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# Research on Greenway Route Selection of Traditional Villages Based on GIS: A Case Study of Xingtai County, China

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## Abstract

Greenway is a green linear corridor connecting scenic spots, residential areas, nature reserves, road traffic, etc. Rational greenway route selection can not only attract tourists to increase the income of local villages, but also arouse people's awareness of the protection of traditional villages. This paper took Xingtai County, Hebei Province, China as an example to practice greenway route selection in the county territory. Eight factors were selected for greenway route planning, namely elevation, water body, mountain, ecological protection redline, cultural relics protection units, population density, road traffic network, and important transportation hub. These eight factors were assigned in the GIS platform, and the suitability evaluation system of each factor was constructed. The analytic hierarchy process (AHP) and entropy weight method were combined to calculate the weight of these eight factors. The raster calculator was used to weight and overlay the suitability evaluation system of each factor, and the comprehensive suitability evaluation map of greenway route selection was obtained. Based on an important transport hub, along with the water body and the road traffic, the final selection greenway route of traditional villages in Xingtai county was formed. The results of the research can provide a certain reference for the greenway route selection at the county scale.

## Keywords

Greenway Route Selection, Suitability Evaluation, AHP, Entropy Weight Method, GIS

## 1. Introduction

The development of the economic level has brought urban problems such as environmental quality pollution and traffic congestion to cities. In recent years, people have deepened their understanding of greenway route selection and construction, and deeply realized that greenway route selection and construction can effectively alleviate urban traffic congestion and improve urban the air quality. Greenway is an indispensable linear corridor connecting natural landscape resources and cultural landscape resources. It is usually established according to natural ecology and artificial corridors such as ridges, rivers, valleys. The reasonable design and selection of greenway routes can not only provide people with convenient leisure passages and maximize environmental equity, but also attract people's attention to and protection of traditional villages, and play the role of ecological protection and transportation guidance.

Greenway lines in the traditional sense are defined [1] through sustainable planning. Scholars analyze ecological functions [2], environmental functions [2], recreational functions [3] [4] and economic functions, and connect important nodes to obtain greenway selection lines [5]. Some scholars have combined ecological protection with historical and cultural heritage to establish a relevant line selection evaluation system [6]. Later, some scholars determined the greenway route through the weighted evaluation method, which showed greater flexibility in underdeveloped areas [7]. Because Analytical Hierarchy Process (AHP) has been applied in many studies as one of the weighted methods, its effectiveness and success have been proved. Some scholars use AHP to build a suitability evaluation system and determine factor weights to achieve green road line selection [8].

As a reliable, efficient and convenient road route selection technology, GIS technology has gradually entered the vision of researchers on the basis of the traditional greenway route selection method. Some scholars begin to gradually use GIS technology and suitability evaluation methods to select greenways [9]. Later, on the basis of GIS technology, an innovative method for developing a multi-functional greenway network using the minimum cost path model, nuclear density analysis and proxy index is proposed, which provides a methodological framework for the development of medium-developed cities [10]. Some scholars use GIS buffer zone analysis, superposition analysis and other methods to select Wuhan East Lake Green Road Line in combination with AHP [11]. Researchers use GIS technology and AHP to achieve sustainable rural development greenways [12]. AHP is used to determine the weight of each factor, and then combined with GIS technology, the appropriate range of greenway line selection is obtained [13]. Using the methods of GIS suitability superposition analysis and AHP, the suitability analysis results of greenway selection are obtained, and then the final green road line is realized according to the path layout [14]. Some scholars have used multi-source urban data and machine learning algorithms to generate urban greenway networks [15]. On the basis of AHP, some scholars have added the principal component analysis method to establish an index evaluation system for green road line selection, and use GIS technology to realize greenway selection [16]. Some scholars use GIS technology to superimpose historical resources, transportation, land and other factors on the selection of green road lines [17]. Some scholars use the entropy weight method to determine the index weight value of the best railway line. The results show that the entropy weight method can make full use of objective data information and reduce the influence of subjective factors [18].

Most of the existing green road line selection studies only use AHP as a method to determine weights, which is subjective and does not take into account changes in objective conditions. As a method to determine the weight on the greenway selection line, the entropy weight method relies more on objective data, has certain objectivity, and fails to take into account the change of subjectivity. Therefore, in order to better evaluate the suitable area of the greenway, this paper introduces a combination of AHP and entropy weighting to calculate the weight of various factors, and uses GIS technology to realize the selection of traditional village greenway paths in the county. This method uses both AHP and entropy weight method to maintain a good balance between subjectivity and objectivity.

## 2. Materials and Methods

### 2.1. Study Area and Datasets

The study area is Xingtai County, which is subordinate to Xingtai City, Hebei Province, China. It is located in the southwest of Hebei Province, with an east longitude of 113˚45' - 114˚38' and north latitude of 36˚58' - 37˚22', as shown in **Figure 1**. The total area is 1927.6 square kilometers. The terrain in the territory is high in the West and low in the East, which is distributed in three landforms: mountains, hills, and plains. Xingtai belongs to a warm temperate semi-arid monsoon climate. The annual average temperature is 12.8˚C, and the annual average rainfall is 558.7 mm per annum. The annual precipitation varies greatly and its distribution is extremely uneven.

As a historical county with excellent natural conditions and rich tourism resources, Xingtai County has the most complete, the largest number and areas of traditional cultural villages in Hebei Province. According to the list of traditional villages that have been selected and publicized in China's traditional villages, there are 13 traditional villages in Xingtai County, namely Cuilu Village, Yaoping Village, Longmen Village, Huangsi Village, Longhua Village, Neiyang Village, Dajia Village, Chajiugou Village, Yulingou Village, Shipotou Village, Dongshishan Village, Baiyangzhuang Village and Taoshuping Village.

The 30 m SRTM DEM data was prepared for evaluating the elevation information of the study area, and the population, ecological data and the cultural relic protection information were obtained from the Statistical Yearbook of Xingtai County. In addition, the mountain, water resources and traffic network

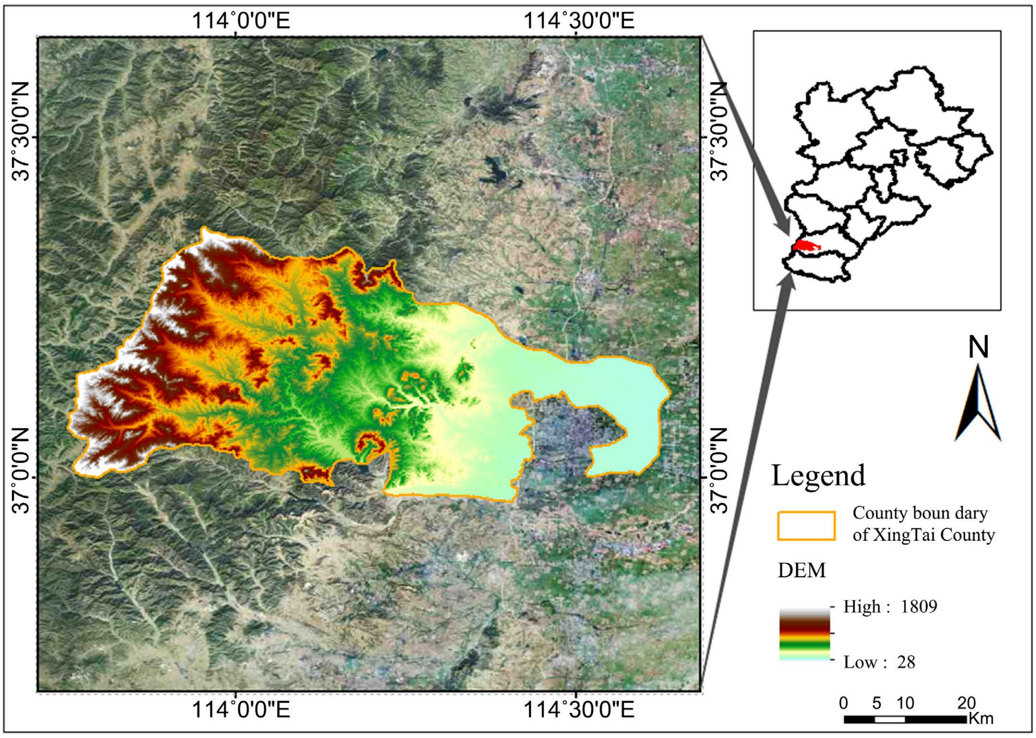



**Figure 1.** Study area location.

data, etc., were collected for further analysis. All of the acquired data were input into the ArcGIS software to build the geospatial database of Xingtai County.

## 2.2. Research Methods

Based on the technology of geographic information system (GIS), the suitability of the greenway route selection of traditional villages in Xingtai County is evaluated by using the combination of AHP and entropy weight method. The technology flowchart of the research is shown in **Figure 2**.

1) Analytic Hierarchy Process

The AHP is a method to solve qualitative problems proposed by operational research scientist T.L. Saaty [19] in the 1970s, which can provide a scientific basis for objective analysis and decision-making.

2) Entropy weight method

The entropy weight method [20] is an objective weight calculation method. It determines the objective weight according to the variability of the index. The greater the variability of the index, the greater the amount of information reflected and the greater the corresponding weight.

3) Spatial analysis method

In this paper, through GIS spatial buffer analysis, the suitability analysis method is used to obtain the suitability evaluation map of each greenway route selection factor, then the evaluation map of each factor is superimposed by the weighted superposition method, finally the comprehensive evaluation map suitable for greenway route selection is obtained.

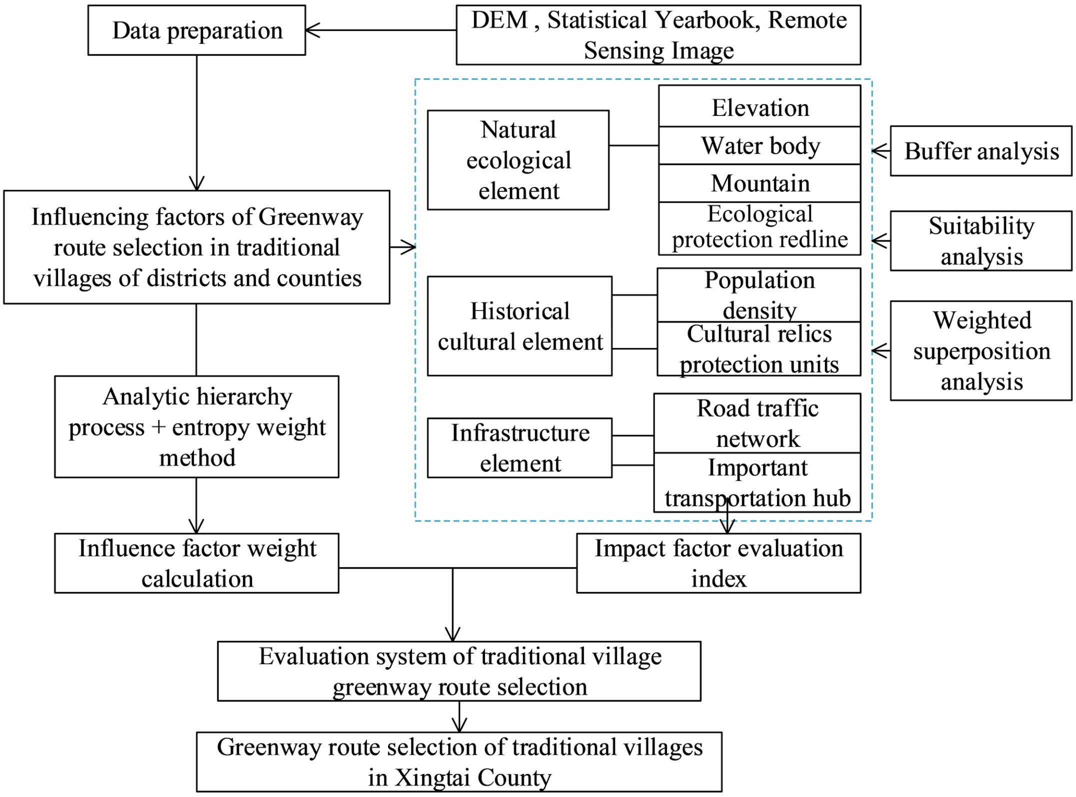



**Figure 2.** Technology flowchart.

## 3. Greenway Route Selection of Traditional Villages in Xingtai County

Based on the literature on greenway route selection, and combined with the current situation of traditional villages, three elements affecting greenway route selection in traditional villages are determined, that is, natural ecological element, historical cultural element and infrastructure element. The natural ecological element include elevation, water body, mountain, and ecological protection redline. The historical cultural element includes cultural relics protection units, and population density. The infrastructure element includes road traffic network, and important transportation hub. After confirmation, the suitability of these 8 factors was evaluated. The information on each influence factor is shown in Table 1 below.

### 3.1. Determination and Calculation of Weight

Each factor has a certain influence on the greenway route selection of traditional villages, but the importance of each factor to the route selection is different. Therefore, a combined AHP and entropy weight method are used to calculate the weight of each factor respectively, and the final weight values are achieved through a combination of weights obtaining from the above two methods, so as to determine the different influence degree of each influence factor on the greenway route selection of traditional villages.

**Table 1.** Influence factor of greenway route selection.

| First-class target | Second-class target |
|---|---|
| Natural ecological element | Elevation |
| | Water body |
| | Mountain |
| | Ecological protection redline |
| Historical cultural element | Cultural relics protection units |
| | Population density |
| Infrastructure element | Road traffic network |
| | Important transportation hub |

#### 3.1.1. Weight Calculation by AHP

The questionnaire was conducted by relevant experts in human geography, urban and rural planning. The results were used for the development of the judgment matrix, which was constructed by comparing the two factors, and the weight value of each factor was calculated. The judgment matrix is shown in Table 2 below.

Then the consistency of the judgment matrix is tested. The maximum characteristic root $\lambda_{\max} = 8.0572 > 8$ of the eighth-order judgment matrix is obtained, so the necessary condition for the consistency of the judgment matrix is formed.

In order to further test whether the matrix has satisfactory consistency, the consistency index $CI$ and consistency ratio $CR$ need to be calculated and compared. According to the formula [19], $CI = (\lambda_{\max} - n)/(n-1) = 0.0082 < 0.1$, indicating that the judgment matrix has consistency. And $CR = CI/RI = 0.0058 < 0.1$, that is, $CI < 0.1$, $CR < 0.1$, so the constructed matrix has consistency, indicating the weight value of each factor has a certain accuracy.

According to the weights of the eight influencing factors of greenway route selection calculated by the above procedure, they are arranged in descending order as a mountain (0.3968), elevation (0.2503), cultural relics protection units (0.105), water body (0.1023), road traffic network (0.0608), ecological protection redline (0.0433), population density ( 0.0262), important transportation hub (0.0152).

#### 3.1.2. Calculation of Weight by Entropy Weight Method

1) Expert scoring and Normalization

The domain experts will score according to the importance of the impact factor, and after scoring, each factor should be normalized, that is, the absolute value of the indicator is converted into relative value. The formula [20] for normalized treatment index is

$$X_{ij} = \frac{x_{ij} - \min\{x_{1j}, \cdots, x_{ij}\}}{\max\{x_{1j}, \cdots, x_{ij}\} - \min\{x_{1j}, \cdots, x_{ij}\}}. \quad (3\text{-}1)$$

where $X_{ij}$ represents the evaluation value of the $j$-th indicator by the $i$-th expert. The normalization results are shown in Table 3 below.

Table 2. Judgment matrix of the influence factors.

| Factor | Elevation | Mountain | Water body | Ecological protection redline | Cultural relics protection units | Population density | Road traffic network | Important transportation hub |
|---|---|---|---|---|---|---|---|---|
| Elevation | 1 | 3 | 1/2 | 6 | 2 | 5 | 4 | 7 |
| Mountain | 1/3 | 1 | 1/4 | 3 | 1/2 | 3 | 2 | 5 |
| Water body | 2 | 4 | 1 | 7 | 3 | 6 | 5 | 8 |
| Ecological protection redline | 1/6 | 1/3 | 1/7 | 1 | 1/5 | 1/2 | 1/3 | 2 |
| Cultural relics protection units | 1/2 | 2 | 1/3 | 5 | 1 | 4 | 3 | 6 |
| Population density | 1/5 | 1/3 | 1/6 | 2 | 1/4 | 1 | 1/2 | 3 |
| Road traffic network | 1/4 | 1/2 | 1/5 | 3 | 1/3 | 2 | 1 | 4 |
| Important transportation hub | 1/7 | 1/5 | 1/8 | 1/2 | 1/6 | 1/3 | 1/4 | 1 |

Table 3. Normalization of index.

| index | N1 | N2 | N3 | N4 | N5 | N6 | N7 | N8 |
|---|---|---|---|---|---|---|---|---|
| 1 | 1.0000 | 1.0000 | 0.5000 | 0.0000 | 1.0000 | 0.2900 | 0.2700 | 0.0000 |
| 2 | 1.0000 | 0.0000 | 0.3000 | 0.4000 | 0.0000 | 1.0000 | 1.0000 | 0.6000 |
| 3 | 0.0000 | 1.0000 | 1.0000 | 0.8000 | 0.3000 | 0.2900 | 0.1000 | 0.8000 |
| 4 | 1.0000 | 1.0000 | 0.0000 | 0.4000 | 1.0000 | 0.0000 | 0.0000 | 1.0000 |
| 5 | 0.5000 | 1.0000 | 0.1000 | 0.6000 | 0.1000 | 0.2900 | 0.2700 | 0.6000 |
| 6 | 0.1000 | 0.5000 | 0.2000 | 1.0000 | 0.1000 | 0.5600 | 0.1800 | 0.4000 |

2) Calculate the proportion of the $i$-th sample value under the $j$-th index in this index, and the formula [20] is as follows:

$$P_{ij} = \frac{y_{ij}}{\sum_{k=1}^{n} y_{ij}}, \left( j = 1, 2, \cdots, m \right). \tag{3-2}$$

The specific gravity of $P_{ij}$ is shown in Table 4 below.

3) Calculate the entropy of index $J$, and its formula [20] is as follows:

$$H\left(y_j\right) = -k \sum_{i=1}^{n} p_{ij} \ln p_{ij}, \left( i = 1, 2, \cdots, n; j = 1, 2, \cdots, m \right). \tag{3-3}$$

The entropy value $H(y_j)$ of each factor is shown in Table 5 below.

4) Calculate factor weight

$$d_j = \frac{1 - H\left(y_j\right)}{m - \sum_{j=1}^{m} H\left(y_j\right)}, \left( j = 1, 2, \ldots, m \right). \tag{3-4}$$

According to the above formula [20], the entropy weight value of each factor can be obtained, as shown in Table 6 below.

According to the above formula, the weights calculated by entropy weight method are as follows: cultural relics protection units (0.1905), road traffic network (0.1772), mountain (0.1565), elevation (0.1219), population density (0.1145),

Table 4. Proportion of indicators.

| $P_{ij}$ | N1 | N2 | N3 | N4 | N5 | N6 | N7 | N8 |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.2780 | 0.2220 | 0.2380 | 0.0000 | 0.4000 | 0.1190 | 0.1480 | 0.0000 |
| 2 | 0.2780 | 0.0000 | 0.1430 | 0.1250 | 0.0000 | 0.4120 | 0.5490 | 0.1760 |
| 3 | 0.0000 | 0.2220 | 0.4760 | 0.2500 | 0.1200 | 0.1190 | 0.0550 | 0.2350 |
| 4 | 0.2780 | 0.2220 | 0.0000 | 0.1250 | 0.4000 | 0.0000 | 0.0000 | 0.2940 |
| 5 | 0.1390 | 0.2220 | 0.0480 | 0.1880 | 0.0400 | 0.1190 | 0.1480 | 0.1760 |
| 6 | 0.0280 | 0.1110 | 0.0950 | 0.3120 | 0.0400 | 0.2300 | 0.0990 | 0.1180 |

Table 5. Entropy value of each index.

| $H(y_j)$ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Entropy | 0.8048 | 0.8821 | 0.7493 | 0.8617 | 0.6948 | 0.8166 | 0.7161 | 0.8728 |

Table 6. Weight value of each factor in the entropy weight method.

| $H(y_j)$ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| weight | 0.1219 | 0.0736 | 0.1565 | 0.0863 | 0.1905 | 0.1145 | 0.1772 | 0.0794 |

ecological protection redline (0.0863), important transportation hub (0.0794) and water body (0.0736).

#### 3.1.3. Calculation of Combined Assignment Weight of AHP and Entropy Weight Method

Combining the advantages and disadvantages of AHP and entropy weight method, and considering the subjectivity and objectivity of the two models, the weights calculated by AHP and entropy weight method are combined to calculate, so as to relatively reduce the systematic error and random error. Here $u_1$ represents the weight value calculated by AHP, and $u_2$ represents the weight value calculated by the entropy weight method.

The combination weight is

$$\omega = \frac{u_1 u_2}{\sum_{i=1}^{n} u_1 u_2}. \quad (3\text{-}5)$$

AHP weight value is: {0.2503, 0.1023, 0.3968, 0.0433, 0.1050, 0.0262, 0.0608, 0.0152}; the weight value of entropy weight method is: {0.1219, 0.0736, 0.1565, 0.0863, 0.1905, 0.1145, 0.1772, 0.0794}; the comprehensive weight values are shown in Table 7 below.

According to the above table, the weight values calculated by combining the AHP with entropy weight method are obtained. From high to low, mountain (0.4472), elevation (0.2197), cultural relics protection units (0.1440), road traffic network (0.0776), water body (0.0542), ecological protection redline (0.0269), population density (0.0216), important transportation hub (0.0087).

Table 7. Comprehensive weight table of AHP entropy weight method.

| Targets | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Weight value | 0.2197 | 0.0542 | 0.4472 | 0.0269 | 0.1440 | 0.0216 | 0.0776 | 0.0087 |

## 3.2. Construction of Greenway Route Selection Suitability Evaluation System

Eight factor layers of elevation, mountain, water body, road traffic network, population density, ecological protection redline and important transportation hub are collected and then imported into ArcGIS software for processing. The reclassification function is used to reclassify each factor based on the suitability of greenway line selection (see Figures 3(a)-(h) below), which is divided into five different grades: 7, 5, 3, 1, and 0. Here the higher the score, the higher the suitability. The assignment of each impact factor is shown in Table 8 below. According to the above treatment, the suitability evaluation of each factor is obtained, as shown in Figure 3 below.

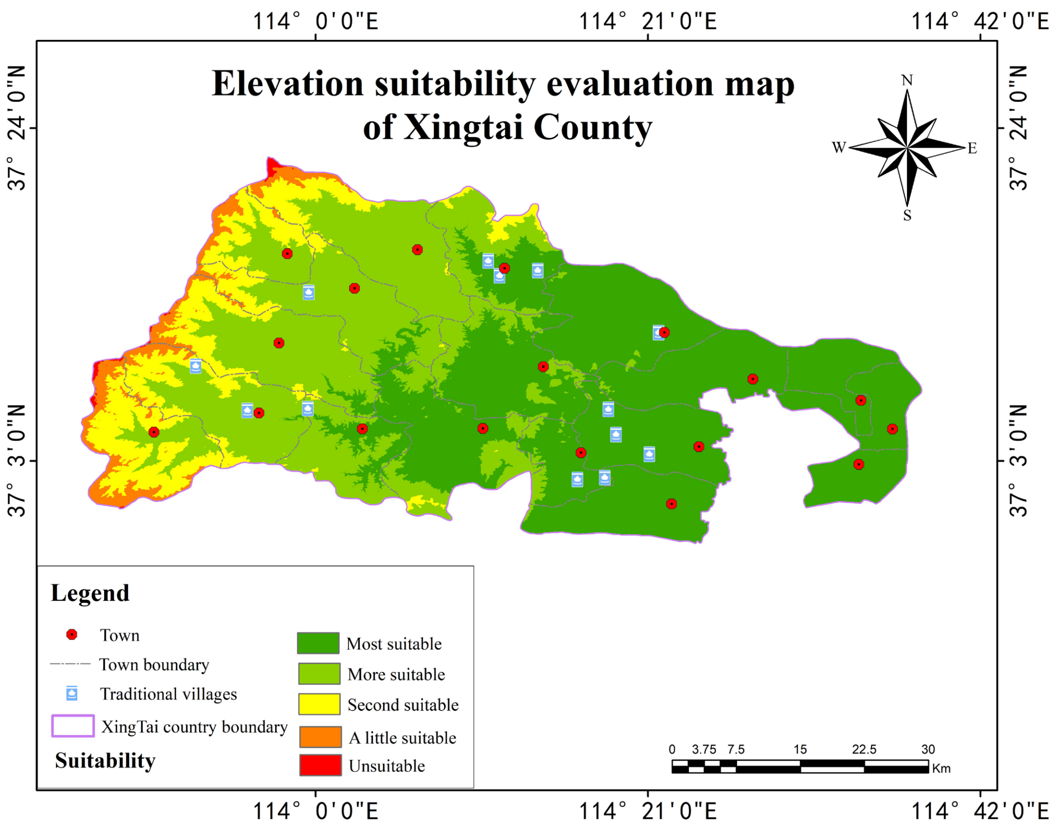
## 3.3. Comprehensive Suitability Evaluation of Greenway Route Selection

The raster calculator in ArcGIS software is used to carry out weighted superposition analysis on the suitability evaluation maps of eight greenway route selection factors, and finally the comprehensive suitability evaluation map of greenway route selection of traditional villages in XingTai County is obtained, as showed in Figure 4 below. It can be found that different colors represent different ranges of greenway route selection. Darker green areas are more suitable for greenway selection in traditional villiages.

# 4. Results

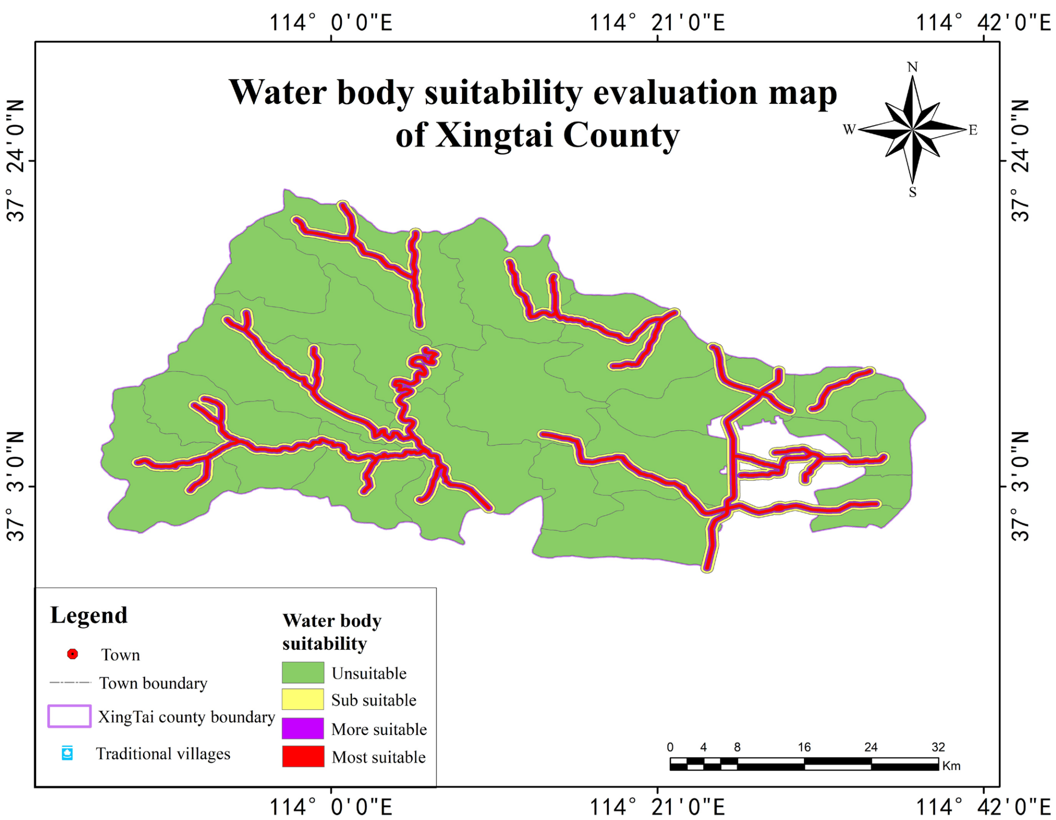
Considering there are many influence factors affecting the selection of greenway route in Xingtai county, it is difficult to connect all of the resources only with one or two routes in the district and county as the greenway route is usually characterized by linear distribution, Therefore, to make the greenway routes effectively connected, multiple branches should be chosen and added to greenway route planning. Here the principle of the shortest distance between two points is not adopted for providing much richer experiences for visitors. Then based on the results of comprehensive suitability evaluation of traditional villages in Xingtai County and the above considerations, the important transport hub, along with the water and road traffic network are integrated into the planning of greenway route to realize the connection the landscape resources and historical resources in Xingtai county as many as possible, and the final greenway route selection of traditional villages in Xingtai county can be formed as showed in Figure 5 below.

It can be observed that the greenway route selection of traditional villages in Xingtai County makes full use of the natural and cultural resources of Xingtai



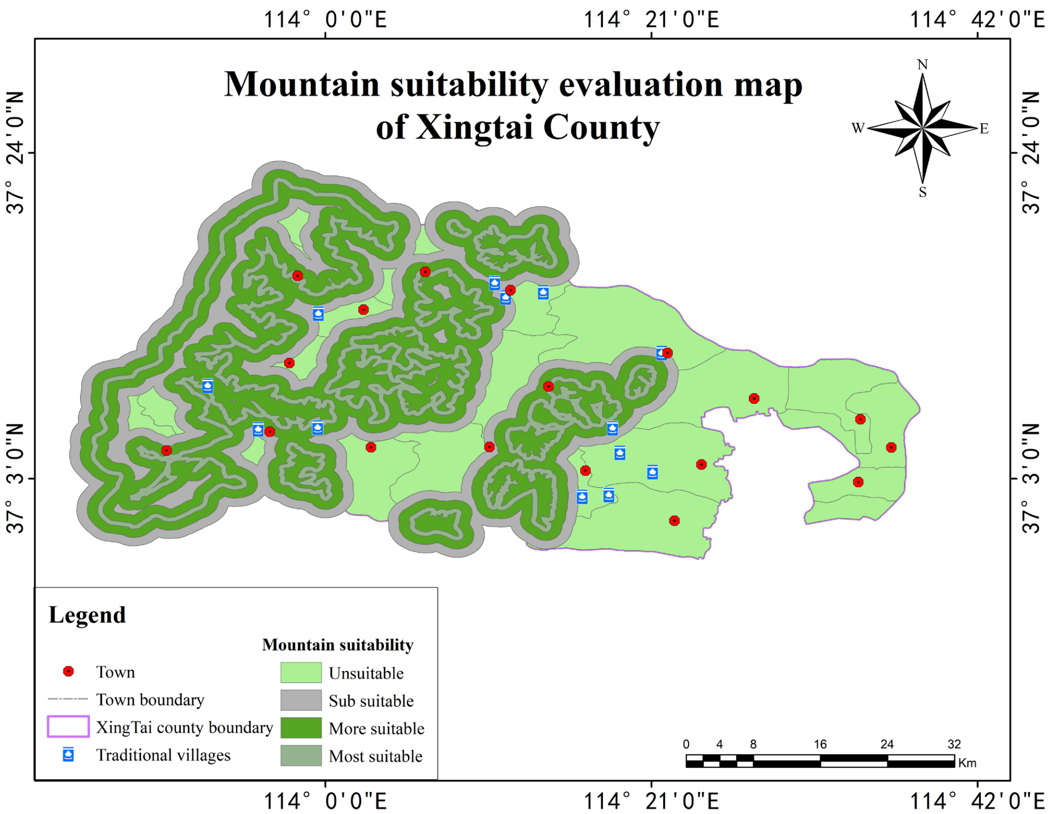
Elevation suitability evaluation map of Xingtai County
114° 0'0"E
114° 21'0"E
114° 42'0"E
37° 24'0"N
37° 3'0"N
N
S
W
E
Legend
Town
Town boundary
Traditional villages
XingTai country boundary
Suitability
Most suitable
More suitable
Second suitable
A little suitable
Unsuitable
0 3.75 7.5 15 22.5 30
Km


(a)

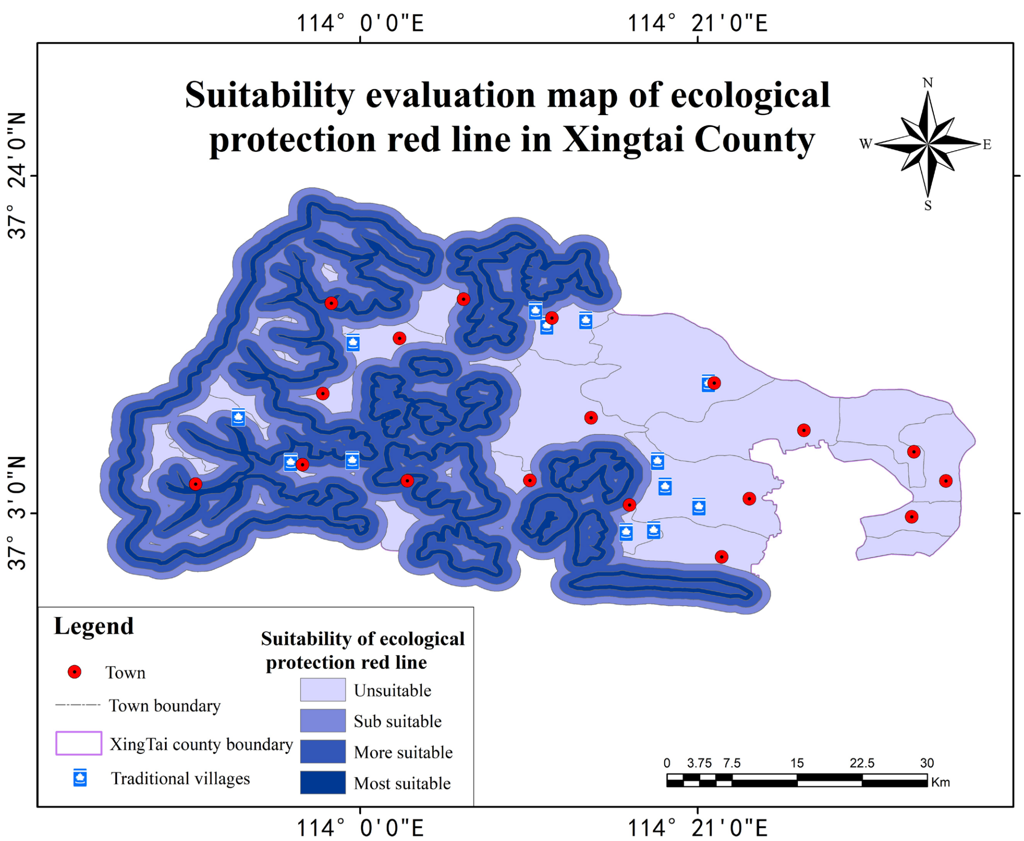


Water body suitability evaluation map of Xingtai County
114° 0'0"E
114° 21'0"E
114° 42'0"E
37° 24'0"N
37° 3'0"N
N
S
W
E
Legend
Town
Town boundary
XingTai county boundary
Traditional villages
Water body suitability
Unsuitable
Sub suitable
More suitable
Most suitable
0 4 8 16 24 32
Km

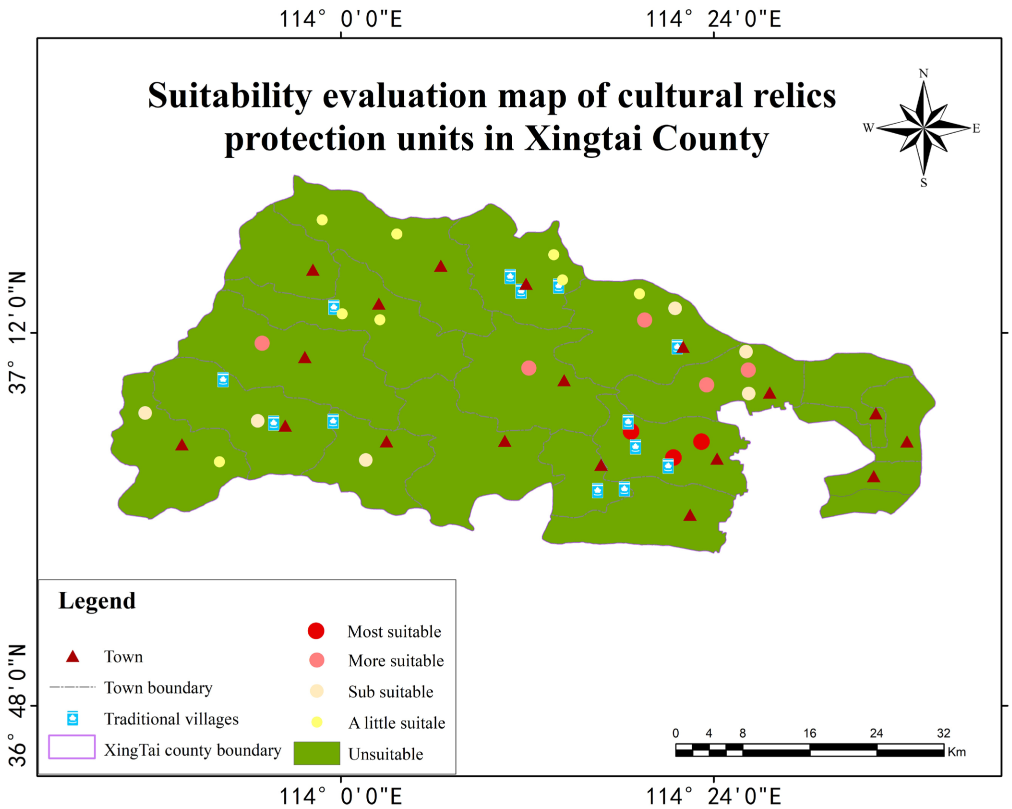

(b)


Mountain suitability evaluation map
of Xingtai County
114° 0'0"E
114° 21'0"E
114° 42'0"E
37° 24'0"N
37° 3'0"N
N
S
W
E
Legend
Mountain suitability
Town
Town boundary
XingTai county boundary
Traditional villages
Unsuitable
Sub suitable
More suitable
Most suitable
0 4 8 16 24 32
Km

(c)

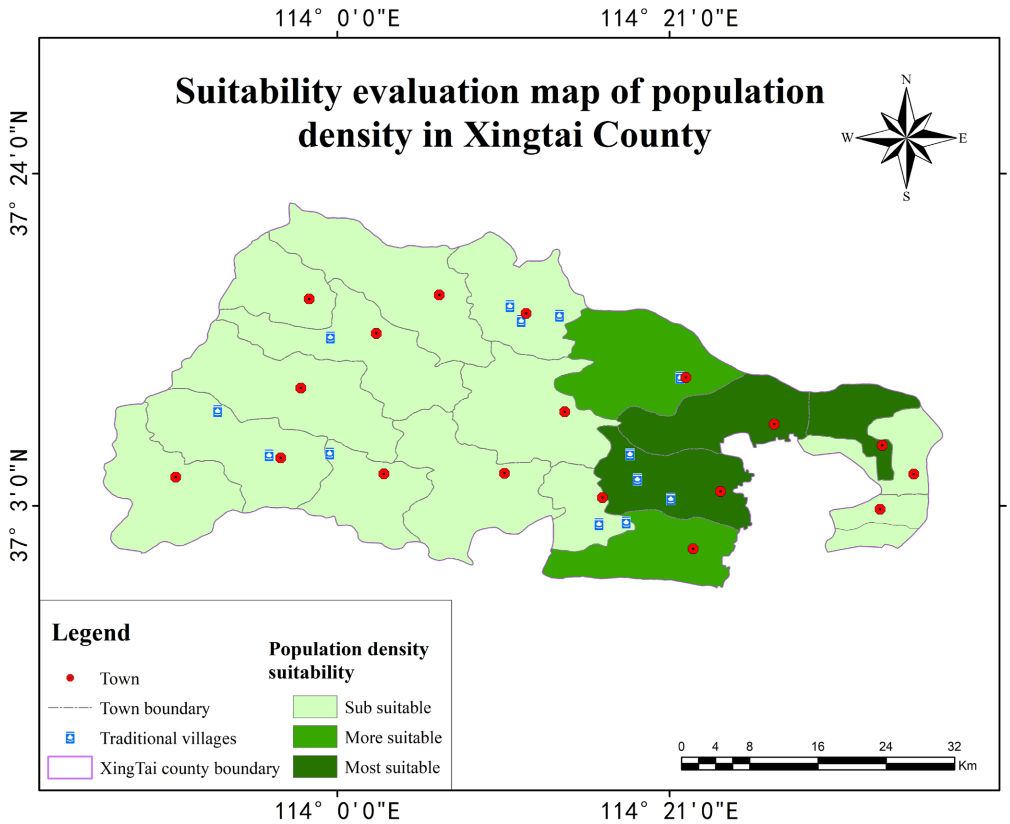

Suitability evaluation map of ecological
protection red line in Xingtai County
114° 0'0"E
114° 21'0"E
37° 24'0"N
37° 3'0"N
N
S
W
E
Legend
Suitability of ecological
protection red line
Town
Town boundary
XingTai county boundary
Traditional villages
Unsuitable
Sub suitable
More suitable
Most suitable
0 3.75 7.5 15 22.5 30
Km

(d)



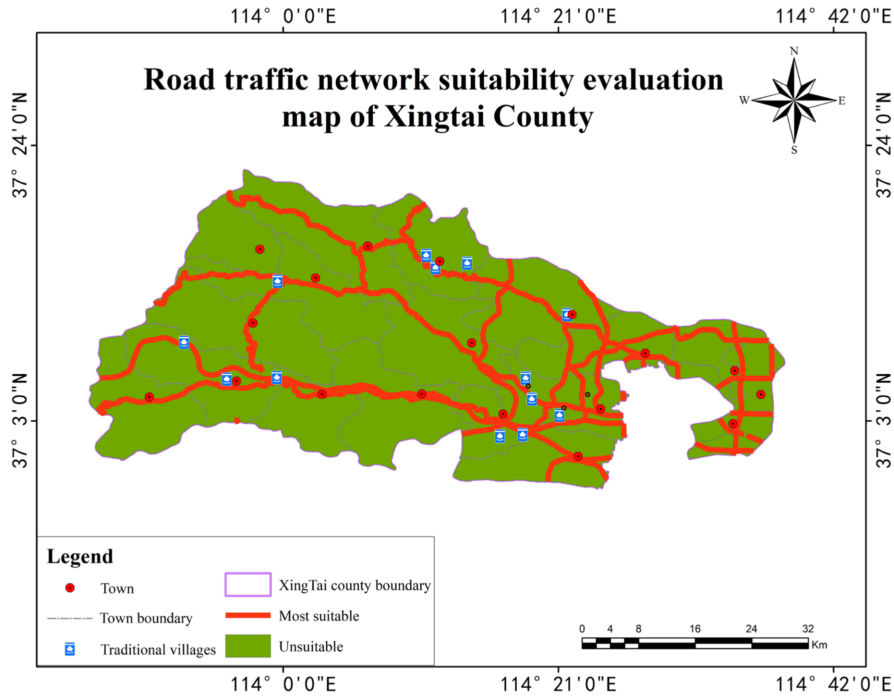
114° 0'0"E
114° 24'0"E
37° 12'0"N
36° 48'0"N
Suitability evaluation map of cultural relics protection units in Xingtai County
N
W
E
S
Legend
Town
Town boundary
Traditional villages
XingTai county boundary
Most suitable
More suitable
Sub suitable
A little suitale
Unsuitable
0 4 8 16 24 32
Km


(e)

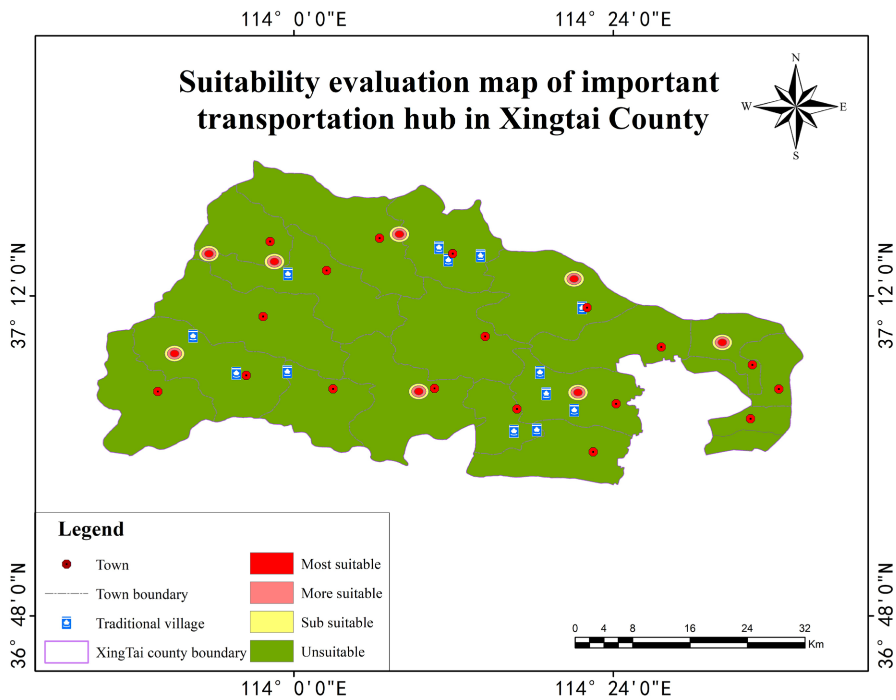


114° 0'0"E
114° 21'0"E
37° 24'0"N
37° 3'0"N
Suitability evaluation map of population density in Xingtai County
N
W
E
S
Legend
Town
Town boundary
Traditional villages
XingTai county boundary
Population density suitability
Sub suitable
More suitable
Most suitable
0 4 8 16 24 32
Km


(f)




(g)




(h)

**Figure 3.** Suitability evaluation of each factor. (a) Elevation suitability evaluation map of Xingtai County; (b) Water body suitability evaluation map of Xingtai County; (c) Mountain suitability evaluation map of Xingtai County; (d) Suitability evaluation map of ecological protection redline in Xingtai County; (e) Suitability evaluation map of cultural relics protection units in Xingtai County; (f) Suitability evaluation map of population density in Xingtai County; (g) Road traffic network suitability evaluation map of Xingtai County; (h) Suitability evaluation of important transportation hub in Xingtai County.

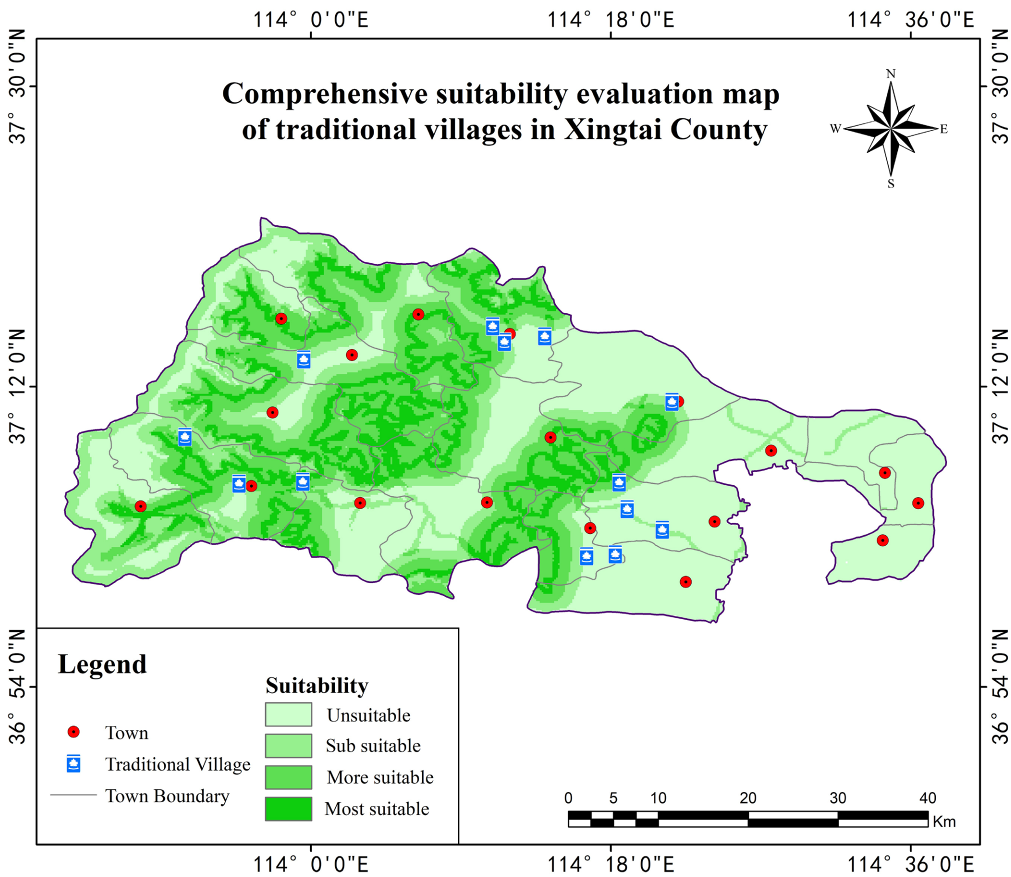



Figure 4. Comprehensive suitability evaluation map of traditional villages in Xingtai County.

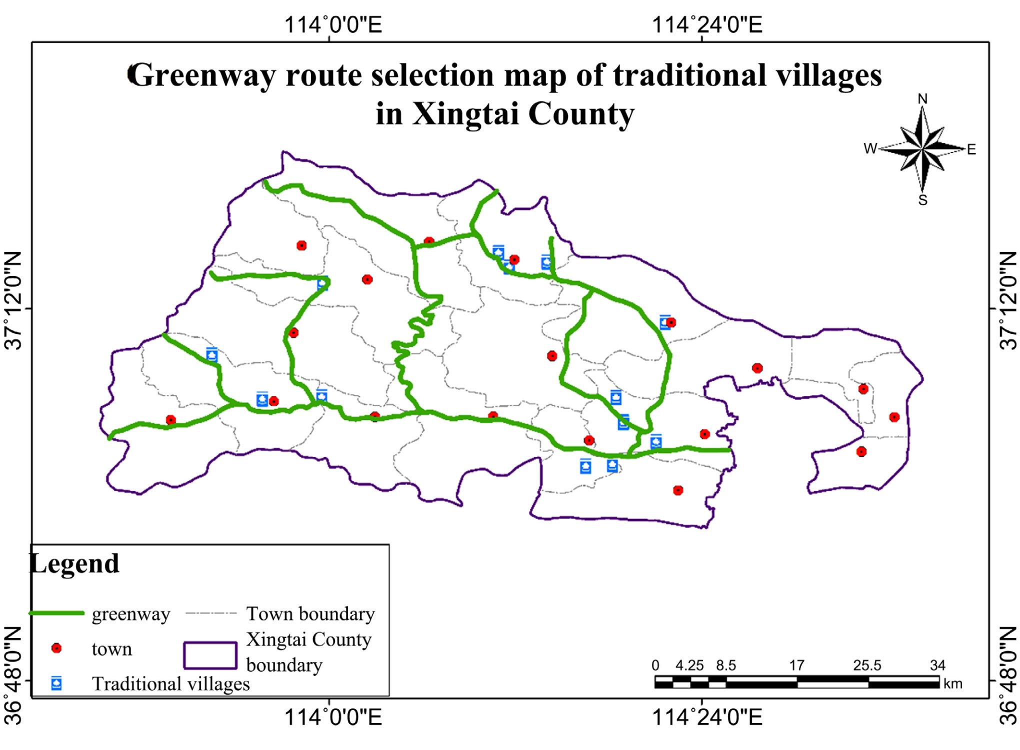



Figure 5. Greenway route selection map of traditional villages in Xingtai County.

Table 8. Assignment of each impact factor.

| First-class targets | | Second-class targets | | Evaluation factor |
|---|---|---|---|---|
| Content | Weight | Content | Weight | Assignment |
| Natural ecological element | 0.7928 | Elevation | 0.2197 | Give it 7, 5, 3, 1, 0 points respectively according to the elevation classification |
| | | Water body | 0.0542 | Seven, five, three, one for the distance from the water body |
| | | Mountain | 0.4472 | 7, 5, 3 and 1 points are given based on the distance close to the mountain |
| | | Ecological protection redline | 0.0269 | The redline classification of ecological protection was assigned 7, 5, 3 and 1 points respectively |
| Historical cultural element | 0.1312 | Cultural relics protection units | 0.1440 | Given a score of 7, 5, and 3 based on the level of heritage conservation units |
| | | Population density | 0.0216 | 7, 5, and 3, respectively, based on population density |
| Infrastructure element | 0.0760 | Road traffic network | 0.0776 | Given a score of 7 or 5, depending on whether the road network is non-highway |
| | | Important transportation hub | 0.0087 | Given 7, 5, 3, 1 points for distance from important transportation hub |

County. At the same time, due to the network structure of greenway route selection for traditional villages in Xingtai County, the greenway users can choose more routes when the connectivity between villages is stronger. And it should be pointed out that by using buffer analysis, superposition analysis and suitability analysis in GIS platform, GIS technology is introduced in the research to form a more scientific and reasonable result of greenway route selection in the study area.

## 5. Summary

Based on GIS technology, this paper studies the greenway route selection of traditional villages at the district and county scale through the utilization of AHP, entropy weight method and spatial analysis methods. Eight impact factors affecting the greenway route selection of traditional villages in Xingtai County are comprehensively selected and evaluated by combing the AHP and entropy weight method, and the buffer analysis and weight superposition analysis of GIS spatial analysis are applied to obtain the most suitable selection for greenway route of traditional villages in Xingtai County, realizing the qualitative and quantitative research of greenway route selection of traditional villages. The combination of AHP and entropy weight method is not only applicable to greenway selection in rural areas, but also to greenway selection in cities or countries.

This study has certain limitations. First of all, the influencing factors on greenway selection are complex, and there are still some shortcomings in the selection and determination of influencing factors. Later, other methods could be explored to select scientific and reasonable influencing factors. Secondly, there is still a lack of systematic line selection of its greenway. In the follow-up research, more basic materials such as factor resources in Xingtai County will be excavated to further optimize the selection of traditional village greenway routes.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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