Adaptability Evaluation of Human Settlements in Chengdu Based on 3S Technology

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Abstract: Taking Chengdu as the research object, the natural eco-environmental factors such as topography, climate, vegetation, land use and vegetation cover were selected, together with human disturbance factors such as traffic and GDP, and the index weights were calculated by AHP. Based on 3S technology, projection transformation, remote sensing interpretation, information extraction and analysis are carried out, and evaluation model of Chengdu's residential environment adaptability is constructed, which reflects the zoning and spatial distribution characteristics of Chengdu's residential environment adaptability. The results show that: **1)** The adaptability index of Chengdu's human settlement environment is between 15.98 and 76.75, and the suitability of human settlement environment is gradually decreasing from the middle to the east and west of Chengdu, and most areas are restricted by human production activities and natural conditions. **2)** According to the actual situation, the suitability index can be divided into High-grade suitable areas (284.36 km^2, 2.01%), relatively High-grade suitable areas (1802.13 km^2, 12.71%), moderately suitable areas (3721.49 km^2, 26.24%) and low suitable areas (3731.49 km^2, 26.31%). **3)** The correlation degree between the spatial distribution of Chengdu population and each index factor is as follows: per capita GDP> topographic relief > temperature and humidity > vegetation coverage > traffic network density > land use > hydrological factors. **4)** There is a good correlation between Chengdu human settlements suitability index and the current population density grid layer, and its correlation coefficient is 0.7326. **5)** The leading impact indicators of human settlements in different regions are different. The results show that the natural environment conditions in Chengdu are superior and the ecological environment quality is relatively stable, but the human settlement suitability index in the southeast and Longmenshan areas of Chengdu is relatively low. Therefore, in the future development planning of Chengdu, it is necessary to combine the actual environmental conditions and resource carrying capacity, and rationally carry out urban optimization and beautiful countryside construction.

Key words: Human settlement; Evaluation; 3s technology; Spatial differentiation; Chengdu city.

Human settlement environment is the space place where man lives in nature, and it is also the space place for human beings to live, work and socialize (Benjamin L et al.,2014). With the continuous development of urbanization and industrialization, radiation from human activities has expanded, and the problems of urban human settlement environment have become increasingly prominent (Bian Tao et al., 2013). The research on human settlements can be traced back to the 1950s, and the Greek scholar Doxiadis put forward the concept of "Ekistics" for the first time, exploring the historical evolution law of human settlement and laying a theoretical foundation for the research on human settlement environment (Janina Kleemann et al., 2017). In 1990s, Wu Liangyong, a domestic architect, introduced the theory of human settlement into China, put forward the science of human settlement environment, and developed the theory and application connotation of human environmental science according to Chinese characteristics (Yi Wang et al., 2017). Since then, the science of human settlements has gradually become a hot issue, and the research scope has expanded, the influencing factors have increased and the evaluation methods have improved (Tao Bian et al., 2017). Among them, the

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research contents of urban human settlements mainly focus on two angles: establishing an "index-evaluation" system and an evaluation system of coupled and coordinated development of human settlements. The "index-evaluation" system refers to constructing a comprehensive evaluation index system consisting of economy, ecology, housing and public service for social construction to quantitatively analyze human settlements. The evaluation system of coupled and coordinated development of human settlements aims to study the coupled and coordinated development of internal subsystems of human settlements and the coupling relationship between human settlements and regional elements (Jun Yang et al., 2018). At present, there are some breakthroughs in the content, scale and method of human settlement environment at home and abroad. From the perspective of research objects, it can be roughly divided into urban, rural and urban fringe areas; From the perspective of research scale, it can be divided into macro-scale with regional and provincial units and micro-scale with municipal and town units; From the perspective of research methods, questionnaire survey method, structural model method, analytic hierarchy process, fuzzy comprehensive evaluation method, GIS spatial autocorrelation method, analytic hierarchy process, principal component analysis method, Delphi method, artificial neural network method and entropy method are mostly used (Yi Wang et al., 2017).

Chengdu, as a scientific, cultural, financial center and transportation hub in southwest China (R. Li et al., 2017), has a large population density and a prominent feature of population settlement, with relatively obvious problems of living environment such as shortage of residential land, traffic congestion and environmental pollution. Based on existing research, many scholars have studied the human settlement environment in Chengdu, but there are few related researches on quantitative evaluation of the spatial pattern of human settlement environment in Chengdu by constructing index system. Based on this situation, this study takes Chengdu, Sichuan Province as the research object, and use the "3S" technology to build the index model of Chengdu's human settlement environment from the perspectives of topography, vegetation, climate, transportation and economy, systematically evaluate the quality and spatial differences of Chengdu's human settlement environment, quantitatively reveal the suitability and spatial distribution characteristics of Chengdu's human settlement environment, and provide scientific theoretical basis and decision-making reference for the economic development and spatial planning of building Chengdu into the only park city under the snowy mountains in the world (Fig 1).

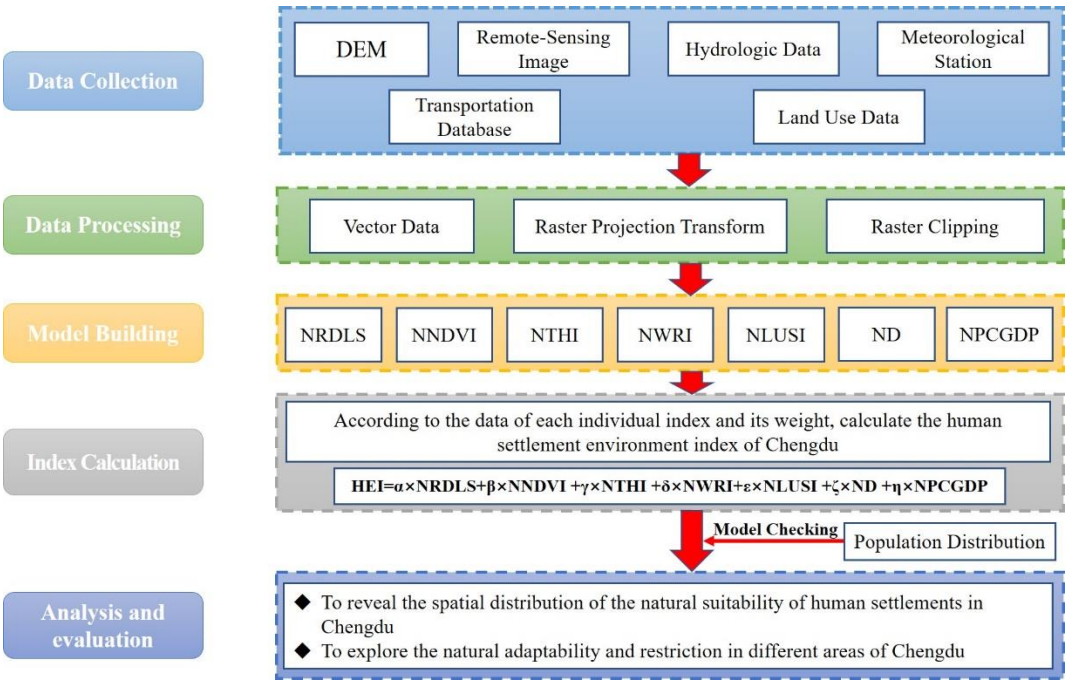

Fig 1 Technical process of natural suitability assessment of human settlements in Chengdu

1 Materials and research methods

1.1 Overview of the study area

Chengdu is located in the central region of Sichuan Province (30°05′～31°26′N，102°54′～104°53′), with an average altitude of 450 ~ 750 m, which belongs to subtropical humid monsoon climate (Fig 2). It is located in the hinterland of Chengdu Plain, and it is the transition zone from western Sichuan Plateau to Sichuan Basin (Sarah C. Kavassalis et al., 2017). The terrain difference is significant, with high northwest and low southeast, which has unique climatic characteristics the region has abundant rainfall and four distinct seasons; There are many quiet winds all the year round; The annual average temperature is 15.2℃ ~ 16.6℃, and the annual average precipitation is 897.0 mm ~ 1265.0 mm; There are significant differences in topography, diverse natural ecological environment and abundant biological resources (Ling Li Jia et al., 2013). As an ancient city with a history of more than 2,300 years, Chengdu is one of the first 24 historical and cultural cities announced by the state. It is also an important national high-tech industrial base, trade and logistics center and comprehensive transportation hub, and an important central city in the western region. Due to the unique natural and social geographical conditions of Chengdu, it is easy for pollutants to diffuse and other human environment pollution, which has a certain degree of impact on citizens' health, production and life (Sarah C. Kavassalis et al., 2017; Minghui Tao et al., 2014).

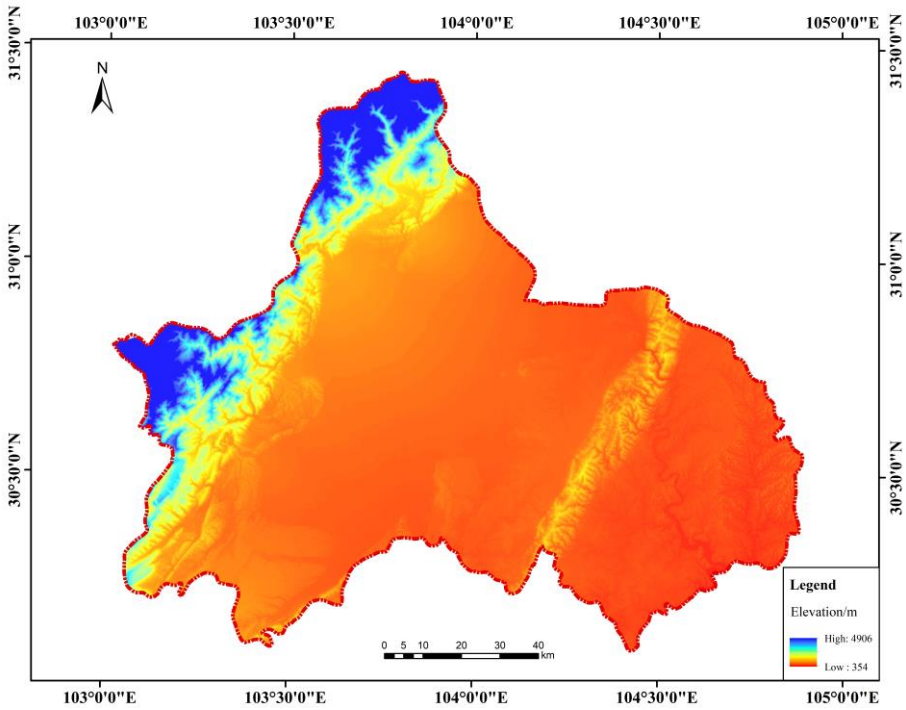

Fig. 2 Bitmap of Chengdu Urban area

1.2 Data sources and processing

1.2.1 Data sources

The 30m×30m digital topographic map (DEM) and remote sensing data images of China come from China geospatial data cloud (http:/www.gscloud.cn). The data of temperature, humidity and precipitation were obtained from China Meteorological Data Network (HTTP :/data.cma.cn) (Li Bohua et al., 2018) and the basic observation data of 23

meteorological points near Chengdu (including 9 within Chengdu); The vegetation data of Chengdu comes from the remote sensing data taken by Landsat8 from July to September 2019, and the data comes from the National Earth System Science Data Sharing Platform (www.geodata.cn); 1km grid population data and 1km grid GDP data come from geographic system science data sharing platform. At the same time, the data of traffic, GDP and population density in the economic and social Statistical yearbook of All Districts of Chengdu in 2019 were consulted and verified.

1.2.2 Data processing

Firstly, the normalized vegetation index (NNDVI) and normalized water body index (NNRI) were calculated by ENVI5.2 software. Then, using ArcGIS10.5 software, density calculation and inverse distance weighting method are applied to meteorological station data, and relevant layer data of precipitation, humidity and temperature are obtained; Then, DEM is processed to extract the slope, height difference, average altitude and other related data (Daniel T. et al., 2016). All spatial data are subjected to projection change, resampling, cropping and grid calculation to construct a unified projection coordinate system. The grid resolution is unified to 30m×30m, and the projection mode is WGS_1984_UTM_Zone_48N. Through the spatial analysis module, this paper analyzes the correlation between the seven indexes and the population density grid data of Chengdu, determines the weights of the evaluation indexes of Chengdu's human settlements adaptability, sums them up by weights, and classifies the suitability of human settlements. Finally, according to the adaptability index map obtained by the human settlement environment evaluation model, it compares with the population density map, By testing the model results and analyzing the spatial difference characteristics of Chengdu city, the research conclusions are drawn.

1.3 Research methods

1.3.1 Topographic relief index model

The surface of the earth is the basis of human activities and survival, and topographic changes and geomorphic features will directly or indirectly affect the selection of human settlements (Cheng Shujie et al.,2015). In this study, the terrain relief NRDLS (formula 1) calculation model proposed by Feng Zhiming et al. (2008) and Wei Wei et al. (2012) is adopted:

$$NRDLS = \frac{(H_{max} - H_{min}) \times [1 - P(A)/A]}{500} \qquad (1)$$

In which NRDLS is topographic relief; H_{max} and H_{min} represent the highest and lowest altitudes of the study area respectively, and the unit is m; P(A) indicates the flat land area in the area, and the area with a slope lower than 5 is designated as flat land (Devesh K. Jha et al.,2018), with the unit of km^2； ; A is the total area of the study area, in km^2. Calculation results of topographic relief (Fig 3a).

1.3.2 Vegetation index model

The vegetation cover index is one of the important factors to reflect the living environment (R. Emmanuel.,2004). The vegetation cover can better reflect the surface water and soil fertility and human survival in the region, and can accurately reflect the plant characteristics in Chengdu (T. Fung et al.,2000; Noemi Guindin-Garcia et al.,2012). Therefore, the

normalized difference vegetation index (NNDVI) model is used to reflect the vegetation coverage in this study, and the calculation formula is as follows:

$$NNDVI = \frac{(\mathrm{NIR}-\mathrm{R})}{(\mathrm{NIR}+\mathrm{R})} \qquad (2)$$

In the formula, NIR is the reflectivity value of near infrared band; R is the reflectance value of infrared band, and after calculating the NNDVI value (Yonghong Yi et al.,2007), the value after standardization is 0 ~ 100. Calculation results of vegetation index (Fig 3b).

1.3.3 Temperature and humidity index model

Temperature and humidity index was first proposed by Russian scholars. As an important factor affecting human activities, it evaluates the comfort of human body under different climatic conditions from meteorology (Xin Tian et al.,2012). Chengdu is located in an environment with unique ecological characteristics. With the change of global climate, the temperature and humidity index NTHI is taken as an important index for evaluating the suitability of human settlements in Chengdu (Werner H,1996), and the calculation formula is as follows:

$$NTHI = 1.8t + 32 - 0.55(1 - f)(1.8\mathrm{t} - 26) \qquad (3)$$

In which NTHI is expressed as temperature and humidity index; T is the monthly average temperature in Celsius, in℃; F is the monthly average air relative humidity in%. Calculation results of temperature and humidity index (Fig 3c).

1.3.4 Hydrological index model

Hydrological conditions are an important part of the natural environment, which have a profound impact on the economy, nature and society (Li Bohua et al., 2018). Water resources play a vital role in maintaining the economic and social development of Chengdu, which directly affects agricultural life, industrial production, plant growth and daily life needs, and is an important part of the study of Chengdu's human settlement environment evaluation model. In this study, the hydrological index model NWRI proposed by Feng Zhiming et al. is used, and the formula for calculating the hydrological index is:

$$NWRI = \alpha \cdot P + \beta \cdot W_a \qquad (4)$$

In the formula, NWRI represents hydrological index; P is the annual average precipitation in mm; W_a is the normalized water area (the highest value is 100 and the lowest value is 0); α and β are the weight values of annual average precipitation and water area ratio, respectively. The water area data in this study were obtained from Landsat8 remote sensing images, and the data were extracted by the normalized water body index method. According to the actual situation of Chengdu and referring to the research results of Hao Huimei et al., the values of α and β are 0.81 and 0.22 respectively. Calculation results of hydrological index (Fig 3d).

1.3.5 land utilization adaptability index model

The land use suitability index (NLUSI) is a basic land resource for estimating human survival and an important evaluation factor for the study of social sustainable development strategy (Li Weifang et al., 2015; Xue Jibin et al., 2011). Different land use types show the strength and weakness of regional resource development and investment. Therefore,

the land utilization adaptability index is also one of the important factors to determine the adaptability of human settlements in Chengdu. The formula for calculating land use adaptation index is:

$$NLUSI = \sum_{i=0}^{n}(K_i \cdot W_i) \qquad (5)$$

In the formula, K_i(i=1, 2, 3,…,n) is the correlation function value for evaluating land utilization types; W_i is the weight value of land use, indicating the weight value of land utilization type. The weights of land utilization types in this study refer to the weights studied by Li Xiaodong et al. The exponential range of NLUSI calculation results is 0 ~ 100, and the larger the value, the more suitable it is. Calculation results of land utilization adaptability index (Fig 3e).

1.3.6 Traffic network density index model

The improvement of urban transportation network will greatly improve the living quality of residents. Therefore, traffic accessibility is regarded as one of the important indicators of human settlement environment model (Ai Sakamoto et al., 2004). In this study, highway network (ND) is selected to calculate traffic accessibility, and the formula for calculating traffic density index is:

$$\mathrm{ND} = \Sigma L_i \,/\, A_i \qquad (6)$$

In the formula, L_i is the length of highway, and the unit is km; A_i is the area of grid area. Traffic network density index model results (Fig 3f).

1.3.7 Economic index model

The higher the level of regional economic development, the greater the impact on the lives of local residents. In this study, per capita gross domestic product (NPCGDP) is selected as the index to measure regional economy, and its calculation formula is:

$$NPCGDP = \frac{GDP}{pop} \qquad (7)$$

In which GDP is the gross domestic product; Pop is the population. Per capita GDP calculation results (Fig 3g).

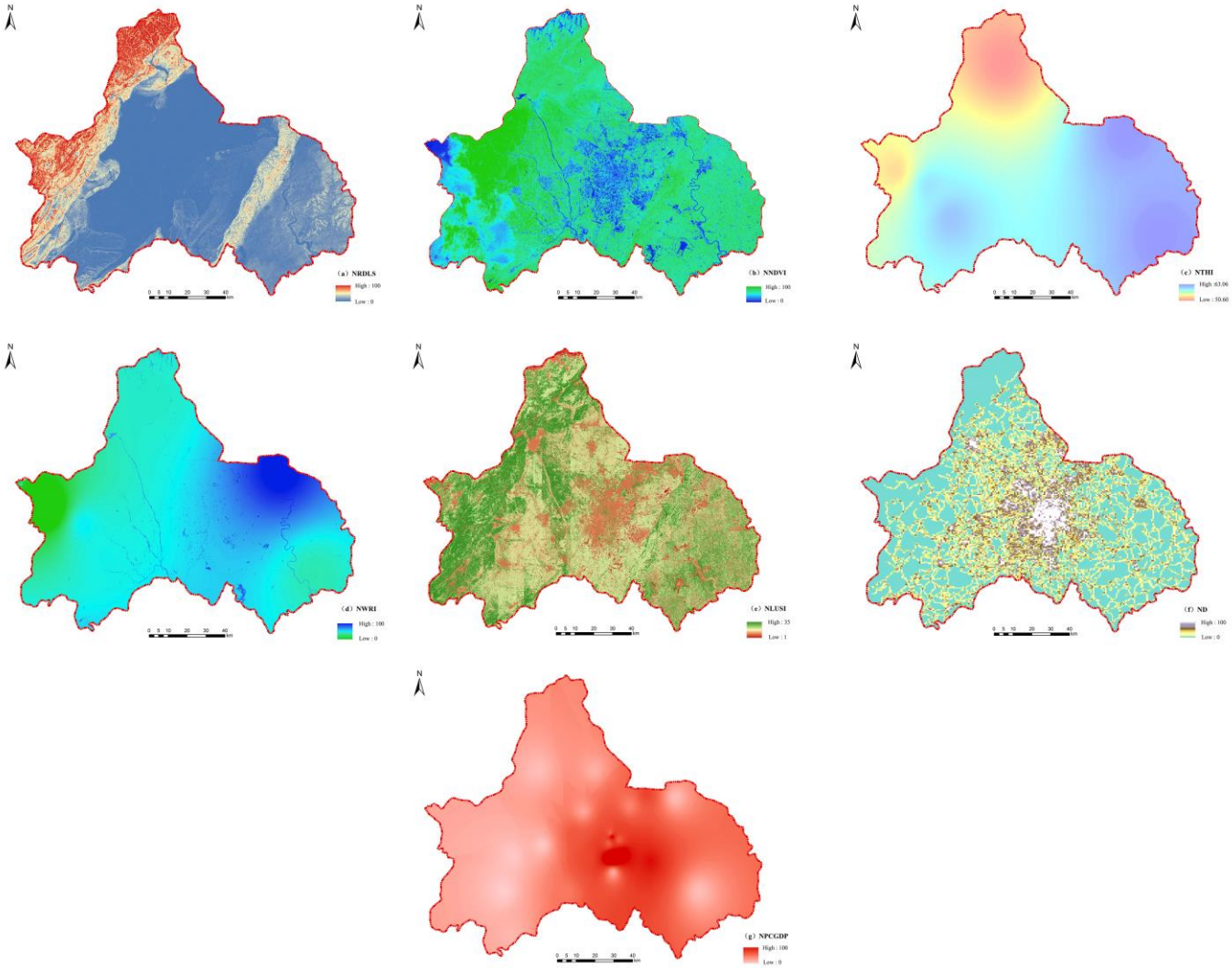

Fig 3 Single factor index of human settlement suitability

1.3.8 The establishment of human settlements evaluation model and the determination of its weight

1.3.8.1 Determination of Index Weight of Human Settlements

In this study, the weight of Chengdu's human settlements adaptability evaluation index is determined by using correlation coefficient weighting method, and the correlation between the above seven indexes and Chengdu's population density grid data is analyzed through ArcGIS10.5 Spatial analysis module, and the obtained correlation coefficients are applied to SPSS statistical analysis software for reciprocal operation and normalization processing (Li Bohua et al., 2018), and the weight of Chengdu's human settlements adaptability evaluation index is obtained. According to the actual situation to determine weight value,α is 0.229, β is 0.114, γ is 0.173, δ is 0.045, ε is 0.062, ζ is 0.098, η is 0.279 (Table 1).

Table 1 Correlation coefficient and weight of each factor and population density in Chengdu area

Index elements	NRDLS	NNDVI	NTHI	NWRI	NLUSI	ND	NPCGDP
Correlation	0.737	0.367	0.557	0.145	0.199	0.315	0.898
Weight property	0.229	0.114	0.173	0.045	0.062	0.098	0.279

1.3.8.2 Establishment of Human Settlements Evaluation Model

On the basis of the analysis and evaluation of individual indicators in the study area, according to the research of

Fen Zhiming (Fen Zhiming et al., 2009) and others, a comprehensive evaluation model of Chengdu's human settlements adaptability, namely Chengdu's human settlements index model, is constructed, and the calculation formula is:

$$HEI=\alpha\times NRDLS+\beta\times NNDVI+\gamma\times NTHI+\delta\times NWRI+\varepsilon\times NLUSI+\zeta\times ND+\eta\times NPCGDP \quad (8)$$

In the formula, HEI is the human settlement environment index, ranging from 0 to 100; Among them, NRDLS, NNDVI, NTHI, NWRI, NLUSI, ND and NPCGDP； respectively adopt the range standardization method to obtain the corresponding standardized topographic relief, standardized vegetation index, standardized temperature and humidity index, standardized hydrological index, standardized land use adaptability index, traffic network density index and standardized per capita GDP; α, β, γ, δ, ε, ζ, η are the normalized weights corresponding to 7 sub-indices respectively (Lou shengxia,2011).

2 Results and analysis

2.1 Chengdu human settlements suitability spatial layout

According to the calculation results of Chengdu's human settlement suitability model (Fig 4), the habitat suitability index ranged from 15.98 to 76.75, with an average value of 43.14, and the overall adaptability gradually decreases from the middle to the west and east. In order to further analyze the distribution characteristics of human settlements suitability in Chengdu, the results of HEI model are statistically classified according to the characteristic values of each single index from high to low, combined with the field investigation in the research area and the discussion of experts in the research group (Table 2), and the suitability of human settlements in Chengdu is divided into High-grade suitable areas, relatively High-grade suitable areas, moderately suitable areas, low suitable areas and unsuitable areas (Wenlong Li,2003). The areas with high human settlements suitability index are mainly distributed in the dual-core country park ring, this region has flat terrain, convenient transportation, superior water resources, suitable climatic conditions, high level of economic development and high population density; The areas with high human settlement environment index are mainly distributed in the ecological ring of Chengdu core area, Dupeng irrigation area, Duying irrigation area and Chongda irrigation area; The areas with general human settlement environment index are mainly distributed in Qiongpu irrigation area, Jinjian shallow hill area and Longquan mountain area; The areas with low living environment index are mainly distributed in Jianyang shallow hill area; The areas with extremely low human settlements index are mainly distributed in Longmenshan area, where the natural conditions are relatively poor. Due to rugged terrain, inconvenient transportation and relatively lagging economic development, the population distribution is sparse.

(1) High-grade suitable area. The suitability index of human settlements ranges from 76.75 to 65.59. The land area is 284.36km2, accounting for 2.01% of the whole study area. The region has good natural conditions and is suitable for human survival and social development. It is mainly distributed in the central plain area, which is just the border area of jinniu district, chenghua district, Qingyang District, Wuhou District and Jinjiang District. This area belongs to subtropical humid monsoon climate zone, with low average altitude, gentle terrain, high vegetation coverage, high temperature and humidity, abundant water resources and relatively developed economic situation. The land use and land cover types are mainly construction land and forest and grassland, and it is the best human habitation in this study area.

(2) Higher degree suitable area. The index of human settlements ranges from 52.44 to 40.28, and the land area is 3721.49km^2, accounting for about 12.71% of the study area. The area has good natural conditions, and the land cover types are mainly composed of cultivated land and construction land, which are suitable for human survival and residence. They are mainly distributed in Xindu District, Qingbaijiang district, eastern Longquanyi District, northern Shuangliu District, southern Pengzhou City, Pidu District, Wenjiang District, eastern Chongzhou city and eastern Dayi County. This area is a sub-developed area in Chengdu, which is densely populated.

(3) Moderate suitable area. The index of human settlements ranges from 64.59 to 52.44, and the land area is 1802.13km2, accounting for 26.24% of the study area. The natural conditions in this area are less limited. If we can make scientific and rational use of development and fully develop potential according to the actual situation and local ecological environment development law, this area is generally distributed around the "high suitability area" (including high-grade suitable area and higher degree suitable area), mainly distributed in Xinjin County, the eastern part of Qionglai City, Pujiang County, Jintang County, the western part of Jianyang city and the eastern part of Longquanyi District. The economic development level of the area is general, the population density is larger. The land cover type is mainly composed of construction land and hilly land, with low terrain and elevation, and relatively lack of precipitation and water resources. If environmental protection is placed at the top of regional development, local natural development laws should be observed and resources should be rationally developed, and the suitability of human settlements in this region will be greatly improved. On the contrary, if the environmental condition is destroyed, the area will become unsuitable due to the fragility of ecological environment.

(4) Low-grade suitable areas. The index of human settlements ranges from 40.28 to 28.13, and the land area is 3731.49km^2, accounting for 26.31% of the study area. The natural conditions in this region are greatly affected by the images of topography, climate and hydrology, and the potential for human settlements to improve and develop is small, mainly distributed in the northwest of Jianyang city and the northeast of Shuangliu District. The economic development level in this area is low, the population density is small, and it is not suitable for human survival and development. This area mainly includes hills and high mountain areas with higher altitude, the terrain fluctuates greatly, the economy is less developed, the traffic construction lags behind, the living environment is poor, and it is not suitable for human habitation (Ayi nur Mohammad et al., 2017).

(5) Unsuitable areas. The index of human settlements ranges from 28.13 to 15.98, and the land area is 4643.33km^2, accounting for 32.74% of the study area. It is mainly distributed in northern Pengzhou, western Dujiangyan, western chongzhou city, western Dayi County and western Qionglai. There are no natural conditions suitable for human development, mainly including alpine areas, which are affected by climate environment and hydrological environment on a large scale. Although there is more precipitation and abundant vegetation coverage in this area, topography and low temperature conditions are the main influencing factors that limit human survival and production. This area is mainly concentrated in Longmenshan area, which is restricted by ecological factors, and is prone to frequent geological disasters due to its steep slope and high mountain height. Most of the areas are the core areas of national space control, so

large-scale development cannot be carried out in principle. Therefore, it can be confirmed that natural factors such as topography, vegetation coverage, climate and environment, water resources and economic conditions are not conducive to human habitation in the whole area of Chengdu.

Table 2 Spatial information classification table of natural suitability of human settlements in Chengdu

Suitability grade	Suitability of human settlement environment	Suitable index range	Area（km^2）	Area ratio (%)	Adaptability evaluation description
I	High-grade suitable area	76.75～65.59	284.36	2.01	Basically not limited by natural factors, the most suitable area for human beings to live in
II	Higher degree suitable area	64.59～52.44	1802.13	12.71	Restricted by natural factors, human beings can live in suitable areas
III	Moderate suitable area	52.44～40.28	3721.49	26.24	To a certain extent, restricted by natural factors, areas where human beings barely live
IV	Low-grade suitable areas	40.28～28.13	3731.49	26.31	Restricted by natural factors, it is difficult for human beings to be suitable for living areas
V	Unsuitable areas	28.13～15.98	4643.33	32.74	Restricted by natural factors, human beings can not live in areas

2.2 Chengdu human settlements adaptability single factor analysis

Using ArcGIS spatial analysis to overlay each evaluation factor with the adaptability of human settlement environment, we can find that the dominant influencing factors of human settlement environment in different regions are different and there are great spatial differences.

(1) Factor analysis of topographic relief. There is a significant negative correlation between Chengdu's human settlements adaptability index and topographic relief, that is, the lower the topographic relief, the higher the topographic relief, the worse the human settlements suitability. As shown in Fig 3a, the topographic relief in Chengdu is quite different on the whole, and the areas with high relief are mainly concentrated in Longmen Mountain and Longquan Mountain, with Chengdu Plain sandwiched between them, which is flat and occupies a large area of Chengdu. The rest areas are mainly mountains and hills.

(2) Factor analysis of vegetation index. As shown in Fig 3b, the vegetation index is low in areas with high population density and suitability of human settlements, which are concentrated in the main urban area of Chengdu and areas with high water and altitude; However, the vegetation index was higher in the sparsely populated mountainous and hilly areas, which are mainly concentrated in Longmen Mountain in the west of Chengdu and Longquan Mountain in the east of Chengdu. Therefore, vegetation index is also one of the important factors that limit the improvement of the suitability index of human settlements in Chengdu.

(3) Factor analysis of temperature and humidity index. As shown in Fig 3c, the temperature and humidity index in

Chengdu shows a decreasing trend from low latitude to high latitude, and also shows a decreasing trend from low altitude to high altitude, and its performance has a certain negative correlation with topographic relief. However, because the whole temperature and humidity index changes in a small range and there is no extreme area, the spatial impact and evaluation results on the adaptability of Chengdu's human settlement environment are small.

(4) Hydrological index factor analysis. As shown in Fig 3d, the correlation degree between human settlements suitability index and hydrological index is weak, showing a gradual decreasing trend from east to west, from mountains and hills to plain areas, which will greatly restrict the continuous improvement of human settlements suitability in Chengdu to a certain extent, but has little impact on the overall spatial suitability distribution.

(5) Factor analysis of land use adaptability index. As shown in Fig 3e, different land use types represent the investment, construction and use of human land resources, and the superiority degree of their land use types is: cultivated land > woodland/shrub > grassland > construction land > water land > unused land (Dawn C. et al. 2003). Therefore, the change of land use type is an important guiding factor for the change of human activities, which can affect the regional distribution of human settlements suitability in Chengdu to a certain extent.

(6) Factor analysis of traffic network density index. As shown in Fig 3f, due to the influence of topographic relief, Chengdu's transportation network covers the plain area of the central city, which has become one of the important factors affecting the quality of human settlements. The overall traffic density network tends to decline from the center to the periphery, and the surrounding traffic is inconvenient.

(7) Analysis of economic development factors. As shown in Fig 3g, there is a positive correlation between Chengdu's human settlements suitability and per capita GDP index, and the correlation coefficient reaches 0.279, which means that the higher the economic development level, the better the human settlements suitability. The most livable area in the whole study area is Chengdu Dual-core Country Park Ring, which is also the most developed area in economic development. Therefore, it is necessary to combine economic development with human settlement environment to build beautiful and livable urban parks.

2.3 Chengdu human settlements suitability evaluation results test

In order to test the accuracy of the research results, based on the analysis of the characteristics of human settlements index, this study analyzes the correlation between the results of Chengdu human settlements suitability model and the spatial distribution of population density in 2019 with the standard of 1km×1km grid scale. Population density reflects the utilization degree of regional natural environment, which is a test of the correlation between the results of human settlement model and population distribution, and reflects the accuracy of the results of human settlement suitability evaluation (Wei Wei et al., 2008). The results of this study are verified as follows: match and analyze the suitability distribution layer of human settlement environment with the population density layer of Chengdu by ArcGIS software, and calculate the population density data layers of suitable areas at all levels (Fig 4 and 5); Through the sampling survey of 1079 residential areas in Chengdu, the results of the suitability model of human settlement environment are compared with the sampling areas where human activities live at present. The test results show that more than 500 residential areas in 1079 residential areas are suitable for human survival, and the population density exceeds 833 people /km^2. There is a high correlation between human settlements index and population density in Chengdu, and its R^2 value is 0.7324 (Fig 6). It shows that the results of human settlements suitability assessment are basically consistent with the actual situation of

the study area, and most of the population in this area is concentrated in High-grade suitable areas, High-grade suitable areas and moderately suitable areas with high human settlements index. The reason is that the human activity area is mainly distributed in the plain area of Chengdu core area, which has the characteristics of little change in topographic relief, abundant water conservation, superior temperature and humidity, developed economy, low vegetation index, suitable climate and environment and high traffic convenience.

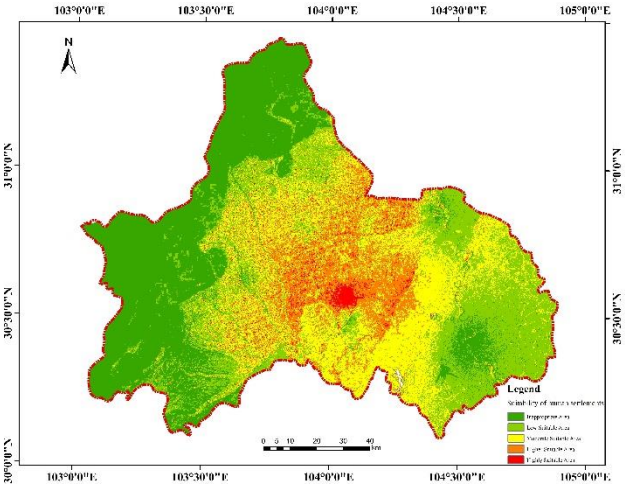

FIG 4 Adaptability Evaluation of Human Settlements in Chengdu

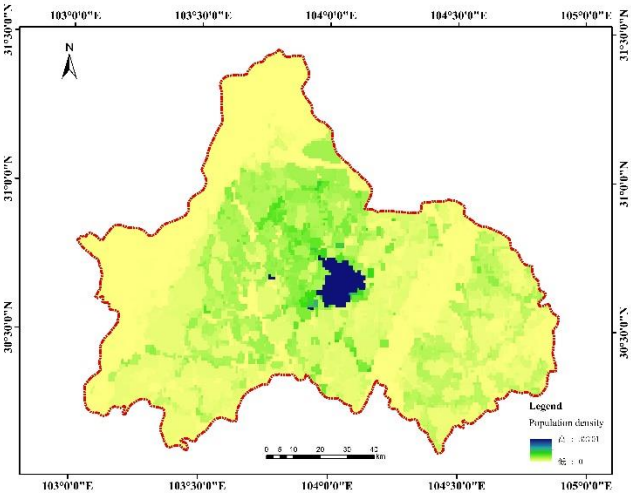

FIG 5 Population density in Chengdu

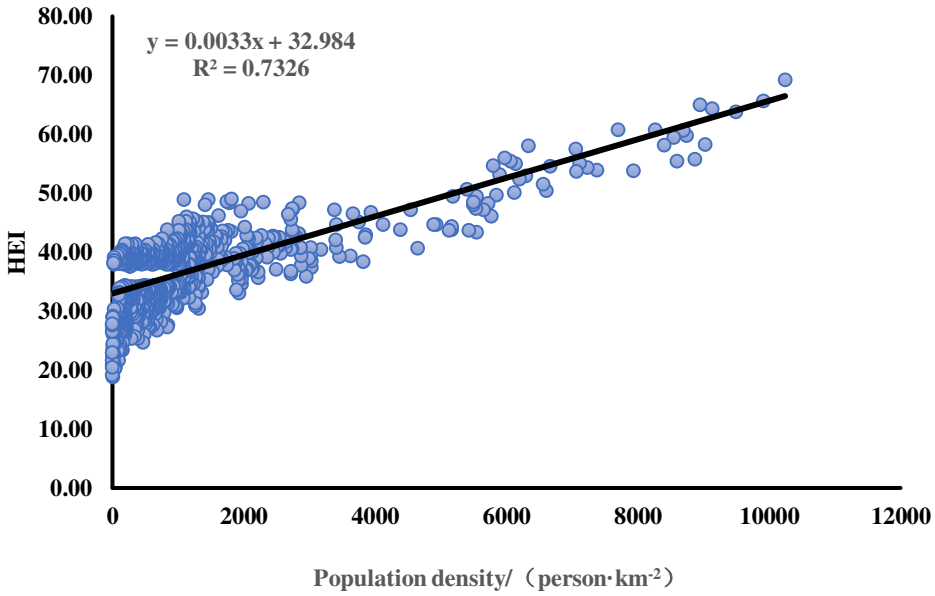

FIG 6 Relationship between Human Settlements Index and Population Density in Chengdu

3 Conclusion

In this study, based on the analysis of five ecological environmental factors including topography, climate, hydrology, vegetation, land use/land cover and two social environmental factors including transportation and economy, the suitability evaluation model of human settlements in Chengdu was established by using 3S technology, and the suitability of human settlements in Chengdu was evaluated and analyzed, and the following conclusions were drawn:

(1) The suitability of human settlement environment gradually decreases from the central plain area to Longmen

Mountain in the east and Longquan Mountain in the west. Among them, according to the suitability index, Chengdu can be divided into five areas: high-grade suitable area, relatively high-grade suitable area, moderate suitable area, low-grade suitable areas and unsuitable area, with the area of 284.36 km^2, 1802.13 km^2, 3721.49 km^2, 3731.49 km^2 and 4643.33km^2 respectively, accounting for 2.01% and 12.71% of the whole study area.

(2) According to the correlation and weight of evaluation factors and Chengdu human settlements index, the correlation degree of population spatial distribution is per capita GDP＞ > topographic relief > temperature and humidity > vegetation coverage > traffic network density > land use > hydrological factors. Therefore, the correlation between population distribution and GDP per capita is the highest. For a typical humid monsoon region like Chengdu Plain, topographic relief, temperature, humidity and vegetation coverage distribution have important influence on the spatial distribution of human activities and socio-economic development in the study area.

(3) According to the results of Chengdu human settlements suitability index, there is a great correlation between the human settlements suitability index and the current population density grid layer, and the correlation coefficient is 0.7326. Thus it can be seen that the space format of human settlement environment suitability constructed by this research is relatively reasonable and can accurately reflect the current situation of human settlement environment in Chengdu.

(4) The main restrictive factors of human settlements in different areas of Chengdu are different. Per capita GDP, topographic relief, temperature and humidity are the main influencing indicators in plain areas with high suitability of human settlements in downtown Chengdu. The main restrictive factors of Longmen Mountain, Longquan Mountain and Jinjian shallow hill area with low adaptability to human settlement environment are topographic relief, economic development level and traffic conditions; Hydrological index has less obvious influence on the spatial distribution difference of human settlements suitability.

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Figures

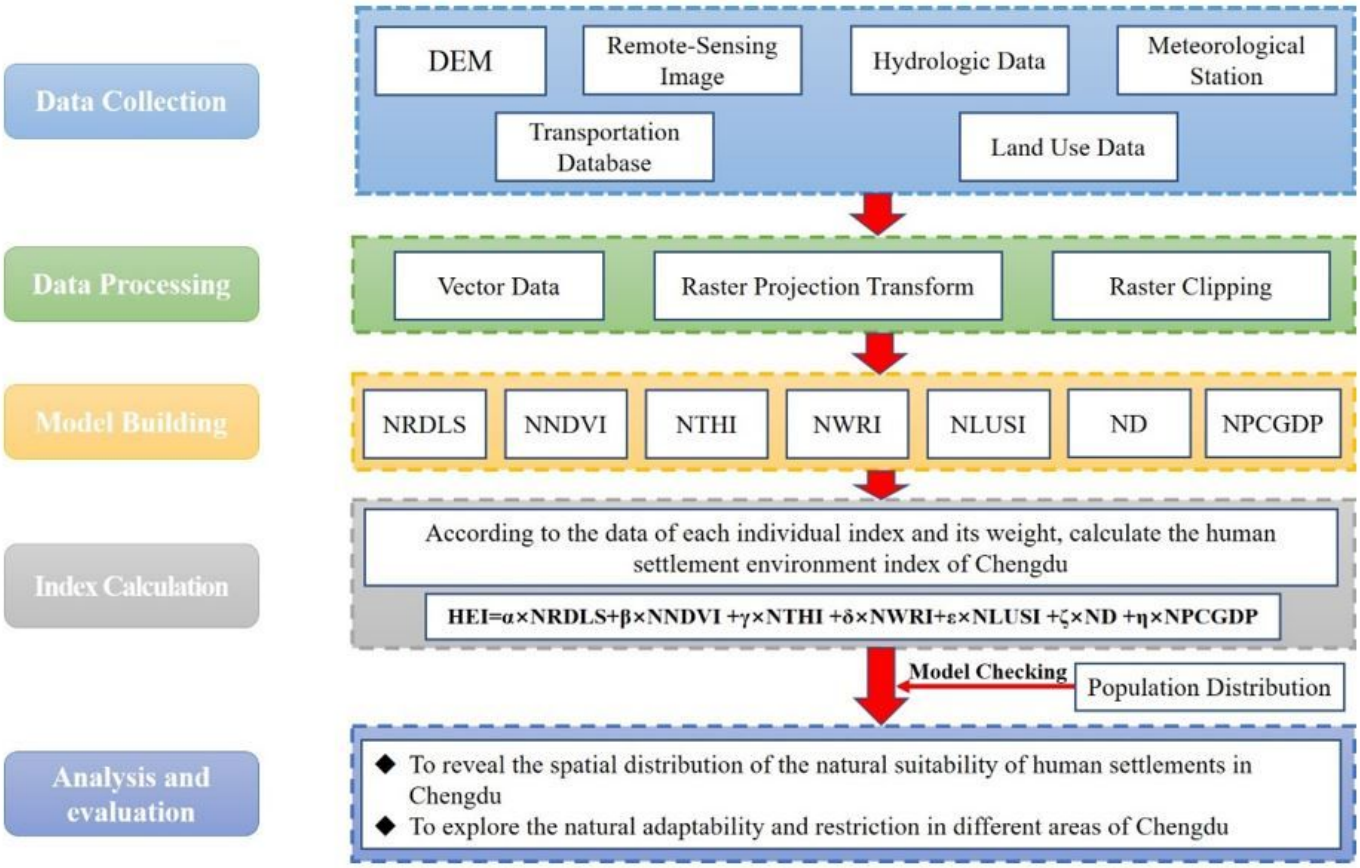

Figure 1

Technical process of natural suitability assessment of human settlements in Chengdu

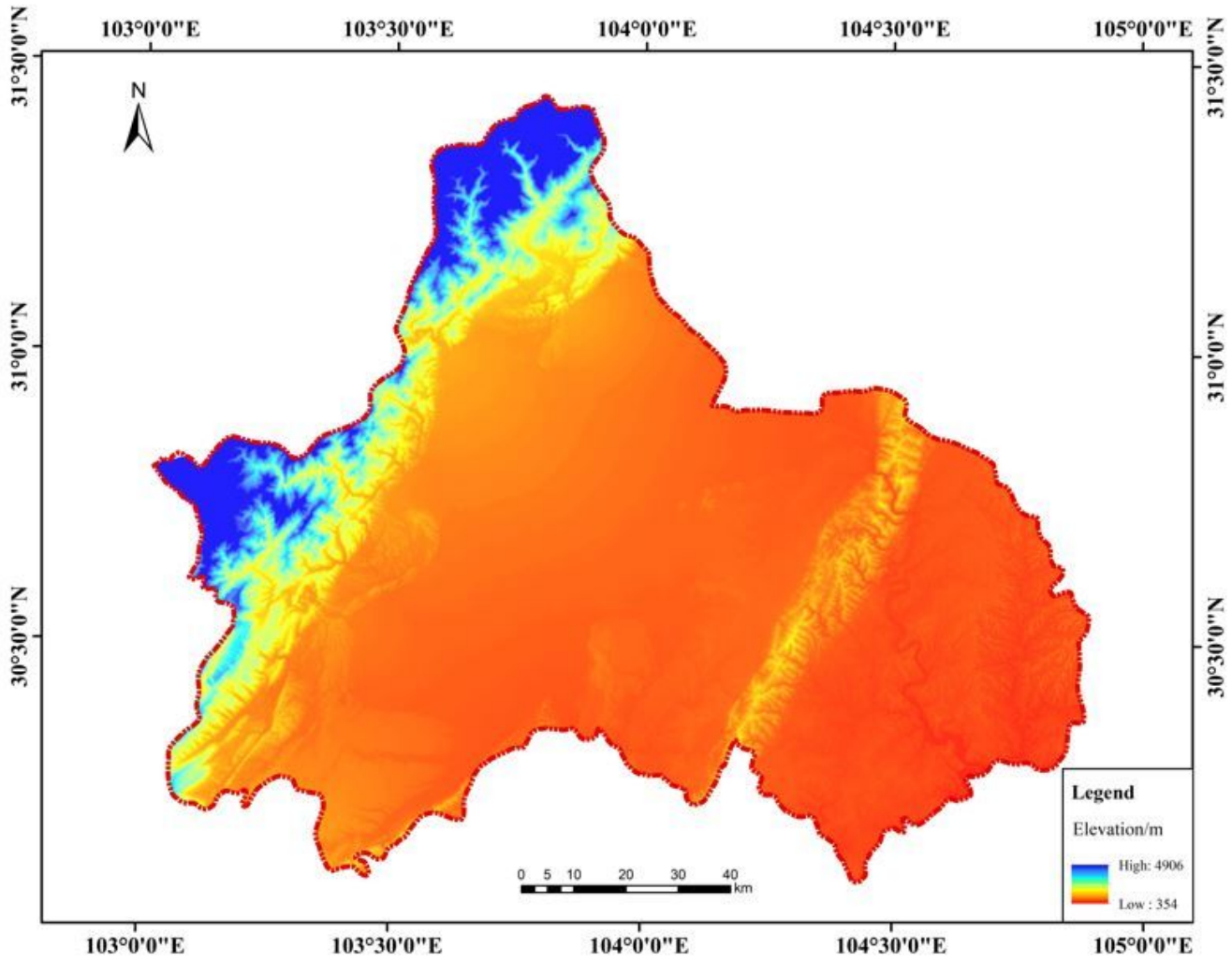

Figure 2

Bitmap of Chengdu Urban area Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

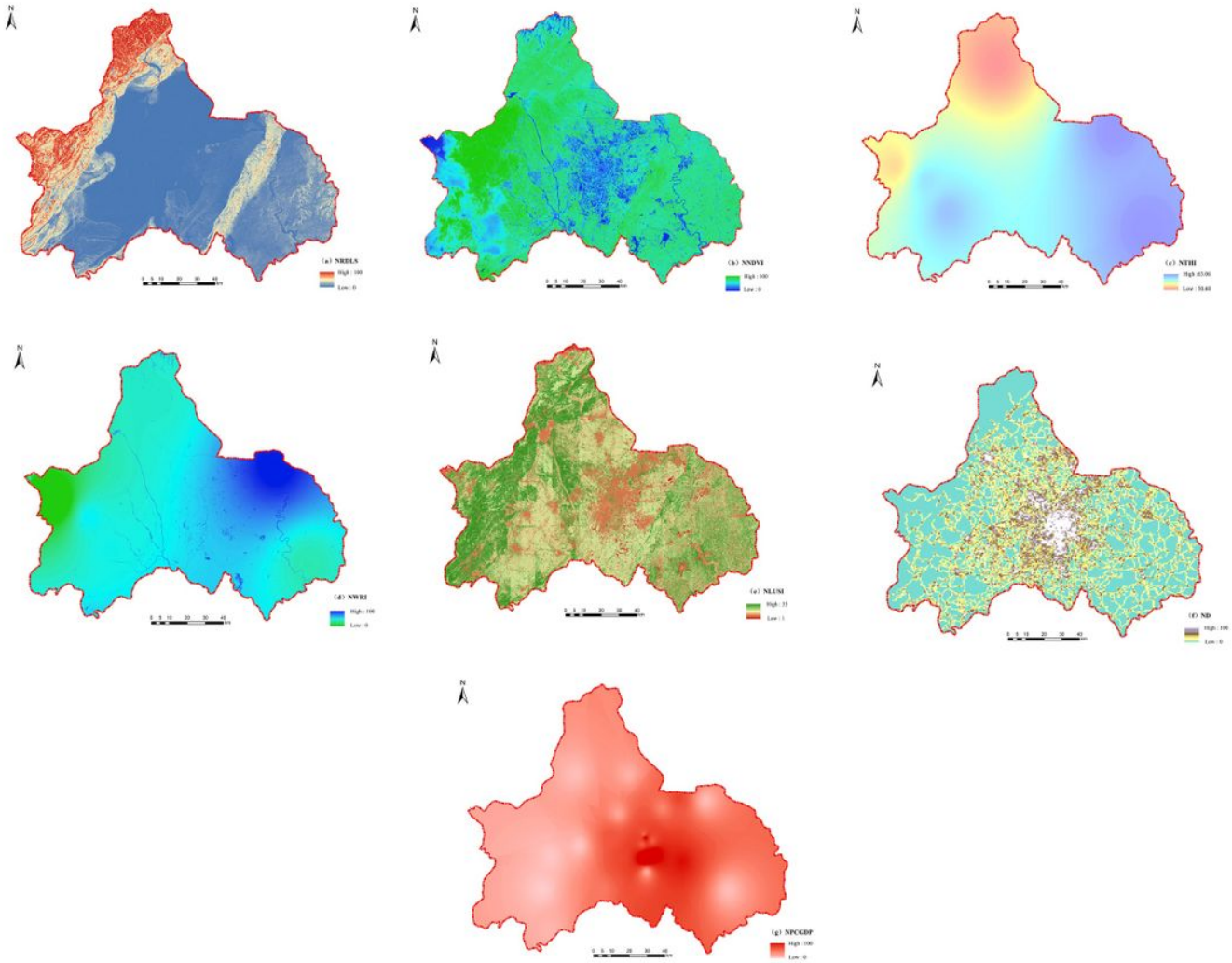

Figure 3

Single factor index of human settlement suitability Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

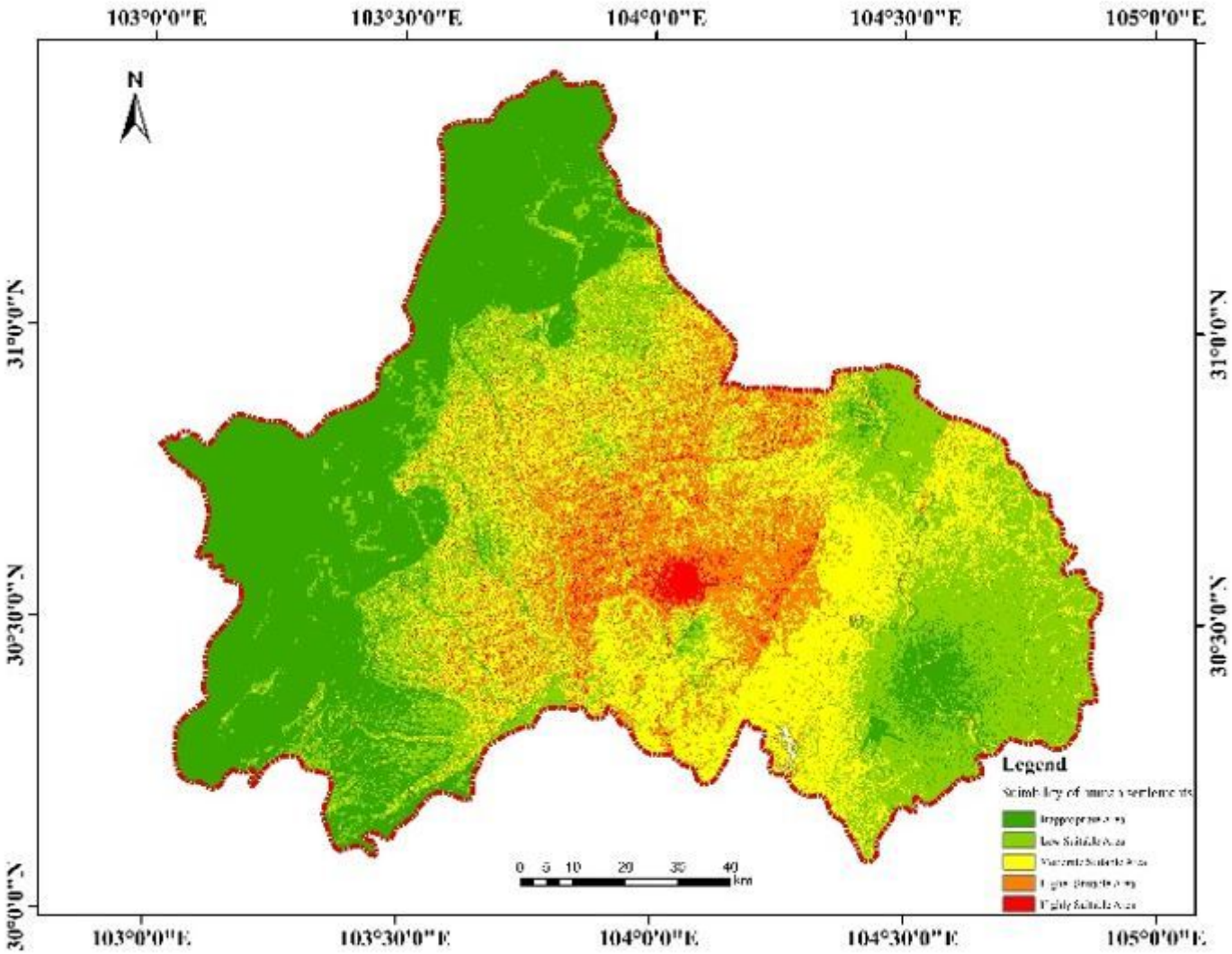

Figure 4

Adaptability Evaluation of Human Settlements in Chengdu Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

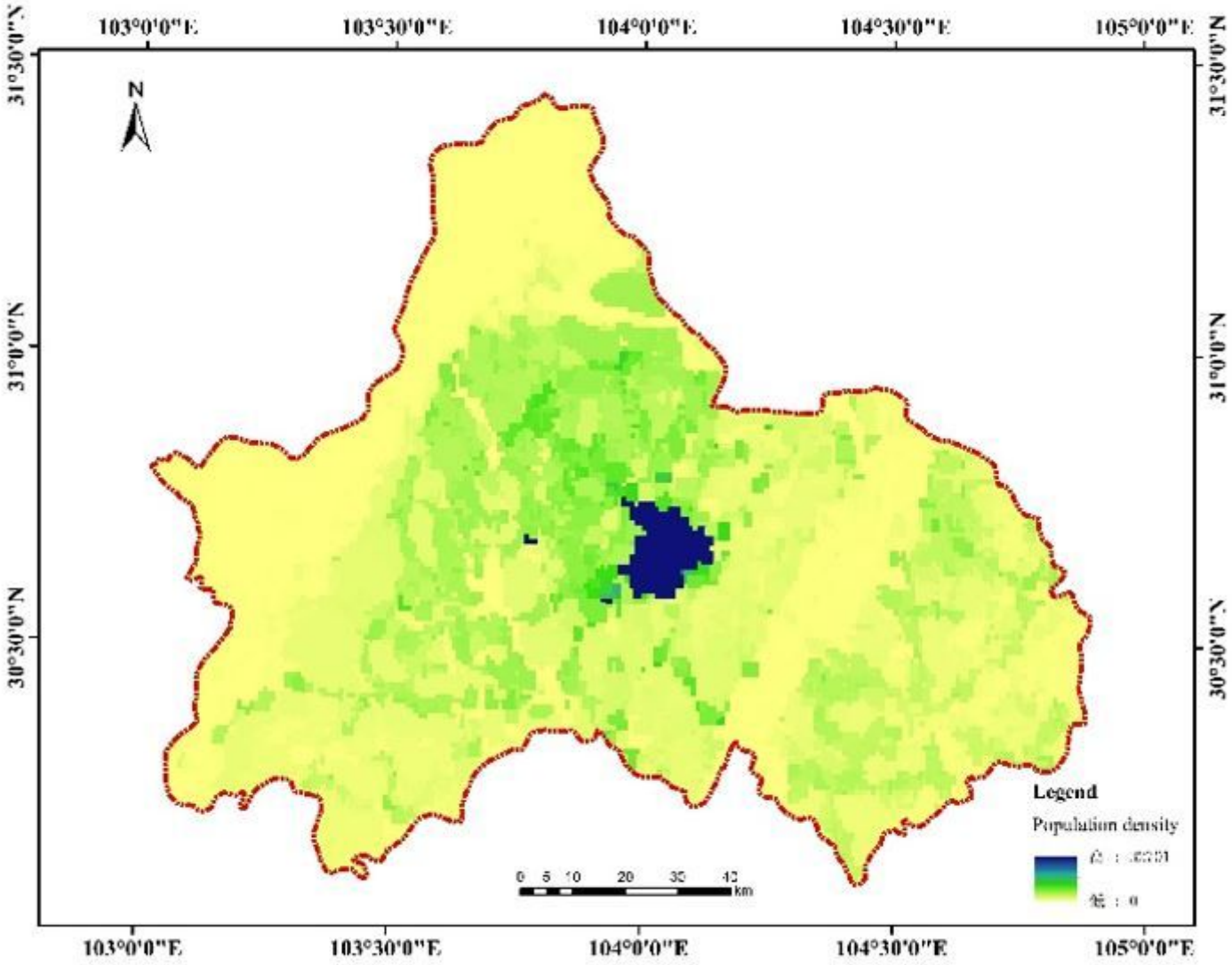

Figure 5

Population density in Chengdu Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

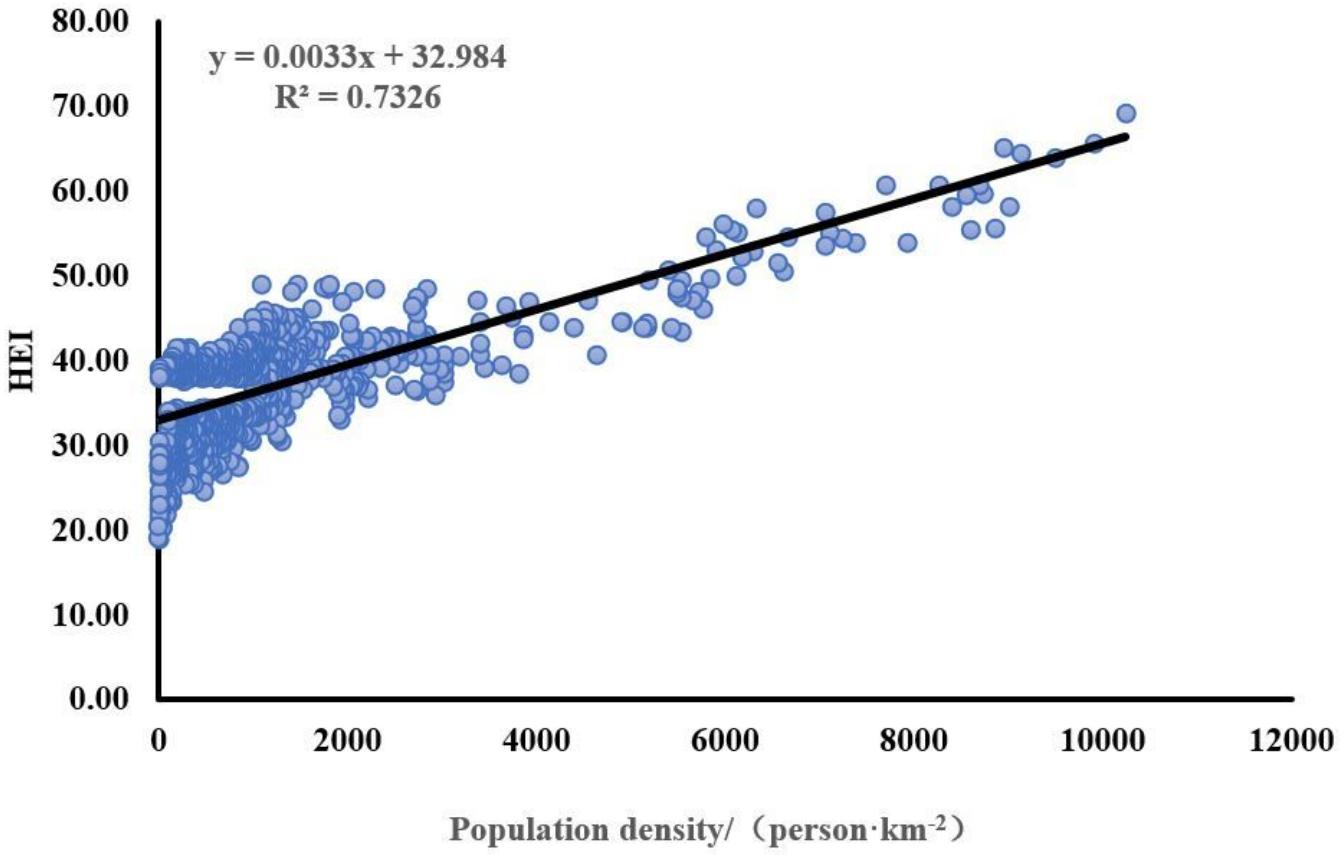

Figure 6

Relationship between Human Settlements Index and Population Density in Chengdu