'radially imbalanced distribution mode', 'multicore central place distribution mode' and 'corridor balanced and imbalanced distribution mode'.

Recently, studies have focused primarily on the relationship between

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rural settlements and socioeconomic elements, such as between population, industry, and residents in rural area (Oldfield, 2005); the impact of rural settlements on public service facilities (Holmes, 2010), and rural sociology in rural areas (Dzanku, 2015). Rural sociology studies focus mainly on community governance and government agencies, immigration of rural youth, protection and economic potential of cultural heritage, rural livelihood and poverty, and rural crime and community safety (Dzanku, 2015; Ali, 2007; Bednaříková et al., 2016). With the development of geographic information systems (GIS) and remote sensing (RS) technology, the study of spatial distribution patterns, spatial morphological characteristics, spatial tropism distribution and the landscape patterns of rural settlements has been strengthened (Danilo et al., 2009; Ren et al., 2014; Yang et al., 2013).

Previous studies have greatly improved our understanding of the spatial distribution pattern of rural settlements and their comprehensive influencing factors, especially those that are socio-economic. However, studies analyzing the impact of traffic conditions on rural settlements' spatial distribution remain rare, especially in different types and levels of roads. In addition, previous studies of rural settlements' spatial tropism distribution have mainly used the method of Euclidean distance and buffer analysis. Different levels of roads have different structures and attributes and, thus, using the Euclidean distance makes it difficult to reflect the spatial distribution of settlements accurately, especially in hilly and gully areas. In light of this, further study of the spatial tropism distribution characteristics of rural settlements based on natural and traffic factors is necessary. Traffic accessibility is an important indicator for measuring the regional traffic network structure and reflects the actual traffic location conditions (Huang et al., 2011; Yang, 2017).

The study area on which this paper is focused is located in the Loess Hilly and Gully Region of China in the northern part of the Loess Plateau. With the implementation of the Great Western Development Strategy, this region is experiencing rural transformation development, the proportion of primary industry is being reduced, and there is depopulation in rural areas. However, the area of rural residential land is on the increase. As an ecologically fragile area, it is imperative to study the rural settlements' distribution and the driving forces thereof. In addition, the terrain of the Loess Hilly and Gully Region is complex and the traditional Euclidean distance analysis method is difficult to express the spatial tropism distribution of rural settlements accurately. Therefore, this study takes Baota District, in the Shaanxi Province, as the study area, exploring the spatial pattern and driving factors of rural settlements with the help of kernel density estimation (KDE), minimum cumulative resistance (MCR), and the logistic regression model.

The specific objectives of this study were, therefore: (1) to refine the study of rural settlements' spatial tropism distribution by using the MCR model, and (2) to explain how natural factors and traffic conditions influence the spatial distribution of rural settlements in the Loess Hilly and Gully Region. We expect to provide insight into the spatial tropism distribution of rural settlements in the Loess Hilly and Gully Region.

2. Materials and methods

2.1. Study area

Baota District is located in the Loess Hilly and Gully Region. In 2015, Baota District covered an area of 3,556 km^2 and encompassed 388.86 km^2 of cropland, 2,159.10 km^2 of woodland, 478.33 km^2 of grassland, and 131.28 km^2 of construction land. Baota District has a warm temperate climate with an average annual rainfall of about 500 mm, mostly concentrated in June–September. The average annual temperature of the district is 9.4 °C. The population of Baota District was approximately 500 000 in 2015. The District has jurisdiction over 11 towns, 611 administrative villages, and 38 urban and rural communities. In 2015, the region's GDP was 269.40 billion yuan, an increase of 13.45% over last year, and the per capita net income in the rural area reached 10,485 yuan (Fig. 1).

2.2. Data sources and processing

Based on 2015 Google Earth remote sensing imagery (0.12-m spatial resolution), we used visual interpretation to obtain vector data of rural settlements, cropland, roads, and rivers. Using the function "feature to point" in ArcGIS software, we obtained the point data of rural residential patches and then analyzed the spatial distribution characteristics of rural settlements through the KDE model. Also, we generated the distance from rural settlements to a river and different level roads. We converted the vector data of different level roads into raster data (30-m spatial resolution), ensuring different levels and types roads could be

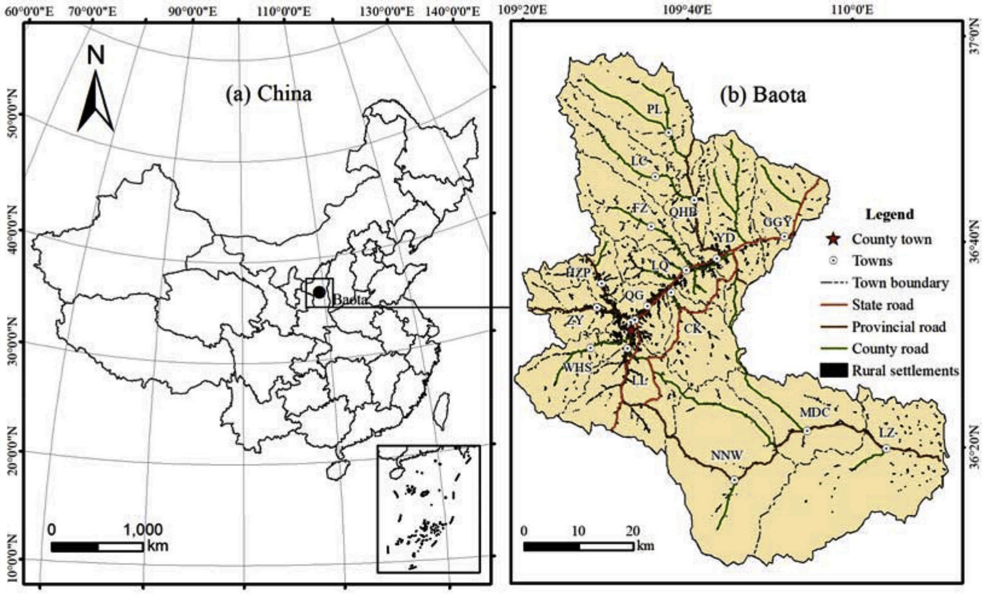


Fig. 1. Location of Baota District and current administrative divisions. (a) Location of Baota District in China. (b) The current administrative division of Baota District. (PL, LC, FZ, YD, QHB, GGY, LZ, NNW, LQ, HZP, ZY, QG, CK, WHS, LL and MDC are the abbreviation of the townships names in Baota, Panlong, Liangcun, Fengzhuang, Yaodian, Qinghuabian, Ganguyi, Linzhen, Nanniwan, Liqu, Hezhuangping, Zaoyuan, Qiaogou, Chuankou, Wanhuashan, Liulin and Madongchuan).

reflected in the raster data. Then, we used the MCR model to calculate the MCR value from rural settlements to city and towns. 1:50 000 DEM data was obtained from the International Scientific Data Mirroring Website of the Computer Network Information Center of the Chinese Academy of Sciences (http://datamirror.csdb. cn). With the help of the ArcGIS 10.2 platform, we generated the elevation data, slope data, and aspect data from the DEM data.

2.3. Methods

2.3.1. Kernel density estimation

KDE is a spatial analysis technique that accounts for the location of features (i.e., destinations) relative to each other (King et al., 2016) and is the most promising spatial tool to assist the understanding of the changing geographies of point patterns (Anderson, 2009). The general definition is: Assuming that $x_1 \ldots x_n$ are independent, identically distributed samples extracted from the distribution density function f, estimating the value of f at a certain point (x, y). The KDE is shown in formula (1):

$$f(x,y) = 1 \Big/ \left(nh^2\right) \sum_{i=1}^{n} K(d_i/h) \tag{1}$$

where $f(x, y)$ is the density estimate at the location (x, y), n is the number of rural settlements, h is the bandwidth or the kernel size, K is the kernel function (i.e. the sizes of land areas), d_i is the distance between the location (x, y), and the location of the ith rural settlement (Anderson, 2009; Sarp and Duzgun, 2015).

2.3.2. Minimum cumulative resistance

The MCR model refers to the model's cost in the process of moving from source to destination. According to the difference of surface resistance coefficient, the model chooses the route with an MCR value. The MCR value reflects the potential and trend of species movement (Li et al., 2015), which can better reflect the spatial location of rural settlements.

Traffic resistance is affected by road grade and slope. In this paper, we assumed that the same types of roads have a similar resistance value and added resistance values to each type of road. According to the relevant traffic regulations, the maximum speed limits of a national road, provincial road, county road, village road, and sandstone road is 80 km/h, 60 km/h, 40 km/h, 30 km/h, and 15 km/h, respectively, in Baota District. Areas without roads were calculated according to walking speed; 5 km/h. Thus, the resistance value of a national road, provincial road, county road, village road, and sandstone road was set to 2, 3, 4, 5, and 8, respectively. The resistance value of areas without roads was set to 30. According to the actual topographical features of Baota District, and referring to the slopes of the mountainous terrain (Liu et al., 2016), we divided the slopes into flat (<3°), gentle (3°–15°), gentle steep (15°–25°), and steep (>25°). The resistance value of flat, gentle, gentle steep, and steep was set to 1, 2, 3, and 4, respectively. Traffic conditions determine the farmer's choice of vehicles and the maximum speed of driving, so traffic conditions play a greater role in the accessibility to rural settlements than the slope. Hence, we set the traffic resistance weight as 0.6 and the slope resistance weight as 0.4. Based on the traffic resistance value layer and the slope resistance value layer, we calculated the cost distance layer, then obtained the MCR value of each grid to destination in Baota District (Fig. 2).

The MCR model is shown in formula (2):

$$M_{ij} = f_{\min} \sum \left(D_{ij} \times R_j\right) \tag{2}$$

Where M_{ij} is the minimum cumulative resistance value from source j to landscape unit I. D_{ij} is the spatial distance from source j to landscape unit i, and R_j is the resistance coefficient.

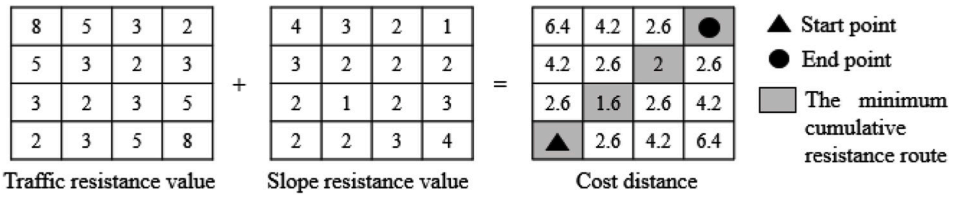
2.3.3. Logistic regression model

Logistic regression is a powerful tool for predicting class probabilities and for classification using predictor variables (Lever et al., 2016). The method was founded by biological mathematician Verhult in 1838 and successfully used in natural hazards (Guns and Vanacker, 2012), medicine (Amo, 2016), land use change (Lin et al., 2014), and other fields. This model is suitable for analyzing binary variable type events, such as rural settlements' distribution. The corresponding regression model is:

$$\ln(p/(1-p)) = \beta_0 + \beta_1 x_1 + \cdots + \beta_i x_i, \tag{3}$$

Where p is the distribution probability of rural settlements, $x_1, \ldots, x_i$ are the impact factors, and $\beta_0, \beta_1, \ldots, \beta_i$ are the undetermined parameters. If β_i is positive and statistically significant, then the probability of rural settlements' distribution increases with the increase in the corresponding independent variable. If β_i is negative and statistically significant, then the probability of rural settlements' distribution decreases with the increase in the corresponding independent variable. In this study, the Binary Logistic module of SPSS software was used to calculate regression coefficient β, standard error $S.E$, Wald statistic of regression coefficient estimation, and significance level P.

Natural geographical conditions are the foundation of the formation and development of rural settlements. Among them, the topography is most dominant; it provides space for rural settlements and, at the same time, has a restrictive effect on the spatial distribution of settlements. Elevation, slope, and aspect are also important factors that affect the spatial pattern of rural settlements. At present, rural areas in China remain dominated by agricultural production. Water resources condition and farming radius are the two major factors of agricultural conditions that affect the spatial pattern of rural settlements (Tian et al., 2014). Farming radius is an effective index used to describe the spatial relationship between farmland and rural settlements. The flow of funds, labor, technology, and other elements between villages also plays a very important role in rural development. However, the flow of elements between regions is affected by traffic conditions and location conditions (Yang, 2017). Thus, based on the rationale, representativeness, and availability of the indicators, together with reference to the relevant research, we selected the MCR value to towns (x_1), the MCR value to counties (x_2), the distance to a state road (x_3), the distance to a provincial road (x_4), the distance to a county road (x_5), elevation (x_6), slope (x_7), aspect (x_8), the distance to a river (x_9), and farming radius (x_{10}) as the influencing factors.



8	5	3	2
5	3	2	3
3	2	3	5
2	3	5	8

Traffic resistance value

+

4	3	2	1
3	2	2	2
2	1	2	3
2	2	3	4

Slope resistance value

=

6.4	4.2	2.6	●
4.2	2.6	2	2.6
2.6	1.6	2.6	4.2
▲	2.6	4.2	6.4

Cost distance

Fig. 2. The calculating process of MCR model.

3. Results and analysis

3.1. Overall spatial pattern of rural settlements

Using the KDE method, we obtained the rural settlement density map of Baota District (Fig. 3), which shows significant differences in the spatial distribution of rural settlements in the Baota District. The overall spatial pattern demonstrates a high density in the north and a low density in the south. The density core area, with a density range of 4–6/km^2, is mainly located in Liqu Township and Yaodian Township, and adjacent to the national road. The secondary density core area, with a density range of 2–4/km^2, is mainly located in Fengzhuang Township, Qinghuabian Township, Liulin Township, and the northern area of Yaodian Township.

The rural settlement density core area is located in the Yan River Basin; the wide valley and flat terrain make it possible for the concentration of rural settlements. There is a science and technology industrial park within the jurisdiction of Liqu Township and a centralized cargo transportation and storage area is planned to be developed in Yan'an City. Yaodian Township is an industrial area in Baota District and is a base for the metallurgy, electric power, and chemical industry in Yan'an. There are steel plants, power plants, transformer plants, nitrogen fertilizer plants, and mining enterprises. In 2015, the total industrial output value of Yaodian Township was 4.76 billion yuan and the resident population reached 30.8 thousand. The total industrial output value of Liqu Township was 130 million yuan and the resident population was 26.1 thousand. Conversely, low-density rural settlements are distributed mainly in the southern part of Baota District, although there are well-developed river valleys in the area. This area is mainly used for agriculture, forestry, and animal husbandry. In 2015, the total industrial output value of Nanniwan Township was only 17.9 million yuan and the resident population was 12.6 thousand. The total industrial output value of Linzhen Township was only 25.1 million yuan and the resident population was 14.5 thousand.

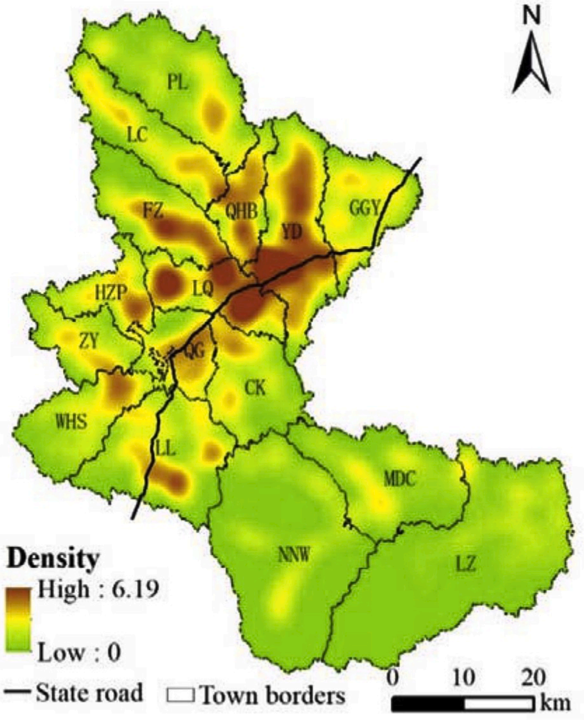


Fig. 3. Kernel density distribution of Baota District. (PL, LC, FZ, YD, QHB, GGY, LZ, NNW, LQ, HZP, ZY, QG, CK, WHS, LL and MDC are the abbreviation of the townships names in Baota, Panlong, Liangcun, Fengzhuang, Yaodian, Qinghuabian, Ganguyi, Linzhen, Nanniwan, Liqu, Hezhuangping, Zaoyuan, Qiaogou, Chuankou, Wanhuashan, Liulin and Madongchuan).

Hence, it can be seen that natural geographical conditions and industrial development are the two major factors driving the concentration of rural settlements.

3.2. Spatial distribution of rural settlements based on natural geographical elements

3.2.1. Topographic condition and rural settlements' distribution

According to the actual elevation range of Baota District and the equal interval method, we divided the elevation into five intervals: <950 m, 950–1050 m, 1050–1150 m, 1150–1250, and >1250 m. Similarly, according to the actual slope range of Baota District and the equal interval method, we divided the slope into five intervals: <10°, 10°–15°, 15°–20°, 20°–25°, and >25°. Then, we statistically analyzed the size characteristic of rural settlements within different elevations and slopes (Table 1).

Rural settlements in Baota District are mainly distributed in areas of 950–1050 m above sea level, with 1577 rural settlements, accounting for 38.73% of the total number of rural settlements and 54.79% of the total area of rural settlements. In areas below 950m, there are 411 rural settlements, accounting for 10.09% of the total number of rural settlements and 21.78% of the total area of rural settlements. Only 87 rural settlements are distributed in the area above 1215m, accounting for 2.14% of the number of rural settlements and 0.23% of the total area of rural settlements.

Rural settlements in Baota District are mainly distributed in areas with slopes below 10°, with 1286 rural settlements, accounting for 31.58% of the total number of rural settlements and 46.74% of the total area of rural settlements. There are 1016 rural settlements distributed in the range of 10°–15°, accounting for 24.95% of the total number of rural settlements and 24.82% of the total area of rural settlements. Only 370 rural settlements are distributed in areas above 25°, accounting for 9.09% of the number of rural settlements and 6.31% of the total area of rural settlements. The distribution of rural settlements first increases and then decreases as the elevation increases, and, as the slope increases, the distribution of rural settlements shows a downward trend.

3.2.2. Agricultural conditions and rural settlements' distribution

The average area of villages in Baota District is 4.7 km^2. Thus, villages can be regarded as circles with a radius of 1225 m. We took the mass point of the rural settlement as the center and calculated the average distance between the central mass point and the neighboring farmland mass point within a radius of 1225 m. We used the average distance calculated above as the farming radius. According to the actual range of farming radii in Baota District and using the equal interval method, we divided the farming radius into five intervals: <600 m, 600–700 m, 700–800 m, 800–900 m, and >900 m. According to the actual distance range from rural settlements to a river in Baota District and using the equal interval method, we divided the distance from rural settlements to a river into five intervals: <1000 m, 1000–2000 m, 2000–3000 m, 3000–4000 m, and >4000 m. We then analyzed the distribution of rural settlements within different farming radii and different distance to a river (Table 2).

The average farming radius of rural settlements is 752.36 m. The number of rural settlements with a farming radius of 700–800 m accounts for 58.96% of the total number of rural settlements. The number of rural settlements with a farming radius of 800–900 m accounts for 22.47% of the total number of rural settlements. The number of rural settlements with a farming radius of 600–700 m accounts for 14.91% of the total number of rural settlements, and the rest only accounts for 3.66%. This shows that the spatial distribution of rural settlements in Baota District is influenced by the cultivated land resources, and the major farming radius in Baota District is 700–800 m.

The number of rural settlements within a distance of 1000 m to a river is 2100, accounting for 51.57% of the total number of rural

Table 1
Rural settlements in different ranges of elevation and slope in Baota District in 2015.

Elevation (m)	Count	Percentage (%)	Area (hm^2	Percentage (%)	Slope(°)	Count	Percentage (%)	Area (hm^2	Percentage (%)
<950	411	10.09%	1198.52	21.78%	<10	1286	31.58%	2571.78	46.74%
950–1050	1577	38.73%	3014.65	54.79%	10–15	1016	24.95%	1365.43	24.82%
1050–1150	1474	36.20%	1018.58	18.51%	15–20	875	21.49%	804.94	14.63%
1150–1250	523	12.84%	257.83	4.69%	20–25	525	12.89%	412.95	7.51%
>1250	87	2.14%	12.67	0.23%	>25	370	9.09%	347.14	6.31%

Table 2
Rural settlements in different ranges of the distance to river and farmland in Baota District in 2015.

Distance to river(m)	Count	Percentage (%)	Area (hm^2)	Percentage (%)	Farming radius(m)	Count	Percentage (%)	Area (hm^2)	Percentage (%)
<1000	2100	51.57%	4197.16	76.28%	<600	43	1.06%	98.59	1.79%
1000–2000	643	15.79%	707.45	12.86%	600–700	607	14.91%	560.53	10.19%
2000–3000	596	14.64%	247.03	4.49%	700–800	2401	58.96%	2392.08	43.47%
3000–4000	322	7.91%	144.20	2.62%	800–900	915	22.47%	1533.87	27.88%
>4000	411	10.09%	206.41	3.75%	>900	106	2.60%	917.17	16.67%

settlements. There are 643 rural settlements distributed in the 1000–2000 m distance range, accounting for 15.79% of the total number of rural settlements. There are 596 rural settlements distributed in the 2000–3000 m distance range, accounting for 14.64% of the total number of rural settlements. The distribution of rural settlements in Baota District shows a decreasing trend as the distance to a river increases.

3.2.3. *Aspect and rural settlements' distribution*

Aspect is defined as the direction of the projection of the normal slope on the horizontal plane. In mountains, the sunshine hours and solar radiation intensity are different on different aspects. According to the equal interval method, we divided aspect into eight intervals (in clockwise order): north-northeast (NNE) or 0°–45°, east-northeast (ENE) or 45°–90°, east-southeast (ESE) or 90°–135°, south-southeast (SSE) or 135°–180°, south-southwest (SSW) or 180°–225°, west-southwest (WSW) or 225°–270°, west-northwest (WNW) or 270°–315°, and north-northwest (NNW) or 315°–360°. Rural settlements in Baota District are mainly distributed in SSW, with 1034 rural settlements, accounting for 25.39% of the total number of rural settlements. There are 826 rural settlements distributed in WSW, accounting for 20.28% of the total number of rural settlements. There are 732 rural settlements distributed in SSE, accounting for 17.98% of the total number of rural settlements. Only 109 rural settlements are distributed in NNW, accounting for 2.68% of the total number of rural settlements and only 178 rural settlements are distributed in NNE, accounting for 4.37% of the total number of rural settlements (Table 3).

SSW, WSW, and SSE belong to sunny slope and half sunny slope with long sunshine hours. These aspects are suitable for growing crops and farmers' production. This clearly shows that the distribution of rural settlements is affected by aspect.

3.3. *Spatial distribution of rural settlements based on traffic accessibility*

Roads, connecting rural settlements, are the main channels for the transfer of material and information between settlements. We considered traffic conditions and terrain conditions in calculating traffic accessibility. This can accurately reflect the impact of the urban on the spatial distribution of rural settlements. According to the equal interval method, the MCR value from rural settlements to the district government was divided into five intervals: <50000, 50000–100000, 100000–150000, 150000–200000, and >200000. According to the equal interval method, the MCR value from rural settlements to the townships was also divided into five intervals: <15000, 15000–30000, 30000–45000, 45000–60000, and >60000. Following this, we statistically analyzed the number and area of rural settlements in every range, separately (Table 4).

Table 3
Rural settlements in different ranges of aspect in Baota District in 2015.

	Aspect(°)	Count	Percentage (%)	Area(hm^2)	Percentage(%)
NNE	0–45	178	4.37%	372.89	6.78%
ENE	45–90	350	8.60%	615.41	11.18%
ESE	90–135	555	13.63%	774.85	14.08%
SSE	135–180	732	17.98%	1015.74	18.46%
SSW	180–225	1034	25.39%	1198.75	21.79%
WSW	225–270	826	20.28%	740.28	13.45%
WNW	270–315	288	7.07%	399.32	7.26%
NNW	315–360	109	2.68%	385.01	7.00%

The number of rural settlements with an MCR value of less than 50000 to the county seat is 1003, accounting for 24.63% of the total number of rural settlements and 63.40% of the total area of rural settlements. Only 285 rural settlements are distributed in the interval with an MCR value to the county seat of more than 200000, accounting for 7% of the total number of rural settlements. The number of rural settlements in the interval with an MCR value to townships less than 15000 is 1195, accounting for 29.35% of the total number of rural settlements and 67.08% of the total area of rural settlements. Only 131 rural settlements are distributed in the interval with an MCR value to townships of more than 60000, accounting for 3.22% of the total number of rural settlements.

The MCR value to the county is significantly different to the MCR value to townships. Traffic accessibility to townships has a greater impact on the spatial distribution of rural settlements than the traffic accessibility to the county.

3.4. *Quantitative identification of influencing factors*

Based on the analysis of rural settlement spatial distribution characteristics, this study further analyzed the major influencing factors of rural settlement spatial tropism distribution, from a quantitative perspective. This study focused on the influence of natural geographical factors and transport accessibility factors in spatial tropism distribution of rural settlements. Independent variables included: MCR value to towns (x_1), MCR value to the county (x_2), the distance to a state road (x_3), the distance to a provincial road (x_4), the distance to a county road (x_5), elevation (x_6), slope (x_7), aspect (x_8), distance to a river (x_9), and farming radius (x_{10}). Prior to the establishment of the regression model, these ten influencing factors were normalized. A random sampling method was used to extract the rural settlement binary raster data and the ten impact factors' raster data (the number of sampling was 121863). The logistic regression model is shown in formula (4):

Table 4
Rural settlements in different intervals of the MCR value to the county and townships in Baota District in 2015.

MCR value to county (10^4	Count	Percentage (%)	Area (hm^2)	Percentage (%)	MCR value to towns (10^4	Count	Percentage (%)	Area (hm^2)	Percentage (%)
<5	1003	24.63%	3488.60	63.40%	<1.5	1195	29.35%	3690.88	67.08%
5–10	1628	39.98%	1134.79	20.62%	1.5–3	1519	37.30%	1289.89	23.44%
10–15	849	20.85%	446.35	8.11%	3–4.5	826	20.28%	368.39	6.70%
15–20	307	7.54%	215.95	3.92%	4.5–6	401	9.85%	126.26	2.29%
>20	285	7.00%	216.56	3.94%	>6	131	3.22%	26.82	0.49%

$$\ln(p/(1-p)) = -0.57 - 0.45x_1 - 2.59x_2 + 1.46x_3 + 0.14x_4 - 0.19x_5 - 1.60x_6 - 0.23x_7 - 0.03x_8 - 0.35x_9 - 0.64x_{10} \tag{4}$$

Table 5 shows that all factors passed the significance test and the ROC test value of the predicted probability is 0.93. The spatial distribution pattern of rural settlements is the result of the combined effects of various factors. From the results of the logistic regression, MCR value to towns, MCR value to the county, the distance to a county road, elevation, slope, aspect, the distance to a river and the farming radius have a negative correlation with the distribution of rural settlements. Conversely, the distance to a state road and the distance to a provincial road have a positive correlation with the rural settlements' distribution. This means that rural settlements are located in the vicinity of the county, towns, a river, farmland, sunny slopes, and a county level road. Therefore, county-level road development plays an important role in the optimization of town-village systems.

4. Discussion

4.1. Spatial differences in rural settlements' distribution

In this study, we found significant differences in the distribution of rural settlements in the northern and southern parts of Baota District. The density of rural settlements in the northern area is significantly higher than that in the southern area. In 2015, the area of rural settlements in the northern area was 14.34 times that of the southern area, and the total area of construction land was 24.46 times that of the southern area. Socio-economic, bio-physical, and other factors affect the development of villages and the expansion of rural settlements (Long and Li, 2012; Song and Liu, 2014). The county government, industrial parks, transportation hubs, and logistics centers are mostly distributed in the northern part of Baota District. The northern part has become a gathering area for population, capital, and other elements. With the transition and advancement of the rural economy and society, the location of rural settlements is gradually tilted from resource dependence to traffic conditions, basic services, and employment chances (Zhou et al., 2013). During the period 1970–2015, the rural settlements in the northern part of Baota District expanded by 1,484.64 ha, which is 25.75 times that of the southern area. Thus, villages in the north have developed rapidly and become high-density areas, while villages in the south have become low-density areas.

Table 5
The Coefficients and significance test results of logistic regression.

	β	*S.E*	*Wals*	*df*	*Sig.*	*Exp (B)*
x1	−0.45	0.02	341.59	1	0.00	0.64
x2	−2.59	0.04	4986.81	1	0.00	0.07
x3	1.46	0.03	2522.18	1	0.00	4.31
x4	0.14	0.01	110.38	1	0.00	1.15
x5	−0.19	0.01	402.50	1	0.00	0.82
x6	−1.60	0.02	8505.28	1	0.00	0.20
x7	−0.23	0.01	583.80	1	0.00	0.80
x8	−0.03	0.01	6.93	1	0.01	0.98
x9	−0.35	0.01	811.97	1	0.00	0.71
x10	−0.64	0.01	2302.94	1	0.00	0.53
constant	−0.57	0.01	2656.05	1	0.00	0.56

4.2. Influence mechanism of rural settlements' tropism distribution

Topography is the dominant factor that affects the distribution and development of rural settlements. In the Loess Hilly and Gully Region, agricultural production conditions at high altitude areas are usually poor, which is not conducive to agricultural production activities. Conversely, low altitude areas are convenient for farmers to live and engage in production activities (Ma et al., 2012). Similarly, as the slope increases, the area of land suitable for cultivation gradually decreases and the cost of engaging in agricultural production activities also increases. In addition, as the altitude and slope increase, the cost of building construction also increases. Thus, rural settlements are often distributed in low elevation and gradual slope areas.

Water resources and farming radii, two major factors of agricultural condition, also affect the spatial pattern of rural settlements. Baota District is a typical Loess Hilly and Gully Region with an annual rainfall of about 500 mm, and the amount of evaporation is large (Yao et al., 2012). In addition, soil and water loss in the Loess Hilly and Gully Region is serious, which leads to water shortages in some areas. Water condition plays an important role in agricultural production and peasant life (Guo et al., 2012). Thus those rural settlements located near rivers are convenient for agricultural cultivation and living. Types of cultivated land in the Loess Hilly and Gully Region include dam land, terraces, and sloped farmland. Sloped farmland and terraces are the main types, which are not convenient for mechanical farming. Considering transportation cost and convenience, farmers often settle in areas close to their cultivated land. Thus, the distribution of rural settlements in Baota District shows a decreasing trend as the distance to a river increases, and the major farming radius in this district is 700–800 m, about ten minutes walking time.

Due to the difference in sunshine hours and solar radiation intensity, the sunny-slopes of the mountains are warm and dry and the shady-slopes are cold and damp. The environmental conditions of sunny-slopes are more suitable for human habitation and sufficient lighting conditions also meet the needs of crop growth. Therefore, in the mountainous areas, the spatial distribution of rural settlements has a significant correlation with aspect (Jiao et al., 2013). Rural settlements in Baota District are mainly distributed in the aspect of 135°–270°.

Traffic and location also play an important role in rural settlements' distribution. Villages in the suburbs have more opportunities for development (Jiang et al., 2007). In rural areas, towns are a central place for geographical functions such as market, science and education, culture and health, consumption, and public services. Towns have a great influence on rural economic and social development and affect the spatial evolution and development of rural settlements (Li and Zhang, 2012). The transportation network connects towns and villages and promotes the circulation of elements between urban and rural areas. Compared to the eastern plains, the influence of county-level roads on the distribution of rural settlements in the Loess Hilly and Gully Region is more prominent (Wu et al., 2013). This is mainly limited by terrain conditions. The state-level roads in Baota District pass mainly through the valleys of the Yan River Basin. Due to the limitation of terrain conditions, the number of rural settlements clustered near the state level roads only accounts for a small part of the total.

4.3. Spatial optimization implications and the limitations of this study

The optimization and reconstruction of rural settlements include internal structure optimization and village-town system optimization. Internal structure optimization is reflected in the optimization of various spaces, such as living spaces, production spaces, ecological spaces, and service spaces. We found that 2.14% of the rural settlements in Baota District are distributed at high altitudes and 9.09% of the settlements on steep slopes. In addition, rural ecological space and agricultural production space face rapid shrinkage and there is insufficient service space with the transformation and development of the rural economy-society (Tang et al., 2014). The optimization of internal structure should focus on the community living space, the intensification of production spaces, and the equalization of ecological spaces and service spaces (Liu et al., 2014). Land engineering is an effective way to realize internal structure optimization (Liu and Li, 2014, 2017b).

Due to the limitation of the upper limit of the urban population carrying capacity and terrain conditions (Wang, 2018), it is difficult for the Loess Hilly and Gully Region to achieve a high urbanization rate like the eastern coastal cities in China. Integration of villages and towns is an important way to solve rural development and the priority should be to rebuild the village-town system (Liu and Yang, 2012). As the political, economic, cultural, and residential service centers of rural regions, small towns play an important role in the optimization of the village-town system (Yang et al., 2016; Gu et al., 2015). The focus of village-town system optimization is to strengthen the central function of small towns and improve the service radius of small towns by improving the transportation network.

It is a complex, systematic project to optimize the spatial pattern of the village-town system. Although, in this study, we have discussed the spatial distribution characteristics and influencing factors of rural settlements' tropism distribution, the evolution mechanism, regional types, structural efficiency of the village-town system, and the spatial optimization model still need to be improved. The optimization of the village-town system needs to establish an institutional mechanism and policy system, and construct a life service circle with towns at the core.

5. Conclusion

Previous studies of the spatial distribution pattern of rural settlements, based on "3S" technology, usually took Euclidean distance as the spatial distance. In mountainous areas, this method does not accurately reflect the traffic accessibility between rural settlements and towns. In this paper, we redefined traffic resistance by integrating traffic networks and slope, and thereby statistically analyzed the spatial distribution pattern of rural settlements. Through the statistical analysis of the spatial distribution of rural settlements in Baota District and quantitative analysis of the influencing factors, the following conclusions have been reached:

Rural settlement density is significantly spatially different in Baota District; the density core area of rural settlements in the district is located in the valley area of an industrial cluster. From the perspective of the regional radiance of county and towns, the central radiance of townships has a greater influence on the spatial distribution of rural settlements. Enhancing the accessibility of rural settlements to towns is the basis for the construction of village and township systems. Furthermore, county-level roads play a major role in the spatial distribution of rural settlements. In the optimization of the town-village spatial pattern in counties, a complete transportation network system should be constructed to strengthen the spatial connections between townships. At the same time, the central service functions of towns should be improved to strengthen the central agglomeration and radiation effects. This study would help us understand the spatial tropism distribution of rural settlements in the Loess Hilly and Gully Region, and provide great insight into the optimization of town-village spatial pattern in counties.

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