

Study on the Temporal and Spatial Evolution of Urban Spatial Morphological Features

-- Taking Xi'an as an Example

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Abstract: Based on the Landsat remote sensing images of the fourth phase of Xi'an, the land use data of ENVI interpretation and classification are used to extract the boundaries of Xi'an's built-up areas, and the urban spatial analysis method based on GIS is used to comprehensively analyze the evolution characteristics of urban space in Xi'an in the past 30 years. The research results show that the built-up area in Xi'an has been expanding rapidly since 2000, mainly in the form of extension, the shape of the built-up area tends to expand in all directions, and the overall compactness is low, and the efficiency of urban land use is significantly reduced. The overall development presents spread trend.

Keywords: Urban space, Morphological features, Emporal and spatial evolution, Xi'an city.

1. Introduction

With the continuous acceleration of world economic integration, the focus of urbanization is gradually shifting to developing countries [1]. With the acceleration of globalization, China's urbanization rate has increased year by year, The rapid urbanization has brought benefits, on the other hand, it has produced urban development problems such as urban disorderly expansion.

The evolution of urban spatial form is the external appearance of urban spatial, which can reflect the trend and law of urban spatial structure evolution [2]. In the last century, foreign scholars focused on the research of evolution of urban spatial form. Boyce et al. (1964) proposed the concept of urban spatial form from the perspective of geography [3]. And foreign scholars have carried out a lot of research on urban spatial form by using mathematical models, GIS spatial analysis and other methods. Batty et al. (1994) chose fractal theory to study the relationship between urban spatial form change and urban land use spatial structure [4]. Since the 1980s, domestic scholars have focused on the spatial-temporal monitoring and analysis of urban built-up land use, the evolution of urban spatial form, the prediction and simulation of urban spatial evolution. Yinfeng Xu et al. (2019) systematically and quantitatively analyzed the evolution of Suzhou's urban spatial form and its impact mechanism from a two-dimensional perspective [5]. In the past, domestic scholars have done more research on the evolution of spatial

forms of large cities in the east and coastal areas, there is more room for research on the evolution of spatial form of western cities.

This paper selects Xi'an, an important node city in the west, as the research object, and tries to study the evolution characteristics of urban spatial form. Optimization suggestions are put forward for urban spatial development problems.

2. Data Sources

The administrative boundary data of Xi'an come from the Resource and Environment Science and Data Center of the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences (<https://www.resdc.cn/>).

The Landsat image data used to interpret the land use types of Xi'an City comes from Geospatial Data Cloud (<http://www.gscloud.cn/>), the track numbers are 126/36, 127/36 and 127/37, and the spatial resolution rate is 30 m, and the imaging time is from May to October, and the cloud cover is less than 5%. The TM/ETM+ and OLI images of Xi'an in 1990, 2000, 2010 and 2020 were selected, processed by radiometric calibration, atmospheric correction, image fusion, etc, and using support vector machine supervised classification and other operations to obtain the fourth phase of Xi'an City Interpretation results of land use classification. (Figure 1)

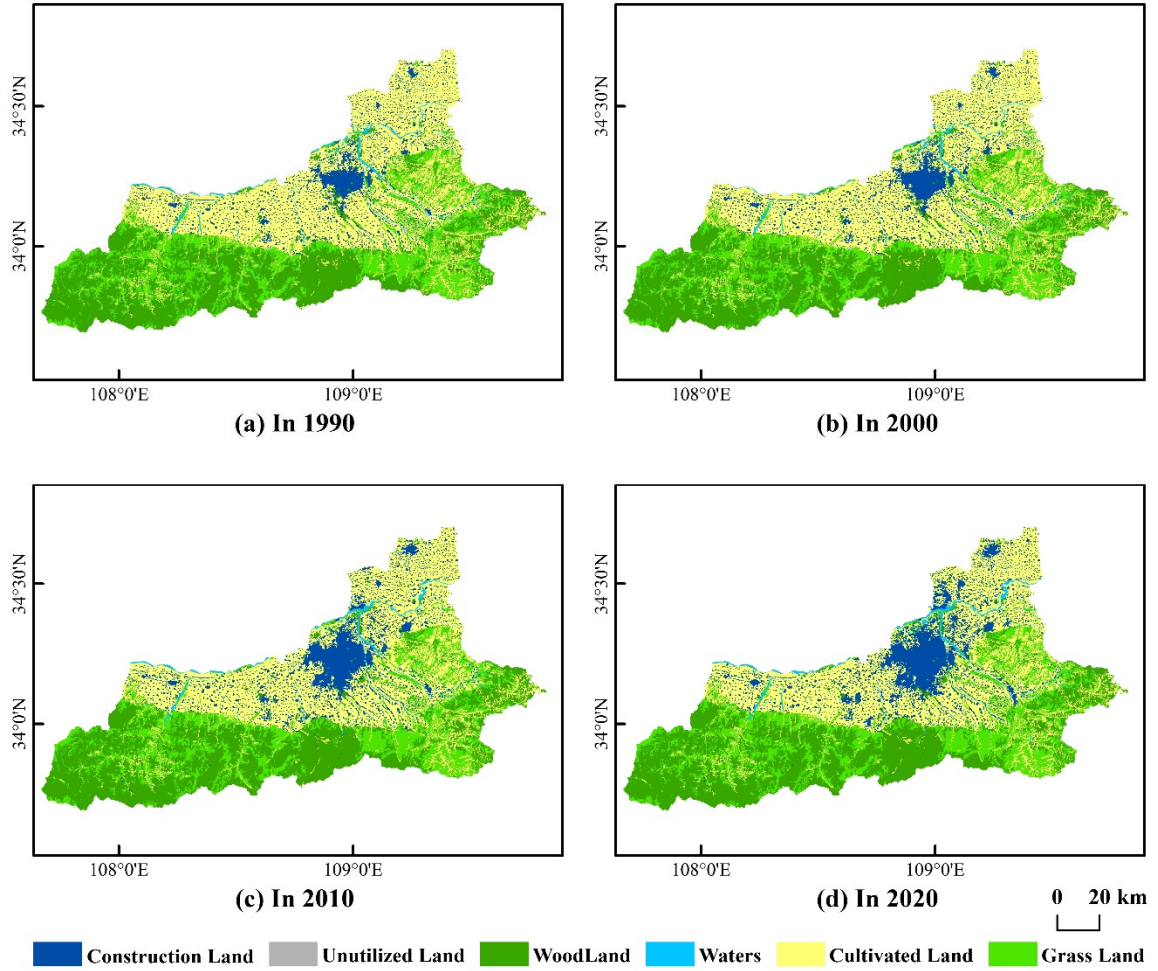


Figure 1. Interpretation results of land use classification in Xi'an

3. Research Methods

quantitatively analyze the urban spatial evolution characteristics of Xi'an in the time dimension. (Table 1)

3.1. Urban Expansion Analysis Method

The introduction of can urban expansion analysis method

Table 1. Urban Expansion Analysis Methods

Index Name	Formula and description
Urban Expansion Speed Index	$V_i = \frac{\Delta U_i}{\Delta T_i}$, where: V_i is the urban expansion speed in the i period, ΔU_i is the expansion area of the built-up area in the i period, and ΔT_i is the time span in the i period.
Urban Expansion Intensity Index	$N_i = \frac{\Delta U_i}{\Delta T_i \times M_i} \times 100\%$, where: N_i is the urban expansion intensity in the i period, ΔU_i is the time span of the i period, ΔT_i is the time span of the i period, and M_i is the total area of the built-up area in the i period.
Type identification of urban built-up area expansion	$S = L_c / P$, where: L_c is the length of the public boundary between the new construction land patch and the existing construction land patch, P is the perimeter of the new construction land patch.

3.2. Analysis method of urban form

Apply the six urban spatial form analysis methods to

analyze the urban spatial form of Xi'an in terms of spatial dimensions evolutionary features. (Table 2)

Table 2. Urban Form Analysis Methods

Index Name	Formula and description
Urban shape rate	$F = A / L^2$, where: F is the urban shape rate, A is the built-up area, and L is the length of the longest axis of the built-up area.
Urban sprawl	$E = L / L'$, where: E is the urban elongation rate, L is the length of the longest axis of the built-up area, and L' is the length of the shortest axis.
City circular rate	$I = 4A / P^2$, where: I is the circular rate of the city, A is the area of the built-up area, and P is the perimeter of the outline of the built-up area.
compactness index	$BCI = 2\sqrt{\pi A} / P$, where: BCI is the compactness index, A is the area of the built-up area, and P is the perimeter of the outline of the built-up area.
Spatial shape fractal dimension	$P = 4(A^{D/2})$, $D = 2\lg(P/4) / \lg(A)$, where: D is the fractal dimension of the spatial shape, P is the perimeter of the plaque, and A is the area of the plaque.
Urban land growth elasticity coefficient	$K = GR / PR \times 100\%$, $GR = (\sqrt[m]{A_t / A_0} - 1) \times 100\%$, where: PR is the average annual growth rate of urban population, GR is the average annual growth rate of urban land, A_t is the area of built-up area at the end of a certain period, A_0 is the area of initial built-up area in a certain period, and Δt is the time span.

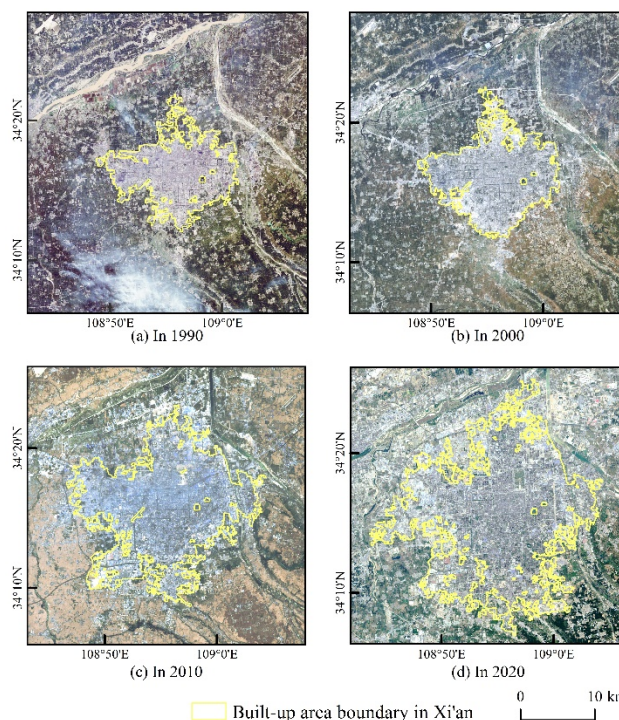
3.3. Analysis method of urban spatial pattern

Combined with the analysis method of urban spatial pattern,

the evolution of urban spatial pattern in Xi'an is analyzed from the perspective of population change and landscape patch development in built-up areas. (Table 3)

Table 3. Analysis methods of urban spatial pattern

Index Name	Formula and description
Urban sprawl index	$SI = \frac{(S_j - S_i)P_i}{(P_j - P_i)S_i}$, where: SI is the urban sprawl index in the period of i to j . S is the built-up area, and P is the urban population.
Maximum plaque index	$LPI = \max(a_m) / A$, where: LPI is the maximum plaque index, a_m is the area of the m plaque, $A = \sum_m a_m$ and is the total area of the space.
Shannon Diversity Index	$SHDI = -\sum_{i=1}^m P_i \ln(P_i)$, where: m is the number of landscape types, and P_i is the proportion of the area occupied by the landscape types i .

**Figure 2.** Schematic diagram of boundary extraction of built-up areas in Xi'an

4. Analysis of Spatiotemporal Evolution of Urban Spatial Form

4.1. Identification and expansion analysis of urban spatial form in Xi'an

(1) The extraction of Urban space boundary

The research on the evolution of urban spatial form is mainly based on the interpretation of land use classification results in various periods, and the range of built-up areas in

Xi'an is obtained by extracting concentrated construction land (Figure 2).

(2) Analysis of urban expansion

Based on the extraction results of built-up area boundaries in Xi'an, the area of built-up areas at each time point and its proportion (Table 4). The area and proportion of Xi'an's built-up area has increased year by year, and the area has expanded from 143.70 km² in 1990 to 452.49 km² in 2020, and its proportion has increased from 1.42% to 4.48%, an increase of nearly three times in 30 years.

Table 4. Area and Expansion Changes of Built-up Areas in Xi'an

	1990	2000	2010	2020
Built-up area (km ²)	143.7	175.65	329.35	452.49
Proportion of built-up area (%)	1.42	1.74	3.26	4.48
Expansion area (km ²)	—	31.94	153.71	123.13
Proportion of expansion area (%)	—	18.19	46.67	27.21

After the 1990s, Xi'an City expanded its construction to the periphery, showing a relatively gentle expansion range. From 1990 to 2000, the expansion area reached 31.94 km², this phenomenon is related to the initial establishment of the district. Entering the 21st century, Xi'an High-tech Zone and Economic Development Zone have been approved as national-level, and the area of the built-up area has been greatly expanded to 3.85 times compared with before.

4.2. Analysis of the time-varying characteristics of urban spatial form in Xi'an

(1) Analysis of urban expansion speed and expansion intensity

The temporal change characteristics of urban spatial form in Xi'an are characterized by expansion speed and expansion intensity (Table 5). The speed of urban expansion V_i can indicate the overall urban development speed of Xi'an. From 2000 to 2010, and from 2010 to 2020, it expanded at a rate of 15.37 km²/a and 12.31 km²/a respectively, which were 10% of the expansion speed in 1990 to 2000 4.81 times and 3.85 times. The intensity of urban expansion N_i can represent the relative speed of urban spatial development. The expansion intensity of Xi'an's built-up areas N_i in 2000-2010 and 2010-2020 is more than three times that of 1990-2000, and the expansion intensity has increased by leaps and bounds.

Table 5. Expansion speed and expansion intensity of built-up areas in Xi'an

	Expansion speed (V_i)	Extended Strength (N_i)
1990—2000	3.19	2.22
2000—2010	15.37	8.75
2010—2020	12.31	3.74

(2) Analysis of urban expansion types

The expansion types of each stage of the built-up area can be identified, which can be summarized as extension, jump, and filling expansion. For the identification of the expansion type of the built-up area, if the new patch in the built-up area has a common boundary with the existing patch, the

expansion of the built-up area is judged as filling or extension. When $S \geq 0.5$, it is filling expansion; when $0 < S < 0.5$, it shows the extension expansion; when $S = 0$, its performance is skip expansion. (Table 6)

Table 6. Expansion types of built-up areas in Xi'an

	Extended Type Index (S)	Extension type
1990—2000	0.53	Filling
2000—2010	0.35	Epitaxial
2010—2020	0.41	Epitaxial

Before 2000, Xi'an was dominated by infill expansion. The internal spatial structure of the built-up area showed a single-core evolution model. After 2000, it was mainly extensional expansion. Filling expansion and extensional expansion always complement. From 2000 to 2010, the peripheral development of urban was obvious. The expansion of built-up areas was manifested in the construction of new development zones. After 2010, the urban spatial structure

turned into a mature multi-core evolution model.

4.3. Analysis of the spatial change characteristics of urban spatial form in Xi'an

(1) Analysis of the apparent evolution of urban spatial form

The shape rate, elongation rate and circular rate are used to analyze the evolution characteristics of the apparent shape of

Xi'an built-up areas (Table 7). The shape rate reflects the regularity of the spatial form of the built-up area, and the smaller it is, the more obvious the band-shaped feature is. The elongation rate E can be used to measure the extension degree of the axial development of the urban form. The larger the value, the greater the extension of the belt. The circular rate I can accurately reflect the degree of dispersion of regional development, the smaller the value, the greater the degree of dispersion.

In 1990, the shape rate F of the built-up area in Xi'an was 0.38, and the elongation rate E was 2.15, which was close to that of a belt-shaped city of the same scale. After 2000, the

value of the built-up area F increased year by year, and the value E was close to 1 year by year, tending to be a square or circular city of the same size. The value I of the built-up area in Xi'an increased in 2000 compared to 1990, but the circular rate of the built-up area dropped suddenly in 2010, which was attributed to the concentrated expansion of the city in all directions from 2000 to 2010. In 2020, the circular rate of Xi'an's built-up areas increased sharply, which is related to the coordinated development of all directions in the built-up areas after 2010.

Table 7. Index of Apparent Characteristics of Urban Spatial Form in Xi'an

	1990	2000	2010	2020
Shape ratio (F)	0.38	0.43	0.54	0.57
Elongation (E)	2.15	1.77	1.67	1.53
Circular rate (I)	0.12	0.17	0.08	0.22

(2) Analysis of the Substantial Evolution of Urban Spatial Form

The essential evolution of urban spatial form can analyze the growth process of the city. Compactness rate BCI is used to measure the degree of dispersion of urban spatial expansion. The closer the BCI value is to 1, the urban space is to more compact; on the contrary, it tends to be discrete [6]. The built-up area of Xi'an BCI is less than 1 and lower for a long time, the built-up area of Xi'an is in a non-compact state. From 2000 to 2020, the compactness of built-up areas in Xi'an showed a "U"-shaped change trend. The degree of compactness increased significantly from 2010 to 2020, indicating that the discrete degree of land use gradually decreased in this stage, which is related to the overall coordinated development of the city.

The fractal dimension of spatial shape D ranges from 1 to 2, and the larger the value, the less regular the shape and the more complex the city shape. From 1990 to 2020, the value D of the built-up area in Xi'an generally decreased, the complexity of the city shape decreased, and the city boundary

tended to change regularly. From 1990 to 2000, the built-up area BCI in Xi'an City rose slightly, and the value D decreased. While from 2000 to 2010, the built-up area in Xi'an was compact. The degree of compactness dropped suddenly, the spatial fractal dimension increased, and the urban structure became more complex. After 2010, the compactness increased, the value D decreased, the urban structure gradually stabilized.

The urban land growth elasticity coefficient K can be used to evaluate the difference between population urbanization and land urbanization. The research results of China Urban Planning and Design Institute show that the reasonable value of this number is 1.12 [7]. When it is greater than 1.12, the efficiency of urban land use will decrease; when it is less than 1.12, urban problems such as urban land shortage will become prominent. The built-up area K value of Xi'an City is generally greater than 1.12 and is increasing year by year. The efficiency of urban land use has dropped significantly, showing the phenomenon of extensive urban land use.

Table 8. Substantial characteristic index of urban spatial form in Xi'an

	1990	2000	2010	2020
Compactness (BCI)	0.20	0.23	0.15	0.26
Spatial shape fractal dimension (D)	1.61	1.52	1.60	1.38
Urban land growth elasticity coefficient (K)	—	1.88	3.32	3.58

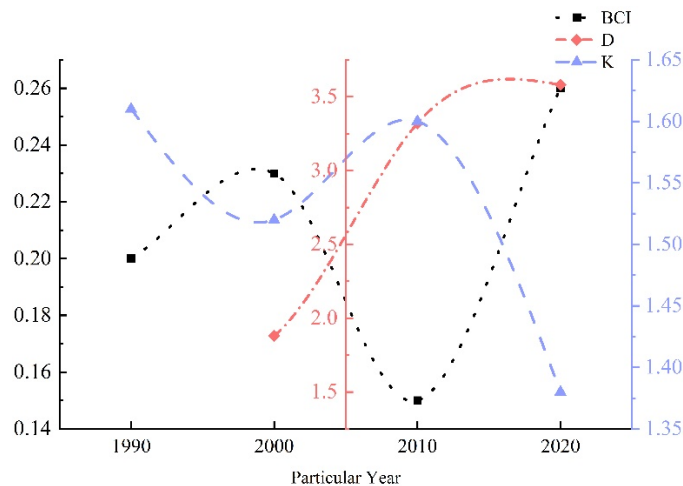


Figure 3. Changes in Substantial Characteristics of Urban Spatial Form in Xi'an

(3) Analysis of the evolution of urban spatial pattern

The sprawl index, largest patch index and Shannon diversity index are used to comprehensively analyze the evolution trend of Xi'an's urban spatial pattern (Table 9). *SI* is used to measure urban sprawl. Using the largest patch index *LPI* can characterize the development status of the built-up area. *SHDI* was used to analyze the uniformity of the spatial distribution of construction land patches, the lower the value, the more homogeneous the composition of the landscape.

In 2000, the value of Xi'an's built-up area *SI* was 0.48, and the value in 2000 was slightly higher than that in 1990, indicating that the urban development of Xi'an was slow from

1990 to 2000. The built-up area values from 2000 to 2010 and 2010 to 2020, the *SI* were 2.94 and 2.95 respectively, showing a relatively high spreading trend on the whole. From 2000 to 2010, the *LPI* value of Xi'an's built-up area increased from 0.21 to 0.29, and it will increase to 0.41 by 2020, indicating that the concentrated and contiguous area of the built-up area has expanded significantly. Since 1990, *SHDI* has decreased year by year, indicating that the overall fluctuation is not large, and the urban landscape distribution balance shows a stable trend.

Table 9. Pattern index of urban spatial in Xi'an

	1990	2000	2010	2020
Spread index (<i>SI</i>)	—	0.48	2.94	2.95
maximum plaque index (<i>LPI</i>)	0.19	0.21	0.29	0.41
Shannon Diversity Index (<i>SHDI</i>)	6.42	6.20	5.51	4.57

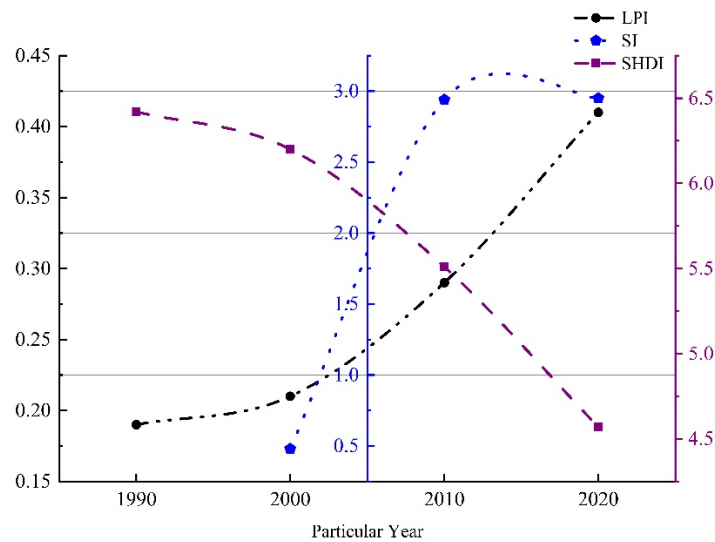


Figure 4. Changes in Xi'an's Urban Spatial Pattern Index

5. Conclusion and Discussion

5.1. Conclusion

Based on the Landsat images of Xi'an, the spatial and temporal evolution characteristics of the urban built-up area in Xi'an in the past 30 years were analyzed, and the following conclusions were drawn:

(1) Since 1990, the expansion speed and expansion intensity of Xi'an's built-up areas have shown the characteristics of slow growth at first and then strong growth. The expansion of construction land in Xi'an is bounded by 2000. The expansion in the early stage is not obvious. And the expansion in the later period is rapid, mainly in the form of extension

(2) After 1990, the shape rate of Xi'an's built-up area increased, the elongation rate decreased, and the circular rate increased. The urban form gradually became non-axial, and the urban form tended to be square or circular. Gradually get bigger.

(3) The compactness of built-up areas in Xi'an was generally low, and the city tended to be non-compact, the fractal dimension of the spatial shape of built-up areas decreased, and the elasticity coefficient of urban land growth

increased year by year Large, extensive development of urban land use.

(4) The overall urban development has shown a large sprawl trend in Xi'an, the concentrated and contiguous areas of built-up areas have expanded significantly, and the types of construction land patches showed a trend of balanced distribution as a whole.

5.2. Discussion

The evolution of urban spatial form will inevitably undergo the conversion of land use types. Aiming at the problems such as the reduction of cultivated land and the uncoordinated development of land use and the environment. Therefore, the following suggestions are proposed:

(1) The evolution of urban spatial form in Xi'an has shown a high evolution trend, and the situation of occupying cultivated land has become serious. It is suggested to rationally plan the encroachment of cultivated land which is not conducive to urban development.

(2) It is suggested to further enhance the integrated development of Xi'an's urban areas, and improve the overall quality and comprehensive competitiveness of Xi'an.

(3) Properly handle the coordinated development of

economic development, agricultural ecological protection and cultural city protection, and create high-quality and economical type city.

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