

# A Study on the Spatio - Temporal Changes of Urban Expansion in Shaanxi Province Based on Nighttime Light Remote Sensing Data

Dan Li \*

School of Tourism & Research Institute of Human Geography, Xi'an International Studies University, Xi'an, China

\* Corresponding author: Dan LI

**Abstract:** With population growth and economic development, timely, accurate information on urban built-up area expansion and in-depth analysis of their spatiotemporal characteristics are crucial for sustainable development. This study utilizes NPP/VIIRS night-time light data from 2013, 2016, 2019, and 2022 to extract Shaanxi's urban built-up areas via the reference comparison method and analyze their expansion's spatiotemporal features. The findings indicate that: (1) From 2013 to 2022, Shaanxi's built-up areas expanded continuously, with an overall "initial increase then gradual decline" trend, and outward growth showed irregular patterns. (2) In terms of compactness and fractal dimension, the city primarily experiences external expansion, with a generally low level of compactness that is decreasing over time. The average fractal dimension showed minimal change, indicating that the urban spatial form in the study area has a regular shape and a simple outline for the urban built-up areas. (3) The standard deviation ellipse area of the built-up area demonstrates a trend of spatial expansion, with a gradual reduction in center movement speed. There are also notable shifts in expansion direction; specifically, there has been an expansion towards the north-south axis and a noticeable contraction along the east-west axis, reflecting the uneven economic development between the north and south of Shaanxi Province. The findings of this study provide insights into the spatiotemporal evolution characteristics of urban expansion in Shaanxi Province and offer theoretical support for the healthy and coordinated development of cities in the region.

**Keywords:** Night light data; NPP/VIIRS; Urban expansion; Standard Deviation Ellipse.

## 1. Introduction

Since the reform and opening up, China's urbanization has accelerated significantly, with urban areas continuously expanding outward. Cities have gradually become growth poles for regional development, and China's urbanization rate has increased from 17.92% in 1978 to 65.22% in 2022 [1]. In the process of advancing urbanization, the expansion of urban spatial scope provides a reliable basis for evaluating and monitoring the level of urbanization [2]. Urban expansion can promote economic development, transformation and upgrading of industrial structure, and improvement of residents' living standards. However, the unordered expansion of cities has also caused a series of negative impacts, not only leading to the overuse of natural resources, but also exacerbating environmental damage, traffic congestion, housing shortages and other social problems. Research and analysis on urban spatial expansion can provide certain references for rational urban layout and solving problems related to urban development.

Remote sensing technology can obtain large-scale, high-resolution image information and is widely used in environmental monitoring, resource survey, agricultural resource management, urban planning and other fields. Nighttime remote sensing data are increasingly used in the study of human activities. With advantages such as spatiotemporal continuity and independent objectivity, they have become an important basis for estimating socioeconomic parameters such as gross national product, population distribution, energy consumption, and poverty level [3]. The use of remote sensing technology to monitor changes in urban built-up areas has always been the first

choice in the field [4]. DMSP/OLS nighttime light data can accurately capture urban lights, clearly distinguish urban areas from non-urban areas, and show extremely high application value in large-scale urban scope definition and real-time monitoring of urbanization processes [5]. The release of the new generation of nighttime light data NPP/VIIRS provides another powerful data support for the study of urban built-up areas. Compared with DMSP/OLS data, it has significantly improved in terms of light capture sensitivity, light recording range, and spatial resolution [6]. In urbanization monitoring applications, NPP/VIIRS data have also been proven to be superior to DMSP/OLS data [7].

Shaanxi Province, located in the inland hinterland of China, is an important economic center in the western region, a new engine for the development of the western region, and a key node of the "Belt and Road Initiative". It has geographical advantages connecting the north and south and linking the east and west. With the advancement of urbanization and rapid economic development, Shaanxi Province has gradually formed a large Guanzhong urban agglomeration with Xi'an as the core. Built-up areas are the concentration of urban population and economy, an indispensable part of the urban system, and one of the key indicators for evaluating the urbanization process. Accurately obtaining information on the spatiotemporal changes of urban built-up areas and exploring the factors affecting urban expansion can provide strong support for the healthy and coordinated development of cities in Shaanxi Province, and is more conducive to the implementation of national strategies.

## 2. Literature Review

Research on urban expansion in developed countries such

as Europe and America started relatively early. Since Croft pioneered the use of DMSP/OLS data for extracting urban built-up areas in 1978, more and more scholars have begun to use nighttime remote sensing data to extract built-up areas and conduct research on urban expansion [8]. In 1997, Imhoff et al. performed threshold processing on DMSP/OLS data, proposed a mutation detection method by analyzing the morphological characteristics of built-up area light spots, extracted and verified urban built-up areas in the United States, which improved the accuracy of built-up area extraction [9]. In 2003, Sutton et al. proposed a scale-adjusted method for measuring urban expansion and put forward the concept of urban sprawl lines [10]. They conducted an empirical study on American cities using nighttime light images, and the results showed that the "urban sprawl" level of west coast cities including Los Angeles was the lowest. Henderson et al. compared and analyzed DMSP/OLS data with TM image data to more accurately determine the threshold for extracting urban built-up areas [11]. In 2013, Pandey et al. semi-automatically extracted urban built-up areas in India using the support vector machine method based on DMSP/OLS data and SPOT data, and evaluated urban growth in India [12]. In 2016, Sharma et al. combined MODIS multispectral data with VIIRS nighttime light data and used a region-specific threshold method to extract urban built-up areas, and the results showed that the extraction accuracy of the combined data was higher [13].

With the continuous development of urbanization in China, research results on the spatiotemporal changes of urban expansion have become increasingly abundant. The use of nighttime remote sensing data for urban expansion analysis has been a research hotspot in recent years. At present, China's research on urban expansion covers spatial scales such as national, urban agglomeration, provincial, and municipal levels.

At the national scale, Li Deren et al. used nighttime light images to analyze the urban development laws of countries along the "Belt and Road Initiative" and found that the development of nighttime lights in these regions shows an obvious east-west axiality, urban development conforms to the rank-size rule, and the primacy ratio of cities has increased [14]. Chen Jin et al. analyzed China's urbanization process by constructing a light index [15]. The study showed that there is a significant correlation between the light index and the composite index reflecting the urbanization level, which can be effectively applied to the analysis of spatial and temporal distribution differences in China's urbanization level and the dynamic monitoring of changes in the urbanization process. Wang Taoyang et al. used a quadratic polynomial model to extract the area of China's urban built-up areas through the empirical threshold method, and introduced an econometric model to analyze the policy-driven factors of urban expansion [16].

At the urban agglomeration scale, Zhang Chao et al. used DMSP/OLS data to analyze the urban spatial structure of the Yangtze River Economic Belt and found that the urban scale concentration is relatively high, and the spatial distribution of urban agglomerations is unbalanced [17]. Zhu Lingyi et al. extracted the built-up areas of urban agglomerations in southern Jiangsu by constructing a squared difference function model, and verified the model accuracy by comparing it with the empirical threshold method [18]. Fan Junfu et al. analyzed the spatial pattern of the Bohai Rim urban agglomeration and found that large cities in this region

have close connections with their satellite cities, and there are a large number of emerging towns [19].

At the provincial and municipal scales, Tian Ying took Yunnan Province as the research object, used the PELANUI index method to extract built-up areas, found that cities are mainly dominated by infilling expansion, and constructed a GTWR model to analyze the influencing factors [20]. Huang Lu et al. used the mutation detection method to extract the built-up area of Nanjing, and found that Nanjing expands outward along the axis with the urban area as the center, which is greatly affected by economic policies and Nanjing's planning [21]. He Siyuan et al. used Fragstats technology to analyze the evolution of Hangzhou's built-up area. The results showed that Hangzhou is generally in a state of low-speed expansion, with built-up areas concentrated in the eastern region and a high degree of landscape fragmentation [22].

To sum up, in-depth research has been conducted on urban expansion analysis using nighttime remote sensing, with diverse and mature research methods. At present, research on the evolution of urban built-up areas mainly focuses on the more developed eastern regions, while there are relatively few studies on urban expansion in central and western regions. Based on this, this paper uses NPP/VIIRS data from 2013, 2016, 2019, and 2022 as data sources, and applies the reference comparison method to analyze the spatiotemporal characteristics of urban expansion in Shaanxi Province.

### 3. Data and Methods

#### 3.1. Overview of the Study Area

Shaanxi Province is located in central China, bordering multiple provinces and regions. It is adjacent to Shanxi and Henan in the east, Ningxia and Gansu in the west, Hubei, Sichuan and Chongqing in the south, and Inner Mongolia in the north. With a total area of 205,624.3 km<sup>2</sup>, Shaanxi Province has jurisdiction over 10 prefecture-level cities. According to statistics, by the end of 2022, the permanent population of Shaanxi Province reached 39.56 million, with an urbanization rate of 64.02% and a GDP of 3,277.27 billion yuan, ranking 14th in the country. Due to its large north-south span, the terrain and climate in Shaanxi Province show significant differences. Northern Shaanxi, located on the Loess Plateau, belongs to the mid-temperate zone; Guanzhong, a plain area with a mild climate and distinct four seasons, belongs to the warm temperate zone; while southern Shaanxi, located in the Qinba Mountain area, belongs to the north subtropical zone with a humid climate and abundant precipitation.

Since China implemented the reform and opening-up strategy, Shaanxi Province has maintained a steady and continuous upward trend in economic development. Since 1996, its economic growth rate has continuously exceeded the national average, showing a positive development momentum. However, affected by multiple complex factors such as geographical environment, social and economic development, and government policy orientation, Shaanxi Province still faces some major challenges. It is regarded as one of the regions with relatively serious poverty problems in the country, mainly reflected in the wide coverage of poverty, a large number of poor people, and the severity of poverty.

#### 3.2. Data Sources

This study selected the annual composite NPP/VIIRS nighttime remote sensing data of 2013, 2016, 2019, and 2022.

The annual data are synthesized from monthly data, and the data have been corrected and filtered to remove the influence of fire, gas combustion, aurora, and background noise, ensuring the credibility and integrity of the data with a spatial resolution of 500 meters. The nighttime light image data are from the Earth Observation Group of the Payne Institute, Colorado School of Mines, USA. This dataset covers nighttime light data from 2012 to 2022, and the data download address is: <https://eogdata.mines.edu/products/vnl/>. In addition, to conduct a comparative analysis with nighttime remote sensing data, the built-up area data of Shaanxi Province in 2013, 2016, 2019, and 2022 were obtained from the China Urban Statistical Yearbook released by the Ministry of Housing and Urban-Rural Development.

### 3.3. Research Methods

The reference comparison method takes the area data in the China Urban Statistical Yearbook as the reference standard and uses preprocessed NPP/VIIRS nighttime remote sensing data to extract the built-up area of Shaanxi Province. This method has been widely used in academic research due to its simple operation process and high calculation efficiency [23].

The study analyzes the temporal variation characteristics of urban expansion in Shaanxi Province by calculating the expansion area, speed, and intensity of built-up areas. It adopts the compactness index and fractal dimension to explore the spatial variation characteristics of urban expansion in Shaanxi Province [24-27].

## 4. Extraction of urban built-up areas OF Shaanxi Province

### 4.1. Preprocessing of NPP/VIIRS Nighttime Light Data

First, the four phases of NPP/VIIRS nighttime light data of Shaanxi Province for 2013, 2016, 2019, and 2022 were obtained through masking. Then, using the resampling tool in ArcGIS software, the projected NPP/VIIRS data were resampled to a 500×500-meter resolution. To ensure the reliability and accuracy of the data, DN value correction was performed on the NPP/VIIRS data: using the raster calculator, DN values less than 0 in the NPP/VIIRS data were set to 0; the maximum DN value of Xi'an was taken as the annual DN value upper limit. To remove negative values and extreme outliers, pixels in other cities with values exceeding Xi'an's maximum were re-assigned as the maximum value of their 8 neighboring pixels.

Continuous correction is a necessary step to ensure that NPP/VIIRS nighttime light image data can more accurately reflect actual conditions. Due to the gradual nature of the

urbanization process, a core principle must be adhered to during data correction: the DN value of a given year must be equal to or higher than the corresponding value of the previous year. Based on this principle, the raster calculator tool in ArcGIS was used to correct the NPP/VIIRS nighttime light data year by year, which not only ensured the continuity and credibility of the data but also provided accurate data support for subsequent urban research.

### 4.2. Extraction Process of the Reference Comparison Method

The extraction of built-up areas via the reference comparison method involves the following steps: First, based on the preprocessed NPP/VIIRS nighttime light data, calculate the pixel area corresponding to each nighttime light brightness value. Second, accumulate the pixel areas corresponding to these brightness values in descending order of light brightness, and compare them with the built-up area data recorded in the statistical yearbook. Through continuous debugging and comparison, the optimal light threshold is determined when the set threshold best matches the actual built-up area. The optimal thresholds are 19 for 2013, 18 for 2016, 21 for 2019, and 23 for 2022. Finally, using the optimal threshold for each year, the extracted result is the urban built-up area. Based on the reference comparison method, the built-up area ranges of Shaanxi Province for the four periods of 2013, 2016, 2019, and 2022 were extracted.

## 5. Analysis of spatial and temporal changes of urban expansion in Shaanxi Province

### 5.1. Analysis of Temporal Characteristics of Urban Expansion

In this paper, the analysis of temporal changes in the expansion of urban built-up areas in Shaanxi Province focuses on three key indicators: the growth volume of built-up area, its expansion rate, and expansion intensity.

Based on the reference comparison method, the urban built-up areas for the four periods of 2013, 2016, 2019, and 2022 were extracted, and a comparative analysis of extraction accuracy was conducted, as shown in Table 1. The built-up areas of Shaanxi Province in 2013, 2016, 2019, and 2022 were 913.61 km<sup>2</sup>, 1121.5 km<sup>2</sup>, 1364.25 km<sup>2</sup>, and 1543.50 km<sup>2</sup>, respectively. From 2013 to 2022, the built-up area of Shaanxi Province increased by a total of 634.75 km<sup>2</sup>, with an overall growth of approximately 1.69 times. Among them, the built-up area increased the most during 2016–2019, and the least during 2019–2022.

**Table 1.** Changes in Urban Built-up Area of Shaanxi Province from 2013 to 2022

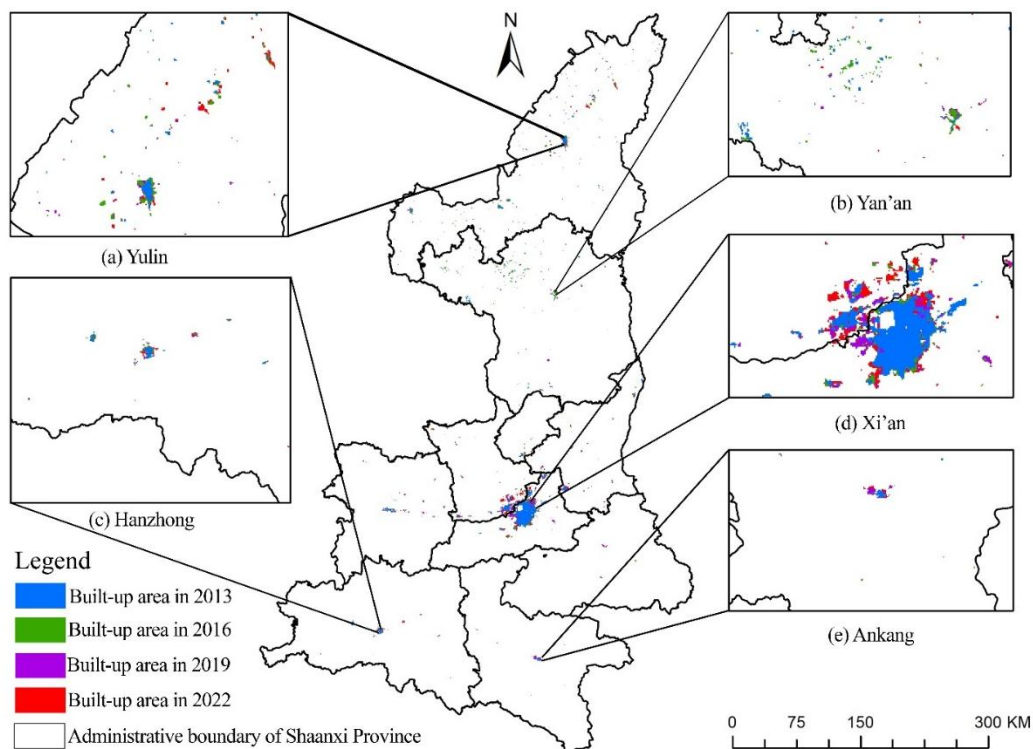
Year	Yearbook Area [km <sup>2</sup> ]	Built-up Area [km <sup>2</sup> ]	Error [%]	Growth Area [km <sup>2</sup> ]	Expansion Rate [km <sup>2</sup> ]	Expansion Intensity [%]
2013	915.02	922.50	0.82%	/	/	/
2016	1127.35	1121.50	0.52%	199.00	66.34	0.29
2019	1357.51	1362.50	0.37%	241.00	80.34	0.35
2011	1553.51	1557.25	0.24%	194.75	64.34	0.28

After analyzing the data of urban built-up areas in Shaanxi Province for the four years of 2013, 2016, 2019, and 2022, the urban expansion speed and intensity of the province during the study period were calculated. The results show that from

2013 to 2016, the expansion speed of built-up areas in Shaanxi Province was relatively slow, and the expansion intensity was also relatively low, showing a stable growth pattern; from 2016 to 2019, the urban expansion speed in

Shaanxi Province accelerated, and the expansion intensity increased significantly, entering a stage of rapid expansion; from 2019 to 2022, the expansion speed slowed down significantly, the expansion intensity weakened accordingly, and the growth of built-up area relatively decreased, showing

a pattern of decelerated expansion. Comprehensive analysis shows that from 2013 to 2022, the expansion rate and intensity of urban built-up areas in Shaanxi Province showed a dynamic change of first increasing and then decreasing, with the peak appearing in 2016–2019.



**Figure 1.** The extraction result of the built-up area of Shaanxi Province from 2013 to 2022

After spatial overlay analysis of the urban built-up area data of Shaanxi Province from 2013 to 2022, a diagram intuitively showing the expansion trend of urban land in this region was obtained, as shown in Figure 1. This not only reveals the spatial distribution pattern of urban built-up areas in Shaanxi Province but also clearly shows the significant trend of cities expanding and extending outward. With the central urban area of each city as the core, its radiation effect is significant, and the extensional characteristics are obvious. Over time, the number of patches in built-up areas continues to increase, indicating that the urban scale is constantly expanding. Specifically, in the Guanzhong region, Xi'an has become the city with the most significant expansion in the region, and its built-up area has grown significantly in space, especially in the north and west directions, with a particularly prominent development trend. This expansion mode takes the main urban area as the core, showing obvious circular expansion characteristics. At the same time, the expansion of Xi'an is also actively driving the synchronous development of surrounding cities. Xianyang is significantly affected by the radiation and driving effect of Xi'an, and its expansion form is mainly in the southeast-northwest direction. In northern Shaanxi, due to the rapid development of the rural economy, abundant mineral resources and their large-scale development and utilization, and the increasingly improved transportation network system, the urban development in this region is faster than that in southern Shaanxi. Yulin and Yan'an both have many small and fragmented built-up area patches, indicating that their urban expansion has multiple cores. Yulin has expanded significantly in the northeast-southwest direction, while Yan'an has mainly expanded in the northwest direction. Cities such as Hanzhong and Ankang in

southern Shaanxi have relatively low urban development levels due to factors such as ecological environment protection. Shangluo has a complex geomorphic structure, with mountains covering most of the city's area. Affected by the terrain, its economic foundation is relatively weak, and large-scale development and construction are difficult. Therefore, the urban expansion of Shangluo is not significant. Overall, the built-up area of Shaanxi Province continues to grow, but there are significant differences in urban expansion among the three regions of northern Shaanxi, Guanzhong, and southern Shaanxi.

## 5.2. Analysis of Spatial Characteristics of Urban Expansion

Table 2 presents the compactness and fractal dimension of cities in the study area for 2013, 2016, 2019, and 2022. During the study period, the compactness of the urban spatial form in the study area continuously decreased, indicating that urban built-up areas were constantly expanding outward. The fractal dimension of Shaanxi's urban built-up areas over the years ranged from 1.39 to 1.41, with minimal changes in the average fractal dimension but an overall upward trend, suggesting that the urban spatial form of Shaanxi is gradually transforming from simple to complex.

**Table 2.** Compactness and Fractal Dimension of Shaanxi Province from 2013 to 2022

Indicator	2013	2016	2019	2022
Compactness	0.452	0.390	0.365	0.347
Fractal Dimension	1.390	1.398	1.402	1.406

The fractal dimension in each year was less than 1.5,

indicating that the shape of Shaanxi's urban built-up areas is relatively regular. This is mainly influenced by urban planning, which aims to rationalize the use of urban resources, facilitate centralized management, and promote healthy urban development. It is also related to data resolution: due to low urbanization levels in some areas, small built-up areas, and coverage of the entire built-up area by a small number of pixels, details are overlooked and complex boundaries are blurred, resulting in a low fractal dimension [28].

## 6. Conclusion and Discussion

### 6.1. Conclusions

This study used NPP/VIIRS nighttime light data as the main data source, combined with data from the China Urban Statistical Yearbook, and applied the reference comparison method to extract the scope of urban built-up areas in Shaanxi Province. Using indicators such as expansion speed, expansion intensity, compactness, fractal dimension, and standard deviation ellipse analysis, the spatiotemporal characteristics of urban expansion in Shaanxi Province from 2013 to 2022 were analyzed, leading to the following conclusions: To start with, from 2013 to 2022, the built-up area of Shaanxi Province continued to grow, with an overall growth rate showing a trend of "first increasing, then slowly decreasing." Xi'an exhibited the fastest economic and urbanization development, while other cities also showed a gradual increase in development speed. During this period, the built-up areas of all cities continuously expanded outward and extended, with an increasing number of built-up area patches, accompanied by a relatively irregular expansion trend. Specifically, the built-up area increased the most during 2016–2019, with the fastest expansion speed and strongest intensity, showing an accelerated expansion mode. From 2019 to 2022, the growth of built-up area was the smallest, with slowed expansion speed and weakened intensity, indicating an obvious decelerated expansion trend. Furthermore, in terms of compactness and fractal dimension of Shaanxi's built-up areas from 2013 to 2022, cities mainly expanded externally. The overall level of compactness and irregularity was low and showed a decreasing trend year by year. The fractal dimension remained between 1.39 and 1.41, with minimal changes in the average value, indicating that the urban spatial form and built-up area shape in the study area were regular with relatively simple outlines. Finally, from 2013 to 2022, the standard deviation ellipse area of Shaanxi's built-up areas showed a spatial expansion trend, with the center moving at an increasingly slower speed. The expansion direction of built-up areas also showed certain changes: there was obvious expansion in the north-south direction, while a certain degree of contraction was observed in the east-west direction. This further reflects the unbalanced economic development between northern and southern Shaanxi.

### 6.2. Limitations

This study is based on NPP/VIIRS nighttime remote sensing data with low resolution, which leads to certain limitations. In extracting urban built-up areas, only the reference comparison method was used, which is highly dependent on the accuracy of statistical data. Errors in statistical data may affect the precision of extraction results. To more accurately depict the scope of urban built-up areas, further consideration of other methods and technologies is needed to reduce the impact of errors. Although this study

analyzed the spatial pattern changes of urban expansion in Shaanxi Province from both spatial and temporal characteristics, due to time constraints and limited capabilities, it lacks an analysis of the landscape pattern of built-up areas in Shaanxi's urban agglomerations. Future work will focus on such research aspects. This study only conducted a spatiotemporal analysis of the results of urban expansion in Shaanxi Province, without considering the impact of planning, policies, and other factors. In-depth research is needed on the underlying drivers and mechanisms of urban expansion in Shaanxi. Future studies should consider urban planning, land policies, economic development strategies, population migration, transportation layout, and other aspects. Data accuracy is also crucial for the research; efforts should be made to collect more comprehensive high-precision data to ensure the accuracy and reliability of the study. In addition, interdisciplinary theories and methods can provide a broader perspective for analysis.

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