ISSN 1330-3651 (Print), ISSN 1848-6339 (Online)
https://doi.org/10.17559/TV-20231214001208
Original scientific paper

Impact Factors of Spatial Distribution and the Ecological Environment Suitability of Tujia Traditional Settlements in China under the background of Sustainable Development Goals

Yunzhang LI, Disi RAN, Junnan LV*

Abstract: To explore the human-land relationship between traditional Tujia settlements and the natural environment, by applying the geographic information systems (GIS), this study constructs a suitability evaluation system for human settlements of the Tujia ethnic minority based on 12 indexes, including elevation, slope, aspect, landform, relief degree of land surface (RDLS), river, vegetation, soil, road, the ancient Sichuan salt route, temperature, and precipitation. It applies the geographical detector (Geodetector) to analyze the driving force of the settlement distribution, and the spatial pattern of human settlements suitability and the spatial relationship between the suitability and the settlement distribution are determined by fuzzy comprehensive evaluation method. The results reveal that among the 12 indexes, RDLS exercises the most significant impact on the spatial distribution of settlements, followed by the elevation, while slope has the most minor importance, and therefore the suitability for farming remained Tujia ancestors' primary concern when selecting the settlement locations. In addition, there appears to be a strong interaction between the indicators and the spatial distribution of the settlements, with the interaction effect of any two indicators being greater than that of one, suggesting that the ancestors selected the sites of their settlements based on comprehensive consideration. Moreover, the settlements are primarily located in more suitable areas with low hills and flat relief; however, some cluster in less suitable areas considering the source of income.

Keywords: geographical detector; human settlements; impact factors; suitability evaluation; traditional settlements; Tujia ethnic minority

1 INTRODUCTION

The traditional settlement is the bright pearl of Chinese traditional farming culture, the preservation place of human material and cultural heritage, and the fossil garden of intangible cultural [1]. And their construction embodies the wisdom of ancient people in establishing a suitable living environment. Meanwhile, both the pleasant natural environment and profound cultural heritage have contributed to preserving the traditional settlement, marking an important field for the study of the human-land relationship. Nature and history are important determinants of settlement and social development [2]. The quality of human settlements directly affects the comfort of humans habitation and thus, affects the cultural protection and sustainable development of settlement [3, 4]. Suitability is the basis of evaluating human settlements and is a major factor affecting development. In the process of modernization, dramatic changes of society, economy and ecological environment system have led to the sharp reduction of the existing number of traditional settlements, and the comfort of human settlements has been seriously affected. Therefore, it is necessary to focus on the study of the suitability of human settlements on the traditional settlement scale.

More and more scholars in sociology, geography, architecture, urban and rural planning, and art have paid close attention to traditional settlements and human settlements with fruitful results [5-8]. Following the development and extensive application of geographic information system (GIS) and remote sensing technology, GIS and remote sensing data have become important tools and means to study the spatial distribution and historical evolution of settlements and the interaction between human and environment. Some studies attempts have been made to integrate settlements with broader elements of the natural environment [9, 10], offering a novel quantitative method to the study of human-environment interactions and cultural development from the standpoint of spatial analysis. Based on remote sensing data, an increasing number of studies on the suitability of human settlements have been performed, focusing on indexes such as elevation, slope, aspect, landform, relief degree of land surface (RDLS), river distance, etc. [11-13] and they provide technical support for the study of this paper. Others have used the analytic hierarchy process (AHP) [14], a more subjective and limited method to analyze the suitability of the settlement location by expert scoring.

Although the existing researches provide rich academic experience and technical support, there is little research that focused on specific ethnic inhabited areas, especially the Tujia, which have mainly concerned the settlement patterns [15], architectural features [16], development strategies [17], and Tujia culture [18] in a single region. There exists a gap in the comprehensive study of Tujia settlements and the impact of terrain, environment, and climate change on settlement evolution and distribution characteristics, and the suitability evaluation of human settlements. In summary, taking the traditional Tujia settlement as the research object, this study aims to explore the driving mechanism and force of the spatial distribution of the settlement, assess the current status of the suitability of the human settlements, and at the same time, supplement the existing research basis. By analyzing the pattern of how the Tujia ancestors selected sites considering the natural environment, this paper provides a strong support for the overall contiguous protection and sustainable development of the traditional Tujia settlements.

2 DATA AND METHODOLOGY
2.1 Research Area

The Chinese Tujia ethnic minority (Tujia language: Bifzivkar) calls itself "Piātpilkhat" [19], which means "native". With a long history from the Qin and Han dynasties to the Three Kingdoms, the ethnic group was named "Linjun Clan", "WulingMan (barbarian)", "BandunMan", "LizhongMan", and "Wuxi Man" according to the Ba people's origin and its location. Since the Song Dynasty, the local people were called "Tu Min", "Tu Ding", and "Tu Man", and a large number of Han Chinese moved into their region, so the ethnic name "Tujia" appeared [20]. For generations, the natives have been living in the middle part of the natural boundary between China's eastern and western regions and in areas between the Dongting Lake Plain, the Jianghan Plain, and the Sichuan Basin. With an area of about 90000 km² ranging from 107.78°00′E to 111.36°00′E and 27.59°00′N to 31.39°00′N, their settlements are located in Hunan, Hubei, Guizhou provinces, and Chongqing municipality where their highlands meet, i.e., the Wuling Mountains, and include the Xiangxi Tujia and Miao Autonomous Prefecture and Zhangjiajie City in northwestern Hunan, the Enshi Tujia and Miao Autonomous Prefecture and the Tujia autonomous counties of Wufeng and Changyang in southwestern Hubei, counties of Qianjiang, Xiushan, Youyang, Pengshui, and Shizhu in southeastern Chongqing, and Tongren in northeastern Guizhou (Fig. 1).

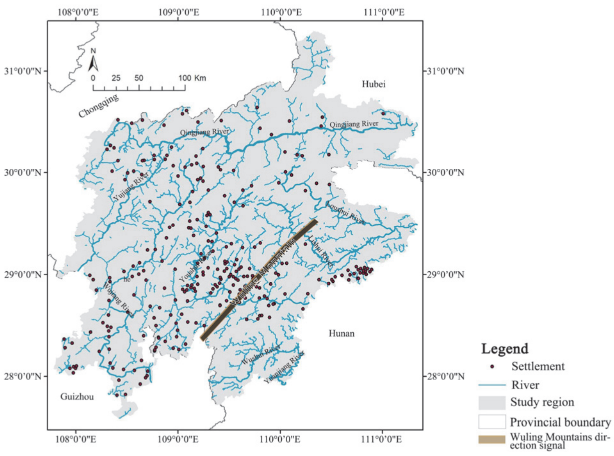

Figure 1 Distribution of traditional Tujia settlements

According to the China Statistical Yearbook-2021, the population of Tujia in China is 9587732, with about 90% of the total living in the Wuling Mountains. As a mountainous area with various types of landforms, including hills, river valleys, plateaus, basins, and plains, the Wuling Mountains have a great impact on the development of the Tujia ethnic group, and at the same time, the complex terrain explains why there are so many traditional Tujia settlements left today. The Tujia traditional settlements in this paper are mainly listed in the five batches of Traditional Chinese Villages Catalog by the Ministry of Housing and Urban-Rural Development of the People's Republic of China (MOHURD) and other departments up to 2021, as well as the National Famous Historical and Cultural Villages published by MOHURD and the National Cultural Heritage Administration of China, with 265 in total (Fig. 1). Mainly built in the Song, Yuan, Ming, and Qing dynasties, the Tujia traditional settlements embody profound historical, cultural, and humanistic legacy, remaining the living cultural treasures of the minority, therefore, they provide essential resources and carriers for conducting the research concerning the relationship between human and land.

2.2 Research Methods

2.2.1 The Suitability Evaluation System of Human Settlements

Based on the macroscopic scope, the study refers to the research results of scholars [12, 13, 21] and combines the actual conditions of the spatial distribution of traditional Tujia settlements to select evaluation indicators according to accessible, complete, and typical data [22]. As demonstrated in Tab. 1, the criterion layer consists of four factors: terrain, environment, society, and climate, and 12 specific indexes include elevation, slope, aspect, landform, RDLS, river, vegetation, soil, road, the ancient Sichuan salt route, temperature, and precipitation. The comprehensive evaluation system for the human settlements of traditional Tujia settlements covers an extensive range of factors for selecting locations.

Table 1 Suitability evaluation factors of human settlements of traditional Tujia settlements

Objective layer	Criterion layer/ h	Index layer/ N	Index definitions	Codes
Suitability evaluation of human settlements	Terrain factors	Elevation	Elevation of the settlement location	X_1
		Slope	Slope of the settlement location	X_2
		Aspect	Aspect of the settlement location	X_3
		Landform	Landform of the settlement location	X_4
		RDLS	RDLS of the settlement location	X_5
	Environmental factors	River	Distance of the settlement from the adjacent river	X_6
		Vegetation	Vegetation types of the settlement location	X_7
		Soil	Soil types of the settlement location	X_8
	Social factors	Road	Distance of the settlement from the adjacent road	X_9
		Ancient Sichuan salt route	Distance of the settlement from the adjacent ancient Sichuan salt route	X_{10}
	Climatic factors	Temperature	Temperature of the settlement location	X_{11}
		Precipitation	Precipitation of the settlement location	X_{12}

2.2.2 Geographical Detector Model

The geographical detector [23] is a statistical tool to measure spatial stratified heterogeneity. By testing the coupling between variables, it detects the possible causal relationships between them, thus revealing the influencing factors. It involves four detectors: risk detector, factor detector, ecological detector, and interaction detector [24]. This paper mainly adopts the factor detector and the interaction detector as they have been applied in many natural and social sciences fields. Therefore, they can be used to study the influence mechanism of settlements' spatial distribution. This research method is more objective because it can avoid the limitation of variables during the calculation process and there are no excessive assumptions.

The factor detector mainly detects the driving force of the settlement distribution and the extent to which a factor explains the spatial heterogeneity, and it is measured by q-statistic [25], which is shown by the following calculation formula:

$$q = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2} = 1 - \frac{SSW}{SST} \tag{1}$$

where h (1, 2, 3, ..., L) means the number of classifications affecting the factor X; N_h and N denote the number of samples in layer h and the total number of samples, respectively; σ_h^2 and σ^2 refer to the variances of the layer h and total variance respectively. SSW and SST represent the sum of squares within h and the total sum of squares. In the equation, q indicates the degree to which the factors determine the settlement distribution, and its value falls within [0, 1], where $q = 0$ denotes that there is no relevance between a factor and the distribution, while $q = 1$ means the ideal state that a factor completely determines the distribution. That is to say, the larger value of q manifests a stronger driving effect of a factor on the settlement distribution [26].

The interaction detector aims to identify interactions between different indexes X_n, i.e., whether factors X_1 and X_2 together would increase or decrease the effect of a dependent variable Y, or whether the effects of these factors on Y are independent [24]. Based on the factor detector, this paper conducts the interaction detector to explore the degree of interactive influence of the factors on the spatial distribution of settlements.

2.2.3 Fuzzy Comprehensive Evaluation

The fuzzy comprehensive evaluation is a synthetic appraisement method based on fuzzy mathematics, which describes the fuzzy boundaries in terms of the membership degree. This study applies the SPSSPRO platform (https://www.spsspro.com/) to conduct a fuzzy weighted evaluation, and by using the operator of the weighted average type (M (*, +)), the model of the fuzzy comprehensive evaluation is as follows:

$$B = A \cdot R = \left(a_1, a_2, ..., a_n\right) \cdot \begin{bmatrix} r_1^1 & \cdots & r_1^m \\ \cdots & \cdots & \cdots \\ r_n^1 & \cdots & r_n^m \end{bmatrix} \tag{2}$$

where B means the equivalent fuzzy subset, A the factor set, R the comment domain, m the number of comment levels, n the number of factors, a_i (i = 1, 2, 3, ..., n) the weight coefficient q of each factor, and r_n^m the membership degree of each indicator to the comment domain. Through normalization processing, the weight percentages of the 12 indexes are obtained to determine the suitability evaluation model of human settlements.

2.3 Data Sources

This study obtains indicators' data through websites, calibrates them in ArcGIS 10.8, and refers to the GCS-WGS-1984 coordinate system. The data sources and processing are detailed in Tab. 2.

Table 2 Data sources and processing

Data	Data type	Data sources	Data processing
Elevation	national elevation data (with 30 m resolution)	Geospatial Data Cloud (https://www.gscloud.cn/search)	By using the "clip" or "extract by mask" tools in ArcGIS, the elevation data are obtained to extract and analyze slope and aspect.
River, Road	distribution map of river system and road in China	Resource and Environment Science and Data Center of Geographic Sciences and Resources Research, CAS (https://www.resdc.cn/)	By applying the "clip" tool in ArcGIS, the river and road data are obtained and then analyzed by the density analysis tool.
Soil type	distribution map of soil type (1:1 million)		By using the "clip" or "extract by mask" tools in ArcGIS, distribution data of soil, vegetation, and terrain types are extracted.
Vegetation type	distribution map of vegetation type (1:1 million)		
Landform type	distribution map of terrain type (1:1 million)		
Ancient Sichuan salt route	distribution map of the ancient Sichuan salt route	Sichuan Salt Trail: Architecture and Villages in the Field of Vision of the Cultural Route [27]	The scanned map is geographically aligned in ArcGIS to trace the ancient Sichuan salt route, and to conduct a density analysis of the route and settlements.

3 RESULTS AND DISCUSSION

3.1 Analysis of Unsupervised Classification Method

Utilizing the factor detector and interaction detection of the Geodetector, this study analyses the influence of terrain, environmental, social, and climatic factors on the spatial distribution of traditional Tujia settlements and their interaction effects [22]. And 12 indicators such as elevation, slope, aspect, and landform are reclassified in a raster dataset in ArcGIS10.8 and overlaid with the settlements (Fig. 4). Their values are extracted using the ArcGIS sampling toolset. Then, as the dependent variable Y, the traditional settlements, and 12 indicators as independent variables X (Tab. 1) are imported into the Geodetector to obtain the weight of the q-value for each indicator.

According to some studies [28-30], different environmental factors and classification methods show relatively significant distinctions in the settlement distribution. Based on the Geodetector model, the data of indicators are processed by four unsupervised classification methods or discrete means in ArcGIS: Equal Interval (EI), Quantile Value (QV), Natural Break (NB), and Geometrical Interval (GI) [28], to compare and explore the degree of the influence of different indicators and classification methods on the settlement distribution and the change of human-land relationship in the same region. The model results demonstrate the degree of influence of factors on the distribution of traditional Tujia settlements and their variation with different classifications, as shown in Fig. 2.

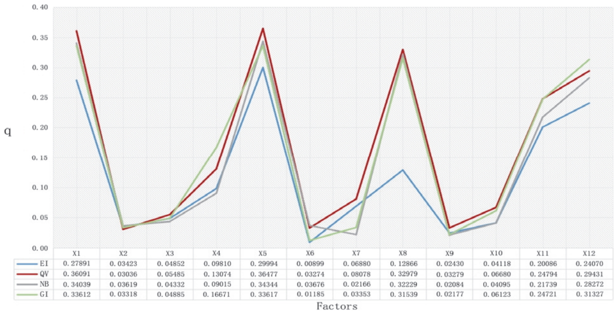

Figure 2 The q-values for each indicator under four classifications

The significant differences in the q-values of the indicators calculated by the four classifications indicate that each indicator exerts a different impact on the settlement distribution. Through comparative analysis, the QV shows the highest value of q among the four methods, so this method is chosen to analyze the impact factors for the distribution of traditional Tujia settlements.

3.2 Influencing Factors of the Spatial Distribution

As different environmental indicators and classifications greatly impact the settlement distribution, the QV method is finally applied to carry out the factor detector and interaction detector analysis to obtain the interaction effect of factors on settlement distribution (Tab. 3).

The results indicate that 12 indexes have different influences on the spatial distribution of traditional Tujia settlements, with the q-values decreasing from RDLS X_5 (0.36477), elevation X_1 (0.36091), soil X_8 (0.32979), precipitation X_{12} (0.29431), temperature X_{11} (0.24794), landform X_4 (0.13074), vegetation X_7 (0.08078), ancient Sichuan salt route X_{10} (0.06680), aspect X_3 (0.05485), road X_9 (0.03279), river X_6 (0.03274), to slope X_2 (0.03036).

Table 3 The results of interaction detector of 12 indicators

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
X_1	0.36091											
X_2	0.53138	0.03036										
X_3	0.53209	0.27152	0.05485									
X_4	0.44195	0.29964	0.37213	0.13074								
X_5	0.40398	0.50032	0.51069	0.46331	0.36477							
X_6	0.52331	0.29808	0.29155	0.30371	0.53142	0.03274						
X_7	0.48129	0.26925	0.31859	0.33455	0.49014	0.26151	0.08078					
X_8	0.49992	0.49340	0.44720	0.43501	0.48195	0.42258	0.47076	0.32979				
X_9	0.50158	0.25865	0.28991	0.30349	0.49685	0.32893	0.27740	0.44644	0.03279			
X_{10}	0.53406	0.28929	0.35289	0.32003	0.56537	0.28388	0.33326	0.51375	0.32734	0.06680		
X_{11}	0.47436	0.43812	0.39929	0.37535	0.47375	0.46083	0.42277	0.45017	0.44141	0.49192	0.24794	
X_{12}	0.58042	0.47479	0.54025	0.49318	0.57545	0.54750	0.50349	0.56891	0.52785	0.50072	0.61315	0.29431

Note: The grey indicates the results of factor detector.

As can be seen from the values, the 6 indicators, including RDLS, elevation, soil, precipitation, temperature, and landform, all have q-values greater than 0.1, indicating that the settlement distribution is mainly influenced by them, with RDLS having the greatest impact, followed by elevation. Therefore, the settlements are mostly located in hilly and low mountain areas with low relief at an altitude of 500 - 1200 m (Fig. 3b, Fig. 3e, Fig. 3f). The q-values of the other 6 indicators, namely vegetation, ancient Sichuan salt route, aspect, road, river, and slope, are all less than 0.1, which means that they have no significant influence on the settlement distribution, with that of slope being the weakest. According to Tab. 3, the RDLS and elevation show a greater tendency to enhance slope. The areas with high relief and altitude are less populated and all have a higher slope (> 15°), as shown in Fig. 3c. As RDLS and elevation can represent slope, the influence of slope on the spatial distribution of settlements is quite low because of the interaction between the two indicators. With water as an indispensable resource, people tend to locate their settlements around lakes and rivers to provide sufficient water for production and living [27]. Although the calculation results show that the distance from rivers does not have a significant impact on the distribution, settlements are generally distributed around rivers, with 58.87% of the distance from rivers within 2000 m. By analyzing the relevant factors, it can be found that the Tujia settlement area has a monsoon-influenced humid subtropical climate, with warm and humid weather, and the annual precipitation is 1068.7 mm - 1635.5 mm, with about 180 rainy days a year, leading to abundant rainfall (Fig. 3l and Fig. 3m). Meanwhile, as the settlement area is home to many rivers, it can be regarded as an area with a dense river network (Fig. 3g). As water resources are more abundant in the area, the influence of this factor on the settlement distribution is low compared to other significant ones.

Moreover, the results of the interaction detector (Tab. 3) show that due to the largest q-value of RDLS, its interaction with other factors brings significant increases, thus indicating the great impact of RDLS on the settlement distribution. And when interacting with other factors, the q-values of slope witness more significant increase from 0.03036 to 0.27152, 0.29964, 0.50032, 0.29808, 0.26925, 0.49340, 0.25865, 0.28929, 0.43812, and 0.47479, respectively. Besides, the interaction between the two climatic factors: temperature and precipitation, results in the largest q-value (0.61315), and the q-values are above 0.35 after their paired interaction with other indicators. Similarly, the q-values after interacting with RDLS or elevation also exceed 0.35. And the q-value changes from 0.06680 to 0.51375 when soil interacts with the ancient Sichuan salt route. Through analyzing these special values of the interaction detector, it can be seen that there exists a strong interaction between each indicator and the settlement distribution, featuring enhancement in dual factors or non-linearity, and the interaction of any two indicators results in a greater q-value than that of a factor alone for the settlement distribution.

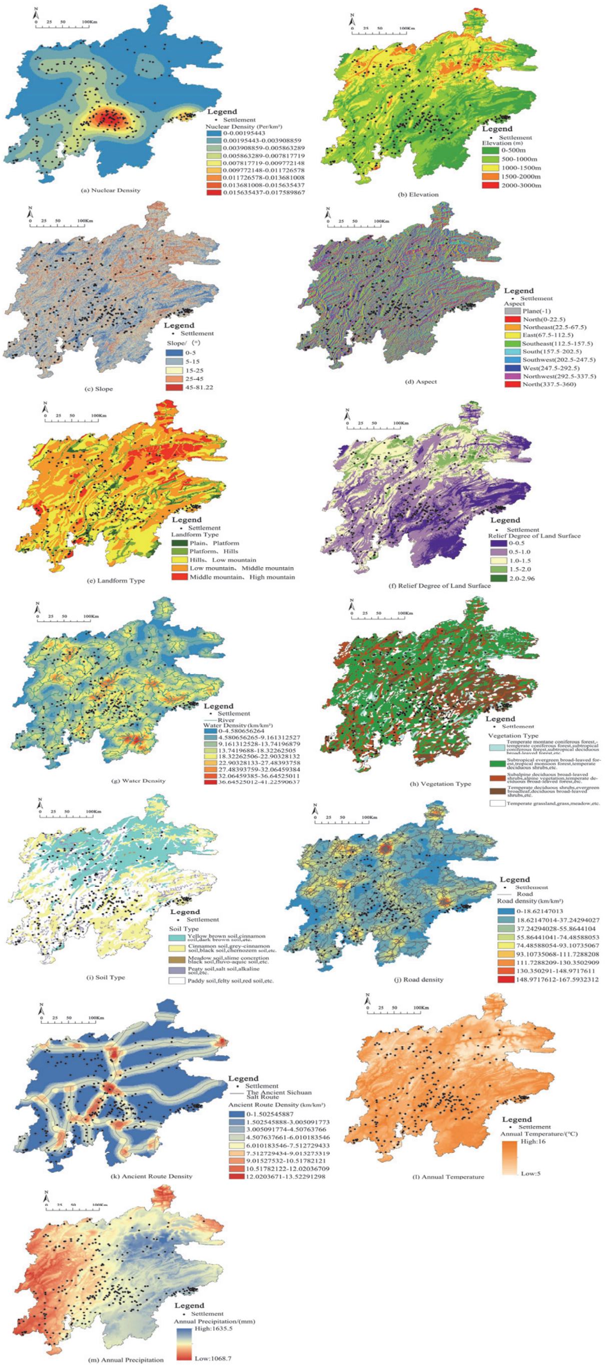

Figure 3 Relationship between settlements distribution and 12 indicators

In summary, through the above analysis, the location of traditional Tujia settlements is subject to the joint influence of RDLS, elevation, soil, temperature, precipitation, and landform, which constitute important factors for Tujia ancestors to consider when engaging in various activities and for the development of regional culture. At the same time, local forebears paid more attention to the farming environment in selecting sites, specifically, they considered whether it was suitable for farming. However, they did not overemphasize this aspect, but considered the living conditions in order to make the best strategic choices. Moreover, the overall distribution of the settlements is also affected by the social factors (e.g., the ancient route of Sichuan salt) because most settlements are distributed along the route, showing a certain overlap between the density map of the ancient road and that of the settlements (Fig. 3a and Fig. 3k).

It can be seen that the traditional Tujia settlements were formed under the comprehensive effect of natural, social and cultural environment, rather than the result of an independent and direct effect of a single factor. Among them, the natural is the basic driving force for the formation and development of settlements, the social is the supporting force affecting the spatial and temporal differentiation of settlements, and the cultural plays an important guiding role in the development of settlements. There are interaction and feedback adjustment mechanisms among the driving factors, which jointly promote the formation of spatial and temporal differentiation characteristics of traditional Tujiasettlements.

3.3 Suitability Evaluation of Human Settlements

In determining the membership degree (r_n^m) of each indicator, firstly, this study classifies the suitability of human settlements into five levels: higher suitability I, high suitability II, medium suitability III, low suitability IV, and lower suitability V, and these five levels are also applied in each indicator. In addition, each indicator is reclassified in the ArcGIS raster to obtain the membership degree of each one according to its specific level. After putting the q-values of factor detector and membership degree matrix into Eq. (2), through normalization process, the weight percentages of 12 indicators are as follows: 0.18, 0.01, 0.03, 0.06, 0.18, 0.02, 0.04, 0.16, 0.02, 0.03, 0.12, 0.15 respectively. Therefore, the comprehensive suitability evaluation model of the traditional Tujia settlements is: $f(Y) = 0.18 \cdot X_1 + 0.01 \cdot X_2 + 0.03 \cdot X_3 + 0.06 \cdot X_4 + 0.18 \cdot X_5 + 0.02 \cdot$ $\cdot X_6 + 0.04 \cdot X_7 + 0.16 \cdot X_8 + 0.02 \cdot X_9 + 0.03 \cdot X_{10} + 0.12 \cdot X_{11} + 0.15 \cdot$ $\cdot X_{12}$, where these 12 indicators (X_n) are the rest dataset of all spatial information of the settlements. By applying the raster calculator of ArcGIS, the suitability zoning of human settlements for the spatial distribution of traditional Tujia settlements (Fig. 4) and the statistics of settlements of each suitability level (Tab. 4) are acquired.

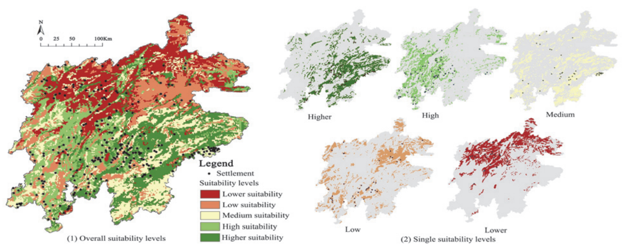

Figure 4 Suitability Zoning of traditional Tujia Settlements

Table 4 Distribution of suitability levels of traditional Tujia Settlements

Suitability levels	Number of settlements	Percentages / %
Higher suitability	72	27.2%
High suitability	81	30.6%
Medium suitability	45	17.0%
Low suitability	39	14.7%
Lower suitability	28	10.5%

In terms of the above 12 indicators, the overall human settlements in Tujia area are suitable for living with relatively high suitability. As shown in Fig. 4 and Tab. 4, most of the settlements are located in areas with good livability, with 74.8% of them having medium or higher suitability, of which 17% have medium suitability, 57.8%

have high or higher suitability, while only 25.2% have low suitability. As seen in Fig. 4, the areas with high suitability are mainly low hills with flat terrain, slope less than 15°, and dense river network. In addition, covered by evergreen broad-leaved forest, these areas feature soil types including cinnamon soil, gray cinnamon soil, red soil, yellow soil, and paddy soil. Therefore, it can be concluded that these settlements boast favorable environments with high comfort. With elevations ranging from 2320 m to 2900 m, and slopes from 25° to 81°, the areas of low suitability are mainly located in the northern part of the settlement area, characterized by large topographic relief, ravines, and gullies. There are mostly northeast and north slopes. The soil types there include yellow brown soil, dark brown soil, and brown soil, but in the past, they were severely acidified because they contained a few alkaline elements such as calcium, magnesium, and potassium. Though unsuitable for living, the Tujia ancestors still settled in the area. According to historical records and literature search [31, 32], during the Five Dynasties period, "the people lived on miscellaneous grains, fishing, and hunting" [33], and "hunting and fishing were one of the sources of livelihood during slack farming seasons" [34]. Therefore, they were mainly engaged in forestry, gathering, farming, fishing, and hunting. In addition, with 70% forest coverage, this area is covered by subtropical coniferous forests, temperate coniferous forests, and evergreen broad-leaved forests, bringing abundant resources available for gathering and hunting. Meanwhile, the high mountains and inconvenient transportation are natural barriers to preventing foreign invasion. Thus, it is concluded that the Tujia ancestors placed their source of income and defense as the key factors when choosing settlements. For the area with low suitability, a series of measures can be taken, such as improving traffic conditions and improving resource utilization efficiency, to improve the suitability of human settlements.

3.4 Limitations

The spatial distribution and driving mechanism of traditional Tujia settlements were investigated, and the spatial relationship between the distribution of the settlement and the human settlements suitability were deeply explored. Although the human settlements have been systematically studied, there are still some limitations: Due to the wide range of Tujia inhabited areas, the research objects were selected based on the Traditional Chinese Villages Catalog and the National Famous Historical and Cultural Villages. Some Tujia villages are well preserved but not included in the catalog, so the objects are not comprehensive enough. In subsequent studies, a comprehensive field investigation should be carried out to increase the comprehensiveness and richness of samples, and the suitability evaluation system of human settlements should be further improved to enhance the scientific, and provide accurate data support for the protection and development of traditional Tujia settlements.

4 CONCLUSIONS

By applying ArcGIS and Geodetector, this study selects the QV as the classification method to explore the impact factors on the spatial distribution of traditional Tujia settlements and the suitability evaluation of human settlements. The conclusions are as follows.

First, among the 12 indicators, RDLS, elevation, soil, precipitation, temperature, and landform have a more significant influence on the spatial distribution of settlements, among which the RDLS exerts the greatest impact. In comparison, the other 6 indicators, including vegetation, ancient Sichuan salt route, aspect, road, river, and slope contribute less to the distribution, with the slope being the weakest. With a dense river network and abundant water resources in the study area, the influence of rivers on the settlement distribution is low compared with other distinctive factors. In general, the Tujia natives attached more importance to the farming environment and primarily considered whether it was suitable for crop cultivation when selecting locations.

Second, when processing the interaction detector, it is found that the interaction of any two indicators brings greater influence than that of a factor alone, and there exists a strong interaction between each indicator and the settlement spatial distribution, featuring enhancement in dual factors or non-linearity. This suggests that, instead of depending on a single factor, the Tujia ancestors considered all the factors to achieve maximum suitability during site selection.

Third, by evaluating the suitability of human settlements of traditional Tujia settlements, it can be seen that located in low hills with flat terrain, the Tujia settlement area is mostly suitable for living, with 74.8% of the settlements having medium or higher suitability. In addition, the Tujia settlements mainly developed during the Five Dynasties, and hunting was an essential source of livelihood for the Tujia ancestors during that period. Therefore, the areas with lower suitability were also inhabited after considering various factors, indicating that they chose their sites based on a comprehensive consideration of multiple factors.

Focusing on the task of village construction to promote rural revitalization, this study explores the driving mechanism of settlement distribution and the suitability of the ecological environment, which plays an important role in formulating measures for the protection of traditional settlements and promoting settlement protection and sustainable development.

Acknowledgments

Funding for this research was provided from the National Philosophy and Social Science Foundation of China (No.16BSH110).

5 REFERENCES

[1] Liu, P. L. (2011). *On Construction and Utilization of Chinese Traditional Settlements Landscape's Genetic Map*. Beijing: Peking University.

[2] Wang, Y., Jin, C., Lu, M. Q., & Lu, Y. Q. (2017). Assessing the Suitability of Regional Human Settlements Environmentfrom a Different Preferences Perspective: A Case Study of Zhejiang Province, China. *Habitat International, 70*, 1-12. https://doi.org/10.1016/j.habitatint.2017.09.010

[3] Zhu, S. H., Choi, B. S., & Kang, C. W. (2021). Establishing and applying a value evaluation model for traditional Pit Kiln villages in the Henan province of China. *Journal of Asian Architecture and Building Engineering, 21*(4), 1262-1274. https://doi.org/10.1080/13467581.2021.1929242

[4] Halik, W., Mamat, A., Dang, J. H., Deng, B. S., & Tiyip, T. (2013). Suitability Analysis of Human Settlement Environment within the Tarim Basin in Northwestern China. *Quaternary International, 311*,175-180. https://doi.org/10.1016/j.quaint.2013.06.018

[5] Li, X., Jia, L. Y., & Lin, Q. (2021). Study on the Spatial Pattern of Traditional Settlement Landscape in the Hilly Areas of Hangjiahu Region. *Modern Urban Research*, (9), 71-76.

[6] Jin, T., Chen, H. S., & Xiao, D. W. (2017). Influences of the Natural Environment on Traditional Settlement Patterns: A Case Study of Hakka Traditional Settlements in Eastern Guangdong Province. *Journal of Asian Architecture and Building Engineering, 16*(1), 9-14. https://doi.org/10.3130/jaabe.16.9

[7] Tong, S. Y., Zhu, Y. F., & Li, Z. (2022). Correlation Study between Rural Human Settlement Health Factors: A Case Study of Xiangxi, China. *Computational Intelligence and Neuroscience, 5*, 10. https://doi.org/10.1155/2022/2484850

[8] Ma, H. D. & Tong, Y. Q. (2022). Spatial differentiation of traditional villages using ArcGIS and GeoDa: A case study of Southwest China. *Ecological Informatics, 68*, 101416. https://doi.org/10.1016/j.ecoinf.2021.101416

[9] Cao, F., Ge, Y., & Wang, J. F. (2013). Optimal Discretization for Geographical Detectors-based Risk Assessment. *GIScience& Remote Sensing, 50*(1), 78-92. https://doi.org/10.1080/15481603.2013.778562

[10] An, Y. Y. & Chen, W. P. (2021). Research on the distribution and suitability of rural settlements based on mathematical statistics: taking Zhuoni County of Gansu Province as an example. *Journal of Gansu Sciences, 33*(4), 120-128.

[11] Liu, L. W., Duan, Y. H., Li, L. L., Xu, L. S., Zhang, Y., & Nie, W. X. (2022). Spatial Distribution Characteristics and Suitability Evaluation of Rural Residential Areas in Shanxi Province. *Chinese Journal of Agricultural Resources and Regional Planning, 43*(01), 100-109.

[12] Du, X. Y., Hu, X. J., Jin, X. L., Cao, S. Y., Luo, Z. W., & Wei, B. J. (2021). Evaluation of Human Settlement Environment Suitability of Neolithic Settlement sites in Hunan Province Based on Geographical Detector. *Journal of Earth Environment, 12*(3), 269-278.

[13] Shao, N. (2020). Analysis of Spatial Distribution Characteristics and Driving Forces of Rural Settlement in Nanyang City. *Chinese Journal of Agricultural Resources and Regional Planning, 41*(2), 220-225.

[14] Liu, G. F., Ju, W. J., Ye, J. M., & Chu, G. M. (2021). Study on the Suitability Evaluation of Settlement Location in Northwest Arid Region Based on AHP-GIS-A Case Study of Turpan City. *Chinese Journal of Agricultural Resources and Regional Planning, 42*(8), 129-139.

[15] Chen, D. X. & Zhang, B. (2014). Explore the Overall Shape Characteristic of Traditional Settlements in Tujia Nationality of Xiangxi. *Urbanism and Architecture*, (8), 372-373.

[16] Fan, J. Y., Zheng, B. H., Zhang, B. Y., Zongsheng, H., & Junyou, L. (2023). Research on the Revitalization Path of Ethnic Villages Based on the Inheritance of Spatial Cultural Genes-Taking Tujia Village of Feng Xiang Xi in Guizhou Province as a Case Study. *Sustainability*, (15), 1303. https://doi.org/10.3390/su15021303

[17] Zheng, H. C., Chen, C. Q., Tang, L., & He, Y. Q. (2013). Research on the Spatial Construction Strategy of Traditional Settlements for the Tujia Nationality. *Applied Mechanics and Materials*, (2546), 357-360. https://doi.org/10.4028/www.scientific.net/AMM.357-360.120

[18] Zeng, X. M. (2017). Historical Context and Heritage Protection of Haocao Gong and Drum of Tujia Nationality in East Sichuan//Proceedings of 2017 International Conference on Humanities, Arts and Language (HUMAL 2017). *Proceedings of 2017 International Conference on Humanities*, 241-245.

[19] Zhou, T. (2014). Research on Adaptability Mechanism of the Evolution of Tujia Architecture in Xiangxi: A Case Study of Yongshun. *Beijing: Tsinghua University*.

[20] The Editorial Board. (2009). A Brief History of Tujia. *Beijing: The Ethnic Publishing House*, 7-11.

[21] Wang, M., Liu, S. M., & Wang, C. X. (2023). Spatial distribution and influencing factors of high-quality tourist attractions in Shandong Province, China. *PLoS ONE, 18*(7): e0288472. https://doi.org/10.1371/journal.pone.0288472

[22] Liang, L. Y., Guan, Y. Y., Liang, Y. Q., & Shi, S. Q. (2020). Spatial-temporal Evolution of Land Economic Density and Its Driving Factors in Beijing-Tianjin-Hebei Urban Agglomeration. *Chinese Journal of Agricultural Resources and Regional Planning, 41*(7), 163-172.

[23] Wang, J. F., Li, X. H., Christakos, G., Liao, Y. L., Zhang, T., Gu, X., & Zheng, X. Y. (2010). Geographical Detectors-based Health Risk Assessment and Its Application in the Neural Tube Defects Study of the Heshun Region, China. *International Journal of Geographical Information Science, 24*(1), 107-127. https://doi.org/10.1080/13658810802443457

[24] Wang, J. F. & Xu. C. D. (2017). Geodetector: Principle and Prospective. *Acta Geographica Sinica, 72*(1), 116-134.

[25] Wang, J. F., Zhang, T. L., & Fu, B. J. (2016). A Measure of Spatial Stratified Heterogeneity. *Ecological Indicators*, (67), 250-256. https://doi.org/10.1016/j.ecolind.2016.02.052

[26] Cui, Z. H. & Yan, Y. (2020). A GIS-based Research on the Spatial Evolution Characteristics and Influence Mechanism of the Rural Settlements in City Island: A Case Study of Baguazhou in Nanjing. *Modern Urban Research*, (2), 90-97.

[27] Zhao, K. (2018). Sichuan Salt Trail: Architecture and Villages in the Field of Vision of the Cultural Route. *Nanjing: Southeast University Press*.

[28] Bi, S. B., Ji, H., Chen, C. C., Yang, H. R., & Shen, X. (2015). Application of Geographical Detector in Human-environment Relationship Study of Prehistoric Settlements. *Progress in Geography, 34*(01), 118-127.

[29]Qiu, J. J., Jin, J. H., Ren, Y. Q., Zuo, X. X., & Li, Z. Z. (2021). Distribution Characteristics and Environmental Background of Settlements from the Neolithic to the Bronze Age in the Tingjiang River Basin, Fujian Province, China. *Mountain Research, 39*(6), 791-805.

[30] Charlie, F. (2014). About the Geometrical Interval Classification Method [EB/OL] 2007-10-18.

[31] Zhu, S. Z. (2002). On the Historical Economic Geography in Tujia Area of Hubei, Hunan, Guizhou Provinces and Chongqing Municipality. *Shaanxi: Shaanxi Normal University*.

[32] Peng, W. L. (2011). Tujia Minority in China. *Yinchuan: Ningxia people's Publishing House 12*.

[33] The Editorial Board of Baojing County. (1990). Baojing County Annals. *Beijing: Chinese Literature and History Press.*

[34] The Editorial Board of Luxi County. (1993). Luxi County Annals. *Being: Social Sciences Academic Press*.

Contact information:

Yunzhang LI
College of Architecture and Environment, Sichuan University, China

Disi RAN
College of Architecture and Environment, Sichuan University, China

Junnan LV
(Corresponding author)
College of Arts, Sichuan University, China
E-mail: 1547863823@qq.com