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Spatial Characteristics Analysis of Urban Expansion in Luoyang, China

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Abstract

The characteristics of urban space expansion reflect the changes of urban spatial layout and structure, as well as the orientation of urban development in the future. This paper uses the regional sector division method to divide the urban land into 8 orientations, based on the urban land space compaction index, and designs a sector partition compaction index. Based on the remote sensing image data of 1990, 2000, 2010, and 2020, the spatial characteristics of urban land expansion of Luoyang are analyzed by using the partition compaction index, expansion intensity index, fractal dimension, and standard deviation ellipse. The results show that: from 1990 to 2020, the urban overall planning of Luoyang has effectively guided the urban development, the urban land expands rapidly, the urban land compaction has been maintained at a low level, and the urban form has been tending to be reasonable; the urban land centroid gradually shifts to the southwest, and the distribution axis rotates clockwise from southwest-northeast to northwest-southeast, and the directionality of distribution gradually disappears; the urban land has gone through the development process of land filling-enlarging-refilling. The urban land expansion is relatively active in the region with an azimuth of 90˚ - 225˚, and the urban expansion in the north of Luo River is relatively stable and is always filling mode.

Keywords

Urban Space Expansion, Compaction Index, Expansion Intensity Index, Fractal Dimension, Standard Deviation Ellipse, Sector Partition, Luoyang

1. Introduction

In recent years, with the rapid development of China's economy, the urbanization rate has been continuing to increase, and the urban land has gradually been expanding. The degree and mode of urban space expansion are affected by urban

economic development and regional topographical conditions, showing obvious regional characteristics [1] [2]. The development of the urban economy and the increase of the non-agricultural population should inevitably lead to the demand for construction land, resulting in a decrease in cultivated land in the surrounding region [3].

For some famous historical and cultural cities, the rapid urban land expansion has a profound impact on urban development; the characteristics of urban are gradually disappearing. Urban planning pays more attention to urban functionality and ignores the creation of the spirit of the urban and the inheritance of history and culture. Many urban have the same appearance, the urban characteristics are gradually blurred. How to reasonably adjust the rate and orientation of urban space expansion on the premise of ensuring urban economic development and the protection of famous historical and cultural cities is one of the main problems faced by many Chinese cities [4] [5]. Studying the history of urban space expansion, and analyzing the characteristics of space expansion, have important guiding significance for analyzing and predicting the changing trend of urban space expansion, compiling scientific urban regional planning and overall planning, improving urban management level, and promoting urban economic development and protection of urban characteristics [3] [6] [7] [8] [9].

Luoyang, one of the first batch of national famous historical and cultural cities, the ancient capital of the thirteen dynasties, has a profound historical and cultural heritage [4]. Recently as the economic development of the sub-central city of the Central Plains Urban Agglomeration, it plays an important leading role in the development of the western region of the urban agglomeration. To promote the economic growth and protection of the famous historical and cultural city, the fourth regional planning and overall planning of Luoyang take the research on the change of urban expansion space pattern as important basic research work for planning compilation. By studying the evolution characteristics of spatial layout and structure in the process of urban expansion, realize the coordinated development of urban space expansion and the protection of famous historical and cultural cities, the rational control of the intensity of urban expansion, and optimization of space structure [3] [7] [10] [11] [12] [13] [14].

The formation and expansion of urban have geographical and temporal characteristics, affected by regional natural conditions, macro social background, economic development status, urban planning strategies, etc. Considering the economic development of Luoyang, corresponding to the implementation process of the first four phases of the overall planning, this paper selects 4-time sections at the end of 1990, 200, 2010, and 2020 to study the spatial distribution characteristics of Luoyang urban land, and the evolution pattern of urban space expansion in three periods.

2. Data and Research Methods

2.1. Research Area Overview

Luoyang urban (34˚30'N - 34˚46'N, 112˚15'E - 112˚38'E) is located in the west of

Henan province, the transition zone between the third and second steps of China's terrain, belongs to the East Qinling fold system, with the characteristics of landscape environment of "surrounded by three mountains, four rivers flowing in, and nine canals running through". Luoyang is surrounded by Mang Mountain in the north, Zhou 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 form the water system framework of the whole urban [1] [4] (see **Figure 1**).

Since the Western Xia Dynasty (2070 B.C.) builds its capital in Luoyang, there are 13 dynasties successively used here as their capital, including Shang Dynasty, Western Zhou Dynasty, Eastern Zhou Dynasty, Eastern Han Dynasty, Cao and Wei Dynasty, Western Jin Dynasty, Northern Wei Dynasty, Sui Dynasty, Tang Dynasty, Later Liang Dynasty, Later Tang Dynasty and Later Jin Dynasty. Nowadays, there are 2 capital urban remains in the urban region (see **Figure 1**) [4] [11].

In 1953, Luoyang begins to compile and implement the first phase of overall planning, transforming consumption urban into industrial production urban [11]. In 1981, the second phase of overall planning (1981-2000) of Luoyang is prepared and implemented, constructing a clean and beautiful, economically coordinated industrial urban with the characteristics of an ancient capital. The urban land expands toward Zhou Mountains in the west, toward the north side of Luo River in the middle, not expand toward Mang Mountains in the north and the south side of Luo River in the south [11]. In 1997, the third phase of overall planning (2001-2010) of Luoyang is prepared and implemented, the urban development crosses Longhai railway to the north, constructs a high-tech industrial zone in the southwest, crosses Luo River and strides over Sui and Tang City Remains to the south, and moves the urban administrative center to the south, with the Luo River as the axis, the two sides develop symmetrically to form a banded group layout. In 2008, the fourth phase of overall planning (2011-2020)

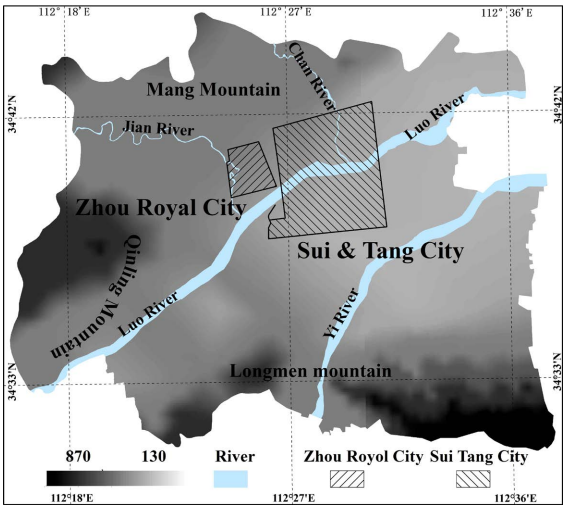

Figure 1. Luoyang urban topographic distribution.

of Luoyang is prepared and implemented, the urban construction focuses on extending to north and west, fills Luonan New District, tapes the land potential in the north side of Luo River, starts the construction of region in the south side of Yi River.

2.2. Data and Processing

The data used in this study mainly include 10 × 10 DEM data and Luoyang traffic network and administrative division data coming from Henan basic geographic information database and meta database, the urban planning data of Luoyang 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/). According to the land use and time series characteristics of the study area, the urban land is manually interpreted. 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 on the urban expansion mode and the exploration of the expansion orientation is mainly based on the urban land interpreted data.

2.3. Research Methods

Urban space expansion is mainly reflected in the continuous expansion of urban land. The purpose of urban space expansion research is to study the spatial-temporal characteristics of urban spatial layout, expansion rate, and expansion orientation, and analyze and predict the change tendency of urban expansion.

2.3.1. Sector Partition

For studying the expansion characteristics of urban land expansion in different orientations, based the urban land centroid in a year as the center, taking the due north direction as the starting line and the central angle 45˚ as the division unit, divides the urban land into 8 sector partitions and named in a clockwise direction. One orientation of urban land includes 2 sector partitions on its left and right in the direction, for example, NE (North-East) orientation includes two-sector partitions of 0˚ - 45˚ and 45˚ - 90˚, that is, the sector partition with the azimuth of 0˚ - 90˚; EE (East-East) orientation includes two-sector partitions of 45˚ - 90˚ and 90˚ - 135˚, that is, the sector partition of 45˚ - 135˚; two adjacent orientations coincide one sector partition, such as the overlapping part between NE and EE is 45˚ - 90˚, to ensure the continuity of analysis results.

2.3.2. Space Compaction Index

The space compaction of urban land is an important indicator to describe the urban space form, reflects the degree of the close relationship between various regions within the urban, and the utilization efficiency of urban land and infrastructure [2] [15]. As the closest relationship between points in a unit region is in a circle, so the space compaction C_i of a map spot of land i is defined as the normalized value of the ratio of the area A_i (unit: km^2) to the perimeter P_i (unit: m)

$$C_i = \frac{2\sqrt{\pi A_i}}{P_i} \tag{1}$$

The urban space compaction C is defined as the weighted average of the map spot of land with the area as the weight

$$C = \frac{\sum_{i=1}^{n} A_i C_i}{\sum_{i=1}^{n} A_i} \tag{2}$$

where n is the number of map spots in the urban, C_i and C belongs to $(0,1]$. As a map spot is close to a circular, it reaches the maximum value of 1; C tends to 1 indicates that the more compacting the urban land, the closer the internal space, and the higher land-use efficiency; C tends to 0 indicates that the worse compaction, the looser the interior, more undeveloped regions, and the lower the urban land use efficiency [2] [10] [15].

Since the radial radius line from the urban land centroid to the urban land boundary is artificially increased when constructing urban map spots in the sector partition, the calculation of Equation (1) cannot fully express the space compaction of the sector partition. Therefore, the space compaction of a single map spot in the sector partition is defined as:

1) If the number of intersections between a radial radius line and the boundary of the map spot i is less than 2, then all the map spot i belongs to the sector partition, the sector partition space compaction of i is calculated using Equation (1).

2) If the number of intersections between a radial radius line and the boundary of the map spot i is equal to 2, then the map spot i spans multiple sector partitions. Calculate the angle α^S ($\alpha^S \le 90^\circ$) between the two lines connecting the urban land centroid and the two intersection points, the length P_i^S of the intercepted segment in the boundary of the map spot i, and the corresponding area A_i^S. The space compaction of the map spot i in the sector partition is defined as the space compaction of the map spot formed by rotating in units of α^S around the urban land centroid, and completing a whole spot,

$$C_i^S = \frac{2\sqrt{360\pi A_i^S/\alpha}}{360 P_i^S/\alpha} = \frac{\sqrt{10\pi\alpha A_i^S}}{30 P_i^S} \tag{3}$$

3) If the number k of intersections between a radial radius line and the boundary of the map spot i is greater than 2, then the map spot i spans multiple sector

partitions. Relative to the urban centroid, the boundary of the map spot i can be divided into two groups, the curves close to the centroid (named inner line) and the curves far away from the centroid (named outer line). The inner line, outer line, and radial radius line of the sector partition form new map spots i', which is a subset of the map spot i in the sector partition. Calculate all the angles $\alpha_{ij}^{S}, j=1,2,\cdots,k-1$ between the two lines of connecting the centroid of i' and all the intersection points, the length P_{ij}^{S} of the intercepted segment in the boundary of the map spot i, and the corresponding area S_{ij}^{S}.

The space compaction C_i^S of the map spot i in the sector partition is defined as the space compaction of the map spot formed by rotating in units of $\alpha_i^S = \alpha_{i1}^S + \alpha_{i2}^S + \cdots + \alpha_{ik-1}^S$ around the land centroid, and completing a whole spot,

$$C_i^S = \frac{2\sqrt{360\pi\sum_{j=1}^{k-1} A_{ij}^S \Big/ \sum_{j=1}^{k-1}\alpha_i^S}}{360\sum_{j=1}^{k-1} P_{ij}^S \Big/ \sum_{j=1}^{k-1}\alpha_i^S} = \frac{\sqrt{10\pi\sum_{j=1}^{k-1}\alpha_{ij}^S \sum_{j=1}^{k-1} A_{ij}^S}}{30\sum_{j=1}^{k-1} P_{ij}^S} \tag{4}$$

The sector partition space compaction C^S is defined as the weighted average of the map spot of land in the sector partition with the area as the weight.

2.3.3. Expansion Intensity Index

The expansion intensity index is used to analyze and describe the state of urban space expansion, is defined as the proportion of urban land expansion area to the base period area in a certain period, which represents the relative (proportional) difference in the expansion rates of different regions in a unit time. The expansion intensity index of a map spot i defined as

$$N_i = \frac{\Delta U_{ij}}{\Delta t_j M_i} \times 100\% \tag{5}$$

where ΔU_{ij} is the expansion area of i during the period j, Δt_j is the period of the period j, M_i is the urban land area in the base time of j [12] [13] [15].

2.3.4. Fractal Dimension

Fractal geometry mainly studies the geometric form of spatial objects based on the self-similarity of spatial objects. The fractal dimension of urban land describes the filling ability of urban land to space, and the complexity of the irregular boundary. The fractal dimension of a map spot F_i is defined as

$$F_i = 2\ln\left(\frac{P_i}{4}\right) \Big/ \ln\left(A_i\right) \tag{6}$$

The fractal dimension of urban land F is defined as the weighted average of the map spot of land with the area as the weight.

$$F = \frac{\sum_{i=1}^{n} A_i F_i}{\sum_{i=1}^{n} A_i} \tag{7}$$

F belongs to $(1,2)$. $F < 1.5$ means that the shape of the map spot tends to be simple, and the urban expansion mainly comes from the natural filling on the

edge of the urban region; $F=1.5$ means that the shape of the map spot is in the state of Brownian random motion, the closer it approaches this value, the worse the stability; $F>1.5$ shows that the shape of the map spot tends to be complex, the irregularity of urban spatial form increases, and the urban expansion is dominated by external expansion. The decrease of fractal dimension shows that the edge of urban land tends to be neat and regular, the land tends to be compact, and the intensity increases [13] [16] [17].

2.3.5. Standard Deviation Ellipse

The standard deviation ellipse reflects the concentration degree, central tendency, and direct distribution tendency of the spatial point set. The center of the ellipse represents the centroid position of the whole data, which is defined as

$$\left(\bar{x},\bar{y}\right)=\left(\frac{1}{n}\sum_{i=1}^{n}x_i,\frac{1}{n}\sum_{i=1}^{n}y_i\right) \tag{8}$$

The major axis direction of the ellipse is the distribution axis direction of the point set, and the slope $K(\tan\theta)$ is defined as

$$K=\tan\theta=\frac{\left(D(X)-D(Y)\right)+\sqrt{\left(D(X)-D(Y)\right)^2-4\left(COV(X,Y)\right)^2}}{2COV(X,Y)} \tag{9}$$

The length of the semi-major axis and semi-minor axis of the ellipse is defined as:

$$\begin{aligned} r_x&=\sqrt{\frac{2\sum_{i=1}^{n}\left[\left(x_i-\bar{x}\right)\cos\theta-\left(y_i-\bar{y}\right)\sin\theta\right]^2}{n}}\\ r_y&=\sqrt{\frac{2\sum_{i=1}^{n}\left[\left(x_i-\bar{x}\right)\sin\theta+\left(y_i-\bar{y}\right)\cos\theta\right]^2}{n}} \end{aligned} \tag{10}$$

where, $D(X)$, $D(Y)$ and $COV(X,Y)$ are respectively the variance of the coordinates x and y, and their covariance. The length of the major and minor axes represents the range of spatial data distribution in this direction of the main direction and its vertical direction. Compared with the major axis, the shorter the minor axis is, the more obvious the centripetal tendency of the point set is; on the contrary, the longer the minor axis, the greater the degree of dispersion of the data. The oblateness $\alpha=\left(r_x-r_y\right)/r_x$ describes the directional characteristics of the spatial point set, the greater the oblateness, the more obvious the directionality of the data [15] [18] [19].

3. The Spatial Characteristics Analysis of Urban Space Expansion in Luoyang

3.1. The Overall Spatial Characteristics Analysis of Urban Expansion in Luoyang

The urban space compaction describes the urban space morphology, the degree of the close relationship between various regions within the urban, the utilization efficiency of urban land and infrastructure. As the urban expands rapidly

and the internal land is not fully developed the urban space compaction decreases; as the urban construction shifts to internal reconstruction and regional filling, the urban space compaction increases.

The remote sensing images of four years (as 1990, 2000, 2010, and 2020) are interpreted manually, and the results are shown in Figures 2-5. Using Equation (1), Equation (5)-(7) to calculate the urban space compaction, expansion intensity index, and fractal dimension of each year, the results are shown in Table 1.

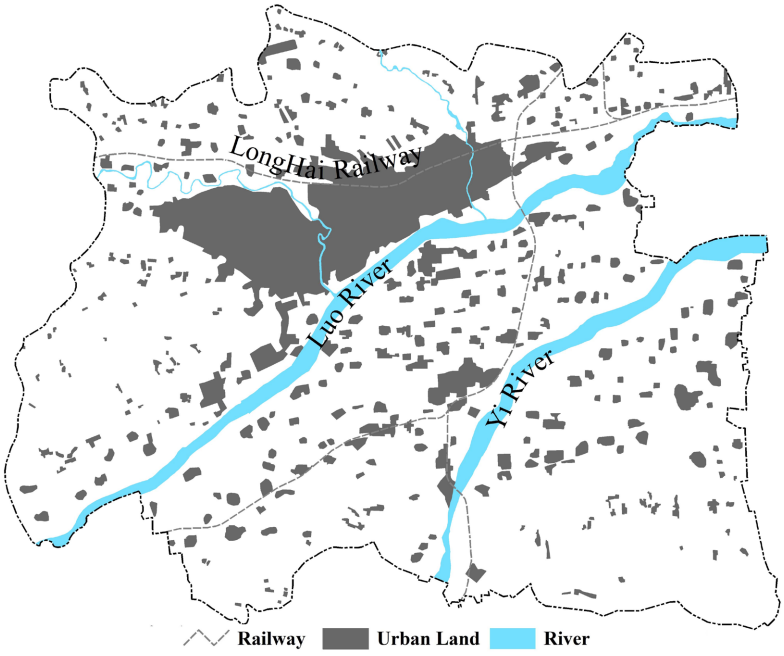

Figure 2. Luoyang urban land in 1990.

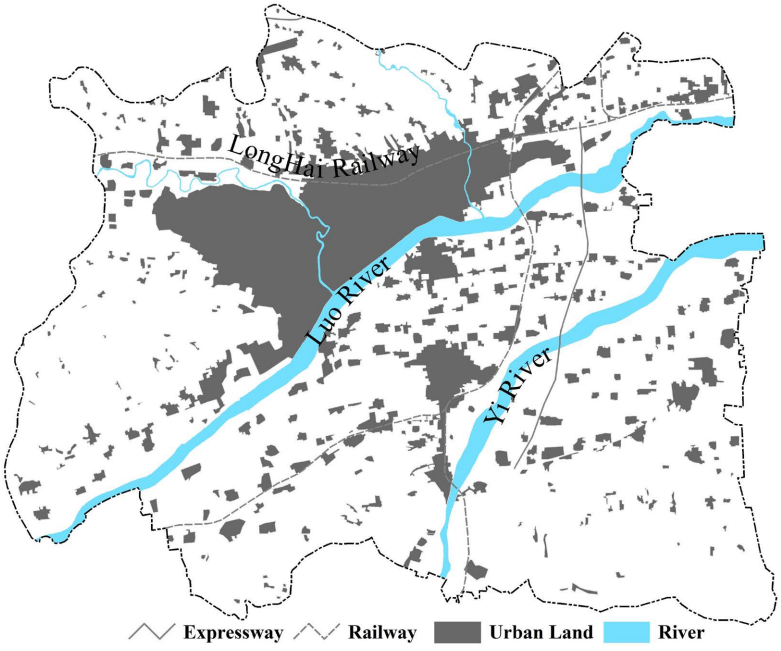

Figure 3. Luoyang urban land in 2000.

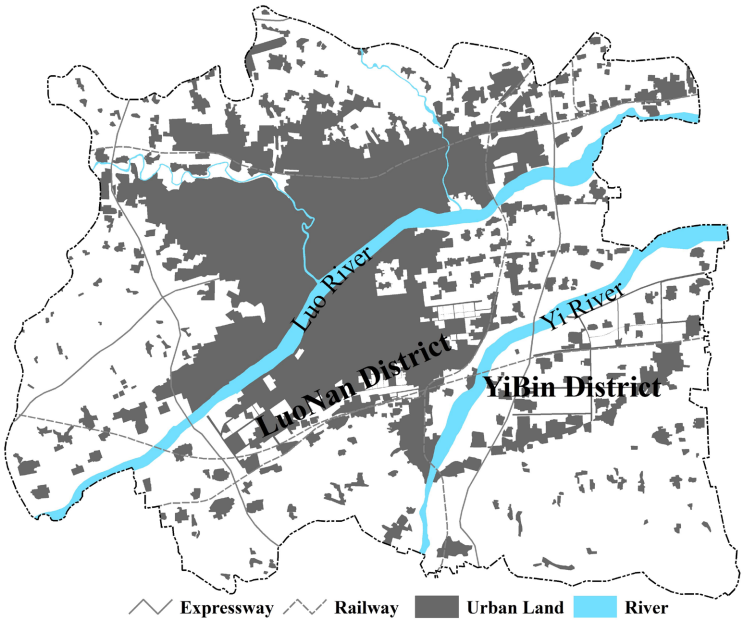

Figure 4. Luoyang urban land in 2010.

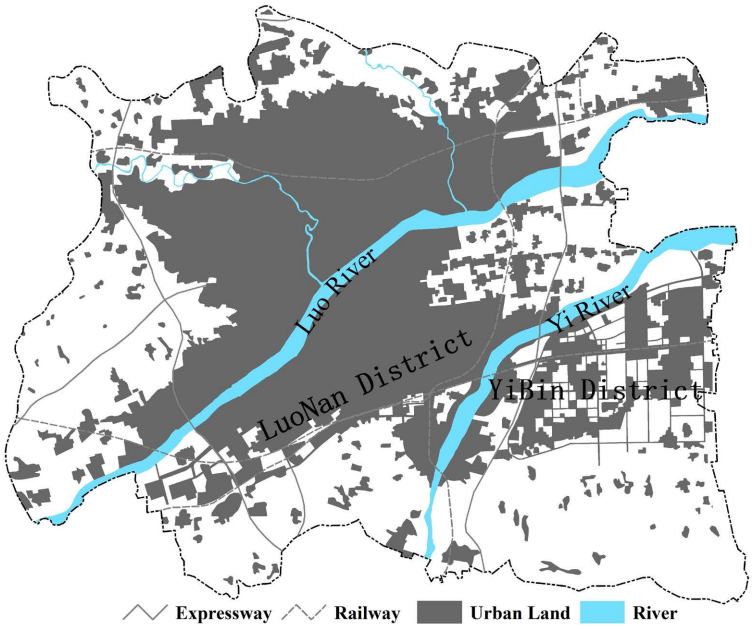

Figure 5. Luoyang urban land in 2020.

Table 1. The overall distribution characteristics of Luoyang urban land (1990-2020).

Year	Urban Land Area (km^2)	Expansion Rate (km^2/a)	Expand Intensity Index	Compaction Index	Fractal Dimension
1990	54.55	-	-	0.35	1.10
2000	71.51	1.7	3.11	0.29	1.12
2010	172.5	10.1	14.12	0.18	1.18
2020	259.89	8.74	5.07	0.31	1.13

From 1990 to 2020, the urban land of Luoyang has gradually expanded, from 54.55 km^2 in 1990 to 259.89 km^2 in 2020, an increase of 4.76 times in the 30 years, with an average annual expansion of 6.84 km^2. In the 3 periods, the expansion of urban land has different characteristics, in the first period, under the control of urban economic conditions and the first phase overall planning, the urban land mainly expands between Luo River and Mang Mountain, the urban expansion mode belongs to slow expansion type [15], the urban land is in a stable stage of natural expansion dominated by infilling, with the smallest urban expansion area, expansion rate and expansion intensity; in the second period, under the guidance of the second phase overall planning, the urban land crosses Luo River and strides over Sui and Tang City Remains, develops to southward, the urban framework is expanded rapidly, and the urban expansion enters the most active stage, the urban expansion mode belongs to the rapid expansion type, the urban expansion area, expansion rate and expansion intensity reach the maximums; in the third period, under the guidance of the third phase overall planning, the urban expansion mainly fills the enlarged urban framework in the second period, and expands also to the south of the Yi River, the urban expansion enters a relatively stable stage, The expansion mode belongs to the medium speed expansion type, and the urban expansion area, expansion rate and expansion intensity are all less than those in the second period, but significantly greater than those in the first period.

Affected by the expansion mode, the change of the urban land compaction is inversely proportional to the expansion rate. From 1990 to 2010, the urban land mainly expands outwards, and the urban framework is artificially enlarged, and the urban land compaction gradually decreases from 0.35 to 0.18, almost a decrease of 1times; between 2010 and 2020, although the urban framework is enlarged to the south of Yi River, due to the effective filling of the Luonan New District, the urban land compaction has been restored to a certain extent.

From the perspective of fractal dimension, the ability to urban space filling is gradually enhanced, the irregular boundary complexity is gradually reduced, and the urban form tends to be reasonable. Before 2000, the urban land is mainly distributed in the narrow and long regions between the north of Luo River and the south of Mang Mountain, the urban land fractal dimension is relatively small, causing the cost of logistics and people flow in the urban is relatively large, and the utilization efficiency of urban infrastructure is relatively low. After 2000, with the construction of Luonan New District, the city develops symmetrically on both sides of Luo River, the urban form tends to be circular, and the urban fractal dimension gradually increases, which effectively reduces the logistics and people flow costs within the urban and improved the utilization efficiency of some infrastructure. However, the southward expansion across Yi River in the later stage makes the urban land fractal dimension reduce to a certain extent.

The standard deviation ellipse reflects the concentration degree, central tendency, and direct distribution tendency of the urban land. Considering 70% of

the urban land, using the Equations (8)-(10) to calculate the standard deviation ellipse each year, the corresponding ellipse parameters are shown in Table 2 and Figures 6-9, here Center X and Center Y are the center coordinates of the ellipse, Major semi-axis, and Minor semi-axis represent the length of the major semi-axis and the minor semi-axis of the ellipse respectively, Rotation is the azimuth of the major axis, and Oblateness is the oblateness of the ellipse.

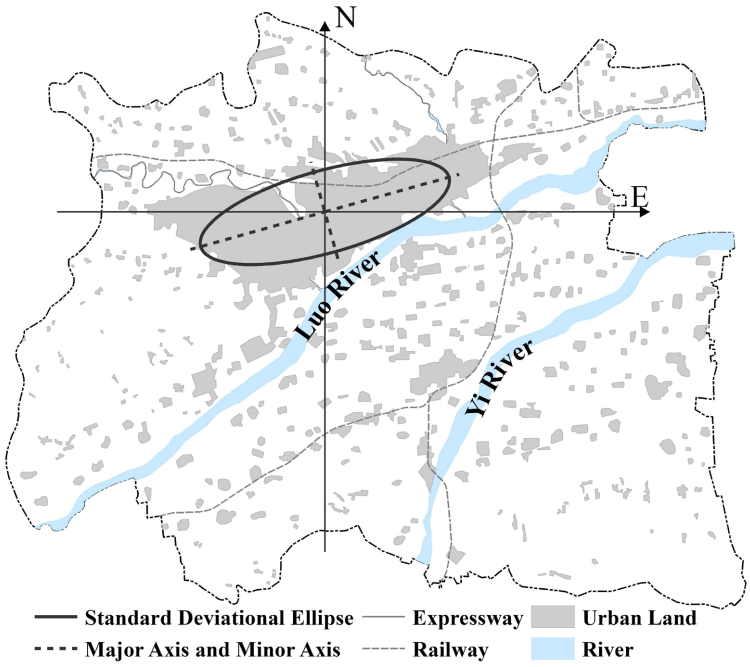

Figure 6. Standard deviation ellipse in 1990.

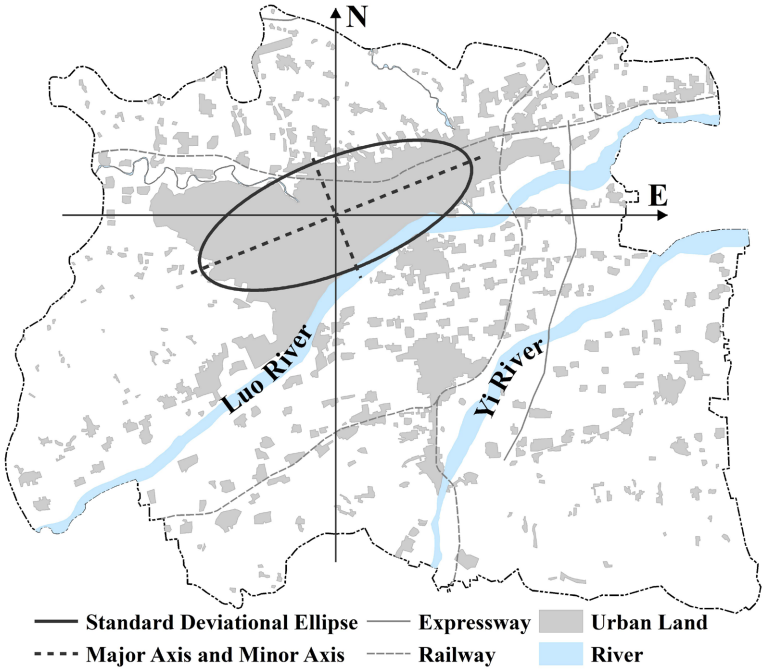

Figure 7. Standard deviation ellipse in 2000.

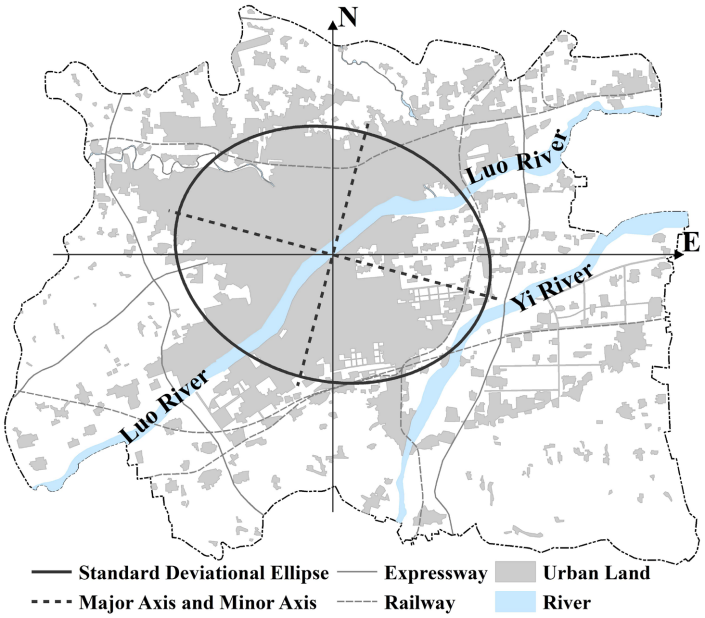

Figure 8. Standard deviation ellipse in 1990.

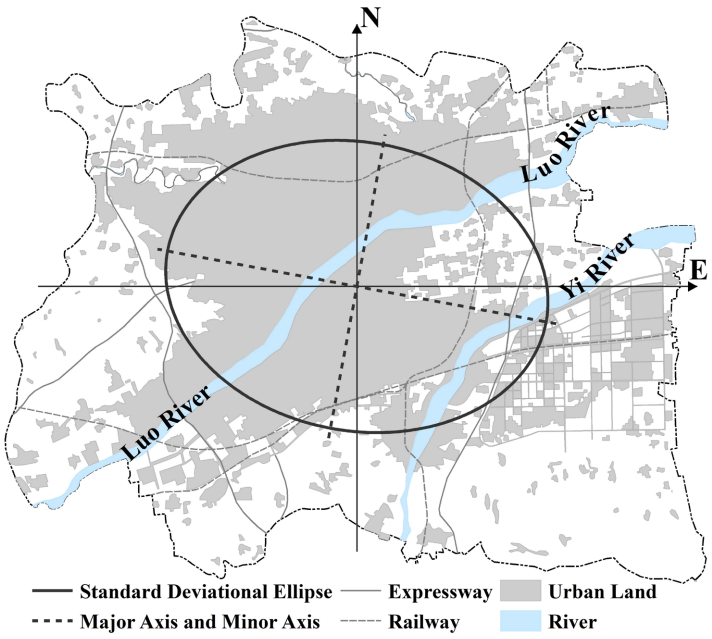

Figure 9. Standard deviation ellipse in 2000.

Table 2. The standard deviation ellipse of Luoyang urban land (1990-2020).

Year	Center X	Center Y	Major Semi-axis	Minor Semi-axis	Rotation	Oblateness
1990	630174.76	3838077.47	5909.41	1886.75	74.37	0.68
2000	630389.75	3837770.61	6506.66	2532.69	68.16	0.61
2010	631580.87	3835026.54	7801.44	6164.92	105.03	0.21
2020	632579.57	3834199.34	9318.92	6961.77	100.58	0.25

From 1990 to 2020, the urban land centroid always shifts to the southeast along the azimuth of 129.64˚ (see Figure 10). The urban land centroids always are located in the north of Luo River; With the development and utilization of Luonan New District, the urban land centroid has moved to the south bank of Luo River in 2010, basically realizing the goal of symmetrical development on both sides of Luo River; by 2020, the urban land centroid continues to migrate to the southeast. The migration rates vary greatly in the three periods, the migration rate in the first period is only 0.37 km/a, which increases by 7.98 times to 2.99 km/a in the second period, and decreases in the third period, but it is still 3.46 times that in the first period.

The major and minor semi-axes of the standard deviation ellipse continue to increase, indicating that urban land continues to expand outward. The symmetry axis of the urban land is the southwest-northeast direction, which parallels to Luo River before 2000, and then gradually rotates clockwise to the northwest-southeast direction (Figures 6-9). Before 2010, the growth rate of the major semi-axis is much lower than that of the minor semi-axis, resulting in the gradual reduction of the oblateness; after 2010, the growth rate of the minor semi-axis axis decreases, and the urban land oblateness increased slightly, indicating that in the process of urban expansion, the urban directional characteristics gradually disappear and the degree of dispersion gradually decreases.

3.2. The Spatial Orientation Characteristics Analysis of Urban Expansion in Luoyang

Based on the urban land centroid in 1990, dividing the urban land into 8 sector partitions, and calculating the partition expansion rate, the partition expansion intensity index, and the partition space compaction index of each orientation respectively by Equations (2)-(5), the results are shown in Table 3 and Figure 11 and Figure 12. To increase their visualization, the space compaction curve and

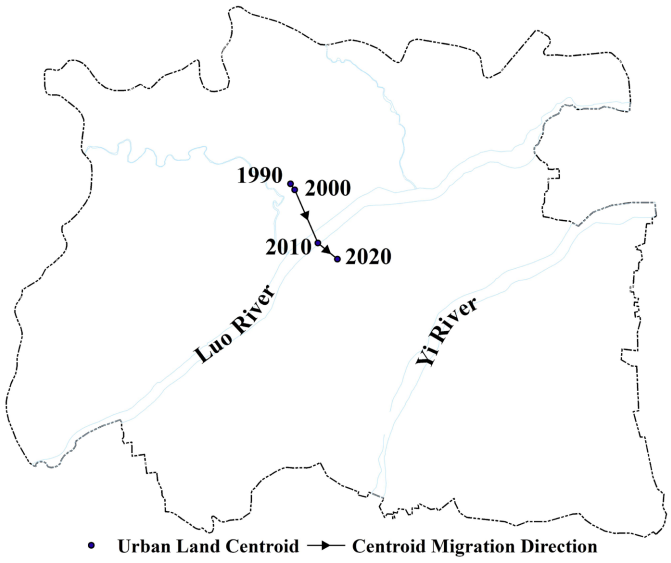

Figure 10. Luoyang urban land centroid distribution.

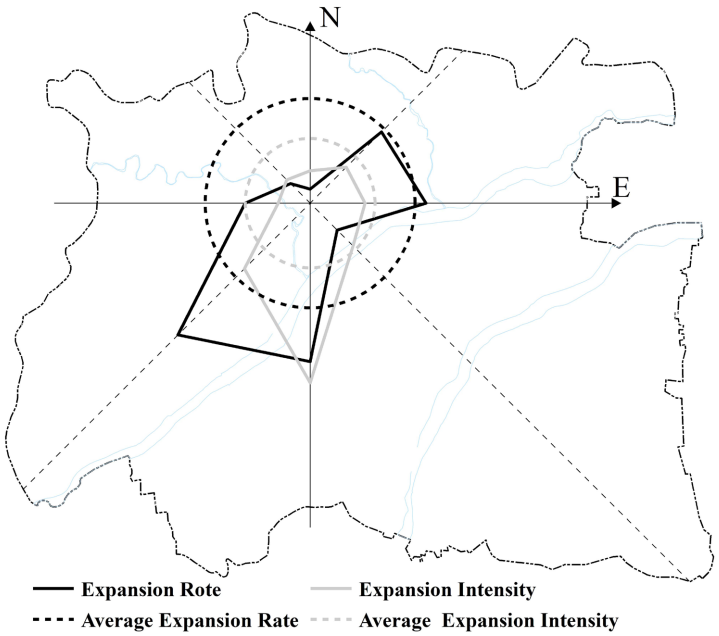

Figure 11. Expansion characteristics (1990-2000).

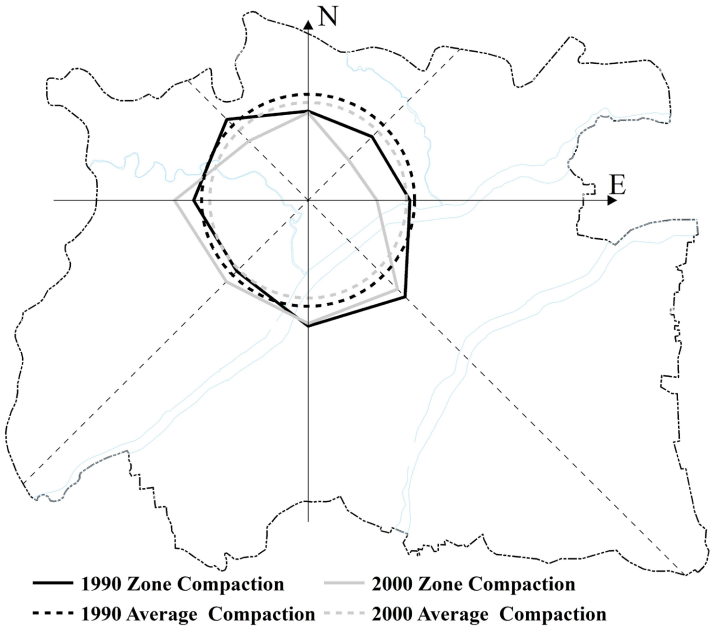

Figure 12. Urban land compaction (1990-2000).

the expansion rate curve in the figures are enlarged by 10,000 times based on the original value (unit: m), and the expansion intensity index is enlarged by 1000 times (unit: m).

From 1990 to 2000, the urban mainly expands in the narrow and long regions in the north of Luo River and the south of Mang Mountain. The expansion rate of urban land is 1.70 km^2/a, and the partition weighted average rate is 0.50 km^2/a. The orientation expansion rates of four orientations are less than the partition weighted average rate, from largest to smallest respectively are NN, WN,

Table 3. Luoyang urban land partition expansion characteristics (1990-2000).

Orientation	Urban land area (1990, km^2)	Compaction Index (1990)	Urban land area (2000, km^2)	Compaction Index (2000)	Expansion Rate (km^2/a)	Expand intensity index
NN	4.32	0.43	4.99	0.42	0.07	1.56
NE	19.76	0.44	24.60	0.28	0.48	2.45
EE	21.09	0.49	26.65	0.33	0.56	2.63
ES	6.29	0.66	8.12	0.61	0.18	2.91
SS	8.82	0.61	16.43	0.60	0.76	8.64
SW	20.08	0.49	29.03	0.56	0.90	4.46
WW	20.32	0.55	23.44	0.64	0.31	1.53
WN	8.43	0.55	9.76	0.41	0.13	1.58

ES, and WW; the orientation expansion rates of NE and EE are equivalent to the partition weighted average rate; the orientation expansion rates of SW and SS are much higher than the partition weighted average rate, which is 13.30 and 11.31 times that of EE respectively.

The expansion intensity index of urban land is 3.11. Based on the K-mean clustering method [20], the orientation expansion intensity index could be divided into four groups; the first group has the smallest orientation expansion intensity index, with a center of 1.56, including three orientations as WW, NN, WN; The second group, with a center of 2.67, includes three orientations as NE, EE, and ES; SW orientation is the third group, with the orientation expansion intensity index of 4.46, which is much less than 8.64 of the fourth group of SS.

In 1990, the urban land compaction of NN orientation is the smallest, and the urban land compaction in ES orientation is the largest. The urban land compactions in the four orientations as NN, NE, SW, and EE are less than their weighted average of 0.51. In 2000, the weighted average of the urban land orientation compaction is reduced to 0.47. In the four orientations of NE, EE, WN, and NN, the urban land compaction is smaller than its weighted average. From 1990 to 2000, the urban land partition of the WW and SW orientations increase; in SW orientation, the urban land compaction changes from less than their weighted average value to greater than their weighted average value; the urban land compactions decrease by about 30% in the NE, EE and WN orientations, especially in the WN orientation, which changes most significantly from greater than their weighted average value to less than their weighted average value. Overall, from 1990 to 2000, the urban mainly expanded to SW and SS orientations, with an azimuth of 135˚ - 270˚, and the expansion mode is mainly filling mode. In the NE and EE orientations, the azimuth is 0˚ - 135˚, the urban land expands outward at a slower rate, and the most significant changes of the urban compaction are in the SW and WN orientations.

Based on the urban land centroid in 2000, dividing the urban land into 8 sector partitions, and calculating the partition expansion rate, the partition expansion intensity index, and the partition space compaction index of each orientation respectively by Equations (2)-(5), the results are shown in Table 4 and Figure 13 and Figure 14. To increase their visualization, the space compaction curve and the expansion rate curve in the figures are enlarged by 10,000 times basis of the original value (unit: m), and the expansion intensity index is enlarged by 100 times (unit: m).

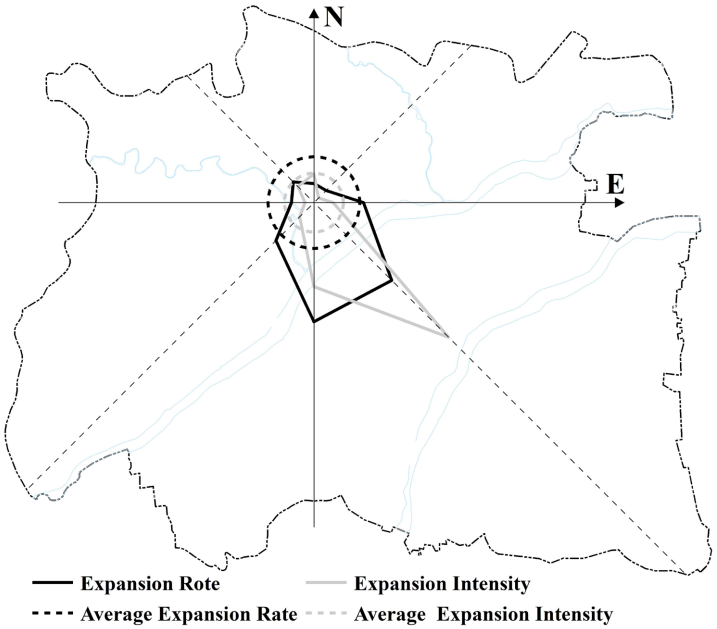

Figure 13. Expansion characteristics (2000-2010).

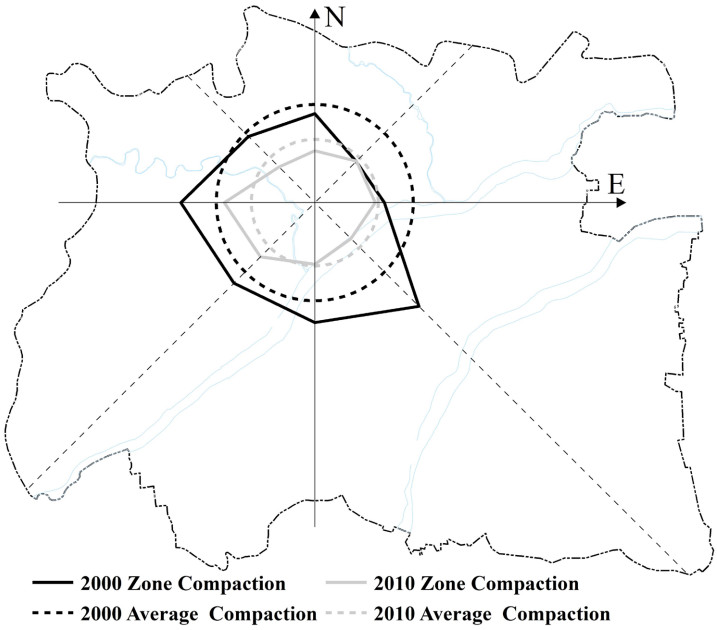

Figure 14. Urban land compaction (2000-2010).

Table 4. Luoyang urban land partition expansion characteristics (2000-2010).

Orientation	Urban land area (2000, km^2)	Compaction Index (2000)	Urban land area (2010, km^2)	Compaction Index (2010)	Expansion Rate (km^2/a)	Expand intensity index
NN	6.65	0.43	15.84	0.25	0.92	13.81
NE	26.10	0.28	34.37	0.28	0.83	3.17
EE	25.66	0.33	49.46	0.29	2.38	9.27
ES	5.78	0.71	58.64	0.25	5.29	91.41
SS	14.20	0.58	71.45	0.30	5.73	40.33
SW	26.73	0.55	52.53	0.37	2.58	9.65
WW	25.00	0.64	35.76	0.43	1.08	4.30
WN	12.89	0.45	26.96	0.24	1.41	10.91

From 2000 to 2010, The urban construction focuses on extending to the north and the west, filling Luonan New District, taping the land potential in the north side of Luo River, starts the construction of the region on the south side of Yi River. The urban expansion crosses Longhai railway to the north, crosses Luo River and strides over the Sui and Tang City Remains to the south, constructs a high-tech industrial zone in the southwest, the expansion rate of urban land is about 2.20 km^2/a.

The expansion rates in the four orientations are much less than the weighted average partition expansion rate, and their values are about half of the weighted average value, from largest to smallest respectively are NE, NN, WW, and WN; in the orientations of EE and SW the values are equivalent to the weighted average value; the values in the orientations of SS and SE are much higher than the weighted average value, which are 2.4 and 2.6 times of it.

The expansion intensity index of urban land is 14.12. The expansion intensity indices of SS and ES are much larger than that of the whole urban, and their values are about 6.47 and 2.86 times of that of the whole urban; the expansion intensity index of NN is equivalent to that of the whole urban; the expansion intensity index of the rest orientations is much smaller than that of the whole urban, especially in NE and WW, The partition expansion intensity indices arc only 22.45% and 30.45% of that of the whole urban.

In 2000, the overall space compaction is 0.29, the partition space compaction of NE is the smallest, the partition space compaction of ES is the largest, and the weighted average value is 0.47. The partition space compactions of NE, EE, NN, and WN are less than the weighted average value. By 2010, the overall space compaction is reduced to 0.18, the partition weighted average value is reduced to 0.31, the partition space compaction of WN is the smallest, and the partition space compaction of WW is the largest. There are four orientations as NE, EE, NN, and WN, whose partition space compactions are less than the weighted average value; the partition space compaction of SS is equivalent to the weighted

average value. From 2000 to 2010, with the expansion of the urban, the partition space compaction of NE remains unchanged, and the partition space compactions in the rest orientations decrease, especially the partition space compaction of SS and WS orientations decrease by 64.79% and 48.28% respectively.

Overall, from 2000 to 2010, the urban land mainly expands to SS and ES, with an azimuth of 90˚ - 225˚. The expansion mode is mainly outward expansion, and the northward expansion is slow, with the natural expansion mode, the compaction of urban land decreases significantly.

Based on the urban land centroid in 2010, dividing the urban land into 8 sector partitions, and calculating the partition expansion rate, the partition expansion intensity index, and the partition space compaction index of each orientation respectively by Equations (2)-(5), the results are shown in Table 5 and Figure 15 and Figure 16. To increase their visualization, the space compaction curve and the expansion rate curve in the figures are enlarged by 10,000 times based on the original value (unit: m), and the expansion intensity index is enlarged by 1000 times (unit: m).

From 2010 to 2020, The urban expansion focuses on extending to the north and west, filling Luonan New District, and starting the construction of the region on the south side of Yi River, the expansion rate of urban land has slowed down, but it is still 8.74 km^2/a. The weighted average partition expansion rate is 2.13 km^2/a, there are four orientations, as WN, NE, WW, and NN, whose partition expansion rates are less than the weighted average value, the value of SS is equivalent to the weighted average value, the values of three orientations, like ES, EE, SW, are greater than the weighted average value; especially, the values of ES and EE are 1.81 and 1.59 times of the weighted average value respectively.

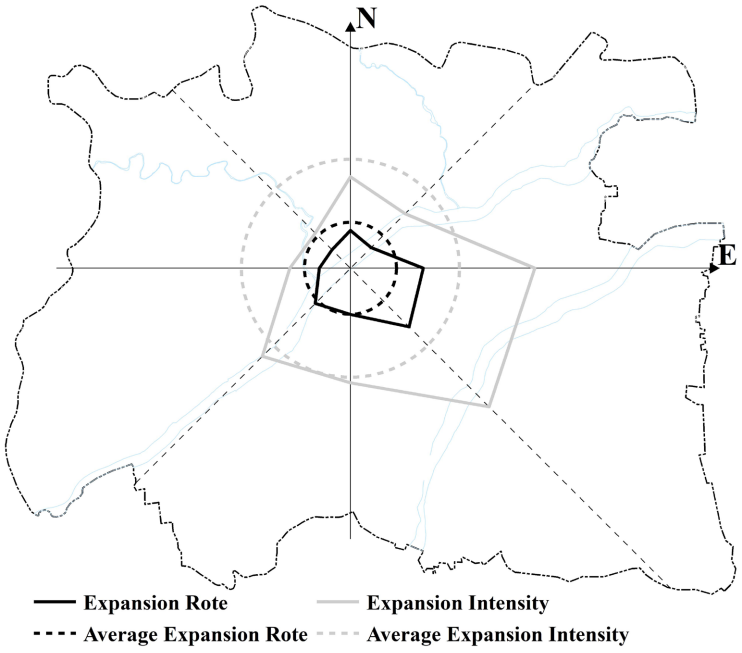

Figure 15. Expansion characteristics (2010-2020).

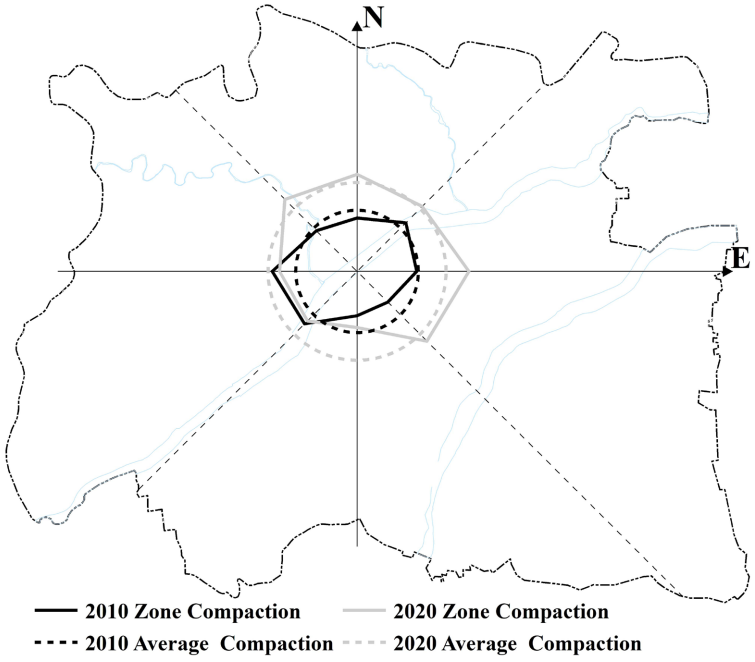

Figure 16. Urban land compaction (2010-2020).

Table 5. Luoyang urban land partition expansion characteristics (2010-2020).

Orientation	Urban land area (2010, km^2)	Compaction Index (2010)	Urban land area (2020, km^2)	Compaction Index (2020)	Expansion Rate (km^2/a)	Expand intensity index
NN	41.39	0.24	58.98	0.44	1.76	4.25
NE	37.81	0.31	51.39	0.42	1.36	3.59
EE	39.51	0.27	73.36	0.51	3.39	8.57
ES	42.32	0.20	80.86	0.45	3.85	9.11
SS	40.35	0.20	61.82	0.26	2.15	5.32
SW	39.99	0.34	63.14	0.32	2.31	5.79
WW	51.26	0.39	65.71	0.35	1.44	2.82
WN	52.38	0.26	64.48	0.47	1.21	2.31

The expansion intensity index of urban land is 5.07. The expansion intensity indices of WN, WW, NE, and NN are less than that of the whole urban, especially, the values of WN and WW are only 46.00% and 55.62% of that of the whole urban; the values of ES, EE, SW, and SS are greater than that of the whole urban, especially, the values of ES and EE are 1.80 and 1.69 times of that of the whole urban.

In 2010, the overall space compaction is 0.18, the partition space compaction of SS is the smallest, the partition space compaction of WW is the largest, and the weighted average value is 0.41. The partition space compactions of SS, ES, NN, WN, and EE are less than the weighted average value. By 2020, the overall

space compaction rise to 0.31, the weighted average value rise to 0.31, the partition space compaction of SS is the smallest, and the partition space compaction of EE is the largest. There are three orientations as SS, SW, and WW, whose partition space compactions are less than the weighted average value. From 2010 to 2020, with the expansion of the urban, the partition space compaction of WW and SW has decreased, the values of the rest orientations have increased, especially the partition space compactions of ES and EE have increased by 125.00% and 88.89% respectively.

Overall, from 2010 to 2020, the urban land mainly expands to ES and EE, with the azimuth of 45˚ - 180˚, and the expansion mode is mainly filling mode; in the NE orientation, the azimuth of 0˚ - 90˚, the urban expansion is mainly filling mode; the region on the north of Luo River is relatively stable, the urban land space compaction has been restored to a certain extent.

4. Conclusions and Prospection

4.1. Conclusions

This paper uses the regional sector division method to divide the urban land into 8 orientations, based on the urban land space compaction index and designs a sector partition compaction index. Based on the remote sensing image data of 1990, 2000, 2010, and 2020, the spatial characteristics of urban land expansion of Luoyang are analyzed by using the partition compaction index, expansion intensity index, fractal dimension, and standard deviation ellipse. The results show that:

1) The urban overall planning of Luoyang has effectively guided the urban development, the urban land expands rapidly, the urban land compaction has been maintained at a low level, and the urban form has been tending to be reasonable.

2) The urban land centroid gradually shifts to the southwest, and the distribution axis rotates clockwise from southwest-northeast to northwest-southeast, and the directionality of distribution gradually disappears.

3) The urban land has gone through the development process of land filling-enlarging-refilling. The urban expansion is relatively active in the region with an azimuth of 90˚ - 225˚, and the urban expansion in the north of Luo River is relatively stable and is always filling mode.

4.2. Prospection

In the process of completing the research of this paper, due to the accuracy of land use remote sensing image data, there are some small regional errors in the process of manual extraction of urban land, which affects the subsequent research work. However, with the progress of space remote sensing technology, the increase of remote sensing image resolution, and the improvement of image recognition technology, on the basis of this paper, more accurate results will be obtained, which is more in line with the actual situation of the studied city.

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Conflicts of Interest

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

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