Research on Temporal-spatial Changes of the Construction Land Expansion in Changsha-Zhuzhou-Xiangtan Urban Agglomeration

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Abstract. The construction land changes from 1994 to 2013 in Changsha-Zhuzhou-Xiangtan are monitored by using multi-period Landsat images in the paper. The characteristics and laws of construction land expansion in Changsha-Zhuzhou-Xiangtan are analyzed by using the construction land index of expansion speed, expansion intensity index, quadrant buffer analysis, and gravity transfer model. The results show that: (1) the construction land of Changsha-Zhuzhou-Xiangtan area increased linearly in the past 20 years. The construction land expansion area is the largest and the expansion intensity is the biggest in 2009-2013. (2) The construction land area showed a trend of accelerating expansion in the 8 quadrant direction between 1994-2013 years. The expansion direction occurs mainly in the seventh, third, fourth quadrant. (3) The urban gravity center shifted southward obviously in Changsha and moved fastest in Zhuzhou and slowest in Changsha.

1. Introduction

With the acceleration of urbanization, urban construction land was expanded at a high speed. As the most direct manifestation of urbanization and urban spatial expansion, the expansion of urban construction land had become a hot issue for scholars at home and abroad (Feng et al., 2013; Wang et al., 2011; Wang et al., 2015; Xu et al., 2011; Angel et al., 2011; Bagan and Yamagata, 2012). The current urban construction land expansion metrics mainly included: index of expansion speed (Zheng et al., 2012), index of expansion intensity (Zheng et al., 2012), relative change rate of urban construction land (Zheng and Ren, 2009), fractal dimension of urban form (Li et al., 2014) and dominance index (Yi et al., 2015). The current urban construction land expansion research models mainly included: Quadrant Buffer Analysis (Tang and Yang, 2004), Typical Location Space Analysis (Ye et al., 2006), Buffer Zone Analysis method (Hu et al., 2013), Influence Degree Index Model (Yi et
al., 2015) and the Gravity Transfer Model (Li et al., 2014) and so on. These indices and models analyzed the characteristics and laws of construction land expansion from different angles.

The construction land changes during the years from 1994 to 2013 in Changsha-Zhuzhou-Xiangtan are monitored by using multi-period Landsat images in the paper. The characteristics and laws of construction land expansion in Changsha-Zhuzhou-Xiangtan are analyzed by using the construction land index of expansion speed, expansion intensity index, quadrant buffer analysis, and gravity transfer model, which provided the spatial distribution planning, construction and management of the construction land for scientific basis.

2. Materials and Methods

2.1. Research area overview

Changsha-Zhuzhou-Xiangtan area is located in the central and eastern part of Hunan Province (26°03′~28°40′N, 111°53′~114°15′E), and is located in the combination of the Beijing-Guangdong Economic Belt, the Pan-Pearl River Delta Economic Zone, and the Yangtze River Economic Belt. The ministries, including Changsha-Zhuzhou-Xiangtan, are the core growth poles of Hunan's economic development. The three cities of Changsha-Zhuzhou-Xiangtan are distributed along the Xiangjiang River in the shape of “goods”. The distance between the two cities is less than 40km. There are green belts and high-speed roads, and the location and traffic conditions are superior. The area is 28,000 km²and the population is 13.96 million. In 2015, the regional GDP was 1,254.8 billion yuan.

2.2. Data source and data preprocessing

Landsat image data of the same or similar phase, small cloud volume and good data quality in Changsha, Zhuzhou and Xiangtan in 1994, 2004, 2009 and 2013 were selected and remote sensing images are preprocessed though radiometric calibration, atmospheric correction, geometric correction and regional cutting. By constructing the Normalized Difference Vegetation Index (NDVI), the Normalized Difference Building Index (NDBI) and the Normalized Difference Water Index (NDWI), and performing false color composite on these three index bands, the supervised classification is used to extract the construction land information (Liang et al., 2015).

2.3. Method

(1) The measuring index of construction land expansion

The measuring index of construction land expansion indicates the annual growth rate of the construction land area during the study and period to characterize the overall scale and trend of construction land expansion. The Expansion Intensity Index (EII) is to standardize the expansion speed by using the area of each spatial unit, so that the expansion speed of construction land in different periods is comparable, which is used to measure the maximum strength per unit area (Wang et al., 2011). The larger the ESI and EII values, the more obvious the expansion trend, and the larger the change of construction land area in different periods, the calculation formula is

$$ESI = \frac{\Delta A}{A} \times 100\%, \ EII = \frac{\Delta A}{A} \times 100\%$$

Where: $\Delta A_j$ for the study area construction land from the period to the period of change; $A_i$ for the first year of construction land area; $\Delta t$ for the study period, $S$ for the study area total area.

(2) The quadrant buffer analysis

The quadrant buffer analysis analyzes the spatial differentiation characteristics of construction land expansion in all directions by establishing quadrant buffers in all directions outward from the regional center point. Taking the barycentric coordinates of the construction land of Changsha-Zhuzhou-Xiangtan in 1994 as the middle point, the angle of the east is 0°, the angle of 45° is the equal angle, and the eight quadrants are divided counterclockwise. By superimposing the spatial distribution map
of 4 time-phase construction land, we can obtain the construction land area of each quadrant buffer zone in each period, so as to analyze the spatial characteristics of the upward expansion of construction land of all parties (Fig.1).

(3) The gravity transfer rate

The spatial center of gravity is an important indicator to describe the spatial distribution of geographic elements. It is often used in urban evolution and land use type change researches. The gravity can be calculated by the barycentric coordinates formula of the construction land, and the spatial differences of the construction land expansion can be analyzed according to the rate change law of the gravity center migration. The calculation formula is as follows (Li et al., 2018):

\[
X_i = \frac{\sum a_{ij} \times x_{ij}}{\sum a_{ij}}, \quad Y_i = \frac{\sum a_{ij} \times y_{ij}}{\sum a_{ij}},
\]

\[
V_{t_i+1-t_i} = \sqrt{(X_{t_i+1} - X_i)^2 + (Y_{t_i+1} - Y_i)^2} / (t_{i+1} - t_i)
\]

Where: \(X_i, Y_i\) are the coordinates of the center of gravity of the construction land in the \(t\) year; \(a_{ij}\) is the area of the \(i\) construction land patch; \(x_i, y_i\) are the coordinates of the gravity of the \(i\) construction land; \(t_{i+1} - t_i\) is the time interval of the gravity of the construction land; \(V_{t_i+1-t_i}\) is the time is \(t_{i+1} - t_i\) The construction land focuses on the annual migration rate.

3. Results and analysis

3.1. The analysis of expansion characteristic.

![Figure 1. Analysis of the change of construction land and quadrant of Changsha-Zhu Zhou-Xiangtan in 1994-2013](image)

The construction land of Changsha-Zhu Zhou-Xiangtan area increased linearly in the past 20 years. Its area extends 1146.80km² with an average annual growth rate of 57.34 km², expanded 5.9 times in the past 20 years.
The time series characteristics of construction land expansion were measured on the time scales of 1994-2004, 2004-2009, and 2009-2013 (Fig. 3). The expansion area of construction land in the three periods were respectively 202.18km², 418.41km² and 526.21km². They respectively accounted for 17.63%, 36.48%, and 45.89% of the total expansion in 1994-2013; ESI was respectively 8.63%, 19.17%, and 12.31%. In the second period (2004-2009), the construction land expanded fastest; EII They were respectively 0.07%, 0.30%, and 0.38%. In the third period (2009-2013), the construction land expansion intensity was the largest, and the average annual growth amounted to 0.38% of the total land area.

3.2. The quadrant buffer analysis
There is a big difference in the area of construction land in Changsha-Zhuzhou-Xiangtan between the various quadrants. In 1994, the difference in construction land area between the various quadrants was relatively small. Among them, the third quadrant had the largest area of 118.18 km² and the eighth quadrant had a minimum of 3.26 km². The eight quadrants were in descending order of construction land area: 3rd>7th>4th>6th>2nd>1st>5th>8th. In 2009 and 2013, the difference of construction land area between each quadrant was significantly increased.

The standard deviation of the construction land area between the quadrants respectively reached 195.90km² and 189.72km², and the construction land showed anisotropy. In 2013, the area of construction land for each quadrant was changed to: 7th>3rd>4th>5th>1st>6th>2nd>8th. In 1994-2013, the rate of increment of construction land in the 8th quadrant was the smallest. It was only 77.61km², followed by the second quadrant, which is 85.35km². The increment of the seventh quadrant is the largest, which is 239.32km², and the increment of the 4th quadrant was second. From 1994 to 2013, the direction of construction land expansion mainly occurred at the 7th. In the 3rd and 4th quadrants, the construction land area in 8 direction showed an accelerated expansion.
From 1994 to 2004, the expansion rate of construction land in the first quadrant was the highest, at 44.76%, the second was the fourth quadrant. The expansion rate of the construction land in the sixth quadrant was the smallest, only 0.79%. The expansion speed of the eighth quadrant construction land were as follows: 1st, 4th, 8th, 2nd, 3rd, 5th, 7th, 6th. In 2004-2009, the expansion speed of the 4th quadrant construction land The maximum was 46.87%, the third quadrant was second, the eighth quadrant had the slowest expansion speed of only 6.57%, and the expansion speed of each quadrant construction land was become: 4th>3rd>7th>5th>6> 2>1st>8th. Between 2009 and 2013, the expansion speed of the eight quadrant construction land were ranked as: 1st>8th>5th>7th>2nd>4th>6th>3rd. On the whole, between 1994 and 2013, excepted for the slow expansion of the sixth quadrant, the expansion speed of other quadrants was between 4% and 5% (Fig. 4-5). During 1994-2004, the sixth quadrant construction land. The maximum expansion intensity was 0.13%, followed by the fourth quadrant, which was 0.12%. In 2004-2009, the expansion intensity of construction land in the third quadrant reached 1.50%. In 2009-2013, the fourth quadrant construction land had the largest expansion intensity of 0.87%, followed by the third quadrant, which was 0.73%. On the whole, between 1994 and 2013, the expansion strength of the construction site of the third quadrant was the largest, 0.59%, and the expansion intensity of the construction site of the seventh quadrant was the smallest, only 0.12%. The expansion strength of the eight quadrant construction land was as follows: 3>4>2nd>6th>8th>5th>1st>7th (Fig. 6-9).
3.3. Spatial center of gravity analysis

Figure 10. Schematic diagram of the center of gravity of the construction land (unit: m)

The spatial center of gravity model was used to calculate the spatial center of gravity of the construction land in the four periods of Changsha-Zhuzhou-Xiangtan. The results showed that the coordinates of the center of gravity of the construction land in Changsha City in 1994, 2004, 2009 and 2013 are (707100, 3124635) and (703112, 3124303), (702796, 3124664) and (703860, 3123466); the coordinates of the center of gravity of the construction land in Zhuzhou City were respectively (722928, 3063253), (733091, 3038905), (737934, 3025365) and (740952, 3021701). The coordinates of the center of gravity of the construction land in Xiangtan City were (678382, 3079183), (675690, 3079651), (672117, 3073552) and (666667, 3077280). It could be seen that during the period of 1994-2013, the urban center of gravity of Changsha City shifted to the south, and the city center of Zhuzhou City gradually shifted to the southeast. The city center of Xiangtan City shifted to the west. In the past two decades, Zhuzhou’s center of gravity had the fastest migration rate, with 2265 meters moving southward each year, and Changsha was the slowest, about 172 meters. From 1994 to 2004, the center of Changsha moved 400 meters/year, and the center of Changsha moved northward in 2004-2009. 96 meters/year, 2009-2013 Changsha center of gravity moved 320 meters/year.

4. Conclusions

In this paper, we used the construction data of four periods of Changsha-Zhuzhou-Xiangtan in 1994, 2004, 2009 and 2013 to interpret the data, and used GIS spatial analysis to carry out a series of spatial analysis on the expansion of construction land of Changsha-Zhuzhou-Xiangtan since 1994. The results showed:

(1) The construction land of Changsha-Zhuzhou -Xiangtan area increased linearly in the past 20 years. Its area extends 1146.80km2 with an average annual growth rate of 57.34 km2, expanded 5.9 times in the past 20 years. Between 2004 -2009 years, the construction land expansion rate is the fastest, in 2009-2013 years, the construction land expansion area is the largest and the expansion intensity is the biggest.

| time quantum | Center of gravity migration rate (m/year) |
|--------------|------------------------------------------|
| ChangSha     | Zhuzhou                                  | Xiangtan                               |
| 1994-2004    | 400                                      | 2638                                   | 273                                    |
| 2004-2009    | 96                                       | 2876                                   | 1414                                   |
| 2009-2013    | 320                                      | 949                                    | 1321                                   |
| 1994-2013    | 172                                      | 2265                                   | 593                                    |
(2) The construction land area showed a trend of accelerating expansion in the 8 quadrant direction between 1994-2013 years. The quadrant expansion speed is between 4%-5% except the sixth quadrant, which expansion rate is slightly slower. The construction land expansion intensity is the biggest in the third quadrant, and the expansion direction occurs mainly in the seventh, third, fourth quadrant.

(3) Between 1994-2013 years, the urban gravity center shifted southward obviously in Changsha, and it gradually shifted to the southeast in Zhuzhou, meanwhile it moved westward obviously in Xiangtan. It moved fastest in Zhuzhou and slowest in Changsha.

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