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Driving Mechanism of Urban Space Expansion in Luoyang, China

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Abstract

Urban space expansion is the result of the interaction between internal and external forces of the urban. Based on the remote sensing image data of 1990, 2000, 2010, and 2020, and the social and economic development data, this paper analyzes the driving mechanism of the Luoyang space expansion characteristics and its correlation characteristics. By using urban land use efficiency index, urban expansion elastic index; urban allometric growth index, and grey correlation analysis in 4 times sections and 3 periods. The research results show that the urban space expansion of Luoyang mainly comes from the needs and support of economic development, the coordination between urban space expansion and population development is poor, and urban space expansion effectively attracts the inflow of external funds, and the settlement of migrants, drives the development of the tertiary industry, and increases the local revenue.

Keywords

Urban Space Expansion, Urban Land Use Efficiency Index, Urban Space Expansion Elasticity Index, Urban Allometric Growth Index, Grey Correlation Analysis, Luoyang

1. Introduction

The development of urban economy, the adjustment and improvement of internal structure, and the acceleration of urbanization, should inevitably lead to the demand of construction land, making the urban area gradually expand to the surrounding regions [1] [2] [3] [4]. Urban space expansion is a dynamic process of corresponding changes in time and space. In time, the development of urban natural environment, economic development, overall planning and humanities have the characteristics of stage and order; in space, it shows the change of urban

spatial pattern [5] [6].

Urban space expansion is the result of the interaction between internal and external forces of the urban, the rapid economic development, the rapid population growth, the rapid development of regional transportation, and the rapid spatial change are the important driving forces; the natural environment, geographical location, regional development policies, and urban planning policies are the main supporting forces [5] [6] [7].

The expansion of urban land area has been occupying the surrounding cultivated land and forest land, seriously impacting the urban ecological environment. How to reasonably adjust the expansion scale and orientation of urban land under the condition of improving and protecting the ecological environment, is one of the main problems faced by many urban in China [1] [5] [8].

Nowadays, there are 127 national famous historical and cultural cities in China, where have profound cultural heritage and major historical events in China's 5000 years history, development and protection are the primary goal of these cities. In recent years, the rapid urban space expansion has a profound impact on urban development, and some urban characteristics are gradually disappearing. The regulation of urban planning pays more attention on the urban functionality, and ignores the creation of the spirit of Genius Loci and the inheritance of history and culture, resulting in the gradual convergence of urban appearance and the gradual blurring of urban characteristics. How to reasonably adjust the space expansion scale and the space expansion orientation on the premise of ensuring urban economic development and the protection of famous historical and cultural cities is another major problem faced by these cities [8] [9] [10].

In recent years, the research on the characteristics and driving mechanism of urban spatial expansion in China have mainly focused on the eastern coastal and southern cities with rapid development, their characteristics of urban space expansion have been studied from the aspects of expansion mode, expansion type, expansion direction and driving factors, all of them have obvious characteristics of rapid expansion in time sequence. There are relatively few studies on the famous historical and cultural cities, entrusting with site protection, in Central China [1]-[8] [10].

Luoyang is one of the first national historical and cultural cities in China, with the ancient capital of thirteen dynasties, where has profound historical and cultural heritage. At the same time, as the sub-center city of the Central Plains Economic Zone, its economic development plays an important leading role in the economic development of the economic zone. In order to promote the economy and the protection of famous historical and cultural cities, the fourth phase of regional planning and overall planning take the research on changes in the spatial pattern of urban expansion as an important basic research work in compiling of the planning. By studying the urban space expansion characteristics and its driving mechanisms, to realize the urban space expansion and ecological improvement, as well as the protection of famous historical and cultural

cities coordinating development, the control of urban development intensity, and optimization of spatial structure [1] [11] [12] [13].

This paper, based on the remote sensing image data of 1990, 2000, 2010, and 2020, and the social and economic development data, analyzes the driving mechanism of the Luoyang space expansion and its correlation characteristics, by using urban land use efficiency index, urban expansion elastic index, urban allometric growth index, and grey correlation analysis in 4 time sections and 3 periods, in order to provide some scientific reference for the compilation of the fourth phase of regional planning and overall planning, and provide research ideas and directions for other famous historical and cultural cities with slow economic development.

2. Data and Research Methods

2.1. Research Area Overview

Luoyang urban (34˚30'N-34˚46'N, 112˚15'E-112˚38'E), with 15,230 km^2 of the municipal administrative area, 2229 km^2 of the urban land area, and 669.81 km^2 of the urban construction control (in 2020), is located in the transition zone between the third and second steps of China's terrain, belongs to the East Qinling fold system, is semicircle surrounded by three mountains, as Mang Mountain in the north, Qingling Mountain in the west, and Longmen Mountain in the south. Luo River (with an average width of 500 m), Yi River (with an average width of 600 m), Chan River, and Jian River run through it (see **Figure 1**) [9] [10] [13].

Luoyang has a civilization history of more than 5000 years, an urban history of more than 4000 years, and a capital history of more than 1500 years. Since the Western Xia Dynasty builds its capital in here, there are 13 dynasties successively using here as their capital, This long-term and continuous capital history has left lots of capital urban remains, as Yanshi Shang City Remains, HanWei Luoyang City Remains, SuiTang City Remains, and Zhou Royal City Remains, among them SuiTang City Remains, and Zhou Royal City Remains, are in the urban construction control regions (see **Figure 1**) [9] [13].

2.2. Data and Processing

The data used in this study mainly include, 10 m × 10 m DEM data and Luoyang traffic network and administrative division data coming from Henan basic geographic information database and meta database, the economic and population data of Luoyang coming from the statistical yearbook of the corresponding year of Luoyang statistical bulletin (http://lytjj.ly.gov.cn/sitesources/lystjj/page_pc/tjsj/tjnj/list1.html), the Luoyang urban planning data coming from the geospatial database and meta-database of Luoyang geographic information center, the remote sensing image data of land use status coming from June to July in the four years of 1990, 2000, 2010 and 2020 with the resolution of 9.87 m and the accuracy of more than 95%, coming from the River map (http://www.Rivermap.cn/).

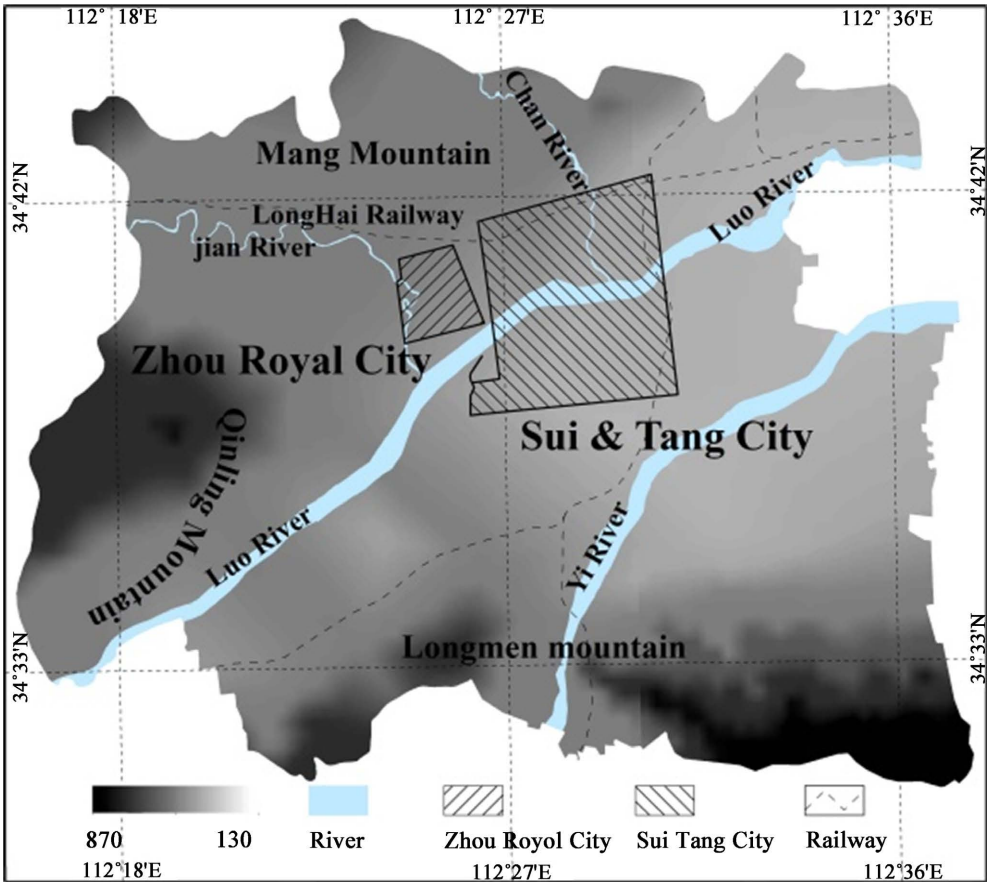

Figure 1. Luoyang urban topographic distribution.

2.3. Research Methods

Urban space expansion intuitively reflects the continuous expansion of urban space, its essence is the inevitable result of the interaction between internal and external forces of the urban. The purpose of the research on the driving mechanism of urban space expansion is to study the temporal relationship between urban space expansion and economic development, population change, traffic optimization, urban development policies and urban ecological environment, and analyze the causes and mechanisms of urban space expansion.

2.3.1. Urban Land Use Efficiency Index

Urban land use efficiency index includes population efficiency index UP_i and economic output efficiency index UG_i, are defined as [5] [8].

$$UP_i = \frac{P_i}{A_i}, \quad UG_i = \frac{G_i}{A_i} \tag{1}$$

where P_i and G_i respectively represent the number of resident population and Gross Domestic Product (GDP) of the urban in the year of *i*.

$\Delta UP_{i,i+1} = UP_{i+1} - UP_i > 0$ indicates that the population density is gradually increasing while the urban is expanding, and the urban space expansion has the demand and support of population increase. $\Delta UG_{i,i+1} = UG_{i+1} - UG_i > 0$ means

that the economic output per unit area is gradually increasing while the urban is expanding, and the urban space expansion has the demand and support of economic development.

2.3.2. Urban Space Expansion Elastic Index

The urban space expansion elastic index describes the coordination relationship between urban space expansion rate and population growth rate, and urban space expansion rate and economic growth rate, reflects the change of urban population density and economic density, the population and economic utilization efficiency of urban land, are defined as [6] [7]

$$EP_i = \frac{RA_i - 1}{RPop_i - 1} \times 100\%, \quad EG_i = \frac{RA_i - 1}{RGDP_i - 1} \times 100\% \tag{2}$$

where RA_i, $RPop_i$, and $RGDP_i$ respectively represent the average annual growth rate of urban land expansion area, the average annual growth rate of urban resident population, and the average annual growth rate of urban GDP during the period of *i*. The smaller EP_i is, indicates that the growth rate of urban resident population rate is larger than that of urban land expansion area, and the urban space expansion is supported by the increase of population; On the contrary, the urban space expansion shows a sparse mode, and the urban land expansion is ahead of the demand of population growth. Relevant research results show that $EP_i = 1.12$ is the optimal value, when $EP_i < 1.12$, the development of urban infrastructure lags behind and many urban diseases gradually appear; as $EP_i > 1.12$, urban land efficiency will be reduced. The smaller EG_i, indicates that the growth rate of urban economy is larger than that of urban land expansion area, and the urban land expansion is supported by economic growth.

2.3.3. Urban Allometric Growth Index

The urban allometric growth index reflects the synergistic relationship between urban land and resident population, is defined as [8] [14]

$$A = aP^b, \quad b = \frac{\ln A - \ln a}{\ln P} \tag{3}$$

where *a* is a nonnegative constant. The researches show that when $b = 0.9$, the urban population and urban area increased at the same rate; as $b < 0.9$, it is negative allometric growth, the population growth rate is greater than the urban land use expansion rate, the urban space expansion has the demand of population growth; as $b > 0.9$, it is positive allometric growth, and the population growth rate is less than that of urban land expansion.

2.3.4. Grey Correlation Analysis

Grey correlation analysis is the method of quantitative description and comparison to the development and change trend of a system, which measures the correlation degree among factors according to the similarity or difference of development trend between factors [6] [15]. Let the system description have $m+1$ variables, as $Y, X_1, X_2, \cdots, X_m$, the correlation degree between the variable Y and

other variables is defined as the geometric similarity between them, by using the standardized variable observations $(y_i, x_{i1}, x_{i2}, \cdots, x_{im}), i = 1, 2, \cdots, n$.

The correlation degree between Y and X_i in the kth group of observations is defined as

$$\xi_i(k) = \frac{\min\limits_i \min\limits_k |y_k - x_{ik}| + \rho \max\limits_i \max\limits_k |y_k - x_{ik}|}{|y_k - x_{ik}| + \rho \max\limits_i \max\limits_k |y_k - x_{ik}|} \tag{4}$$

where ρ is the resolution, the smaller of ρ, the less import of $\max\limits_i \max\limits_k |y_k - x_{ik}|$ on the $\xi_i(k)$, the larger of ρ, and the stronger the ability to distinguish, generally takes $\rho = 0.50$. The correlation degree between Y and X_i is defined as the mean of $\xi_i(k)$

$$r(Y, X_i) = \frac{1}{n} \sum_{k=1}^{n} \xi_i(k) \tag{5}$$

3. Driving Mechanism of Urban Space Expansion in Luoyang

According to temporal sequence characteristics of the land use in the study area, the urban land is manually interpreted, the results are showed in Table 1. The results of manual interpretation in 2020 are randomly sampled in the urban-rural fringe, the total of 20 samples with the sample size 20 × 20 m are selected, their statistical analysis shows that the average error is less than 1%. The interpreted urban land data in the other three years compared with the built-up area data in the statistical yearbook of Luoyang in the corresponding year, the errors are less than 3%. Therefore, the later research is mainly based on these urban land interpreted data [1] [10].

3.1. Temporal Characteristic Analysis of the Urban Space Expansion in Luoyang

From 1990 to 2000, the goal of urban construction is to build an industrial urban with ancient capital characteristics. Restricted by topographic conditions, urban space expansion is mainly carried out between Mang Mountain and Luo River. The western part is developed to Qinling Mountains, and the central part is developed to the north side of the Luo River. Influenced by Longhai railway, there is little expansion to the northward. The urban space expansion is mainly infilling type, the urban land area has increased by 19.96 km^2 with an average annual

Table 1. The urban space expansion characteristics of Luoyang (1990-2020)

Year	Urban land area	Gross Domestic Product	Urban resident population	Population efficiency	Economic efficiency	Population elastic indices (EP_i)	Economic elastic indices (EG_i)
1990	54.55	68.52	120.22	2.20	1.26		
2000	71.51	377.45	140.03	1.96	5.28	1.79	0.15
2010	172.5	1825.76	174.43	1.01	10.58	4.14	0.54
2020	259.89	2010.31	223.74	0.86	7.74	1.66	4.32

growth rate of 0.03 km^2, established two satellite towns, as Guanlin and Baima Temple.

From 2000 to 2010, the city's administrative center moves southward, the urban space expansion crosses Longhai railway to the north, expanding to Mang Mountain, formed an industrial land group; expands to the southwest Qinling Mountains, formed a high-tech industrial zone; and crosses Luo River and Sui and Tang city Remains to the south, formed Luonan New District. Luo River has become the symmetry axis of the urban pattern, and the urban framework has been rapidly expanded, but the Luonan New District has not been effectively filled in this period, and the urban land area has increases by 100.99 km^2, with the average annual growth rate of 0.09 km^2.

From 2010 to 2020, the urban land mainly expands to the north and west, the Luonan New District has been effectively filled. The urban space expansion crosses Yi River to the southeast, formed Yibin New District, the urban land area increases by 87.39 km^2, with the average annual growth rate of 0.04 km^2 [1] [10].

3.2. Spatial Characteristic Analysis of the Urban Space Expansion in Luoyang

In the study period, the urban land area has expanded rapidly, and the urban space expansion belongs to the type of rapid expansion. The urban land area has increased by 3.76 times, the urban compaction index has been kept at a low level, and the urban layout has become more reasonable; The urban land centroid gradually shifts to the southwest, the distribution axis rotates clockwise from the southwest-northeast to the northwest-southeast, and the directionality of the distribution gradually disappears; The urban has gone through the development process of urban land filling-enlargement frame-refilling, The urban expansion is relatively active in the direction with an azimuth of 90˚ - 225˚, and the expansion in the north of Luo River is relatively stable, mainly filling type [1] [10].

3.3. Driving Mechanism Analysis of Urban Space Expansion in Luoyang

3.3.1. Urban Land Use Efficiency Analysis

Use Formula 1 and 2 to calculate the urban land use efficiency and urban land expansion elastic index in the four years. The results are shown in **Table 1**.

From 1990 to 2020, Luoyang urban land gradually expanded outward, the resident population continues to increase, and the urban land population efficiency continues to decrease. In 1990-2010, with the rapid economic development, the economic output efficiency of urban land continues to increase from 126 million RMB/km^2 in 1990 to 1.058 billion RMB /km^2 in 2010. From 2010 to 2020, the economic output efficiency of urban land decreases, about the same as that in 2005. In the study period, the population elastic index of urban land expansion is 2.64, about twice the reasonable value. In 1990-2000 and 2010-2020, the population elastic index of urban land expansion is basically the same, slightly higher than the reasonable value. In 2000-2010, the value is about 3.70

times the reasonable value. The economic elastic index of urban land expansion is 2.64, twice the reasonable value. The economic elastic index of urban land expansion gradually increases, which is only 0.15 in 1990 to 2000, increases by 3.66 times in 2000 to 2020, and 8.02 times in 2010 to 2020.

3.3.2. Coordination Analysis of Urban Space Expansion and Population Development

The data of urban land area and resident population obtained in the study only have 4 groups, corresponding to 4 years. In order to increase the fitting accuracy of Formula 4, the grey prediction model [16] is used to predict the urban land area and resident population for the next 10 periods, and getting 14 groups of corresponding data. Using these data to fitting Formula 4, the urban allometric growth model of Luoyang urban space expansion is

$$A = 0.1716P^{1.325} \quad (R^2 = 0.9679,\ Sig. = 0.0001).$$

The urban allometric growth index $b = 1.325$ is much greater than 0.9 of the same speed growth indices. Compared with the same growth rate $A = 0.1716P^{0.9}$, the growth rate of urban land is 0.0547 km^2/a faster, the most obvious is that in the second period, the value is 0.1761 km^2/a, followed by 0.0641 km^2/a in the first period, and 0.0633 km^2/a in the third period. Which show that the growth rate of urban land in Luoyang is much faster than the growth rate of urban resident population. From the perspective of population, urban expansion is in a relatively unreasonable state.

3.3.3. Correlation Analysis of Social and Economic Factors of Urban Land Expansion

Urban space expansion is the result of the interaction between man and land. In the process of rapid urbanization in China, economic, cultural driving, and policy regulation are the main driving forces for the urban land space expansion in China [5] [6]. Combined with the characteristics of Luoyang as a famous historical and cultural city and a new type of industrial city, this paper selects six economic and social factors related to urban expansion, as the urban resident population (10,000 people), the gross domestic product (billion Yuan), the secondary industry income (100 million Yuan), the tertiary industry income (billion Yuan), the public financial revenue, and the fixed asset investment (billion Yuan), as the main related factors of urban space expansion. Carrying out grey correlation analysis on the urban land area in each year, study the influence degree of these factors in the process of urban space expansion.

Use Formula 4 to calculate the correlation indices between the urban land area and the various factors, the results are shown in **Table 2** and **Table 3**.

There are obvious differences in the correlation indices between the driving factors and the urban land expansion of Luoyang. The greatest impact on the urban land expansion is the change in the number of resident populations, in other words, the change in the number of resident populations is the most important driving factor in the impact of socio-economic factors on urban land

Table 2. The driving factor of social and economic of urban space expansion.

Year	Urban land	Total Population	GDP	Secondary Industry	Tertiary Industry	Public Financial Revenue	Total Investment
1990	54.55	120.22	68.52	38.05	18.52	7.317	12.82
2000	71.51	140.03	377.45	202.37	137.79	21.20	121.01
2010	172.5	174.43	1825.76	1121.46	536.73	376.7	1768.80
2020	259.89	223.74	2010.31	800.33	1193.36	383.9	5861.98

Table 3. The grey correlation indices of the urban land.

Items	Total Population	Public Financial Revenue	Tertiary Industry	Secondary Industry	Gross Domestic Product	Total Investment
grey correlation indices	0.986	0.965	0.90	0.884	0.786	0.735
grey correlation level	1	2	3	4	5	6

expansion. The number of urban resident population and urban land area are positively correlated with each other.

Among the six factors, the local fixed asset investment has the least correlation with the urban space expansion, indicates that the funding source for urban space expansion and the construction of infrastructure to a large extent involves the participation of funds outside the urban. The second place is the public financial revenue, the continuous expansion of urban land areas and the construction of infrastructure have promoted the economic development of the urban, and increases the local public financial revenue.

In terms of GDP, the tertiary industry has the highest correlation with urban space expansion, indicating that Luoyang, as a famous historical and cultural city, the development of the tertiary industry has played a certain role in promoting urban space expansion. Some large industrial enterprises are still the pillar of the secondary industry in Luoyang, as an old industrial base, its correlation with urban expansion is not high.

4. Conclusion and Prospect

4.1. Conclusion

Based on the remote sensing image data of 1990, 2000, 2010, and 2020, and the social and economic development data, this paper utilizes urban land use efficiency index, urban expansion elasticity index; urban allometric growth index, and grey relational analysis, analyze the driving mechanism of the Luoyang space expansion and its correlation characteristics in 4 times sections and 3 periods. The research results show that:

1) The urban space expansion in Luoyang mainly comes from the needs and support of economic development. From 1990 to 2000, urban economic development causes the demand for urban space expansion. After 2000, the urban space expansion does not bring about the same rate of economic growth.

2) The coordination between urban land expansion and population development is poor, and the growth rate of urban land is much faster than that of resident population.

3) The urban space expansion effectively attracts the inflow of external funds and the settlement of migrants, drives the development of the tertiary industry, and increases the local revenue.

4.2. Prospect

During the research process of this paper, due to the accuracy of remote sensing image data of land use, there would be some small regional errors in the process of manual interpretation of urban land, which should affect the later research accuracy to a certain extent; the accuracy of analysis results should simultaneously be affected by the urban land and socio-economic development data for fewer years.

However, with the progress of space remote sensing technology, the increase of remote sensing image resolution, and the improvement of image recognition technology, the accurate results should be obtained on the basis of this paper, which should be more in line with the actual situation of the urban studied.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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