Gradient Analysis of Urban Construction Land Expansion in the Chongqing Urban Area of China

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Abstract: Urban construction land-use expansion is an important topic in the field of land-use change research. In the present study, the temporal and spatial changes of urban construction land use in the Chongqing urban area are analyzed, based on land-use maps from 1975, 1987, 1995, 2000, and 2010. Using gradient analysis, the study area was divided into nine buffer zones and eight quadrants. The study analyzed the compactness of the urban construction land in different buffer ranges and different directions, and further fitted the compactness degrees and different gradients. The results indicated that there was a rapid growth of urban construction land use in the Chongqing urban area in the period of 2000–2010, and the land use for urban construction sharply increased at an average annual rate of 5.69%. The expansion pattern showed a spatial mode of one center and multiple subcenters. Furthermore, although the key regions (the fastest-growing regions of urban construction land) of urban expansion showed higher compactness degree than the nonkey regions (the slowest-growing regions of urban construction land) of urban expansion, the compactness degrees were decreasing in the key regions but increasing in the nonkey regions. Specifically, the urban construction land had three highly compact zones in the buffer radius gradient—zones of radius 5, 25, and 40 km—and the compactness degrees gradually increased. When analyzed by the quadrant gradient of buffers, quadrants 45–90° (WNW), 90–135° (WSW), and 315–360° (NNE) were the key regions of urban expansion, and quadrants 225–270° (ESE) and 270–315° (ENE) were the nonkey regions. In addition, the change in compactness degree was highly correlated with changes in the buffer radius and quadrant azimuth. DOI: 10.1061/(ASCE)UP.1943-5444.0000204. © 2014 American Society of Civil Engineers.

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Introduction

The effects of land use include farm land use and construction land use. During the development of human society, population growth requires sustainable energy and food. Hence, land use, especially the use of land for urban expansion, is unavoidable. The concept of urban expansion was first described in the United States as the outward and low-density expansion of urban areas, followed by studies in European countries (Nechyba and Walsh 2004). In China, rampant urban growth as a result of the 1978 economic reform has led to many land-related problems (Yeh and Li 1997; Li and Hui 2012). Overall, the uncontrolled expansion of urban construction land and the distribution of low-density housing have become a major challenge for urban spatial planning and land-use planning (Hasse and Lathrop 2003; Durieux et al. 2008). Urbanization is the process of nonurban land near an urban area being transformed into urban land (Kline and Alig 1999; Jiang et al. 2007). Urban expansion is one of the most noticeable effects of urbanization on land use (Xie et al. 2007) and is generally believed to have both direct and indirect impacts on land-use transformation. Urban construction land is part of urban land and has become an important vector of urbanization (Fang 2009). Urban construction land belongs in the category of construction land (MLR 2007). There are significant differences in among urban construction land, urban land, and urban built-up land. Urban construction land includes lands under residential use, public management and public service, commercial service facility, industrial, warehousing, transportation facilities, and city government green land uses (MHURC 2011). Urban land includes urban areas and waters (Wang and You 2004). Urban built-up land refers to developed urban construction land, which has complete municipal utilities and public facilities in the urban administrative area (MHURC 1998).

Research on the spatial-temporal process of urban construction land expansion is not only important to urban development research but also to research on global environment changes (Turner et al. 2007). The urbanization rate in the developing country of China has accelerated since 1978 and is 2.14% higher than the world average (Wang and Fang 2011). The expansion of land use for urban construction is a complex process, and the mode of urban expansion is related to the regional historical and social contexts. In China, urban expansion follows a dual mode, in which government-led and spontaneous urban expansion coexist. Government-led urban expansion results from increasing demand for urban construction land due to growth in the nonagricultural population, whereas for spontaneous urban expansion, the increasing demand for urban construction land results from the accelerated urbanization of small towns (Shen 2000; Wong et al. 2003; Ma et al. 2007).

The influencing factors and dynamic mechanisms of urban construction land expansion are important topics of urban development research, which examines the reasons and mechanisms of urban expansion.
construction land expansion and provides corresponding countermeasures for predicting urban construction land expansion (Zhou and He 2007). First, population urbanization is one of the most important internal reasons for urban construction land expansion (Li et al. 2003). Liang and Wang (2002) observed that the ratio between the growth rate of urban construction land and the growth rate of population was a constant at one stage. China’s urban population increased dramatically from 170 million in 1978 to 456 million in 2000, and its share of the total population rose from 18% to 36% (Xie et al. 2007). Chinese authorities anticipate that another 250 million people will move into cities and towns in the next 15 years; at that point, half or more of China’s population would be urbanized (Fan 2002; Liang and Ma 2004). Second, economic development is the external driving force of increased urban construction land (Li et al. 2003). The central locations and agglomeration economies that characterize urban settlements give rise to land values and rents that are significantly higher than those of rural land, and lead to an urban-rural differential that is sufficiently profitable to attract the conversion of land from rural to urban uses (Zhou and Ma 2000; Ho and Lin 2004; Ding 2004). Deng et al. (2010b) observed that urban construction land growth of 3% corresponded to economic growth of 10%.

Current methods of measurement of urban construction land expansion include absolute and relative methods (Bhatta and Saraswati 2010). Due to unclear definitions of urban construction land expansion in past studies, multiple methods have been developed based on different conceptual definitions (Kupfer 2006; Ewing et al. 2002; Razin and Rosentraub 2000; Wilson et al. 2003; Frenkel and Ashkenazi 2008; Schneider and Woodcock 2008). Furthermore, it has been difficult to compare urban growth management strategies between different countries because distinct data were used for different counties or towns. As a result, many different methods have been developed based on distinct data sets to measure urban construction land expansion (Maria-Pia et al. 2009). At present, the integration of geographic information systems (GIS) and remote sensing (RS) is the most basic method for researching urban construction land expansion (Yeh and Li 1997; Tian 2003).

Research on spatial-temporal processes and traits of urban construction land expansion analyzes the spatial distribution traits and change rules by certain technical means adopted from multi-time statistics or remote sensing data (Chen et al. 2000). The integration of GIS and RS into urban construction land expansion management involves two processes: land-use change detection and evaluation of the impact of land-use change on land resources (Yeh and Li 1997; Zhu and Zheng 2012). Davis and Schaub (2005) analyzed the speed of urban construction land expansion by comparing the population density of the neighborhood area with the allowed number of new houses constructed. In addition, Lien and Anton (2009) studied urban construction land expansion by comparing the shape index of the area-weighted mean patch with an employment potential index based on landscape changes and employment development. Jochen et al. (2010) developed 13 criteria for method selection and studied four different methods including urban dispersion, total expansion, penetration of urban landscapes, and unit area expansion. Yan and Huang (2006) analyzed the characteristics and modes of urban construction land expansion using the urban expansion intensity index. Li et al. (2007) analyzed modes and trajectory models of urban construction land expansion based on the growth pole core theory, and both Sun et al. (2006) and Li et al. (2010) adopted buffer radius gradient analysis to study the spatial-temporal characteristics of urban construction land expansion.

In the present study, it was hypothesized that (1) the center of urban construction land expansion and the gradient distribution were reasonable, and (2) the urban construction land expansion presented gradient changes. The methods of GIS and RS were integrated and a buffer radius gradient analysis was adopted to analyze urban construction land expansion. First, the quantitative traits and spatial forms in the Chongqing urban area from 1975–2010 were analyzed. Second, the mechanisms and differences of urban construction land expansion at different buffer radius gradients based on compactness degrees were researched. Third, the differences in urban construction land expansion among Chongqing, Beijing, Shanghai, and Guangzhou were compared. This study provided scientific guidance for the land-use planning and expansion management of the Chongqing urban area.

Study Area

The Chongqing urban area is located at the confluence of the Yangtze and Jialing Rivers, which is the head of the Three Gorges Reservoir Area (Fig. 1). The Chongqing urban area is a mountainous and hilly area with a subtropical humid monsoon climate characterized by warm summers and winters, a moderate amount of light, a long frost-free period, high precipitation, and high humidity. The Chongqing urban area includes the districts of Dadoukou, Shapingba, Jilingong, Nan’an, Beibei, Jiangbei, Yubei, Yuzhong and Ba’nan. The research area of this paper includes all urban construction land in the nine districts.

Data and Methods

Data

The present study made use of remote sensing images from five different time periods, including 1975 MSS images and 1987, 1995, 2000, and 2010 TM images. The acquired remote sensing images were analyzed using the ERDAS 8.5 system. In the first step, radiation and geometric corrections were conducted using the Krasovsky ellipsoid and transverse Mercator projection. Following integration, the images were geometrically corrected using the cubic polynomial approach based on a 1:10,000 topographic map. Using point inspection, the variation was controlled to be less than one pixel. Based on the corrected images and the land-use classification criteria of the Chinese Academy of Sciences, a human-computer interactive interpretation approach divided the land use of the Three Gorges Reservoir Area into ten types: <25% cultivated land, >25% cultivated land, forest, grassland, river, other water, urban construction land, rural settlements, other construction land, and unused land. The urban land use in the study area was selected using ARCGIS 9.2 software.

Methods

At present, many methods have been developed to study urban expansion, but the scope and direction of the expansion of local urban construction land need to be further studied. The urban construction land in the Chongqing urban area showed a circular expansion mode and a strong directional preference. In this study, the study area was divided into nine buffer zones and eight quadrants, the compactness of the urban construction land in different buffer ranges and different directions was analyzed, and the compactness degrees and different gradients was fitted by gradient analysis.
Gradient Analysis

Gradient analysis is an effective method for measuring urban construction land expansion. At present, gradient analysis is widely used in the measurement of landscape changes and land-use changes (Gong and Xia 2007; Chen et al. 2008; Li et al. 2010; Cao et al. 2011). In the process of urbanization, the distance to the center of an urban area can be used to measure the spatial characteristics of urbanization. The center of the urban area is surrounded by asymmetric circles. The magnitude of landscape change will decrease with the expansion of the circle, which will cause a gradient effect. The gradient paradigm is a useful method to study the ecological effects of urbanization (Li et al. 2009). A buffer zone is a zone that does not exceed a certain distance from an object boundary, point, or point group (Wu et al. 1999). It is helpful to build buffer zones for gradient analysis, which provide quantitative references for determining the urban center (Sun et al. 2006). Gradient effects and gradient analysis can reveal the direction of urban expansion, the spatial patterns of urban expansion, and trends of urban development (Gong and Xia 2007).

It is important to determine the center of the urban area or the buffer zones. In this analysis, we chose the intersection of the Jialing River and Yangtze River as the center of the urban area and buffer zones. The Chongqing urban area has been divided into three parts by the City Planning of Chongqing (2005–2020). These three parts are divided according to the intersection of the Jialing River and Yangtze River. The northern part lies to the north of the Jialing River, the southern part to the east of the Yangtze River, and the western part lies to the south of the Jialing River and the west of the Yangtze River (PGCC 2005). In the Chongqing urban area, urban construction land had an organized structure surrounded by by-land formed by the intersection of the Jialing River and Yangtze River (Fan and Li 2012). The intersection is near the Jiefang Monument business center. The expansion of urban construction land showed an obvious direction (Cao et al. 2009). It is critical to use gradient analysis and buffer zones to reveal the expanding characteristics of urban construction land.

To determine the circular buffer zones, we established concentric buffer zones using the Buffer module of ARCGIS 9.2 software. The radii of the buffer zones were 0–5 km (R1), 5–10 km (R2), 10–15 km (R3), 15–20 km (R4), 20–25 km (R5), 25–30 km (R6), 30–35 km (R7), 35–40 km (R8), and 40–45 km (R9), which covered all the urban construction land of the Chongqing urban area and were numbered as shown in Fig. 2.

To determine the quadrant positions, we established a Cartesian coordinate system in ARCGIS 9.2 software using center 1 as the origin of the coordinates. Then, we further divided the four quadrants into eight quadrants by rotating the two axes 45° counterclockwise; the eight quadrants were (in counterclockwise order): north-northwest (NNW) or 0°–45°, west-northwest (WNW) or 45°–90°, southwest (SSW) or 90°–135°, south-southwest (SSE) or 135°–180°, south–southeast (ESE) or 180°–225°, east–southeast (ENE) or 225°–270°, east–northeast (ENE) or 270°–315°, north-northeast (NNE) or 315°–360°. They are labeled as shown in Fig. 2.

Compactness Degree

Compactness degree, which indicates the spatial concentration pattern of a city (Li and Yeh 2004), was used to depict the extent of urban aggregation. The compactness degree follows the morphology dependent principle, which states that the more circular the land, the higher the compactness degree (Cai et al. 2007). The expansion of urban construction land has two modes: infill expansion and extensional expansion. The development level of a city is determined not only by population and area, but also by the extent of urban aggregation (e.g., infill expansion) (Yu et al. 2004). As the empty spaces inside the urban area are gradually filled, the urban edge will become flat, so that the urban morphology should become more compact, whereas if the urban expansion is the extensional type, the morphology should be less compact. The external urban contour is determined by urban expansion and is essential for the analysis of urban socio-economic problems. Urban surface morphological changes can affect the planning and construction of transportation, communication, production,
and life. The compactness of urban surface morphology is an important concept that reflects the urban morphology (Liu et al. 2003) and can be calculated as follows:

$$CD = 2\sqrt{\frac{\pi U}{C}}$$

where $CD =$ urban compactness degree; $U =$ area of urban construction land; and $C =$ contour perimeter of the urban construction land. Urban construction land and contour perimeter were automatically calculated by the ARCGIS 9.2 software. Usually, the $CD$ value ranges between 0 and 1. The higher $CD$ value represents more compact morphology, and vice versa.

**Results**

**Changes in the Area of Urban Construction Land**

The changes of urban construction land in the Chongqing urban area between 1975 and 2010 were divided into two periods. The first period was from 1975 to 2000. During this period, the area of urban construction land increased by 3309.22 ha. The average annual rate of increase remained stable at 0.74% from 1975 to 1987, 0.73% from 1987 to 1995, and 0.83% from 1995 and 2000. The second period was from 2000 to 2010, during which the area of urban construction land sharply increased by 4126.31 ha with an average annual rate of increase of 5.69%.

Meanwhile, the proportion of total urban land classified as urban construction land also gradually increased, with a similar pattern to that of the changes in urban construction land. From 1975 to 2000, the proportion slowly increased from 2.67 to 3.27%, whereas from 2000 to 2010, the proportion sharply increased to 4.39%.

**Spatial Changes in Urban Construction Land**

The urban construction land of the Chongqing urban area is largely distributed along the Yangtze and Jialing Rivers and at their intersection (Fig. 3). As shown in Fig. 3, the southwest-northeast-oriented river is the Yangtze River, and the northwest-southeast-oriented river is the Jialing River, which is a tributary of the Yangtze River. The intersection of the two rivers in the Chongqing urban area is called Chaotianmen. From 1975 to 2000, urban construction land showed a spatial mode of one center and three subcenters. Center 1 showed stable spatial changes. Subcenter 2 was far from the center and was developed in 1975, and thus showed stable changes between 1975 and 2000. Subcenter 4 was close to...
center 1. Subcenter 4 and, especially, subcenter 3 were gradually developed. In 2010, the urban construction land showed a spatial mode of one center and four subcenters, and subcenter 3 was spatially connected to center 1 and subsequently formed a new subcenter 5. The entire Chongqing urban area exhibited a bottle shape.

Expansion of Urban Construction Land

The urban construction land maps and the buffer map were integrated and resampled to obtain the area and perimeter of the urban construction land patches in each buffer zone. The compactness degree in a buffer zone was calculated using Eq. (1). In the process of calculating, $U$ was the total urban construction land area in one buffer zone or in one quadrant azimuth, $C$ was the summation of perimeter of all urban construction land patches in one buffer zone or in one quadrant azimuth. There is one $CD$ in one buffer zone or in one quadrant azimuth.

Urban Construction Land Expansion in the Buffer Radius Gradient

The trends of the buffer radius gradient are shown in Fig. 4. From 1975 to 2010, the compactness degree of the urban construction land in each period showed similar changing patterns among buffer radii 1–8. The compactness degrees gradually decreased in buffer radii 1–3, indicating that the urban construction land became less compact. However, the compactness degrees increased in buffer radii 3–5, indicating that the urban construction land became more compact. Buffer radius 6 had no construction land, and subsequently became the boundary of the central city and small towns. The compactness degrees gradually increased in buffer radii 7–8, indicating that the urban construction land became more compact. In buffer radius 9, the compactness degrees showed large variation.

Within a 15-km range from the center of the buffer area, the compactness degrees decreased with increasing distance from the center, whereas within the 15–25 km and 30–40 km ranges, the compactness degrees increased with increasing distance from the center.

The scatter diagram of compactness degree and the buffer radius of each year indicated that the scatter points of 1975, 1987, 1995, and 2010 were highly similar (Fig. 5). Furthermore, for 2010, the scatter points of buffer radii 1–8 showed a high similarity to other years. Further analysis revealed that the compactness degree and the buffer radius showed a very high fitting degree in each year, which is shown as follows:

$$CD = A_1 R^6 + A_2 R^5 + A_3 R^4 + A_4 R^3 + A_5 R^2 + A_6 R + C$$

where $CD = $ compactness degree in a buffer zone; $R = $ radius of a buffer zone; $C = $ constant; and $A_1$–$A_6$ are coefficients.
The coefficients of different years were very similar between 1975 and 1987 and between 1995 and 2000. However, the coefficient of 2010 was very different from other years, most likely because buffer radius 9 of this year showed a sharply increased compactness degree. Furthermore, the coefficients of each year showed the same polarity, indicating consistency of the fitted curves.

Urban Construction Land Expansion in the Quadrant Angle Gradient

The trends of quadrant angle gradient analysis are shown in Fig. 6. The compactness degree of the urban construction land in each year showed a U shape. In quadrant 1, the compactness degree remained at 0.3514 between 1975 and 2000, and decreased to 0.2845 in 2010. In quadrant 2, the compactness degree increased from 0.1492 in 1975 to 0.2098 in 2000, and then decreased to 0.1396 in 2010. In quadrant 3, the compactness degree increased from 0.1639 in 1975 to 0.1759 in 2000, and then decreased to 0.1280 in 2010. In quadrant 4, the compactness degree increased from 0.1019 in 1975 to 0.1219 in 2000, and then decreased to 0.1117 in 2010. In quadrant 5, the compactness degree increased from 0.1010 in 1975 to 0.1205 in 1995 and then decreased to 0.1140 in 2010. In quadrant 6, the compactness degree increased from 0.0923 in 1975 to 0.1135 in 2000, and then decreased to 0.0981 in 2010. In quadrant 7, the compactness degree remained at 0.2711 between 1975 and 2000 and then decreased to 0.1979 in 2010. In quadrant 8, the compactness degree remained at 0.4475 between 1975 and 2000 and then decreased to 0.3480 in 2010. During the whole study period, the compactness degree decreased for quadrants 1, 2, 3, 8, and, especially, 7, which was reduced by

\[
CD = \sum_{i=1}^{n} (R_i - \mu)^2
\]

\[
R^2 = \frac{\sum_{i=1}^{n} (Y_i - \bar{Y})^2}{\sum_{i=1}^{n} (Y_i - \bar{Y})^2}
\]

\[
Y_i = b_0 + b_1 X_i + \epsilon
\]

\[
R^2 = 1 - \frac{\sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2}{\sum_{i=1}^{n} (Y_i - \bar{Y})^2}
\]

\[
R^2 = \frac{\sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2}{\sum_{i=1}^{n} (Y_i - \bar{Y})^2}
\]

Fig. 5. (Color) Fitting of compactness degree and buffer radius

Fig. 6. Compactness degree of urban construction land in different quadrant gradients

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26.99%. Meanwhile, the compactness degree increased for quadrants 4, 6, and, especially, 5, which increased by 12.86%.

The scatter diagram of compactness degree and the quadrant azimuth of each year indicated that the scatter points of 1975, 1987, 1995, 2000, and 2010 were highly similar (Fig. 7). Further analysis revealed that the compactness and the quadrant azimuth showed a very high degree of fit in each year, which is shown as follows:

\[ CD = B_1D^3 + B_2D^2 + B_3D + C \]

where \( CD \) = compactness degree in a quadrant azimuth; \( D \) = angle of quadrant azimuth; \( C \) = constant; and \( B_1-B_3 \) are coefficients.

The coefficients of 1975, 1987, and 1995 showed very similar values and the same polarity. However, the coefficient of 2000 showed slightly different polarity from other years, largely because of the variation in the quadratic coefficient. By comparing the value for 2000 to that of 1995, we observed that the variation in the quadratic coefficient was mainly caused by the increased compactness in quadrants 2 and 3 and the increased difference between them.

\[ R^2 = 0.9279 \]

\[ R^2 = 0.9541 \]

\[ R^2 = 0.9655 \]

\[ R^2 = 0.9710 \]

\[ R^2 = 0.9258 \]

\[ R^2 = 0.928 \]

**Fig. 7.** (Color) Fitting of compactness degree and quadrant angle

### Discussion

**Spatial-Temporal Changes of Urban Construction Land**

The spatial morphologies of urban construction land expansion differ by urban area. In the Beijing urban area, the complex degree of urban construction land boundary increased, and the compactness degree decreased after 2001 (Mu et al. 2012). In the Shanghai urban area, urban construction land expanded in a multicore style after 2000 (Liu and Shen 2006). In the Guangzhou urban area, urban construction land expanded in multicore and multiaxis styles after 2000 (Zhou and Yan 2005). During urban construction land expansion, multicenter and organized expansions appear in the Chongqing urban area. From 1975 to 2000, urban construction land showed a spatial mode of one center and three subcenters.

In 2010, the urban construction land showed a spatial mode of one center and four subcenters. The concept of urban construction land is different from that of built-up land; therefore, the area of urban construction land is also different from that of built-up land. However, the expansion of the built-up land drove the expansion of urban construction land in the Chongqing urban area, and the rate of expansion of urban construction land was less than that of built-up land.
Distinct Stages of Urban Construction Land Expansion

In the process of urban construction land expansion, the morphological characteristics and internal dynamic mechanisms of urban construction land expansion were notably changed in an evolution of distinct stages (Liu and Shen 2006).


These urban areas share the same critical period of urban construction land expansion, which was after the year 2000, but the expansion in the Chongqing urban area was the largest. The increasing ratios of urban construction land in the Beijing, Shanghai, Guangzhou, and Chongqing urban areas were 45.30, 37.92, 35.96, and 71.64%, respectively (NBS 2002, 2012).

Other research has also indicated the presence of two stages, but the areas of urban construction land studied by others may be different from those in this report. The research area of this report includes all urban construction land in nine districts. The area of urban construction land increased markedly after the initiation of the reform and opening policy, especially after 1995 (Chen et al. 2002). Zhao and Yang (2008) demonstrated that the area of urban construction land was 943.30 ha in 1993, and occupied 5.85% of the total land. The area increased by 786.90 ha from 1993 to 2001, and by 1560.50 ha from 2001 to 2006. The rate of increase of urban construction land from 1993 to 2001 was two times faster than from 2001 to 2006. Fan and Li (2012) indicated that the dynamic degree of urban construction land expansion from 1986 to 2000 was 4.30%, and 21.70% from 2000 to 2007. Deng et al. (2010a) also showed that the area of urban construction land increased to 3290.70 ha from 1998 to 2007, and the area increased to 943.30 ha from 1978 to 1998; the increase in area in the former phase was six times larger than that in the latter phase. Furthermore, during urban construction land expansion, a large amount of cultivated land, especially on low-altitude plains, was occupied (Cao et al. 2009, 2013). Zhao and Yang (2008) indicated that the urban construction land was mainly from cultivated land, and the occupied areas from 1993 to 2001 and from 2001 to 2006 were 1528.00 ha and 469.40 ha, respectively.

**Gradient Differences of Urban Construction Land Expansion**

The gradient differences in urban construction land expansion are in the cycle and the direction. The Chongqing, Beijing, Shanghai, and Guangzhou urban areas showed expansion by cycle style and direction style. In the Beijing urban area, the urban construction land expansion proceeded in the cycle style and expanded along the ring streets (Xie et al. 2007). In the Guangzhou urban area, the urban construction land expanded in the cycle style with two cycles: one at 1–14 km from the center and the other at 15–26 km from the center (Ye and Zhou 2013). In the Chongqing urban area, the urban construction land expansion cycle style was less obvious than for the Beijing urban area and Guangzhou urban area.

The urban construction land had three buffer zones with high compactness degree, which were buffer zones 1, 5 and 8. The buffer radii were 5, 25, and 40 km, respectively, and the compactness degree increased gradually. Buffer zone 1 was the old urban area of Chongqing, which includes the Yuzhong district, Nan’an district, Bă’nan district, and its expansion had stabilized. From 1975 to 2010, the average annual rate of increase was 0.61% for the urban construction land area, and 0.56% for the land patch perimeter. Because of the landform confinement in the old urban area, there was little exterior expansion. Interior expansion from 1980 to 2010 increased the compactness degree (Huang et al. 2012). Buffer zone 5 had a small area of urban construction land, and showed the fastest urban expansion rate. From 1975 to 2010, the average annual rate of increase was 7.41% for the urban construction land area, and 1.02% for the land patch perimeter, lower values than other buffer zones. Buffer zone 8 had an even smaller area of urban construction land, and the average annual rate of increase was 0.66% for the urban construction land area and 1.05% for the land patch perimeter. Due to the quadratic effects of compactness degree on the urban construction land area, the compactness degree of buffer zone 8 was larger than that of buffer zone 5. The compactness degree of buffer zone 3 was the smallest because of the exterior expansion in the Yubei district and Bă’nan district. The expansion index in the Yubei district was the highest, at 0.41 from 2000 to 2005, and it became the first expansion core (Cao et al. 2009).

In the direction style, the directions of urban construction land expansion were to the east and north of the Beijing urban area, and east was the main expansion direction (Xie et al. 2007). In the Shanghai urban area, the main expansion directions were to the east and the south (Quan et al. 2011). The direction was obvious in the Chongqing urban area, and quadrants 45°–90° (WNW), 90°–135° (WSW) and 315°–360° (NNE) were the key regions of urban expansion.
The compactness degree gradually decreased in the Chongqing urban area, starting from quadrant 1 and reached the smallest values at quadrant 6. These quadrants included the Yubei, Beibei, Shapingba, Dadoukou, and Nan’an districts. Huang et al. (2012) and Hu et al. (2012) demonstrated that the expansion in the Dadoukou district was the fastest before 1997, after which the obvious expansion regions were the Yubei, Shapingba, Nan’an, southwestern Dadoukou, and Beibei districts. Following these expansions, the compactness degrees started to increase. The compactness degrees of 2010 were the smallest for all quadrants. Within a 0–270° range of the coordinate system, the compactness degrees for all years decreased in a counter clockwise direction, indicating that the morphology of the urban construction land became less compact within this range, whereas within the 270–360° range, the compactness increased in a counter-clockwise direction, indicating that the morphology of the urban construction land became more compact.

Conclusions

1. During the process of urban construction land expansion, multicenters were formed and organized expansion appeared. Urban construction land expansion showed a spatial mode of one center and three subcenters from 1975 to 2000, and the urban construction land expansion showed a spatial mode of one center and four subcenters from 2000 to 2010. The urban construction land expansion in the Chongqing urban area from 1975 to 2010 occurred in two stages. The first stage was from 1975 to 2000, during which the area of urban construction land increased slowly. The second stage was from 2000 to 2010, during which the area of urban construction land increased sharply.

2. The expansion of urban construction land presented pronounced gradient effects, and the changes of compactness degrees were highly correlated with the changes in the buffer radius and quadrant azimuth. The urban construction land had three buffer zones of high compactness degree: buffer zones 1, 5, and 8. The buffer radii were 5, 25 and 40 km, respectively. The quadrants 45°–90° (WNW), 90°–135° (WSW), and 315°–360° (NNE) were the key regions of urban expansion. The compactness degrees gradually decreased, starting from quadrant 1, and reached the smallest values at quadrant 6. Following that, the compactness degrees started to increase. Quadrants 2 and 3 were the key regions of urban expansion, and quadrants 5 and 6 were the nonkey regions. The key regions showed higher compactness degrees than the nonkey regions, but the compactness degrees decreased in the key regions as they increased in the nonkey regions.

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