Driving Mechanisms of the Spatial Evolution of Rural Settlements in Hilly and Mountainous Areas of Southern Hubei Based on Geodetector and GWR: A Case Study of Chongyang County

LIU Ziyan[1], LIU Xiancheng[2], TIAN Congxiang[1]

(1. Yangtze University College of Arts and Sciences, Jingzhou, Hubei 434020, China; 2. Yangtze University, Jingzhou, Hubei 434023, China)

Abstract Exploring the evolution mechanisms of the spatial pattern of rural settlements in hilly and mountainous areas holds considerable theoretical and practical importance for advancing new urbanization and optimizing the spatial layout of rural territories. This study focuses on Chongyang County, a representative hilly and mountainous area in southern Hubei Province. Utilizing land use spatial data from three time points (2010, 2015, and 2020), an indicator system was developed from three dimensions: natural environment, geographical location, and socio-economic factors. The geodetector method and geographically weighted regression (GWR) model were employed in a comprehensive manner to quantitatively assess the primary driving factors influencing the spatial evolution of rural settlements and their spatiotemporal variations. The findings indicated that the spatial evolution of rural settlements in Chongyang County was influenced by multiple factors operating in a coordinated manner. Key determinants included slope, proximity to urban areas, geological disaster risk, and per capita GDP. Interactions between double factors exhibited either bi-factor enhancement (BE) or nonlinear enhancement (NE). The combined explanatory power of socio-economic factors and geographical location increased significantly over time. The GWR model revealed pronounced spatial heterogeneity in the driving forces. The rigid constraint of natural factors such as elevation and slope diminished progressively, whereas the positive driving effects of urban attraction, population agglomeration, and economic development intensified. This research demonstrates that the spatial reconstruction of rural settlements in the hilly and mountainous areas of southern Hubei has undergone a significant transformation, shifting from "a natural foundation-restricted type" to "one dominated by socio-economic factors and location".

Keywords Rural settlement, Spatial layout, Driving mechanism, Geodetector, Geographically weighted regression (GWR), southern Hubei

DOI 10.16785/j.issn 1943-989x.2026.3-4.003

Rural settlements are the fundamental spatial carriers of agricultural civilization, bearing significant local history and regional cultural values. The dynamic evolution of their spatial patterns is a direct reflection of the transformation of regional socio-economic structure and the reconfiguration of human-land relationships. Currently, with the ongoing advancement of new urbanization and rural revitalization strategies, rural areas have undergone significant transformations in social structure, industrial models, and living environments. The differentiation, reorganization, and transition of rural settlement spatial patterns have become increasingly pronounced, becoming an inevitable trend in the process of urban-rural transformation and development[1]. Traditional rural settlements develop their spatial layout according to the clan system, centering around public cultural spaces such as ancestral halls and temples. This arrangement results in a rural spatial form characterized by distinct circles and stable patterns. However, the rapid progression of industrialization and urbanization has led to a significant outmigration from rural areas. The population base, production models, and social structures that supported the survival of traditional settlements have gradually disintegrated, leading to a continuous decline in the traditional rural spatial form[2]. Meanwhile, market-oriented development and the widespread adoption of modern agricultural production methods have reshaped the logic of rural spatial development, leading to the gradual replacement of traditional settlement patterns by new forms of settlement. In the context of accelerated global urbanization, the contraction and depopulation of rural settlements have become prevalent phenomena, significantly restricting the optimal allocation of rural resources and presenting numerous challenges to the implementation of rural revitalization strategies and the pursuit of high-quality development in rural territorial spaces.

Previous studies on the spatial patterns of rural settlements have mainly employed qualitative approaches. These studies have primarily focused on individual micro-courtyards or broader macro-settlements, with research objects ranging from courtyards and settlements to townships, counties, and towns. The objective has been to provide a comprehensive understanding of the relationships among people in various regions and their lives, production activities, interactions, and the environments[3-4]. However, given the rapid transformations currently occurring in rural settlements across China, quantitative analysis has become increasingly essential in this domain. A quantitative examination of rural settlement spaces can yield clearer insights into their distribution characteristics, historical evolution, and potential future trends, thereby facilitating practical planning and supporting the benign development of rural areas[5-6]. Furthermore, quantitative methods are well-suited for evaluating policy effectiveness and informing subsequent policy adjustments.

1 Overview of the study area and construction of the indicator system

1.1 Overview of the study area

Chongyang County is situated within the low hilly and mountainous terrain of a branch of the Mufu Mountain in southeastern Hubei Province. The area is encircled by mountains, with basins and river valleys dispersed throughout the central region. The landscape is characterized

Received: April 8, 2026 Accepted: June 2, 2026

Sponsored by Philosophy and Social Sciences Research Project of the Education Department of Hubei Province (24G152).

by a complex combination of mountains and hills, comprising approximately 80% of the total area, alongside water bodies accounting for about 5%, primarily formed by the main stream of the Jun River and its tributaries. Cultivated land, representing roughly 15% of the area, is scattered in river valleys and gentle slopes. This distinctive topography and landform pattern create an intricate ecological context in which the regional ecological background, industrial economy, and human settlement living space are closely intertwined and mutually constraining. Consequently, a unique human-land relationship emerges, marked by significant topographic limitations and a high population density. Chongyang County thus serves as a typical case for examining the spatial evolution and human-land interactions of rural settlements in the hilly and mountainous areas of southern Hubei.

1.2 Construction of the indicator system

The spatial evolution of rural settlements is influenced by both natural background constraints and human planning interventions. Chongyang County, situated in the low hilly and mountainous area of the Mufu Mountain in southern Hubei Province, is characterized by complex terrain and enclosed landforms. Initially, the spatial distribution of rural settlements was predominantly determined by natural environments and geographical conditions. However, with ongoing urbanization and rural transformation, human factors, such as policy regulation, social development, and economic growth, have increasingly played a significant role in reshaping settlement patterns. To accurately reveal the driving mechanisms underlying the spatial evolution of rural settlements in Chongyang County, this study adheres to the principles of scientific rigor, representativeness, and quantifiability, and selects eight core indicators across three dimensions: natural environment, geographical location, and socio-economic factors. These indicators include elevation, slope, geological disaster risk, distance from rivers, transportation accessibility, urban location, population density, and per capita GDP[7-8].

2 Results and analysis

2.1 Identification of the intensity of influencing factors (global analysis of geodetectors)

This study employed differentiation and factor detectors to perform a comprehensive global analysis of the explanatory power (q value) of each driving factor influencing the spatial pattern of rural settlements in Chongyang County for the years 2010, 2015, and 2020. The results are presented in Table 1. All indicator factors passed significance tests, confirming their role as key drivers in the spatial evolution of rural settlements.

(1) When considering the average explanatory power for each year throughout the research period, the factors influencing the spatial pattern of rural settlements were ranked as follows: slope (X2)> distance from towns (X6) > geological disaster risk (X3) > per capita GDP (X8) > elevation (X1) > distance from rivers (X4) > population density (X7) > distance from transportation (X5). Overall, terrain conditions and urban location emerged as the two primary determinants constraining the spatial evolution of rural settlements in the study area, playing a fundamental role in reshaping their distribution and patterns.

(2) From the perspective of temporal evolution trends, the rigid constraints of natural environmental factors had progressively intensified over the years, with the "threshold effects" of terrain and disasters becoming increasingly pronounced. The explanatory power of individual factors such as slope (X2) and geological disaster risk (X3) had steadily increased. Specifically, the q value for slope rose from 0.642 in 2010 to 0.765 in 2020, while the q value for geological disaster risk increased from 0.472 to 0.579. These findings indicate that the restraining action of hilly and mountainous terrain conditions and geological security patterns on the site selection of rural settlements and the expansion of residential buildings are continuously intensifying. The spatial expansion of mountainous settlements can no longer be considered independent of the stringent constraints posed by natural conditions such as terrain slope and geological security.

Socio-economic and locational factors exhibited distinct characteristics of phased transformation. In 2010, per capita GDP (X8, q=0.866) and distance from towns (X6, q=0.784) demonstrated the highest explanatory power and served as the primary controlling factors influencing settlement patterns. During this period, the expansion of rural settlement scale was mainly governed by the regional economic level and the radiation effect of towns. After 2015, the explanatory power of these two factors declined steadily, reaching 0.239 and 0.506, respectively, by 2020. This decline can be attributed to poverty alleviation initiatives and the coordinated development of rural areas across the region, which facilitated a more balanced allocation of regional economic resources. As a result, the constraining effects of early economic disparities and urban locational differences on settlement expansion diminished, leading to a more balanced development of settlement space.

The transportation location factor showed a consistently increasing potential driving effect throughout the study period. The explanatory power of the distance from transportation (X5) increased steadily from 0.130 to 0.267, exhibiting an upward trend each year. This pattern aligns with the progressive development of the regional road network and the continuous enhancement of transportation accessibility. The directive effect of transportation location on the spatial agglomeration and pattern optimization of rural settlements has become increasingly significant.

2.2 Analysis of the interaction of influencing factors

The spatial evolution of rural settlements is influenced by the combined effects of multiple factors, with the impact of any single factor being limited. Interaction analysis using the geodetector method revealed that, throughout the study period, the interaction types among driving factors in Chongyang County were characterized solely by bi-factor enhancement (BE) and nonlinear enhancement (NE). No instances of independent effects or factor weakening were observed, reflecting the complexity and multi-factor synergistic nature of rural settlement evolution in hilly and mountainous regions (Table 2).

The dominant interaction factors exhibited distinct spatiotemporal differentiation characteristics, with the coupling of location and socio-economic factors consistently prevailing. In 2010, the interaction between urban location and economic development (X6∩X8, q=0.370 8) primarily influenced the evolution of settlement space. From 2015 to 2020, the combination of urban location and population density (X6∩X7) remained the principal interaction factor, with its explanatory power increasing from 0.254 9 to 0.340 8. This trend indicates a progressively strengthened driving effect of population agglomeration, induced by urbanization, on the reshaping of rural settlement patterns.

Significant differences were observed in the interaction patterns among various factors. The interaction between terrain factors, such as elevation and slope (X1, X2), and human-related factors was primarily BE, with the fundamental constraints imposed by the terrain background on settlement development remaining stable over an extended period. In contrast, urban location (X6) and population and economic factors (X7, X8) predominantly exhibited high-intensity NE. This suggests that, throughout the process of urban-rural transformation, the driving effects of socio-economic factors are progressively amplified, thereby underscoring their increasingly prominent role in the evolution of mountainous settlements.

2.3 Spatiotemporal differentiation characteristics of driving mechanism (GWR local heterogeneity analysis)

(1) A spatial visualization analysis of the regression coefficients for the driving factors influencing settlement evolution in each village was performed using the GWR model (Fig.1). The findings revealed significant local spatial heterogeneity in the driving mechanisms of rural settlements in Chongyang County. Both the intensity and direction of each factor's influence exhibited clear regional differentiation and temporal evolution. Overall, the rigid constraints imposed by the natural environmental background on settlement space tended to diminish, with the "absolute restrictive effects" of natural factors gradually weakening.

The regression coefficients of elevation and slope on settlement scale exhibited significant variations in both the intensity and direction of their spatial effects. In central river valley plain regions, including Baini Town, Qingshan Town, and Tongzhong Township, settlement agglomeration was relatively pronounced, with the slope regression coefficient demonstrating a significant negative value. This indicates that the undulating terrain exerted a strong inhibitory effect on the spatial expansion of settlements. Temporal analysis revealed a gradual decrease in the absolute value of the slope coefficient over time, suggesting a diminishing terrain suppression effect and a transition in settlement expansion from rapid growth to stable convergence.

The elevation regression coefficients in the southwest and northwest high-altitude mountainous areas, including Guihuaquan Town, Xiaoling Township, and Jintang Town, shifted from negative to positive. This change indicated that as construction land in the central plains approached saturation and the conflict between population and land intensified, gentle slopes and buffer zones within mountainous areas increasingly became critical spaces for the expansion of rural residences. Nevertheless, the negative constraining effect of slope in these regions continued to intensify. The stringent limitations imposed by terrain conditions and construction environments were not entirely overcome, resulting in human settlements in deep mountainous areas relying primarily on local lowlands and gentle slopes, thereby exhibiting fragmented and small-scale clustered distribution patterns.

(2) From the perspective of geographical location factors, rural settlements in the study area showed distinct characteristics of functional reorganization and spatial guidance. The driving patterns of the three types of location factors, namely rivers, transportation, and towns, had undergone significant temporal transformation and spatial differentiation.

The driving effect of river location underwent a gradual transformation. In 2010, the regression coefficients associated with river factors exhibited a spatial gradient, transitioning from positive values in the southwest to negative values in the northeast. By 2020, the enhancement of regional centralized water supply systems, ponds, dams, reservoirs, and other water conservancy infrastructures had significantly reduced rural settlements' reliance on natural rivers as their sole water source. The river constraint effect, primarily driven by traditional water intake, was greatly diminished. Simultaneously, emerging development demands, such as waterfront ecological protection and river flood control, became increasingly prominent. These shifts redefined the spatial layout logic of settlements along rivers, facilitating the orderly aggregation of rural living spaces along water systems and networks, and establishing a new distribution pattern oriented towards ecology and safety.

There was a pronounced east-west spatial differentiation in the driving effect of

Table 1 Geographical exploration results of spatial influencing factors of rural settlements in the study area

Year	X1	X2	X3	X4	X5	X6	X7	X8
2010	0.294	0.642	0.472	0.219	0.130	0.784	0.180	0.866
2015	0.418	0.665	0.543	0.400	0.141	0.458	0.208	0.233
2020	0.412	0.765	0.579	0.349	0.267	0.506	0.154	0.239
Average	0.375	0.691	0.531	0.323	0.179	0.583	0.181	0.466

Note: The above data passed the significance test at the 1%, 5%, and 10% levels, respectively.

Table 2 Interactive analysis of spatial influencing factors of rural settlements in the study area

Rank	2010			2015			2020		
	Interaction factor	q		Interaction factor	q		Interaction factor	q	
1	X6∩X8	0.370 8	NE	X6∩X7	0.254 9	NE	X6∩X7	0.340 8	NE
2	X6∩X5	0.256 2	NE	X6∩X8	0.245 1	NE	X5∩X4	0.254 4	NE
3	X5∩X8	0.255 1	NE	X6∩X3	0.228 8	NE	X8∩X7	0.238 0	NE
4	X8∩X7	0.247 5	NE	X6∩X5	0.128 2	NE	X8∩X5	0.233 7	NE
5	X6∩X7	0.222 5	NE	X6∩X4	0.128 1	NE	X6∩X8	0.213 0	NE
6	X5∩X7	0.217 4	NE	X5∩X8	0.124 1	NE	X6∩X5	0.200 4	NE
7	X6∩X4	0.183 6	NE	X4∩X8	0.117 6	NE	X6∩X4	0.176 1	NE
8	X4∩X8	0.181 1	NE	X5∩X7	0.117 5	NE	X8∩X4	0.170 1	NE
9	X3∩X8	0.169 9	NE	X7∩X3	0.112 6	NE	X6∩X3	0.170 0	NE
10	X6∩X1	0.165 9	NE	X8∩X3	0.112 1	NE	X7∩X5	0.166 4	NE
11	X6∩X2	0.159 7	NE	X8∩X7	0.108 4	NE	X8∩X3	0.142 7	NE
12	X6∩X3	0.158 1	NE	X6∩X2	0.103 7	NE	X7∩X4	0.139 5	NE
13	X4∩X5	0.151 7	NE	X5∩X4	0.100 4	NE	X5∩X3	0.130 8	NE
14	X2∩X8	0.140 5	BE	X4∩X7	0.100 3	NE	X4∩X1	0.130 1	NE
15	X1∩X8	0.135 0	BE	X5∩X3	0.097 5	NE	X6∩X2	0.112 8	NE
16	X5∩X2	0.127 0	NE	X6∩X1	0.093 3	NE	X6∩X1	0.109 7	NE
17	X3∩X5	0.116 0	NE	X5∩X2	0.087 9	NE	X7∩X3	0.108 5	NE
18	X4∩X7	0.111 3	NE	X5∩X1	0.087 1	BE	X4∩X3	0.104 4	NE
19	X5∩X1	0.107 8	BE	X8∩X2	0.086 8	NE	X7∩X2	0.103 0	NE
20	X2∩X7	0.090 0	NE	X7∩X2	0.081 9	NE	X8∩X2	0.099 2	NE
21	X4∩X2	0.073 3	NE	X4∩X1	0.076 4	NE	X5∩X1	0.099 0	NE
22	X4∩X1	0.068 6	NE	X4∩X3	0.076 3	NE	X8∩X1	0.097 5	BE
23	X1∩X7	0.067 3	NE	X8∩X1	0.072 9	BE	X5∩X2	0.093 1	NE
24	X3∩X7	0.061 2	NE	X7∩X1	0.070 9	BE	X7∩X1	0.081 4	NE
25	X1∩X2	0.047 4	BE	X4∩X2	0.069 2	NE	X4∩X2	0.081 3	NE
26	X3∩X1	0.040 4	NE	X3∩X1	0.052 0	NE	X3∩X1	0.047 4	NE
27	X3∩X4	0.039 4	NE	X3∩X2	0.050 8	NE	X3∩X2	0.047 1	NE
28	X3∩X2	0.038 0	NE	X1∩X2	0.045 4	BE	X1∩X2	0.041 6	BE

Note: BE. Bi-factor enhancement; NE. Nonlinear enhancement.

transportation location on settlement patterns. The overall regression coefficient for traffic accessibility was significantly negative, indicating that the size of settlement patches was inversely correlated with road distance. Proximity to the transportation network corresponded with a more pronounced agglomeration and expansion of settlements. This negative effect exhibited a gradient pattern, intensifying progressively from east to west. The western region's complex mountainous terrain results in high costs for road network construction and limited transportation resources. The impact of road network coverage on the spatial expansion of settlements is particularly strong in this area. Enhancements in transportation accessibility can rapidly stimulate the developmental vitality of mountainous settlements. In contrast, the eastern river valley plain features a dense road network and a well-developed transportation system, where the influence of transportation factors on settlement patterns tends to be stable, with only weak marginal heterogeneity effects observed.

The agglomeration effect driven by urban proximity had been progressively strengthened. The negative regression coefficient associated with the urban location factor (X6) had increased annually, indicating a continuous intensification of urban directionality and central centripetal forces in the spatial evolution of settlements. The core high-impact areas, such as Tiancheng Town and the Central Economic Development Zone, had gradually contracted, while low-impact areas had become more dispersed. This trend suggests a transition in the development of county-level towns from a single-core agglomeration model to a multi-node radiation pattern. The industrial and administrative functions of both urban and rural areas are increasingly extending to more remote villages. Rural settlements in suburban and peripheral areas are progressively integrating into the developmental framework of county-level towns, highlighting pronounced characteristics of urban-rural integration and agglomeration (Fig.2).

(3) The reshaping of rural settlements by socio-economic factors demonstrated evolutionary characteristics of "agglomeration polarization and adaptive equilibrium". The driving patterns of population and economic factors revealed distinct phased spatial reconstruction patterns.

Population density (X7) consistently served as a positive determinant influencing the spatial expansion of settlements. Between 2010 and 2015, a pronounced trend of population concentration was observed in the northeastern plain of the county, with considerable regional variation in the intensity of population-driven forces. By 2020, the regression coefficients for both southwest mountainous areas and northeastern plains of the county stabilized within a high-value range of 2.2–2.6, indicating a balanced population-driven effect across the entire region. This pattern suggests that adaptive regulatory mechanisms, including labor force return and village integration, have effectively optimized the spatial distribution of the population within the county, facilitating a transition in settlement patterns from polarization and differentiation toward overall equilibrium.

Per capita GDP (X8) exhibited a significant positive correlation with the scale of rural settlements, indicating a continuous spatial differentiation in economic drivers. The southern region of Tiancheng Town had consistently functioned as a core economic growth pole with a strong driving effect. The area of high economic value had gradually shifted from the mountainous southwest to the industrial belt in the northeast. Owing to constraints of terrain

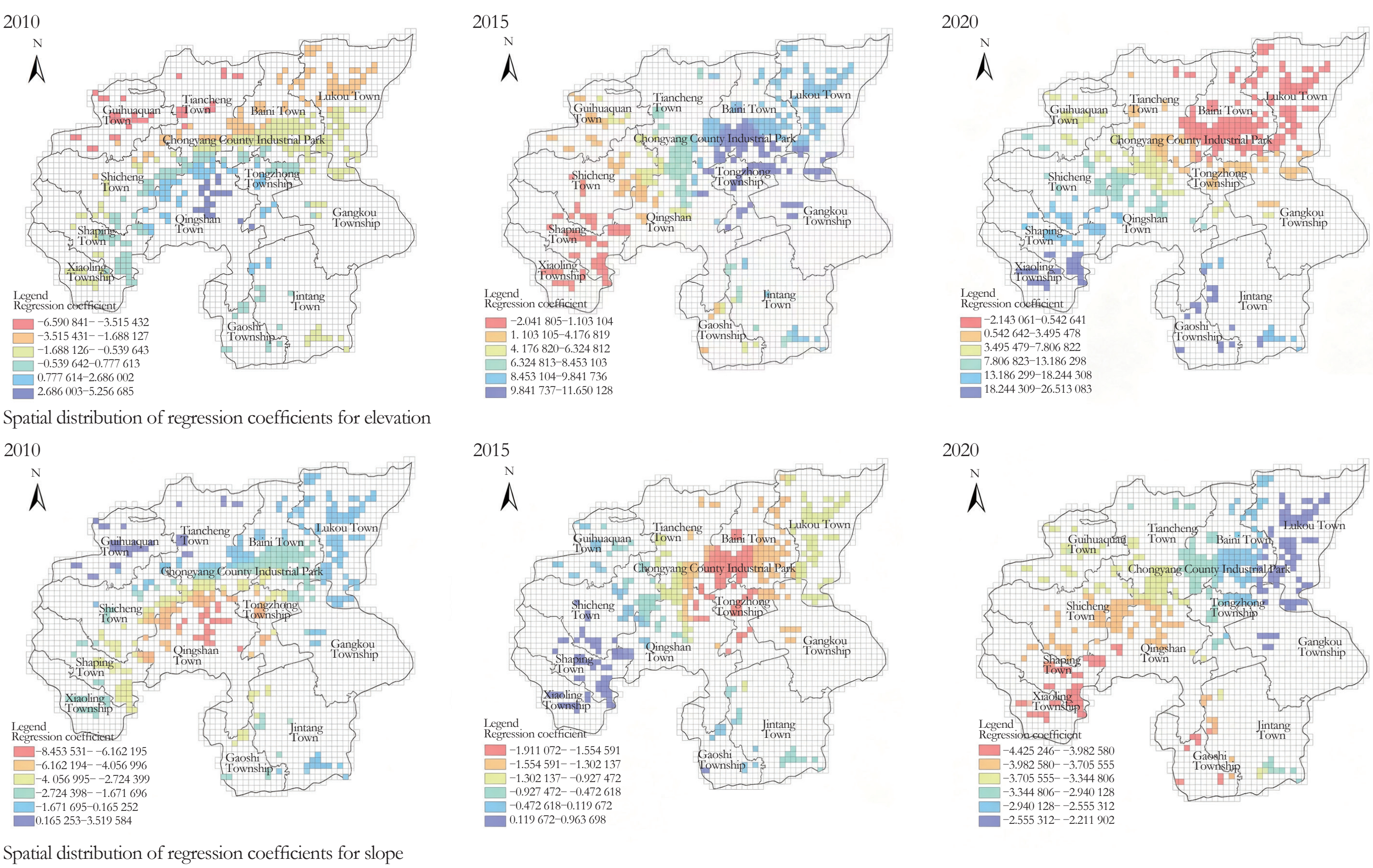


Fig.1 Spatial distribution of regression coefficients for elevation and slope

conditions, resource endowments, and variations in industrial layout, the economic driving efficiency between the mountainous southwest and the northeastern plains had remained unequal. The economic impetus underlying settlement evolution had demonstrated a persistent spatial imbalance (Fig.3).

3 Conclusions and planning implications

3.1 Conclusions: conceptual model of the dynamic mechanism of evolution

Based on the analysis of the spatiotemporal evolution of settlements, factor detection, and spatial heterogeneity, it is evident that the evolution of rural settlements in Chongyang County is a systematic process characterized by the interaction, coupling, and dynamic feedback of multiple factors. A conceptual model illustrating the dynamic mechanism of settlement evolution with closed-loop characteristics can be developed (Fig.4). The driving principles of this process are primarily manifested in two core aspects: the collaborative symbiosis among multiple drivers and the transformation and differentiation of spatiotemporal patterns.

From the perspective of driving mechanisms, the evolution of rural settlements in Chongyang County is jointly influenced by three primary factors: natural environments, geographical location, and socio-economic conditions. Each factor has distinct functions and they interact in a coupled manner. Specifically, natural environments establish the safety baseline for human settlement construction and constrain the developmental scope of the settlement foundation. Geographical location determines the spatial boundaries for expansion and governs the overall layout of settlements. Socio-economic factors contribute to agglomeration and attraction processes, thereby facilitating the continuous reconstruction of settlement

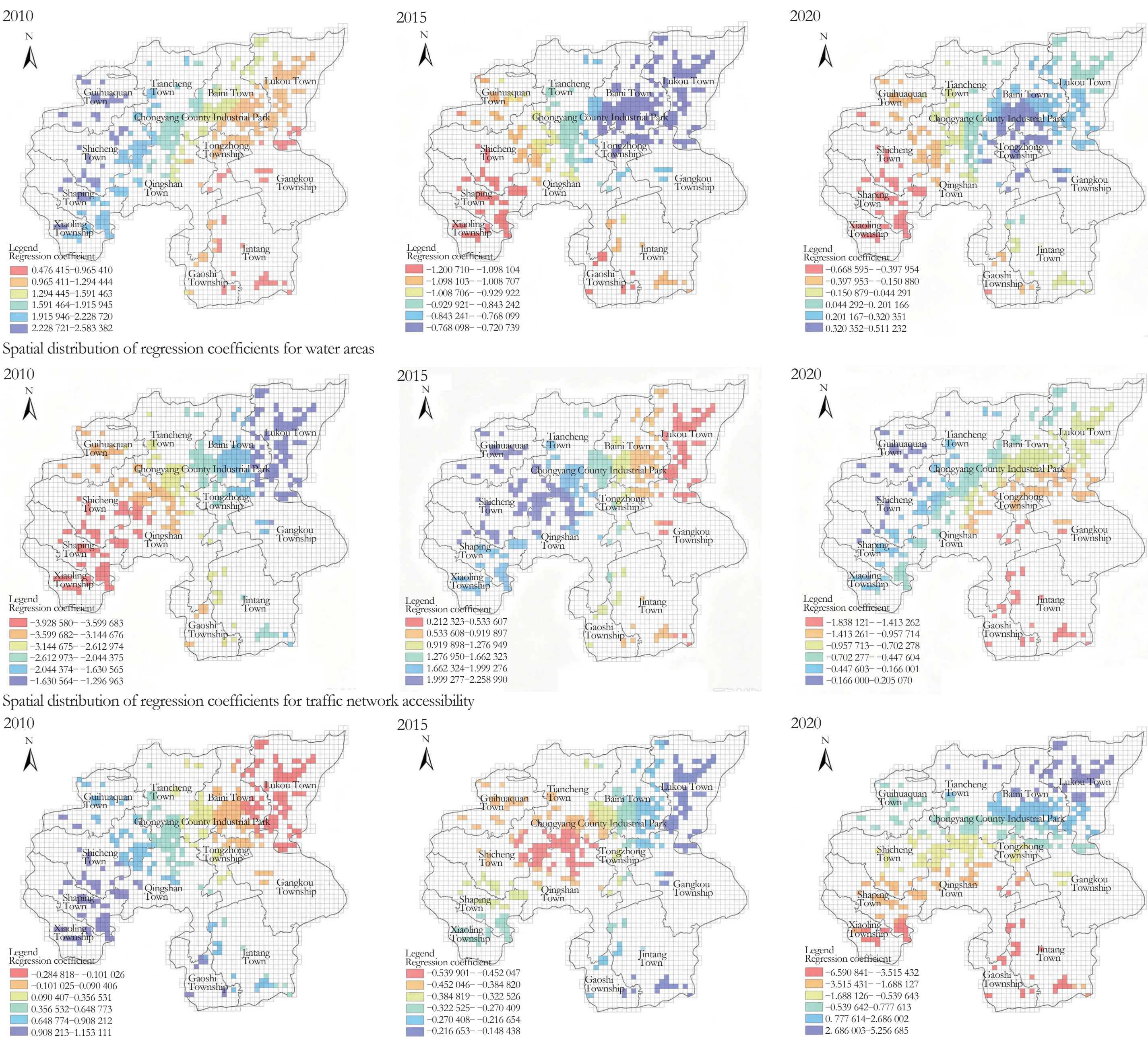
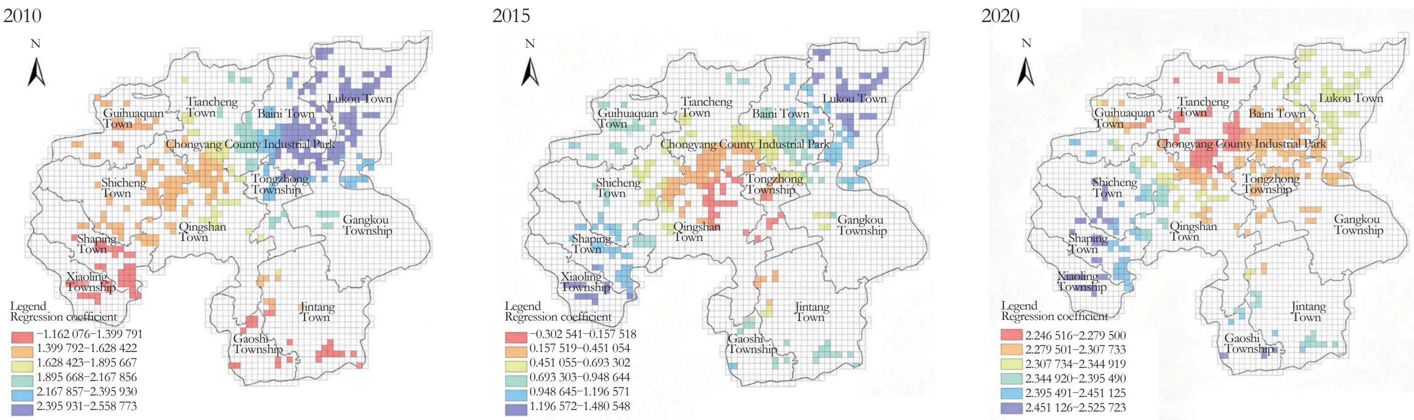
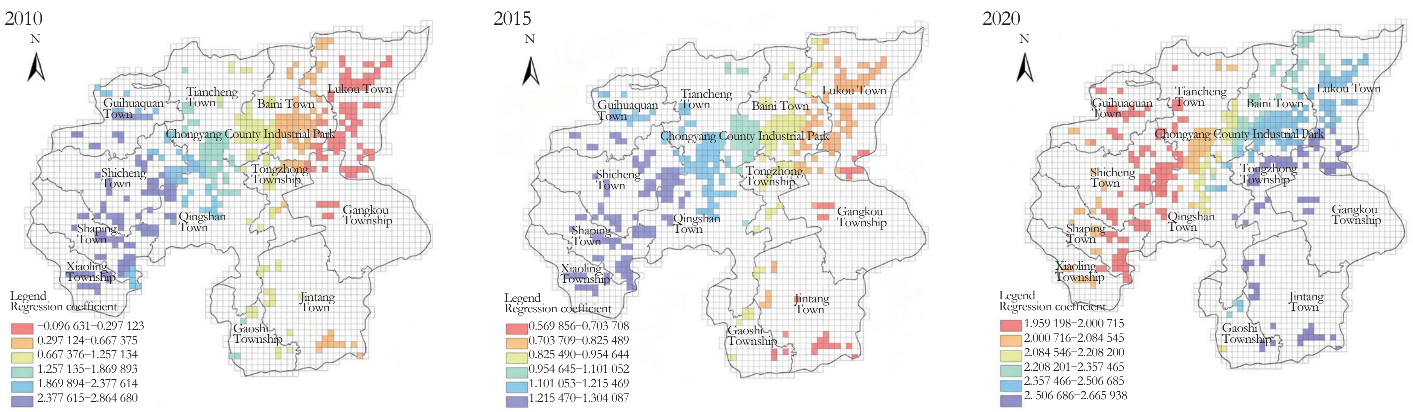


Fig.2 Spatial distribution of regression coefficients for water areas, transportation, and urban centers



Spatial distribution of regression coefficients for population density



Spatial distribution of regression coefficients for per capita GDP

Fig.3 Spatial distribution of regression coefficients for population density and per capita GDP

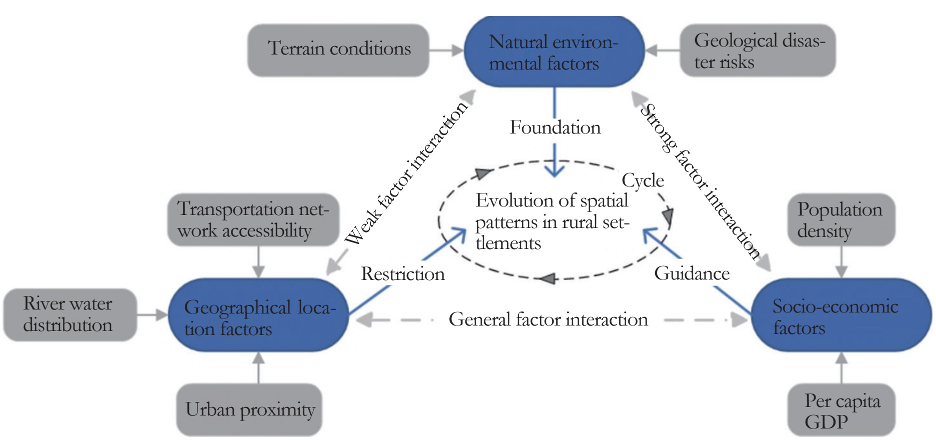


Fig.4 Dynamic mechanism of the spatial pattern evolution of rural settlements

patterns. These factors operate synergistically through interactions characterized as BE or NE, collectively driving the spatial iterative evolution of settlements in hilly and mountainous areas.

From the perspective of spatiotemporal evolution characteristics, the development model of rural settlements in the study area has undergone a significant transformation. Initially, it was characterized by a natural foundation-restricted type, constrained by terrain, water, and soil conditions. Over time, it has evolved into a type driven primarily by socio-economic, and location factors, with development influenced by factor flows and functional adaptation. Due to regional variations in terrain and location, the spatial pattern of settlements exhibits pronounced regional differentiation. In the deep southwest mountainous areas, settlements are distributed in a fragmented and discontinuous linear pattern, constrained by transportation limitations and geological risks. Conversely, the northeastern plain, benefiting from urban influence, industrial development, and population agglomeration, has experienced continuous integration and optimization of settlements, resulting in a block-shaped spatial pattern characterized by large, clustered areas with a regular layout.

3.2 Planning implications and regulatory strategies

Based on the above empirical research findings, this paper proposes differentiated spatial optimization and regulatory strategies, offering practical guidance for the improvement of territorial spaces and the enhancement of human settlement patterns in comparable mountainous rural regions.

First, it is important to adhere to fundamental safety principles and implement a rigorous spatial reconstruction strategy to mitigate disaster risks. The southwest mountainous regions exhibit complex terrain and high geological risks, accompanied by significant natural constraints. Planning efforts must consider the heterogeneity of the terrain and geological safety requirements. The widespread model of dispersed on-site expansion should be discontinued. Instead, orderly relocation and avoidance strategies should be employed for scattered settlements located in disaster-prone and ecologically fragile areas. The construction of new rural houses should be strictly prohibited in areas susceptible to steep slopes and landslides. Such measures will effectively eliminate safety risks associated with human settlements at their source and establish a robust natural foundation for the spatial development of rural settlements.

Second, it is essential to promote differentiated regulation through multi-center agglomeration by leveraging the radiation of towns. GWR analysis demonstrates that urban location and economic development exert a significant positive impact on settlement agglomeration. The radiation range of towns should be delineated with the central urban area of Tiancheng Town, key towns, and major transportation arteries as focal points, thereby establishing a multi-nodal agglomeration development system. For low-efficiency settlement patches characterized by dispersion, hollowing, and inadequate supporting facilities in deep mountainous regions, a gradient spatial integration strategy should be adopted to guide the orderly concentration of settlement resources toward suburban areas of towns, central villages, and flatland industrial zones. The concentrated allocation of population, land, and public resources can improve the efficiency of facility utilization, optimize the human-land interaction patterns in mountainous regions, and promote the efficient and sustainable development of regional territorial spaces.

References

[1] Ma, X. (2019). The forms of early Chinese villages from the perspective of the origin of civilization. *Social Sciences in China*, (8), 166-186.

[2] Li, X., Cui, H. & Li, H. P. et al. (2020). A review and the prospect of researches on the development principles of Chinese rural settlements in the past four decades: The comparative perspective of urban and rural planning and geography. *Urban Planning Forum*, (6), 79-86.

[3] Yu, Z. C. (2019). Courtyard neighborhood remodeling: Study on rural settlement mode in Guanzhong, Shanxi Province. *Architecture & Culture*, (2), 39-41.

[4] Luo, W., Jasiewicz, J. & Stepinski. T. et al. (2016). Spatial association between dissection density and environmental factors over the entire conterminous United States. *Geophysical Research Letters*, *43*(2), 692-700.

[5] Li, C. X., Li, F. R. (2024). Geographically weighted regression for spatial data with replicates. *Periodical of Ocean University of China*, *54*(1), 156-164.

[6] Li, X. M., Du, J. & Shen, J. F. (2016). The study of regional integration based on GWR of Nanjing–Zhenjiang–Yangzhou(NZY) Region. *Economic Survey*, *33*(1), 14-18.

[7] Kang, J. Y., Zhang, J. H. & Hu, H. et al. (2016). Analysis on the spatial distribution characteristics of Chinese traditional villages. *Progress in Geography*, *35*(7), 839-850.

[8] Ji, Z. X., Xu, Y. Q. & Lu, L. H. et al. (2021). Research progress and prospects for spatial optimization of rural settlements. *China Land Science*, *35*(6), 95-104.

****

(Continued from P8)

Table 2 Precision comparison of deep learning methods for diseased tree monitoring based on UAV remote sensing images

Model	Number of visual interpretation targets	Number of detections	Number of correct detections	Precision	Recall	Miss rate
Proposed method	558	496	451	0.909 3	0.808 2	0.191 8
HRNet	558	465	365	0.785	0.654	0.346
DenseNet	558	482	397	0.824	0.711	0.288
ResNet	558	435	375	0.862	0.672	0.327

replace traditional manual surveys and provide technical support for the prevention and control of pine wilt disease and other forest pathogens in large-scale forest areas.

(3) Future research will further enrich the sample library covering multiple scenarios and disease stages, optimize the model’s ability to distinguish spectrally confused ground objects, and improve the identification accuracy of early-stage diseases.

References

[1] Wang, Z., Zhang, X. L. & An, S. J. (2007). Spectral characteristics analysis of Pinus massoniana suffered by Bursaphelenchus xylophilus. *Remote Sensing Technology and Application*, *22*(3), 367-370.

[2] Wang, X. Z., Cao, Y. F. & Wang, L. F., et al. (2018). Occurrence and control status of pine wilt disease. *Journal of Environmental Entomology*, *40*(2), 256-267.

[3] Hu, G. S., Zhang, X. M. & Liang, D., et al. (2013). Identification of diseased pine trees in remote sensing images based on weighted support vector data description. *Transactions of the Chinese Society for Agricultural Machinery*, *44*(5), 258-263, 287.

[4] Huang, M. X., Gong, J. H. & Li, S., et al. (2012). Study on pine wilt disease hyper-spectral time series and sensitive features. *Remote Sensing Technology and Application*, *27*(6), 954-960.

[5] Lin, Z. W., Tu, W. H. & Huang, J. H., et al. (2019). Tree species recognition of UAV aerial images based on FC-DenseNet. *Remote Sensing for Land and Resources*, *31*(3), 225-233.

[6] Huang, H. H., Ma, X. H. & Huang, H. Y., et al. (2018). A preliminary study on monitoring of dead pine trees caused by pine Wilt disease With fixed-Wing unmanned aerial vehicle. *Journal of Environmental Entomology*, *40*(2), 306-313.

[7] Zeng, Q., Sun, H. F. & Yang, Y. L., et al. (2019). Precision comparison for pine wood nematode disease monitoring by UAV. *Journal of Sichuan Forestry Science and Technology*, *40*(3), 92-95, 114.

[8] Deng, S. Q. (2019). *Study on monitoring method of dead pine trees in pine wilt disease epidemic areas based on satellite-aerial-ground collaboration* (Master’s thesis). Retrieved from China National Knowledge Infrastructure.