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Analysis of Spatiotemporal Evolution Characteristics of Urban Development in the Yimeng Old Revolutionary Base Area

Jinyan WANG[1], Yongting WANG[2]

1. School of Architectural Engineering and Spatial Informatics, Shandong University of Technology, Zibo 255000, China; 2. School of Tourism, Taishan University, Taian 271000, China

Abstract [**Objectives**] To make a systematic analysis was conducted on the spatiotemporal evolution characteristics of urban land expansion in the region. [**Methods**] Utilizing land use data from five temporal points (1980, 1990, 2000, 2010, and 2018), the study applied expansion speed, expansion intensity index, and fractal dimension model for analysis. [**Results**] Regarding expansion speed, the period from 1980 to 2000 represented a phase of low-speed expansion, followed by a rapid expansion phase from 2000 to 2010. Expansion speed subsequently moderated from 2010 to 2018, marking a transition to a medium-speed expansion phase. Spatially, the expansion of Linyi urban district was most pronounced, displaying contiguous sprawl centered on the old urban core. Local expansion patterns were identified as belonging to three types: strip-like, sprawling, and leapfrog development. An analysis of land use conversion revealed that approximately 62.93% of the newly expanded urban land was derived from cultivated land, with industrial/mining/residential land and grassland representing the secondary sources. [**Conclusions**] Urban expansion in the study area demonstrates an evolutionary trend characterized by initial rapidity followed by stabilization, and the overall spatial structure remains relatively intensive.

Key words Yimeng Old Revolutionary Base, Land use, Urban expansion, GIS, Spatio-temporal evolution

0 Introduction

Land use/cover change (LUCC) represents one of the core areas of current global environmental change research[1]. Within this context, urban land expansion, as the category exhibiting the most rapid transformation and the most pronounced environmental consequences, has increasingly emerged as the dominant trajectory of land use change, garnering heightened scholarly interest in the field[2]. Since the initiation of reform and opening-up, China has witnessed accelerating urbanization and continuous enlargement of urban hinterlands. An analysis of the spatiotemporal evolution of urban land expansion offers a direct and objective portrayal of urbanization pace and spatial morphology, thus providing reliable references for promoting efficient and green urban development and supplying a scientific foundation for strategic decision-making concerning the new-type urbanization paradigm.

Existing research has largely concentrated on the land expansion patterns of large and medium-sized cities[3], primarily focusing on the eastern and central macro-regions, with coastal economically developed cities receiving the greatest attention. In contrast, the expansion of built-up land in smaller-scale, less-developed areas has received comparatively limited scholarly scrutiny. Nevertheless, small and medium-sized cities constitute a substantial share of the total urban count and have demonstrated a notable upward trend in recent years[4]. Accordingly, this paper takes the Yimeng Old Revolutionary Base as the study area. This region is a typical mountainous and hilly area in northern China marked by ecological vulnerability, where the topography imposes certain limitations on the outward extension of urban boundaries. At the same time, policy interventions and the optimization of the industrial structure have exerted positive effects on its spatial growth.

Since the 1990s, the expansion rate of urban construction land in China has accelerated significantly. Many domestic researchers have studied urban land expansion using various methods. Based on data from the resource and environment remote sensing database of the Chinese Academy of Sciences, Tian Guangjin *et al.*[5] and Liu Jiyuan *et al.*[6] found that between 1990 and 1995, influenced by rapid economic development and the reform and opening-up policy, the rate of urban expansion was relatively high. Due to China's specific national conditions and differences in regional development foundations, the urbanization of China exhibits distinct regional characteristics. With the support of technologies such as remote sensing and geographic information systems, domestic research has achieved considerable results; however, most studies focus on economically developed metropolises[7], paying insufficient attention to small and medium-sized cities, and there are relatively few studies on the development of old revolutionary base areas with relatively backward economies. Therefore, this study selects the Yimeng Old Revolutionary Base and, with the support of remote sensing and geographic information system technologies and reference to relevant research findings from both domestic and international sources, analyzes the spatiotemporal evolution of urban land expansion and its driving factors.

1 Overview of the study area and research methods

1.1 Overview of the study area As a typical mountainous and hilly region in northern China, the Yimeng Old Revolutionary Base features complex geological and geomorphological types, a fragile ecosystem, and a very prominent human land conflict. Lo-

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Jinyan WANG, masters' degree candidate, research fields: urban and rural planning.

cated in the central southern part of Shandong Province, the base covers the administrative areas of Linyi City, Linqu County, Yiyuan County, Sishui County, Xintai City, Wulian County, and Ju County. Its altitude ranges from about 20 to 1 156 m, with hilly and mountainous terrain accounting for roughly 70% (Fig. 1 and Fig. 2). The dominant soil types are brown soil and cinnamon soil, and the mountainous and hilly areas are suitable for the development of economic forests.

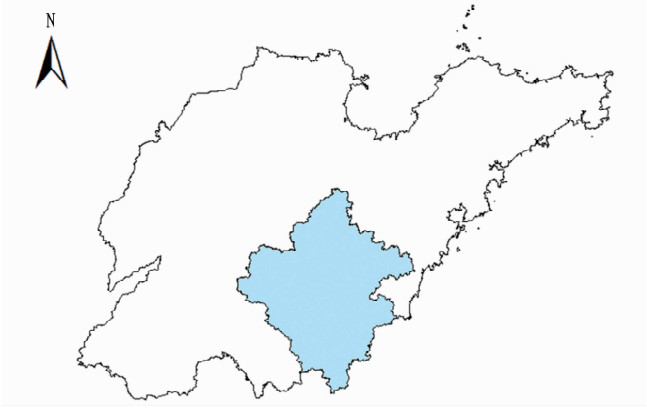


Fig. 1 Geographical location of Yimeng Old Revolutionary Base

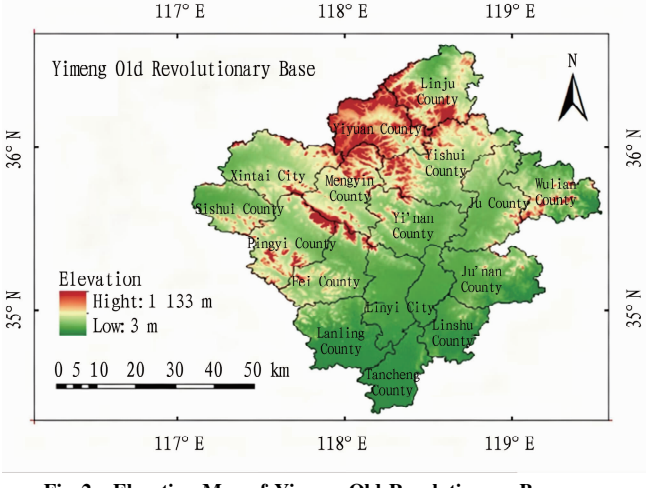


Fig. 2 Elevation Map of Yimeng Old Revolutionary Base

1.2 Research methods

1.2.1 Urban land expansion speed. The urban land expansion speed, denoted as U_v, is defined as the average annual increase in urban land expansion area in the study area over the period 1980 – 2018. It is used to characterize the overall magnitude and tendency of urban land expansion during this phase.

$$U_v = (U_{pa} - U_{oa}) / \triangle t \quad (1)$$

where U_v is the expansion speed of urban land, U_{pa} denotes the urban land area at the end of a certain time period, U_{oa} is the urban land area at the beginning of a certain time period, and $\triangle t$ is the time period (generally in years)[9].

1.2.2 Urban land expansion intensity index. The urban land expansion intensity index (U_i) refers to the ratio of the average annual urban land expansion area to the total land area. Using the percentage of the expansion area relative to the total area, the comparison of expansion speeds between different regions or different time periods is placed on the same benchmark.

$$U_i = (\triangle U_{ea} \times 100) / (\triangle t \times L_{ta}) \quad (2)$$

where U_i is the urban land expansion intensity index, $\triangle U_{ea}$ is the amount of urban land expansion during a certain time period, $\triangle t$ is the time period (generally in years), and L_{ta} is the total land area of the study area[9].

1.2.3 Urban land expansion fractal model. The fractal model is used to study urban spatial changes, analyzing the intensity and rationality of urban land use from a data perspective. Urban spatial change can be expressed by the following formula:

$$D = 2\ln \frac{P}{4} / \ln A \quad (3)$$

where D is the fractal dimension value, A is the urban area in a given period, and $P(t)$ is the urban edge perimeter in that period. Since the urban expansion model operates in two-dimensional space, the theoretical value of D should range between 1.0 and 2.0. The D value reflects the intensity of urban land use; the larger the value, the higher the intensity of land use[10].

2 Results and analysis

2.1 Urban land expansion speed and intensity index Between 2000 and 2010, the urban land area in the Yimeng Old Revolutionary Base grew at the fastest rate speed of 842.63. This was followed by the period 2000 – 2010 as well, with an expansion speed of 225.21. As can be seen from Table 1, the construction land in the study area increased significantly from 8.55% in 1980 to 14.42% in 2018, although the growth showed a slowing trend from 2010 to 2018. Except for water bodies, all other land use types exhibited decreasing trends, with grassland experiencing the most notable reduction, falling from 14.9% to 9.6%.

Table 1 Changes in area of different land use types in the Yimeng Old Revolutionary Base from 1980 to 2018

Type	Code	1980		1990		2000		2010		2018	
		Area//km^2	%	Area//km^2	%	Area//km^2	%	Area//km^2	%	Area//km^2	%
Farmland	1	17 143.68	63.42	17 090.95	63.22	16 942.17	62.67	17 338.72	64.14	17 057.29	63.10
Woodland	2	2 643.68	9.78	2 638.10	9.76	2 647.80	9.80	2 513.04	9.30	2 500.41	9.25
Grassland	3	4 027.89	14.90	4 034.72	14.93	4 023.93	14.89	2 593.23	9.59	2 595.12	9.60
Waters	4	809.89	3.00	797.59	2.95	795.79	2.94	833.28	3.08	922.11	3.41
Construction land	5	2 311.66	8.55	2 375.73	8.79	2 527.52	9.35	3 680.38	13.61	3 898.93	14.42
Unused land	6	95.45	0.35	95.03	0.35	95.02	0.35	73.93	0.27	58.71	0.22
Total		27 032	100.00	27 032	100.00	27 032	100.00	27 032	100.00	27 032	100.00

Between 1980 and 2010, urban land expansion in the Yimeng Old Revolutionary Base exhibited a clear upward trend (Table 2). However, from 2010 to 2018, the expansion intensity weakened significantly. The highest expansion intensity occurred in the 2000 – 2010 period, reaching 3.12 which was several times the level of other periods, reflecting a high rate of land expansion at that time. Afterwards, under the influence of rational spatial planning for urban land and the new-type urbanization paradigm, the expansion intensity decreased.

Table 2 Urban land expansion speed and intensity index from 1980 to 2018

Period	Expansion speed	Intensity index
1980 – 1990	21.41	0.08
1990 – 2000	130.11	0.48
2000 – 2010	842.63	3.12
2010 – 2018	225.21	0.83

2.2 Fractal dimension of urban land expansion By analyzing the changes in urban land area across counties and districts of the Yimeng Old Revolutionary Base, it was found that the urban land expansion rate was fastest in Linyi urban area, exhibiting a spreading trend centered on the early urban core. Therefore, this study takes Linyi urban area as the key research region. Using the fractal dimension formula and the extracted urban land patches from different periods, a statistical table of fractal dimensions of urban land structure was obtained (Table 3). The results show that from 1980 to 2018, the fractal dimensions of the spatial structure of urban land in Linyi urban area ranged from 1.301 3 to 1.331 9, all below 1.5, indicating relatively intensive urban land use. During 1990 – 2010, the fractal dimension increased from 1.304 6 to 1.331 9, mainly due to increased agglomeration in urban areas and expansion along transportation arteries, which intensified the density of urban land use. After 2010, the spatial dimension of land use declined, as urban development was increasingly constrained by administrative boundaries, rivers, topography, and other factors.

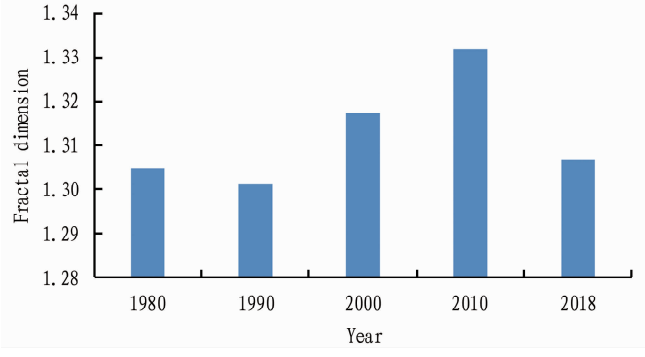
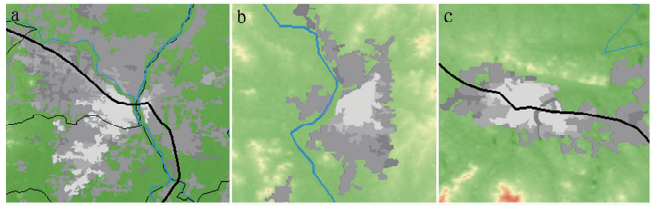


Fig. 3 Fractal dimension histogram of urban land use from 1980 to 2018

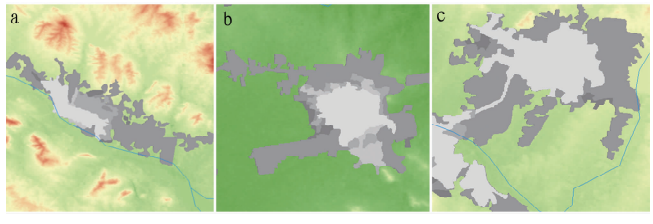
2.3 Patterns of urban land expansion On the whole, over the past four decades, urban land expansion in the Yimeng Old Revolutionary Base has been predominantly outward (externally oriented), with infill development as a secondary mode, along with enclave expansion. From a local perspective, a more detailed understanding of the spatial expansion of urban land in different areas can be obtained[9]. The local expansion patterns of urban land in the Yimeng Old Revolutionary Base mainly include three types: ribbon (linear) expansion, sprawling expansion, and leapfrog (jumping) expansion[8].

2.3.1 Ribbon-type expansion. Urban land tends to extend outward along rivers and roads[10]. Over the study period, urban land expansion in the Yimeng Old Revolutionary Base was characterized by a river road dependent pattern. More specifically, Linyi urban area expanded northeastward along the Yihe River (Fig. 4a); by 2018, Yishui County had shown expansion along both sides of the Yihe River (Fig. 4b); and Fei County developed in the north south direction along National Highway 327 (Fig. 4c).



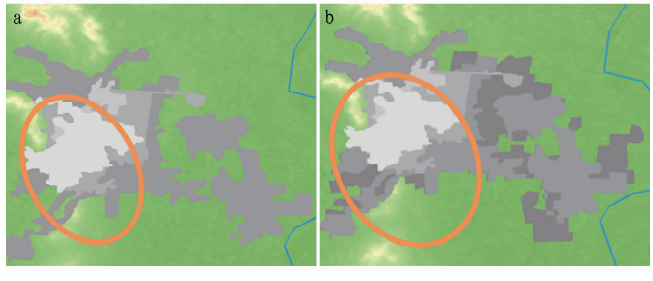
NOTE a. Linyi urban area; b. Yishui County; c. Fei County.

Fig. 4 Axial expansion of urban land along the Yihe River



NOTE a. Mengyin County; b. Ju'nan County; c. Xintai City.

Fig. 5 Concatenated expansion map of urban land use



NOTE a. Yinan Economic Development Zone in 2010; b. Yinan Economic Development Zone in 2018.

Fig. 6 Leapfrog expansion of urban land use

2.3.2 Dispersed expansion. Dispersed expansion is the continuous outward growth of urban land into city fringe areas. It is a common mode of urban spatial expansion before natural topographic constraints become significant[10]. In Mengyin County, Ju'nan County, and Xintai City, urban land expanded outward from the old city centers (Fig. 5). Due to the presence of mountains and hills in both the south and north of Mengyin County, its expansion shows a ribbon-like pattern as it spreads along the urban fringe

(Fig. 5a). In contrast, Junan County and Xintai City exhibit a "concentric ring-like" sprawling pattern (Fig. 5b, Fig. 5c).

2.3.3 Leapfrog expansion. Leapfrog expansion occurs when new land use areas emerge on the outskirts of a city. These areas are usually large, have their own infrastructure, and are relatively less dependent on the central city. In the Yimeng Old Revolutionary Base, each county and district has established independent functional zones, such as economic development zones and high-tech industrial development zones, which allow urban construction land to expand toward the suburbs by "leapfrogging" over urban development barriers. The new districts grow in coordination with the main urban area, and the connections between them have become increasingly strong. Supported by the main urban area, the new districts can develop quickly. The development trajectory of the development zone in Yi'nan County illustrates the growing closeness between the main urban area and the development zone (Fig. 6a, Fig. 6b).

3 Conclusions

Using the Yimeng Old Revolutionary Base as the study region, this research analyzed the driving factors behind urban land expansion since 2000, based on raster data from land use classification and relevant statistics for five years: 1980, 1990, 2000, 2010, and 2018. Through an examination of the characteristics, patterns, and land sources of urban expansion, the following conclusions can be drawn:

(i) Urban land expansion in the Yimeng Old Revolutionary Base was fastest during 2000 – 2010, qualifying as rapid expansion. The pace slowed during 2010 – 2018, indicating medium speed expansion. From 1980 to 2000, due to relatively underdeveloped economic conditions, and because the study area includes one of 18 contiguous impoverished regions designated by the state, urban land expansion was very slow, representing low speed expansion.

(ii) The local urban land expansion patterns in the Yimeng Old Revolutionary Base mainly fall into three types: ribbon type expansion, dispersed expansion, and leapfrog expansion.

(iii) During urban land expansion in the Yimeng Old Revolutionary Base, about 62.929% of the newly expanded land came from cultivated land, followed by rural industrial and mining residential land, and then grassland. In terms of area, the cultivated land occupied amounted to 83.325 5 km^2, significantly more than other land types.

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