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Environmental Suitability Evaluation for Human Settlements of Rural Residential Areas in Hengshui, Hebei Province

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Abstract: To improve the development quality of rural residential areas in plain areas requires scientific evaluation. Based on the rural residential area in Hengshui City, Hebei Province, the study selected four indicators of location, production, ecology, and management, to build an evaluation model for the suitability of human settlements and evaluated rural residential areas in Hengshui City. The findings indicated the following: (1) The most suitable areas are mainly concentrated in the geographical center of Hengshui City. The generally suitable areas are mainly distributed in the east of the city. The basic suitable areas are scattered in the west and northeast of the city. The unsuitable areas are mainly concentrated in the north of the city. Most of the area of Hengshui City is suitable for the residence and development of rural residential areas, and 72.86% of rural residential areas are located in suitable areas, which is consistent with the geographical environment characteristics of plain areas. (2) The rural residential areas in unsuitable areas are mainly due to the low income, serious population loss and low urbanization rate, which are in line with the characteristics of rural residential areas. (3) The suitability of human settlements in rural residential areas in plain areas is mainly affected by the per capita agricultural land area, hydrology index, distance to river, distance to country, distance to a slow road, and distance to the fast road are low-level driving factors, of which distance to a fast road has the weakest influence. (4) There is a significant positive correlation between the environmental suitability and the distribution density of rural residential areas. The improvement of the suitability of human settlements can effectively promote the aggregation and distribution of rural residential areas. High-high clustering areas are mainly concentrated in the middle and northeast of Hengshui City, while low-low clustering areas are scattered in the north and southwest of Hengshui City. (5) The location index (LI) and management index (AI) play a limiting role in the suitability of human settlements in the northeast of Hengshui City, and the government should strengthen management intervention and infrastructure construction in the northeast of Hengshui City. The production index (PI) plays a limiting role in the suitability of human settlements in the west of Hengshui City and should consider the improvement of production capacity in the west of Hengshui City. The research results play a vital role in improving the carrying capacity of regional resources and the environment in the plain area, improving rural production, and living conditions, and promoting the development of rural planning in the whole region.

Keywords: rural residential areas; suitability of human settlements; suitability evaluation; Hengshui

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1. Introduction

The spatial layout and development of human settlements are composed of the unique natural conditions of the settlements and the subjective initiative of the residents. Its main purpose is to meet the needs of the residents for survival. The research on human settlements cover landscape [1], ecology [2], climate [3], energy conservation [4], and other fields. In the 1950s, Greek planner Doxiadis first proposed the concept of human settlement science [5]. In 1961, the World Health Organization proposed "suitability" as

one of the basic requirements for the construction and development of human settlements. The suitability of human settlements has become a comprehensive evaluation method for the degree of habitability, which is used to describe and evaluate the quality of human settlements scientifically and quantitatively. In studying the urban human settlements in Australia, Sri Lanka, etc., we must consider economic, traffic, and other human factors, evaluate thermal comfort [6,7], and study rural human settlements, mainly evaluating the impact of natural, climate, and other factors, on the development of rural residential areas [8,9]. With the rapid development of China in recent years, study on the suitability of the natural environment of human settlements in China found that the suitability of the natural environment for human settlements is significant [10,11] and proposed the suitability index of human settlements in arid areas [12]. Using the meteorological data of Chuxiong in recent 30 years, it was found that the meteorological index is moderate, which is conducive to improving the suitability of human settlements [13]. Based on previous studies, the suitability of human settlements can be defined as the appropriate combination degree of the following elements: climate, terrain, water and soil resources, hydrothermal conditions, atmosphere, land use, land cover, and natural disasters, all of which have an impact on human settlements [14].

The rural residential area reflects the production relationship and social culture of rural residential areas. It is a multi-disciplinary and multi-level surface space system closely related to human activities and has three functions: life, agricultural production, and non-agricultural production [15]. As a large population country, China began to formulate a dual structure of urban and rural areas in the 1950s, defining the functional positioning of urban and rural areas, respectively. The main role of rural areas is to solve food supply and other problems. Rural residential areas rely on a large number of cultivated lands to become the geographical basis for productive life activities [16]. Rural residential areas have been widely concerned by experts in geography, ecology, and sociology for a long time [14,17,18]. Mendelas, a French rural sociologist, pointed out that economic and social development, changes in family economic income, and population growth, had a significant impact on the layout of rural residential areas when summarizing the rural revival in the 1980s [19]. Nowadays, the acceleration of urbanization and industrialization has led to the tension of resources and energy and the increase of pressure on the ecological environment, which has led to changes in the security situation of the human living environment [20] and has put forward higher requirements for a series of factors, such as the surrounding natural environment, economic conditions, entertainment facilities, and convenient life [21]. It urges scholars to shift from research on the form and type of rural residential areas to research on human settlements and their suitability [22,23]. Research perspectives mainly include planning, ecology, and geography; for example, the transformation of planning methods [24], land use [25,26], ecological suitability [27], evolutionary mechanism [28,29], and suitability evaluation [30,31]. Research methods are mostly qualitative and quantitative. Based on the analytic hierarchy process (AHP) and ArcGIS technology, the minimum accumulation resistance model [32], the niche suitability model [33], the maxEnt model [34], and the multi criteria model [35], etc., are established to evaluate the suitability of rural residential areas. There are obvious regional differences in research; for example, research on rural residential areas in new residential areas in southeast Türkiye [36], and research on urban and rural land use change in Mexico [37]. The spatial differentiation of the rural residential area in the arid inland river basin is studied [38], the suitability of rural human settlements in Gansu Province is evaluated, the differentiation characteristics are clarified [39], and the suitability of rural residential areas layout in Yixing City is studied [30]. This is based on the traditional land suitability evaluation indicators, such as natural factors such as elevation, slope, and aspect [15], and location factors such as distance from roads and towns [30]. Added to this are the factors that reflect the difference of evaluation target orientation [40], and the ecological environment factors, such as land use type and vegetation coverage [27]. However, the current evaluation of the suitability of rural residential areas mainly considers the influence

of elevation, slope, relief amplitude, and other topographic factors, and lacks consideration of administration factors. In addition, the number of samples for study on the suitability of rural residential areas is insufficient, especially the rural residential areas in plain areas, which are less limited by topographic characteristics and natural disasters, and are ignored due to lack of characteristics.

In recent years, the central government has issued a series of special policies to support the construction of human settlements in rural residential areas. At present, the geographical distribution of rural residential areas in the plain area is relatively scattered, and their relationship with the city cannot be as closely linked with the city as the rural areas in the coastal areas of China. The main reason is that the plain area has been constrained by the urban-rural dual structure for a long time, and is under the guidance of the development strategy of "valuing the city over the countryside". The rural residential areas in the plain area are different from other areas in improving the human settlements. While improving the human settlements, we must adhere to the issue of food security for the Chinese population [41]. Hengshui City, as a typical representative of the North China Plain, has also successively issued the Implementation Plan for Comprehensively Promoting Rural Human Settlements Improvement [42], trying to provide a good living environment for rural residential areas. However, the problems of "rural diseases", such as extensive land use, single function, lack of planning, hollowing, and poverty, which have been formed in rural residential areas for a long time, are becoming more and more serious [43]. The key to rural revitalization is livability, and the suitability evaluation of settlement is the prerequisite for rural renovation, optimization and reconstruction, and the improvement of human settlements [23]. Therefore, based on the scientific and objective suitability evaluation results, and based on the actual development of regional settlements, research on the suitability of human settlements has become key to solving these problems.

Based on the above analysis, this study: establishes a suitability evaluation model based on the AHP method; selects four indicators of location, production, ecology, and administration to evaluate the suitability of rural residential area in Hengshui City; clarifies the geographical and spatial relationship between various indicators and rural residential area; and clarifies the relationship between rural residential area in the appropriate areas and various factors, so as to provide new ideas for the optimization and improvement of settlement and the improvement of human settlements.

2. Research Scope and Data Sources

2.1. Overview of the Study Area

Hengshui City is in the southeast of Hebei Province. The land scope is 115°10′–116°34′ east longitude and 37°03′–38°23′ north latitude. The city size is 98.13 km wide from east to west and 125.25 km long from south to north (Figure 1). It belongs to Hebei Plain, with flat terrain, the elevation difference of the whole area shall not exceed 25 m, 9 rivers in total, and a continental monsoon climate. It belongs to the Bohai Rim Economic Circle and the Capital Economic Circle. It is dominated by agriculture. The total land area of the city is about 8836.78 km^2, of which farmland accounts for about 65% of the land area. The total lighting hours throughout the year are 2609.9 h, and the average precipitation over the years is 524.2 mm. By the end of 2021, Hengshui has a population of 4.589 million, the agricultural population accounts for more than 80% of the total population governing two municipal districts, one county-level city, and eight counties. The rural residential area of the city is 97,368 hectares, accounting for 11.02% of the city's land area. The number of rural residents is large, but the scale is small. The rural production base is difficult to adapt to the requirements of modern agricultural mechanization and large-scale production, resulting in low land production efficiency and urgent need to improve agricultural production conditions.

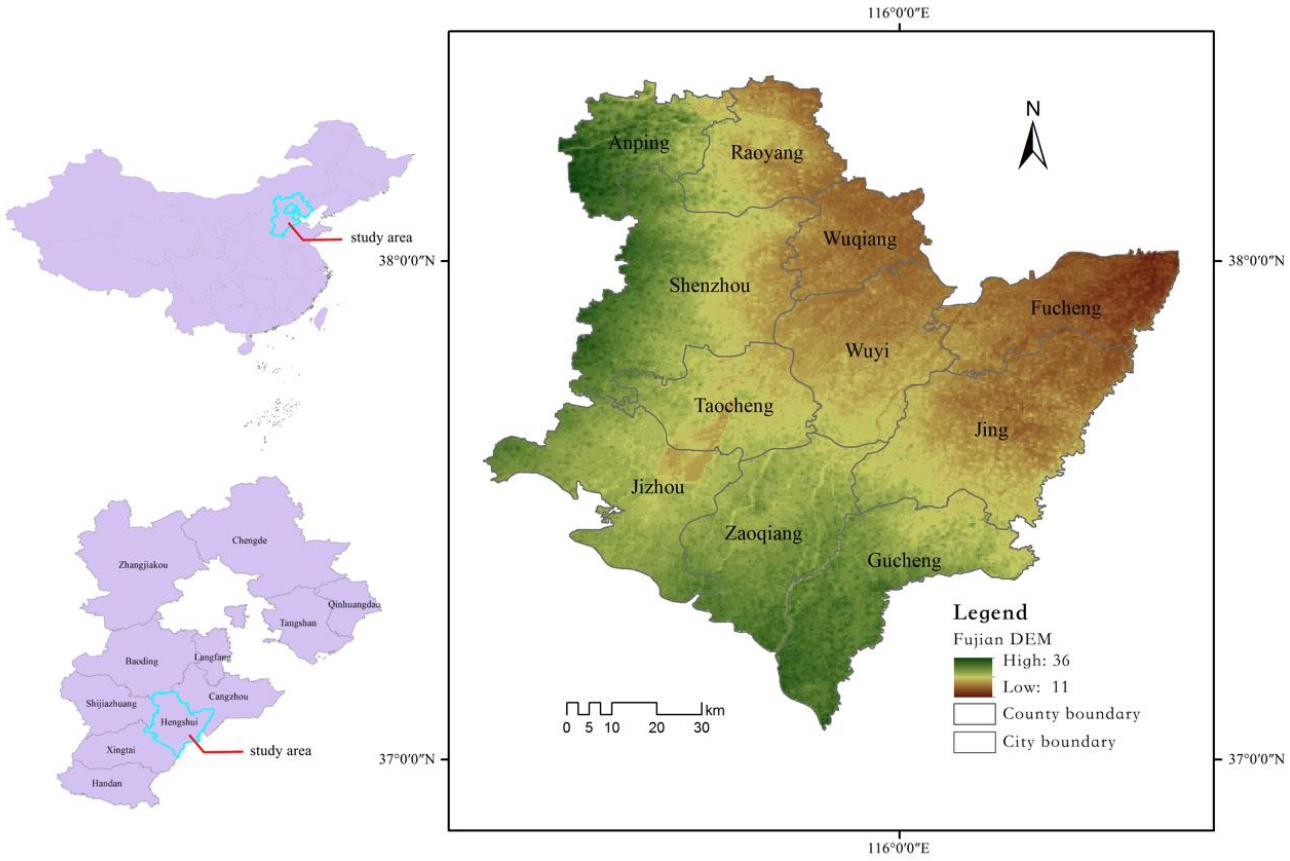

Figure 1. Geographic location map of Hengshui city.

2.2. Data Sources and Processing

Rural residential areas are represented as point elements on the macroscopic scale. Therefore, in the study, the spatial coordinates of rural residential areas are used to replace the rural residential area with a certain regular shape. The detailed directory and relevant data of 4911 rural residential areas were obtained through field research and retrieval of the Hengshui Municipal Planning and Natural Resources Bureau website. On this basis, the POI (Points of Interest) spatial location of each rural residential area in the Baidu map was obtained with the help of the Geosharp software for positioning and coordinate picking (the coordinate picking point is subject to the location of the rural residential area committee, accessed on July 2022).

The selected data include land use data, socio-economic statistics, digital elevation data, planning data, and interest point data, with specific names and sources (Table 1). These parameters were gathered from various sources and are processed and converted into raster data of 30 × 30 m for convenient handling using the ArcMap 10.8 software.

Table 1. Data and data sources.

Category	Remarks	Data Source	Date	Source Location
Distance to fast road	It reflects the development degree of external transportation and represents the convenience of connecting in rural residential areas and cities. The shorter the distance, the better [5].	National Geographic Information Resources Directory Service System	accessed on 2 June 2022	https://www.webmap.cn/

Table 1. *Cont.*

Category	Remarks	Data Source	Date	Source Location
Distance to slow road	It reflects the development degree of external traffic and represents the convenience of traffic in rural residential areas. The shorter the Euclid distance, the better [44].	National Geographic Information Resources Directory Service System	accessed on 2 June 2022	https://www.webmap.cn/
Distance to County	Reflecting geographical position and Convenience of life [20].	National Geographic Information Resources Directory Service System	accessed on 2 June 2022	https://www.webmap.cn/
Distance to river	Reflecting water resources condition [20].	Resource and Environmental Science Data Center	accessed on 5 November 2021	https://www.resdc.cn/
Population of the county	Reflect the economic production capacity of the region [30].	Hengshui statistical yearbook 2020	accessed on 7 November 2021	http://www.shujuku.org/
Urbanization degree	Reflecting the process of urbanization, it is usually expressed as the percentage of the urban population in the total population, which is used to reflect the process and degree of population gathering in the city. The higher the degree of urbanization, the stronger the productivity [30].	Hengshui statistical yearbook 2020	accessed on 7 November 2021	http://www.shujuku.org/
Non-agricultural industry degree	The ratio of the population engaged in secondary and tertiary industries to the total population, Reflects the regional employment structure [31].	Hengshui statistical yearbook 2020	accessed on 15 April 2022	http://www.shujuku.org/
Per capital income of farmers	Reflecting the average income level of rural residents in a region [14].	Hengshui statistical yearbook 2020	accessed on 15 November 2021	http://www.shujuku.org/
Hydrology Index (HI)	Reflect the optimization of land use structure. More construction can be carried out to improve the public living environment [38].	Geographic remote sensing ecological network platform	accessed on 11 May 2022	http://www.gisrs.cn/
Vegetation coverage	Reflect the optimization of land use efficiency and ecological environment suitable for human habitation [37].	Resource and Environmental Science Data Center	accessed on 11 May 2022	https://www.resdc.cn
Temperature Humidity Index (THI)	It reflects the development degree of external transportation and represents the convenience of connecting in rural residential areas and cities. The shorter the distance, the better [38].	Geographic remote sensing ecological network platform	accessed on 11 July 2022	http://www.gisrs.cn/
Proposed development proportion of construction land	It reflects the development degree of external traffic and represents the convenience of traffic in rural residential areas. The shorter the Euclid distance, the better [5].	Hengshui city land acquisition development plan (2021–2023) (Draft for comments)	accessed on 8 July 2022	http://zrgh.hengshui.gov.cn/
Per capita agricultural land area	Reflecting geographical position and Convenience of life [18].	Hengshui city land acquisition development plan (2021–2023) (Draft for comments)	accessed on 8 July 2022	http://zrgh.hengshui.gov.cn/

2.3. Research Framework

The suitability of rural residential areas in Hengshui City is analyzed by establishing an evaluation model for the suitability of human settlements. The basic principles are

as follows: first, screen out the main factors that affect rural residential area, establish a suitability evaluation system, determine the weight of each factor using the AHP, then assign values to the grading of these impact factors through expert scoring, and use the ArcMap10.8 software to grid the data. Using the layer overlay analysis function, the grid map of each factor is weighted and superimposed to obtain the comprehensive evaluation results of the suitability of human settlements suitability. On this basis, it is superimposed with the rural residential geographic space points and graded to determine the characteristics of human settlements' suitability. Its research route is shown in Figure 2.

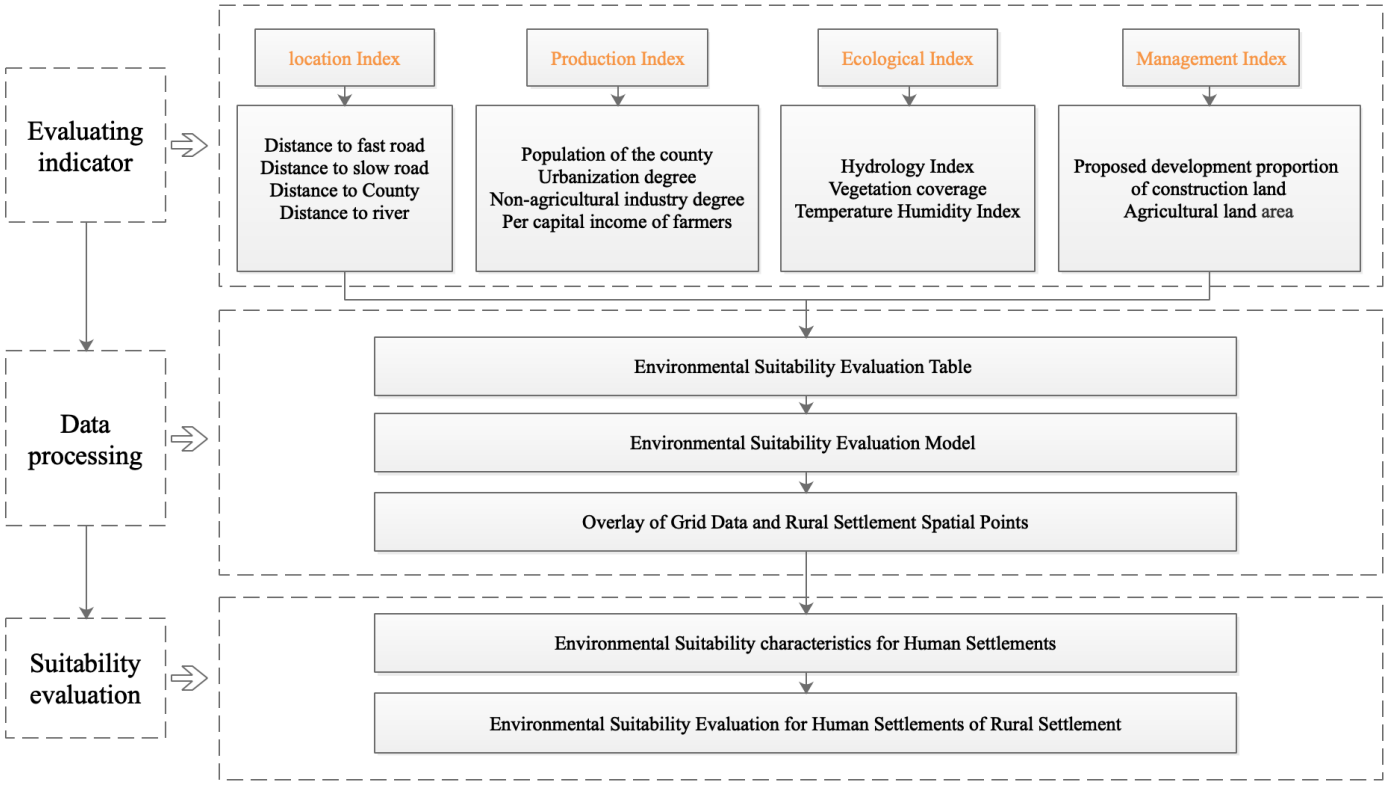

Figure 2. Research flow chart.

3. Research Methodology and Experiments

3.1. Human Environment Suitability Index Model (HEI Model)

In this paper, the suitability evaluation model of human settlements is used to evaluate the suitability of rural residential areas in Hengshui. The purpose is to give corresponding weights to different factors in a fuzzy environment with multiple determining factors, and finally give a relatively scientific comprehensive evaluation result to the evaluation object. The specific formula is as follows:

$$HEI = \alpha \times NLI + \beta \times NPI + \gamma \times NEI + \delta \times NMI \quad (1)$$

where *HEI* is the Human Settlements Environment Index. *NLI* is the normalized *LI*, *NPI* is the normalized *PI*, *NEI* is the normalized *EI*, *NMI* is the normalized *MI*. α, β, γ, and δ, respectively, represent the weight of four indexes.

3.2. AHP-Weighted Information Content Method

(1) Construct judgment matrix A (orthogonal matrix), and use a_{ij} represents the comparison result of the i factor with respect to the j factor:

$$A = (a_{ij})_{n\times n} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \quad (2)$$

(2) Geometrically average the vectors in each row of matrix A (square root method), and then normalize them to obtain the weight of each evaluation index and the eigenvector W:

$$W_i = \overline{W}_i / \sum_{i=1}^{n} \overline{W}_i, \quad W = \begin{Bmatrix} W_1 \\ W_2 \\ \vdots \\ W_n \end{Bmatrix} \quad (3)$$

(3) Consistency test, $CI = 0$, with complete consistency, CI is close to 0, with satisfactory consistency, The larger the CI, the more serious the inconsistency:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (4)$$

where λ Is the maximum characteristic root, N is the unique non-zero characteristic root. To measure the size of CI, CR is used to define the consistency ratio, the formula is as follows:

$$CR = \frac{CI}{RI} \quad (5)$$

where RI is a random consistency index. when the consistency ratio $CR < 0.1$, it is considered that the degree of A's inconsistency is within the allowable range, and there is satisfactory consistency, which passes the consistency test.

3.3. Geographical Detector (GeoDetector)

The Geodetector is one of the powerful tools for scholars to carry out driving force and factor analysis at present, which can detect both numerical data and determinative data [45]. The influence of each factor on suitability can be quantified by statistical analysis of the superposition results of factors and suitability. The influence of each factor is measured by q value, and the algorithm is as follows:

$$\mathrm{q} = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2} = 1 - \frac{SSW}{SST} \quad (6)$$

where h = 1,2 … … , L is the stratification of variable Y or detection factor X, i.e., classification or partition, σ^2 and σ_h^2 is the variance of the whole region Y value and layer h respectively, N and N_h is the unit number of the whole area and layer h, respectively, SST is the total variance of the whole region, SSW is the sum of variance within the layer, and the range of q value is [0~1]. The larger the q value is, the stronger the influence of the detection factor on the suitability is otherwise, the weaker the influence is.

3.4. Coefficient of Geographic Association

The coefficient of geographic association can reflect the matching between two geographical activities or elements in the region [46]. The difference in similarity reflects the

difference in spatial structure, which can be used to express the overall spatial connection level of rural residential distribution and suitability. The formula is as follows:

$$GL = 100 - \frac{1}{2}\sum_{i=1}^{n}|S_i - P_i| \quad (7)$$

where GL refers to the geographic connection rate between the distribution and suitability of rural residential area, N is the number of units, S_i and represents the percentage of the element values of each field in Region I, respectively. The higher the GL value is, the closer the geographical relationship between the two is and the more consistent the geographical distribution is.

3.5. Bivariate Spatial Autocorrelation

Bivariate spatial autocorrelation has high effectiveness and applicability when Moran's I is used to describe the relationship between two geographical things, including global spatial autocorrelation and local spatial autocorrelation [46]. It can be used to describe the spatial consistency and correlation between rural residential areas and suitability. The formula is as follows:

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i - \overline{x})(y_j - \overline{y})}{\sigma^2 \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} \quad (8)$$

where I is the spatial correlation strength of two types of geographic transactions, x_i and represent transaction i and j respectively, N is the number of units, σ^2 is the sample variance, w_{ij} is the spatial weight matrix. When $I = 1$, there is an absolute spatial correlation between them, when $I = -1$, there is absolute dispersion, when $I = 0$, it indicates random distribution.

3.6. Establishment of HEI Model

3.6.1. Establish Evaluation Index System

Rural residential areas are comprehensively affected by nature geography, social economy, and other factors. According to the principle of AHP, the evaluation index system is reasonably divided into the following three different levels: in the first level, the target level refers to the general objective of the suitability evaluation of rural residential areas; in the second level, the criteria level mainly includes four aspects, namely, location index (LI), production index (PI), ecological index (EI), and management index (MI); in the third level, the indicator layer is, respectively: distance to a fast road, distance to a slow road, distance to county, distance to river, population of the country, urbanization degree, non-agricultural industry degree, per capita income of farmers, hydrology index (HI), vegetation coverage, temperature humidity index (THI), the proposed development proposal of construction land, and agricultural land area. Based on the domestic and international suitability of human settlements suitability evaluation studies, this study classifies and summarizes various evaluation elements, and constructs Hengshui City's suitability of human settlements suitability evaluation index system (Figure 3) according to the hierarchical relationship, including four first-degree indicators and 13 s-degree indicators.

3.6.2. Establish Suitability Evaluation Index Table

Based on the division of the target layer, middle layer, and indicator layer in the suitability indicator system, the relative importance and intensity relationship of each impact factor are determined by expert scoring, and the pairwise judgment matrix of the target layer, middle layer, and indicator layer is constructed. The YaAHP software is used to calculate the weight of factors at this level to the factors at the next level and combined with the impact trend of each factor on the suitability of rural residential areas, each factor grading is assigned by 0~9 to generate the evaluation table of suitability indicators for rural residential areas (Table 2).

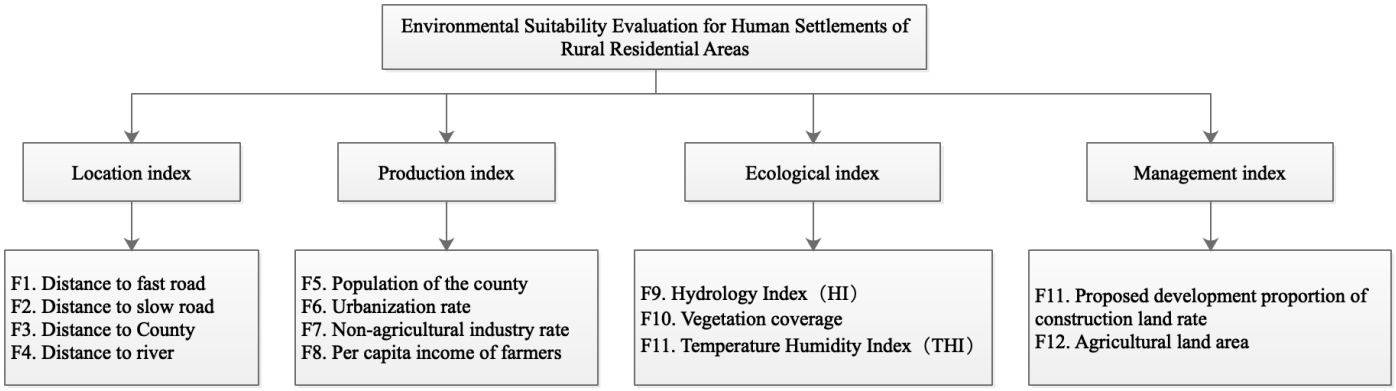

Figure 3. Evaluation index system of rural residential suitability.

Table 2. Table of suitability evaluation indicators.

Middle Layers	Weight	Indicators	Weight	Factor Classification	Value
location index	0.1756	Distance to fast road (km)	0.0298	<5	9
				5~10	7
				10~15	5
				15~20	3
				>20	1
		Distance to slow road (km)	0.0419	<1	9
				1~2	7
				2~3	5
				3~4	3
				>4	1
		Distance to County (km)	0.0693	<8	9
				8~16	7
				16~24	5
				24~32	3
				>32	1
		Distance to river (km)	0.0346	<2	9
				2~5	7
				5~10	5
				10~15	3
				>15	1
Production index	0.2887	Population of the county (k)	0.0407	>477	9
				418~477	7
				370~418	5
				315~370	3
				<315	1
		Urbanization rate (%)	0.0813	>70.0	9
				59.6~70.0	7
				51.5~59.6	5
				47.6~51.5	3
				<47.6	1
		Non-agricultural industry rate	0.0693	>86.1	9
				82.5~86.1	7
				79.3~82.5	5
				74.2~79.3	3
				<74.2	1
		Per capital income of farmers (k)	0.0974	>30.9	9
				28.6~30.9	7
				27.2~28.6	5
				25.6~27.2	3
				<25.6	1

Table 2. *Cont.*

Middle Layers	Weight	Indicators	Weight	Factor Classification	Value
Ecological index	0.247	Hydrology Index	0.081	>0.54	9
				0.47~0.54	7
				0.40~0.47	5
				0.33~0.40	3
				<0.33	1
		Vegetation coverage (hm^2)	0.0645	> 35,400	9
				28,400~35,400	7
				23,100~28,400	5
				17,900~23,100	3
				<17,900	1
		Temperature Humidity Index	0.1016	>89.5	9
				88.7~89.5	7
				87.7~88.7	5
				86.6~87.7	3
				<86.6	1
Management index	0.2887	Proposed development proportion of construction land rate (%)	0.1443	>24.6	9
				19.6~24.6	7
				16.7~19.5	5
				14.0~16.7	3
				<14.0	1
		Agricultural land area (hm^2)	0.1443	>63,700	9
				55,900~63,700	7
				48,300~55,900	5
				40,200~48,300	3
				<40,200	1

4. Results

4.1. Human Environmental Suitability Characteristics

According to the suitability evaluation model, the suitability of human settlements in rural residential areas of Hengshui City is quantitatively analyzed. With the help of the inverse distance weight interpolation function in the ArcMap10.8 software, the data of each factor is rasterized, and the grid map of each factor is weighted and superposed to form the suitability evaluation grid surface map of rural residential areas (Figure 4). It can be seen from the figure that the suitability range of rural residential area is 2.3712~7.3922, and the high value is in the geographical center of Hengshui City.

4.2. Classification of the Suitability of Rural Residential Area

In order to clarify the suitability differences between the whole study area, and facilitate the subsequent provision of corresponding protection strategies, the suitability grade zoning of rural residential areas is delineated. The natural discontinuity method is used to classify the suitability range to form the threshold value of the suitability level (Table 3). The suitability classification map of rural residential areas is generated based on the grid map of the suitability evaluation of rural residential areas with threshold values (Figure 5). The results show that there are obvious differences between the most suitable and unsuitable regions: (1) The most suitable area is mainly concentrated in the geographical center of Hengshui City, where the agricultural land use rate is high, the proportion of construction land to be developed is high, the vegetation coverage area is large, and the non-agricultural industry rate is high. This region provides better policy guidance for residents. (2) The generally suitable area is mainly distributed in the east of Hengshui City, and the agricultural land use rate in this region is next to the most suitable region. The temperature and humidity index, hydrological index, and plant coverage rate, are relatively high, which can provide more comfortable climatic conditions and

ecological environment for residents. (3) The basic suitable areas are scattered in the west and northeast of Hengshui City, with convenient transportation and good unknown conditions. (4) Unsuitable areas are mainly concentrated in the north of Hengshui City, with a small population, urbanization rate, income, temperature, humidity index, and hydrological index, lower than in other areas.

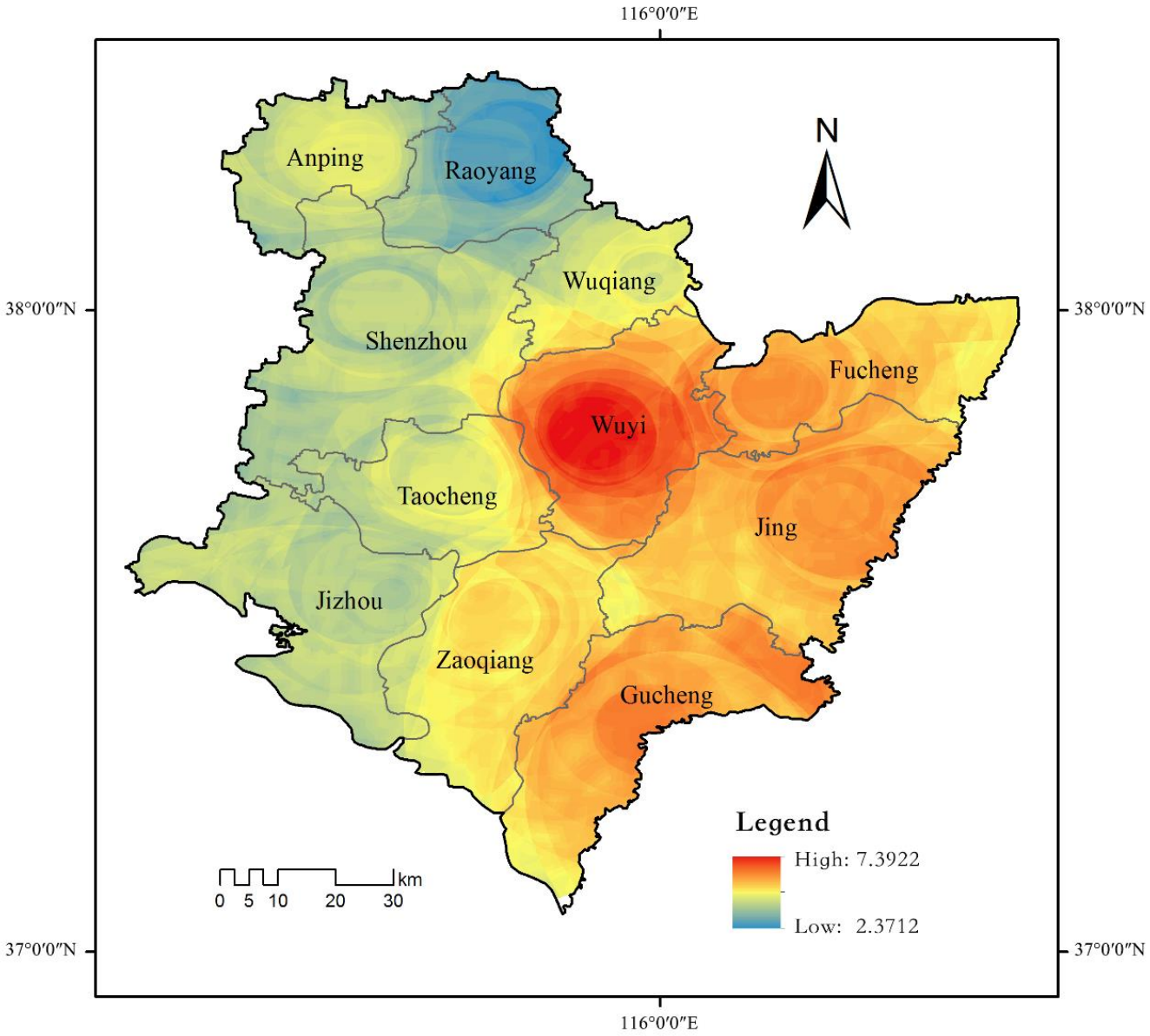

Figure 4. Suitability evaluation grid surface map.

Table 3. Classification standard for suitability evaluation of rural residential areas.

Grade	Threshold Value Division	Suitability Zoning
Grade I suitable area	2.3712–3.7930	Unsuitable
Grade II suitable area	3.7930–4.8796	Basically suitable
Grade III suitable area	4.8796–5.8856	Generally suitable
Grade IV suitable area	5.8856–7.3922	Most suitable

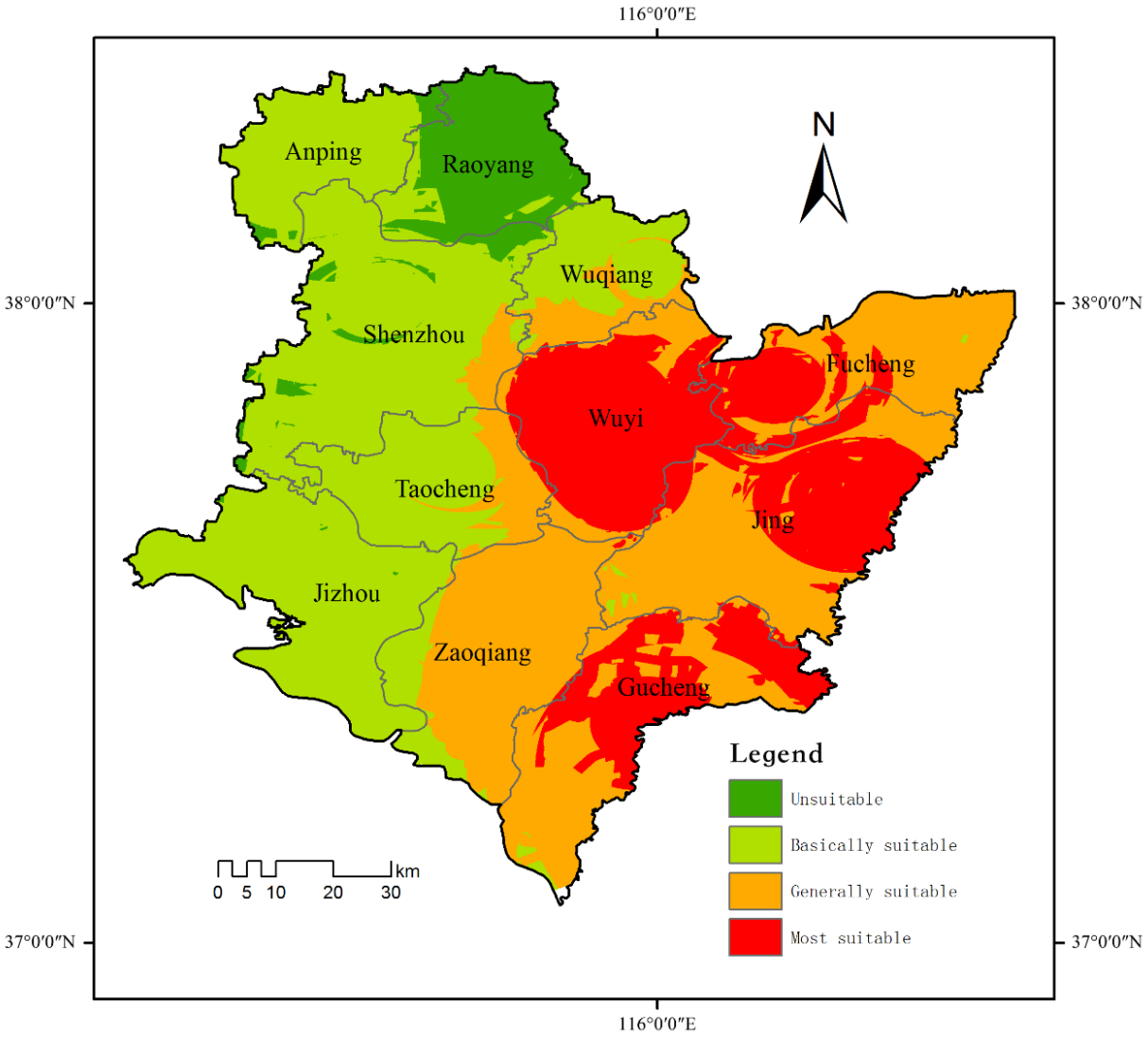

Figure 5. Suitability classification diagram.

The map algebra method is used to calculate the element values of each grid unit and obtain the suitability classification statistical table of rural residential areas (Table 4). The results show that: (1) The suitable area accounts for 7.01%, and 4.44% of rural residential areas are distributed in this area. (2) The general suitable area accounts for 39.42%, and 31.25% of rural residential areas are distributed in this area. (3) The area of the basically suitable area accounts for 31.96%, and 37.17% of the rural residential area are distributed in this area. (4) The area of unsuitable areas accounts for 21.61%, and 27.14 rural bureau settlements are distributed in this area. In general, 78.39% of the area of Hengshui City is suitable for the residence and development of rural residential areas, and 72.86% of rural residential areas are in suitable areas.

Table 4. Statistical results of suitability classification of the rural residential areas in Hengshui.

Grade	Percentage of Area	Number of Villages	Percentage of Numbers
Grade I suitable area	7.01%	218	4.44%
Grade II suitable area	39.42%	1535	31.25%
Grade III suitable area	31.96%	1826	37.17%
Grade IV suitable area	21.61%	1333	27.14%

4.3. The Difference in Suitability Distribution of County-Level Units

There are differences in the suitability of rural residential areas in the study area. Analysis under the restriction of administrative divisions is conducive to finding the reasons for the suitability differences. According to the municipal administrative divisions, the suitability of ethnic minority villages was analyzed by level (Table 5). The results show that the rural residential areas in Wuyi County and Jingxian County are the most suitable for living. A total of 33.31% and 32.41% of the rural residential areas are in the most suitable area; 4.55% and 23% of the rural residential areas are in the general suitable area; and no rural residential areas are in the unsuitable area. The rural residential area in Fucheng County and Gucheng County are also relatively suitable for living. In all, 15.15% and 18.75% of the rural residential area are in the most suitable area, respectively, and 22.29% and 15.5% of the rural residential area are in the general suitable area. The rural residential area in Jizhou County, Taocheng County, Wuqiang County, and Zaoqiang County are basically suitable for living. All rural residential areas are in general suitable areas and basically suitable areas, and no rural residential area are in unsuitable areas. Anping County, Raoyang County, and Shenzhou County, all have rural residential areas located in unsuitable areas, among which Raoyang County has the largest number, and 84.86% of the rural residential area are in unsuitable areas, mainly due to low income, serious population loss, and low urbanization rate.

Table 5. Statistics on the suitability of rural settlement in each county.

County	Numbers	Percentage	Percentage of Rural Residential Areas in Each Suitability Level			
			Grade I	Grade II	Grade III	Grade IV
Anping	246	5.01%	4.59%	15.38%	0.00%	0.00%
Fucheng	610	12.42%	0.00%	0.07%	22.29%	15.15%
Gucheng	538	10.95%	0.00%	0.33%	15.50%	18.75%
Jizhou	390	7.94%	0.00%	25.42%	0.00%	0.00%
Jing	856	17.43%	0.00%	0.26%	23.00%	32.41%
Raoyang	200	4.07%	84.86%	0.98%	0.00%	0.00%
Shenzhou	469	9.55%	10.55%	26.73%	1.97%	0.00%
Taocheng	272	5.54%	0.00%	15.91%	1.48%	0.08%
Wuqiang	242	4.93%	0.00%	9.39%	5.37%	0.00%
Wuyi	528	10.75%	0.00%	0.07%	4.55%	33.31%
Zaoqiang	560	11.40%	0.00%	5.48%	25.85%	0.30%

5. Discussion

5.1. Correlation between Impact Factors and Suitability of Human Settlements

The factor detector of GeoDetector is used to analyze the correlation between each factor and suitability, quantify the influence of each factor on suitability (q value), and use the interaction detector to test the interaction influence of each factor. The suitability value of each element unit is selected as the dependent variable, and each factor is the independent variable.

According to the factor detection results (Table 6), the environmental suitability of rural settlement in Hengshui City is significantly affected by various factors. The specific order is per capita agricultural land area > vegetation coverage > population of the county > per capita income of farmers > construction land rate > temperature humidity index > non-agricultural industry rate > urbanization rate > hydrology index > distance to river > distance to county > distance to slow road > distance to fast road. Among them, per capita agricultural land area has the highest influence, which is 0.702. This shows that the suitability of the rural residential environment is mainly affected by the area of per capita agricultural land. The level of specialization and modernization of agricultural production has been improved, farmers have developed towards professionalism, and have relatively rich cultivated land resources, providing favorable conditions for the layout of rural residential areas [47,48]. The residential environment of rural residential areas in

hilly areas is mainly affected by rivers, elevations, and slopes [33]. The influence values of HI, distance to river, distance to county, distance to slow road, and distance to fast road, are 0.097, 0.015, 0.010, 0.009, and 0.004, respectively, which are less than 0.1, indicating that they are low-level driving factors, of which distance to fast road has the weakest influence.

Table 6. Impact factor detection analysis table.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13
q	0.004	0.009	0.010	0.015	0.542	0.132	0.137	0.364	0.097	0.655	0.305	0.330	0.702
p	0.012	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

It can be seen from the factor interaction detection results (Table 7) that the relationship between factors is double factor enhancement, and there is no nonlinear enhancement, independence, or weakening relationship. The interaction influence of per capita agricultural land area and hydrology index is significantly enhanced, which is significantly higher than the influence of single factor per capita agricultural land area of 0.702 and the influence of single factor hydrology index of 0.097. Based on existing research, this study did not include elevation, slope, and aspect in the evaluation index of human settlements suitability in rural residential areas in plain areas, and the interaction effect of two factors was significantly enhanced. The research improves the rationality and scientific of the evaluation results, improves the evaluation system, and can provide reference for the suitability evaluation of other rural residential areas.

Table 7. Interaction analysis table of impact factors.

——	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13
F1	0.004	——	——	——	——	——	——	——	——	——	——	——	——
F2	0.020	0.009	——	——	——	——	——	——	——	——	——	——	——
F3	0.029	0.023	0.010	——	——	——	——	——	——	——	——	——	——
F4	0.026	0.033	0.049	0.015	——	——	——	——	——	——	——	——	——
F5	0.574	0.548	0.635	0.559	0.542	——	——	——	——	——	——	——	——
F6	0.141	0.157	0.212	0.165	0.692	0.132	——	——	——	——	——	——	——
F7	0.161	0.155	0.238	0.208	0.651	0.397	0.137	——	——	——	——	——	——
F8	0.395	0.387	0.464	0.412	0.703	0.471	0.489	0.364	——	——	——	——	——
F9	0.131	0.118	0.165	0.208	0.786	0.431	0.387	0.563	0.097	——	——	——	——
F10	0.674	0.661	0.710	0.703	0.760	0.680	0.811	0.809	0.859	0.655	——	——	——
F11	0.335	0.337	0.374	0.334	0.861	0.540	0.627	0.616	0.520	0.847	0.305	——	——
F12	0.345	0.353	0.409	0.355	0.745	0.614	0.556	0.663	0.488	0.789	0.603	0.330	——
F13	0.717	0.710	0.761	0.741	0.775	0.745	0.799	0.836	0.861	0.762	0.848	0.836	0.702

5.2. The Spatial Relationship between the Suitability of Human Settlements and Rural Residential Areas

In rural China, settlements are usually located near farmland for convenient agricultural production [49]. The GeoDa1.20 software is used to analyze the suitability of human settlements and the distribution density of rural residential areas, and the geographic connection rate between them reaches 96.34, indicating that there is a high degree of mutual connection and interaction between them. From the perspective of global spatial autocorrelation (Figure 6), the bivariate Moran's I index of the suitability of human settlements and the distribution density of rural residential areas is 0.513, and the *p* value is less than 0.01, indicating that there is a significant positive correlation between them. The improvement of the suitability of human settlements can effectively promote the aggregation and distribution of rural residential areas.

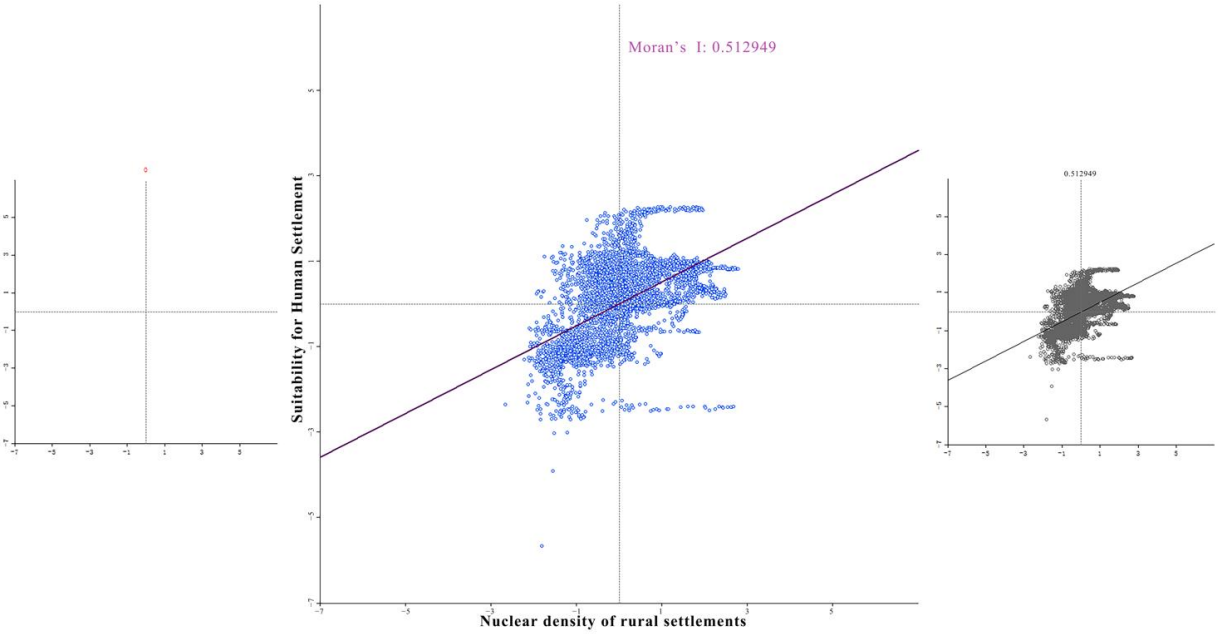

Figure 6. Spatial global autocorrelation.

The suitability of human settlements is spatially related to the distribution density of rural residential areas. As can be seen from Figure 7, the p values of several regions are less than 0.05, indicating that all spatial distribution patterns are unlikely to be generated from random processes. The high-high cluster areas of the suitability of human settlements suitability and rural residential distribution density are mainly concentrated in the middle and northeast of Hengshui City. The suitability of human settlements and rural residential distribution density in these areas are both high, and they show a significant interaction. Low-low cluster areas are scattered in the north and southwest of Hengshui City. The suitability of human settlements and the distribution density of rural residential areas in these areas are both low, showing a significant interaction between them. The supporting and leading role of the suitability of human settlements in rural residential areas need to be further strengthened. High-low concentration areas are mainly concentrated in the east of Hengshui City, with a large area, relatively high density of rural residential areas, but relatively low suitability of human settlements. Low-high cluster areas are mainly distributed in the east and southeast of Hengshui City. The density of rural residential areas in these areas is relatively low, but the suitability of human settlements is relatively high.

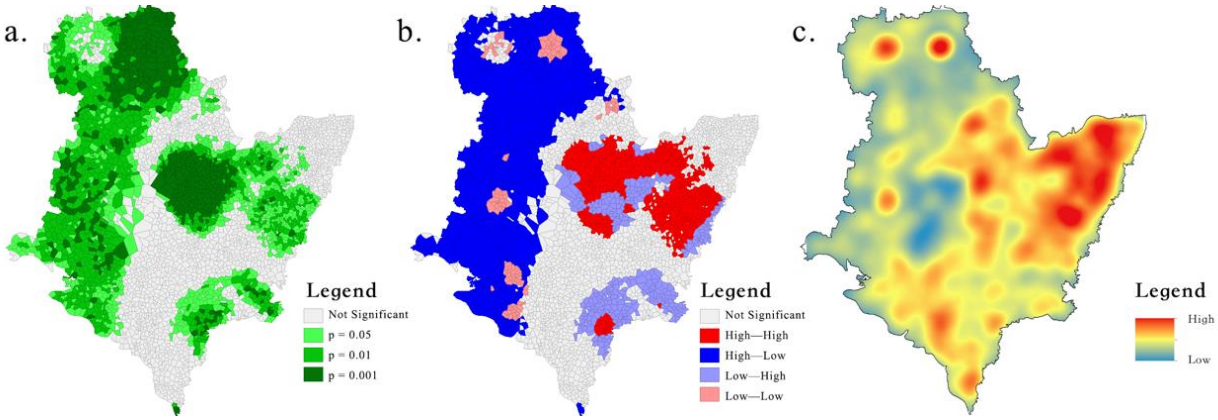

Figure 7. LISA cluster diagram of the spatial correlation between the suitability of human settlements and the distribution of rural residential areas: (**a**) Local autocorrelation p value distribution map; (**b**) local autocorrelation cluster diagram; (**c**) nuclear density map of rural residential areas.

5.3. Differentiation of Suitability Evaluation of Human Settlements

Superposition the single factors in LI, PI, EI, and MI to obtain the suitability distribution map of the middle layer indicators LI, PI, EI, and MI, and compare it with the suitability distribution map of human settlements; it can be found that they have a high degree of similarity and fusion (Figure 8). In the study of rural residential areas in hilly areas, the slope, orientation, and undulation of terrain factors are added to the study. The final result is that rural residential areas are most affected by the terrain, but this result is not applicable to plain areas [31].

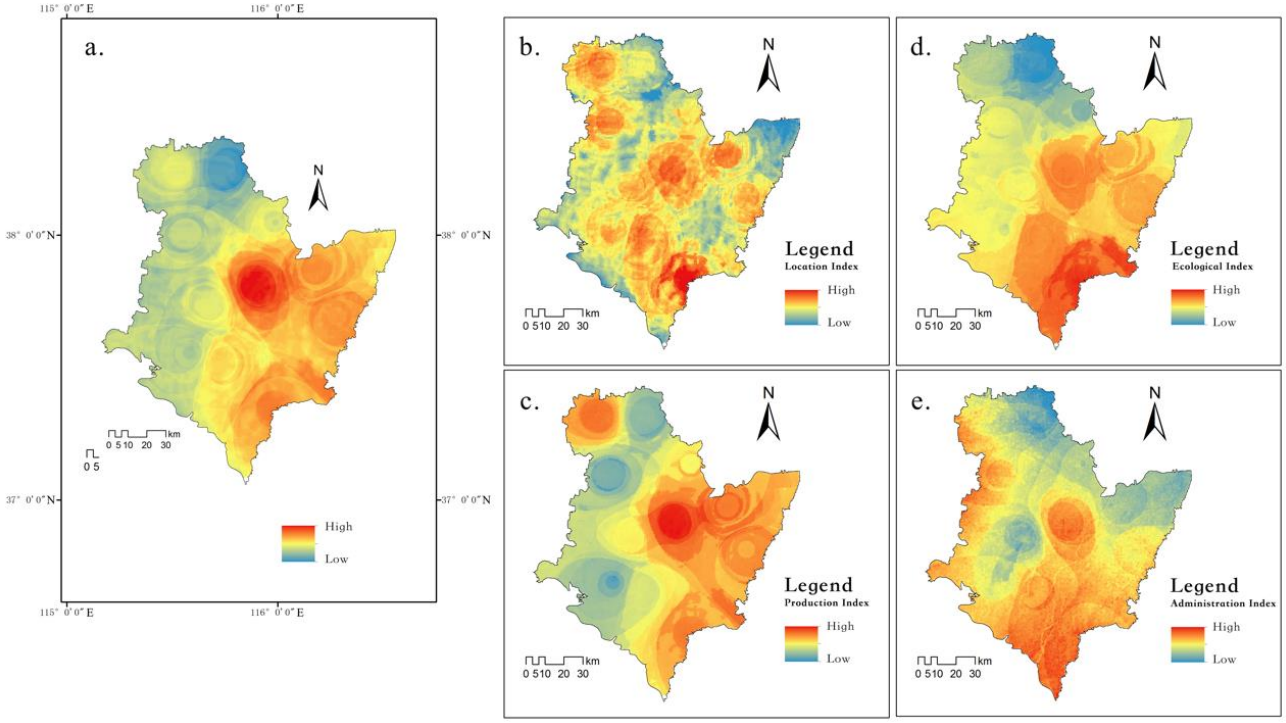

Figure 8. Spatial comparison between the middle layer index suitability distribution map and the human settlements suitability distribution map: (**a**) the human settlements suitability distribution map; (**b**) location index suitability distribution map; (**c**) production index suitability distribution map; (**d**) ecological index suitability distribution map; (**e**) administration index suitability distribution map.

LI, PI, EI, and MI are high in the most suitable area for human settlements. The human settlement environment is generally suitable for the region. The PI and EI are high, while the LI and MI play a certain role in limiting the suitability of the human settlement environment in the northeast of Hengshui City. The government should strengthen the intervention in this region and strengthen the infrastructure in this region, The value of the LI is higher in the northwest of Hengshui City, the MI is higher in the west, and PI is higher in the northwest of Hengshui City, and PI is lower in the west. PI plays a certain role in limiting the suitability of human settlements, so we should pay attention to the intervention of production in Hengshui City. The values of the four indexes are low in unsuitable areas, so administrative intervention should be strengthened in this area to improve production efficiency, increase infrastructure, and strengthen ecological protection.

The rural residential area is a choice made by human beings in the long-term production and living practice process, which adapts to and interacts with many factors such as nature and society. This study is based on one year's data, and little consideration is given to the evolution process of rural residential areas. At the same time, when evaluating the suitability of the residential environment of rural residential areas, the impact of humanity and farmers' wishes is ignored. The shortcomings of the study will be further discussed in the future.

6. Conclusions

(1) The most suitable area is mainly concentrated in the geographical center of Hengshui City, accounting for 7.01% of the total area. In all, 4.44% of the rural residential areas are distributed in this area. The general suitable area is mainly distributed in the east of Hengshui City, accounting for 39.42% of the total area. Totaling 31.25% of the rural residential areas are distributed in this area, the basic suitable areas are scattered in the west and northeast of Hengshui City, accounting for 31.96% of the area, and 37.17% of the rural residential areas are distributed in this area. Unsuitable areas are mainly concentrated in the north of Hengshui City, accounting for 21.61% of the area. In all, 27.14 rural bureau settlements are distributed in this area. In general, 78.39% of the area of Hengshui City is suitable for the residence and development of rural residential areas, and 72.86% of rural residential areas are in suitable areas. From the perspective of spatial distribution and the quantity of rural residential areas, the distribution of suitable rural residential areas conforms to the geographical environment characteristics of plain areas.

(2) Wuyi County and Jingxian County have the most livable rural residential areas; Raoyang County has the most uninhabitable rural residential areas. The rural residential area is located in an uninhabitable area, mainly because of its low income, serious population loss, and low urbanization rate.

(3) The suitability of human settlements in rural residential areas is mainly affected by per capita agricultural land area, with the highest influence value of 0.702. The influence values of HI, distance to river, distance to county, distance to slow road, and distance to fast road are 0.097, 0.015, 0.010, 0.009, and 0.004, respectively, which are less than 0.1, indicating that they are low-level driving factors, of which distance to fast road has the weakest influence. These factors provide reference for the establishment of the evaluation system of the suitability of human settlements in rural residential areas in plain areas.

(4) The high-high cluster areas of human settlement suitability and rural residential distribution density are mainly concentrated in the middle and northeast of Hengshui City. Low-low cluster areas are scattered in the north and southwest of Hengshui City, and the supporting and leading role of the suitability of human settlements in rural residential areas need to be further strengthened. High-low concentration areas are mainly concentrated in the east of Hengshui City, with a large area, relatively high density of rural residential areas, but relatively low suitability of human settlements. The low-high cluster areas are mainly distributed in the east and southeast of Hengshui City. The suitability of human settlements in these areas is relatively high, but the density of rural residential areas is relatively low. It shows that the evaluation model is suitable for the study of the suitability of rural residential areas in plain areas, and there is a significant positive correlation between the suitability of human settlements and the distribution density of rural residential areas. The improvement of the suitability of human settlements can effectively promote the aggregation and distribution of rural residential areas.

(5) LI and MI have a certain impact on the suitability of human settlements in the northeast of Hengshui City, and we should strengthen management intervention and infrastructure construction in the northeast of Hengshui City. The PI plays a limiting role in the suitability of human settlements in the west of Hengshui City, and we should pay attention to the improvement of production capacity in the west of Hengshui City. We should strengthen management intervention in the northwest of Hengshui City, improve production efficiency, increase infrastructure, and strengthen ecological protection.

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