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Spatiotemporal patterns of urbanization over the past three decades: a comparison between two large cities in Southwest China

Wenyuan Qu · Shuqing Zhao · Yan Sun

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Abstract China's economic development over the past three decades has been remarkable due to the establishment of the "Reform and Opening-up" program. Meanwhile, urbanization, one of the most intensive human activities, has significantly changed the land cover across China. Here we used remote sensing data and landscape metrics to explore the spatiotemporal patterns of urbanization in two large Chinese cities, Chengdu (1978–2010) and Chongqing (1976–2010). Results suggested that urban land in both cities experienced a significant growth and became 9.8 and 6.3 times larger than the initial for Chengdu and Chongqing, respectively. The edge-expansion was the major urban growth form for both cities, accounting for more than 40 % of total three types (i.e., edge-expansion, infilling, and outlying) although fluctuating during the whole period. Both cities started a spurt growth in the 1990s although the starting times were different (1992 and 1996 for Chengdu and Chongqing, respectively) because of different policies. Spatial distribution of the newly developed urban lands was largely constrained by topography. Landscape analysis not only revealed an increasing fragmentation and complexity in the study area under the impact of urbanization, but also tested the hypothesis on urbanization patterns.

Keywords Urban growth · Landscape metric · Remote sensing · Chengdu · Chongqing

Introduction

After a marvelous increase over the last 200 years, the total number of world population has been over seven billion as October 31, 2011 (http://www.chinanews.com/). Urban population in the world has a bigger rate of growth than the rural population and nearly 60 % of the world's people will crowd into urban regions by 2030 (UN 2012). In the meantime, the area of urban land around the planet has become bigger and bigger owing to a rapid urbanization process, which can be defined as a dynamic land cover transformation from non-urban land types to urban land by human activities (Ramachandra and Bharath 2012; Xu et al. 2012).

W. Qu · S. Zhao (✉) · Y. Sun
College of Urban and Environmental Sciences, and Key Laboratory for Earth Surface Processes of the Ministry of Education, Peking University, Beijing, China 100871
e-mail: sqzhao@urban.pku.edu.cn

With an impressive growth momentum, this process has had a huge impact on our daily life as well as on the environment where we live in, such as air pollution (Meyer and Turner 1992; Civerolo et al. 2007; Shen et al. 2008), water pollution (Jeong 2001; Foley et al. 2005), increase in anthropogenic greenhouse gas emissions (Liu and Deng 2011), urban heat islands (Zhou et al. 2004; Chen and Zhang 2013), and reduction of biodiversity (Pauchard et al. 2006). Therefore, characterizing the spatial and temporal patterns of urbanization is an essential basis to understand the urbanization process and its impacts.

Remote sensing data provide long-term spatially explicit observations with global-scale covers and high spatial resolution (Ward et al. 2000; Weng 2002; Groom et al. 2006), which has made detecting urbanization easier and more frequent. Landscape metrics (indices) can help characterize the spatiotemporal patterns of urbanization (Aguilera et al. 2011; Wu et al. 2011; Angel et al. 2012). With increased availability and improved quality of multi-spatiotemporal remote sensing data and development of landscape metrics, many researches have been carried out to quantify the patterns of urbanization in different regions and on different scales (Liu et al. 2004; Shen et al. 2008; Jerzy 2009; Frondoni et al. 2011; Xu et al. 2012).

China has experienced a rapid urbanization since the establishment of the “Reform and Opening-up” policy in the late 1970s (Song and Timberlake 1996). Previous studies on urbanization of China have been mainly focused on the metropolitans like Beijing and Shanghai (Zhao et al. 2006; Li et al. 2012; Xu et al. 2012) and southeastern coastal regions (Seto and Fragkias 2005; Gong et al. 2009; Ma and Xu 2010; Su et al. 2011), where urbanization started earlier and urban growth was faster triggering by central government policies. There were relatively few ones documenting the urban dynamics in the western inland of China whose urbanization lagged behind considerably (Schneider et al. 2005; Mu et al. 2008). However, in the late 1990s Chinese government implemented the “Go West” program, with one of the central task is to industrialize and modernize the western cities in China. As a result, many of the western cities are likely to step into a rapid urbanization process, suggesting the knowledge of urban dynamics in the west, especially a comparison among cities would be an integral part of a comprehensive understanding on urbanization in China. In this study, we quantified and compared the spatial and temporal patterns of urban growth in Chengdu and Chongqing, two inland cities in western China, over the past three decades using both remote sensing data and landscape metrics. Chengdu and Chongqing used to belong to the same province, Sichuan, but with distinct landforms (as a plain city and mountainous city for Chengdu and Chongqing, respectively) and political status (Chongqing became the municipality directly under the central government in 1997) in the history. This suggests Chengdu and Chongqing should be the ideal locations for a comparison of urbanization among the western cities.

Data and methods

Study areas

The study areas were two large cities in the western China: Chengdu and Chongqing, which used to belong to the same province, Sichuan (Fig. 1). Chengdu, located at the west of Sichuan basin, with a history of more than 2,500 years, is the capital of Sichuan Province with a total area of 12,121 km^2 (30°05′~31°26′ N, 102°54′~104°53′ E) (Schneider et al. 2005). Chongqing is one of the four municipalities (others are Beijing, Shanghai and Tianjin) directly under the central government of China, which was originally under the jurisdiction of Sichuan Province

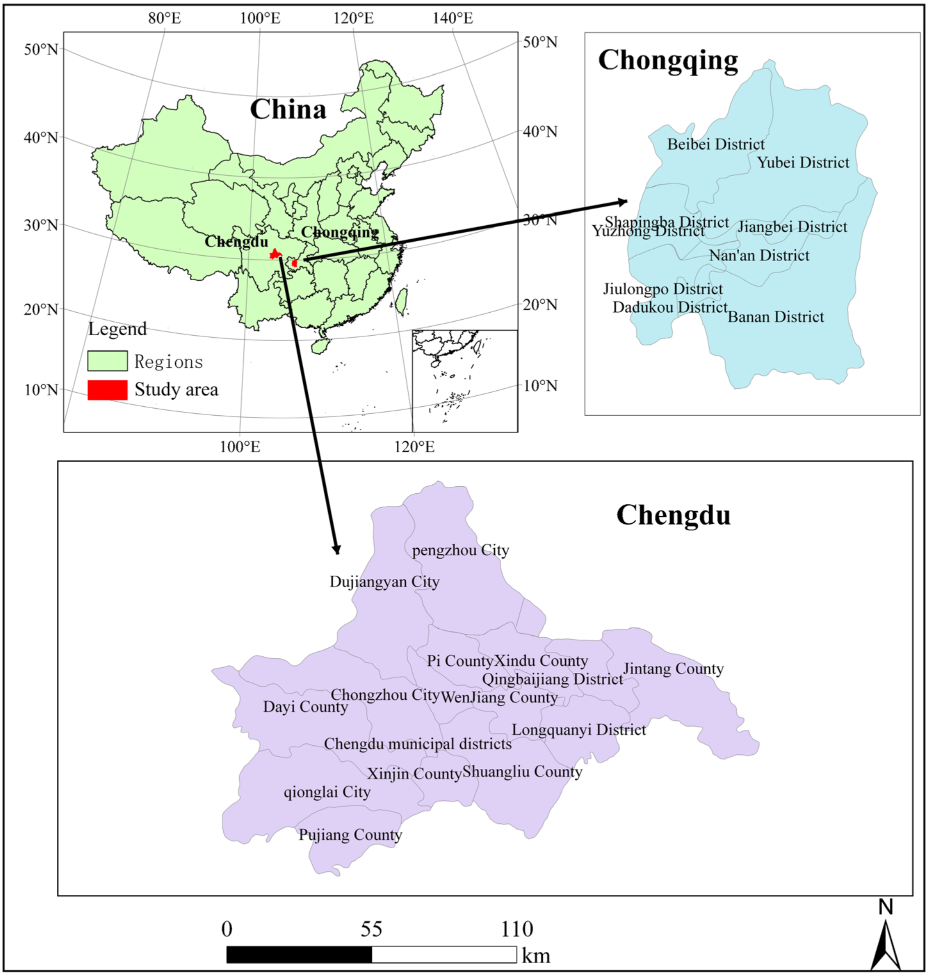

Fig. 1 The location of two large cities (Chengdu and Chongqing) in Southwest China

and became a municipality in 1997, covering an area of 82,400 km^2 (28°10′~32°13′ N and 105°11′~110°11′ E), including 40 districts and counties. We chose the major urban part of Chongqing municipality as our study area, which consists of nine districts (Dadukou, Nan'an, Yubei, Yuzhong, Banan, Jiangbei, Beipei, Jiulongpo and Shapingba) with an area of 5,465 km^2. These districts between Yangtze River and Jialing River are the traditionally defined Chongqing city. Both Chengdu and Chongqing were covered by "Go West" program, and Table 1 lists socio-economic indicators for representative cities of the targets of "Go West" program. Chengdu and Chongqing have a higher level of socio-economic development than other cities.

Remote sensing data and data processing

LANDSAT satellite images from the late 1970s to 2010 were used to acquire long-term information on Land Use and Land Cover Change (LUCC) of the study areas. The data

Table 1 Socioeconomic indicators for representative cities of the targets of "Go West" program

	Non-agricultural population (10^4)				Gross domestic product (10^8 [b])			
	1980	1990	2000	2010	1980	1990	2000	2010
Chengdu	192.0	251.0	345.9	650.9	46.3	194.1	1156.8	5551.3
Chongqing	373.3	493.0	660.9	1107.0	[a]	327.8	1791.0	7925.6
Kunming	114.8	148.2	189.2	412.1	19.1	115.2	636.1	2120.3
Xi'an	172.9	227.0	285.8	374.6	31.7	116.5	646.1	3241.7
Guiyang	[a]	[a]	152.4	185.5	[a]	[a]	264.8	1121.8
Lanzhou	100.2	127.1	159.8	202.9	25.7	77.9	300.3	1100.4
Xining	56.6	76.6	112.0	140.7	[a]	27.7	101.7	628.3

Sources: Chengdu Statistical Yearbook 2011, Chongqing Statistical Yearbook 2011, Kunming Statistical Yearbook 2011, Xi'an Statistical Yearbook 2011, Guiyang Statistical Yearbook 2011, Lanzhou Statistical Yearbook 2011, Xining Statistical Yearbook 2011, Xining Statistical Yearbook 2001, Xining Statistical Yearbook 1996

[a] means no data

[b] equals to 0.1653$

source for the year before 1980 and the year after 1980 were Multispectral Scanner (MSS) and Thematic Mapper (TM/ETM+), respectively. The specific information about path/row and date of these images are listed in Table 2. Images with least clouds and snow collected during the period from June to September were selected to make sure a high quality of LUCC map.

Land cover classification maps were produced using ERDAS Imagine version 9.3 which is a professional software for processing remote sensing data. As the issues of urbanization were the primary focus of our study, the land covers were divided into five types (Fig. 2): cropland, green land, urban land, water body and unused land (no unused land for Chongqing) using maximum likelihood method (Strahler 1980; Jensen 1986). Cropland is the lands used for crop

Table 2 The specific information about path/row and date of images for Chengdu and Chongqing

Path	Row	Period (Year-mouth-day)						
Chengdu		1978	1980	1992	1996	2000	2005	2010
129	39			1992-8-16	1996-7-10	2000-5-10	2005-3-5	2010-3-19
130	38			1993-6-7	1994-6-24	2000-3-30	2005-4-13	2010-3-18
130	39			1993-6-7	1994-6-24	2000-3-30	2006-5-2	2010-3-18
139	38	1978-8-3	1978-8-8					
139	39	1978-8-21	1980-4-6					
140	39	1976-3-14	1982-5-21					
Chongqing		1976	1979	1993	1996	2001	2005	2010
127	39			1988-6-4	1995-5-7	2000-7-31	2006-8-9	2010-8-12
127	40			1988-6-4	1995-5-7	2000-7-31	2004-8-3	2010-10-31
128	39			1993-5-24	1996-6-17	2001-5-22	2006-9-1	2010-9-20
128	40			1988-9-15	1996-6-17	2001-5-22	2004-9-1	2010-9-20
137	39	1977-9-2	1978-8-19					
137	40	1976-10-31	1979-11-3					

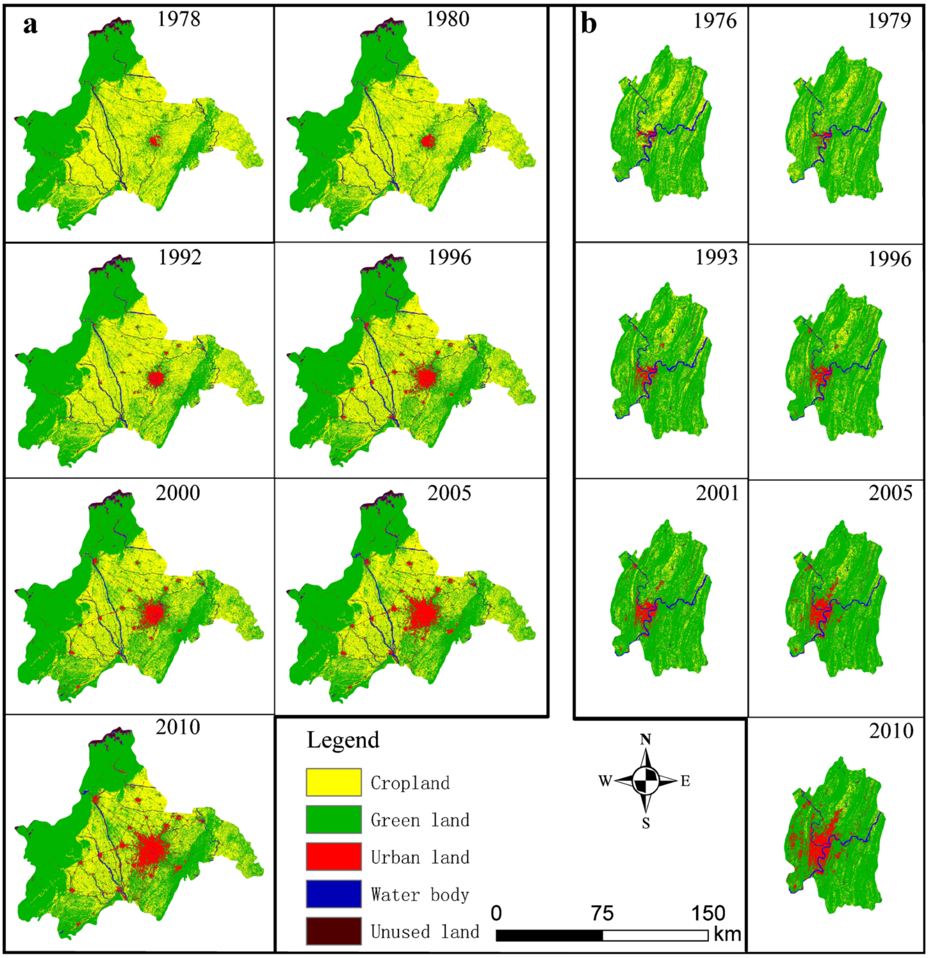

Fig. 2 Spatial distribution of land cover changes in Chengdu (**a**) and Chongqing (**b**) during the study period

cultivation. Green land contains forest, grass land and garden plots. Urban land includes built-up land, transportations, hydraulic structures in countries and cities. Water body consists of rivers, lakes, channel, and ponds. Unused land refers to the mountain top without any vegetation. MSS images were resample to the resolution of 30 m×30 m to keep consistent with that of TM images. ArcGIS version 9.3 was used for some post-classification processing and mapping.

Accuracy assessment is a vital step to validate whether the land cover classification map is reliable, and generating an error matrix is the most important part for the analysis of accuracy (Foody 2002). Information provided by Google Earth Pro® (GE) was used as the reference data to produce the error matrix (Luedeling and Buerkert 2008). The accuracies of classification results of 2010, and those before 2010 were assessed for each city following the approach of Zhou et al. (2012), and the Kappa coefficients were calculated through the error matrix. Results showed that the overall Kappa coefficients were more than 0.80 for both cities, and the value of Kappa coefficients for urban land were more than 0.85 (Table 3).

Table 3 Accuracy assessment for image classifications of Chengdu and Chongqing

Land cover types	Kappa coefficient			
	Chengdu		Chongqing	
	Prior 2010	2010	Prior 2010	2010
Cropland	0.78	0.73	0.67	0.67
Green land	0.71	0.77	0.88	0.78
Urban land	0.98	0.86	0.88	0.85
Water body	0.95	0.83	0.98	0.95
Unused land	0.72	0.91	[a]	[a]
Overall	0.82	0.81	0.84	0.80

[a]means no data

Data analyses

Annual rate of urban growth

To make a comparison between Chengdu and Chongqing, annual urban growth rate (AGR) was calculated through the following equation to remove the size effect of city:

$$AGR = 100\% \times \left((A_{end}/A_{start})^{1/d} - 1 \right) \tag{1}$$

AGR is the annual rate of urban land expansion, A_{end} and A_{start} is the extent of the urban land area at the start and end time of period, respectively, and d is the time span of the study in years.

GIS spatial analyses of urbanization

Detailed spatial patterns of urban growth were analyzed through the following two steps implemented in ArcGIS version 9.3:

Firstly, the urban growth types including outlying, infilling and edge-expansion were defined according to the following equation (Xu et al. 2007):

$$E = L_{com}/P_{new} \tag{2}$$

E determines urban growth type, P_{new} is the perimeter of a newly developed urban patch, L_{com} is the length of common edge of this newly developed urban patch and existed urban patch or patches. The value of E will range from 0 to 1. Urban growth type is defined as infilling when $E>0.5$, edge-expansion when $0<E\leq0.5$, and outlying when $E=0$.

Secondly, the urbanization intensity index (UII) was generated to reveal a spatially explicit distribution of urban growth (Li et al. 2010). The following equation was used to calculate UII:

$$UII_i = \left(\frac{UA_{iL} - UA_{iF}}{TA_i} \right) \times \frac{1}{N} \tag{3}$$

To achieve an efficient spatial recognition of the results, a 2 km×2 km grid was created for the land cover map of each city. In Eq (3), i is a code for each grid unit, and UII_i means the index of urbanization intensity for each unit i, UA_{iL} and UA_{iF} represents the total urban area of unit i in the last year and the first year of our study period respectively, TA_i is the total area of unit i and N stands for the length of the study period. The values of UII were divided into five classes by a custom standard <10 %, 10–25 %, 25–45 %, 45–70 %, 70–100 %, which corresponds to the urbanization intensity of very low, low, moderate, high and very high, respectively.

Landscape metrics

The metrics of landscape pattern and structure were calculated to examine the impact of urbanization using FRAGSTATS 3.3 (McGarigal and Marks 1995). The criteria for selecting landscape metrics were that the metrics should be relevant to the objectives of the study and are not redundant (Riitters et al. 1995; Wu et al. 2011). Six landscape metrics: Mean patch size (MPS), Patch density (PD), Shannon's diversity index (SHDI), Mean patch fractal dimension (MPFD), Contagion index (CONTAG) and Landscape shape index (LSI), and six class-level indices: Mean patch size (MPS), Patch density (PD), Edge density (ED), Number of patches (NP), Mean patch fractal dimension (MPFD) and Large patch index (LPI) for urban land were chosen in this study (Table 4).

Table 4 Landscape metrics description in the study modified from Wu (2007)

Landscape metric	Abbreviation	Description	Application scale	Unit
Number of patches	NP	The total number of a certain patch type or whole landscape.	Class/landscape	#
Mean patch size	MPS	The total area of a certain patch type (or whole landscape) divides by the NP of this class (or whole landscape)	Class/landscape	ha
Patch density	PD	The number of patches per square kilometer (i.e., 100 ha)	Class/landscape	#/100 ha
Edge density	ED	The total edge (unit: m) of all patches divides by the total area of whole landscape (unit: m^2), then multiplies by 10^6.	Class/landscape	m/ha
Large patch index	LPI	The area of the largest patch of whole landscape (or a certain patch type) divides by total area of landscape, and then multiplies by 100.	Class/landscape	%
Landscape shape index	LSI	An index for the shape complexity of the whole landscape or a certain patch type that Created by the modified perimeter-area ratio.	Class/landscape	
Mean patch fractal dimension	MPFD	An index for the shape complexity of the whole landscape or a certain patch type that equals to the arithmetic mean of the sum of each patch fractal dimension.	Class/landscape	
Shannon's diversity index	SHDI	An indice for the landscape heterogeneity which is created by the area of each patch type.	landscape	
Contagion index	CONTAG	A measures to depict the degree of agglomeration or the trend of extension of different patch types in the landscape.	landscape	%

Results

Temporal changes of urban land

Both Chengdu and Chongqing have experienced an accelerating process of urbanization (Fig. 3). The area of urban land in Chengdu increased from 75 to 807.9 km^2, with an annual increase of 22.9 km^2 during the period 1978–2010. In contrast, the size of Chongqing's urban land grew from 70.5 to 513.2 km^2 during the period 1976–2010, with an annual increase of 12.6 km^2 (Fig. 3a). Over the study period, annual urban growth rate (AGR) was 7.7 % and 6.0 % for Chengdu and Chongqing, respectively (Fig. 3b). When examining detailed temporal changes of urban land through the whole study period, we observed the magnitude of urban land growth varied with time, and a turning point (TP) when a very significant change occurred was found around 1992 and 1996 for Chengdu and Chongqing, respectively. As indicted in Fig. 3b, both cities had a higher growth rate after their TPs, especially for Chongqing. The values of AGR for Chengdu and Chongqing were 6.6 % and 3.7 %, 8.6 % and 15.2 % before TP and after TP periods, respectively. Although the AGR of urban land in Chengdu for the whole period was a little higher than that in Chongqing, this value after TP in Chongqing become almost twice as that in Chengdu.

Spatiotemporal changes of urban growth types

Figure 4 illustrated the composition of three different urban growth types (i.e., edge-expansion, outlying and infilling) for the newly developed urban land during two neighboring periods over the entire time period for Chengdu and Chongqing. The edge-expansion was the primary urban growth type for both cities during the study period (except the period 1976–1979 for Chongqing when outlying was the primary one), which accounted for more than 40 % of urban expansion, and the highest amount for Chengdu and Chongqing was 56.6 % during 1992–1996 and 60.5 % during 2001–2005, respectively. Over the whole study period the contribution of outlying for Chongqing showed a pendular pattern with the higher values in two ends (48.7 % in the period 1976–1979 and 33.7 % in the period 2005–2010). In contrast, the contribution of outlying for Chengdu came to a peak (41.0 % in the period 1992–1996) then went down and climbed to a lower peak again (33.7 % in the period 2000–2005). The infilling type was generally the least contributor to the total urban expansion for both cities. However, relatively high contribution of infilling occurred in the period 2000–2005 for Chengdu and 1993–1996 for Chongqing, which amounted to 24.0 % and 24.8 %, respectively.

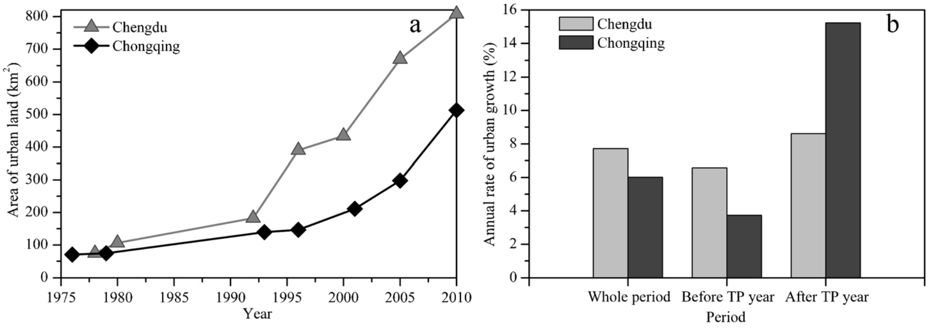

Fig. 3 Temporal changes in the area of urban land (**a**), and annual rate of urban growth (**b**) for Chengdu and Chongqing. The Turning point (TP) year for Chengdu and Chongqing was 1992 and 1996, respectively

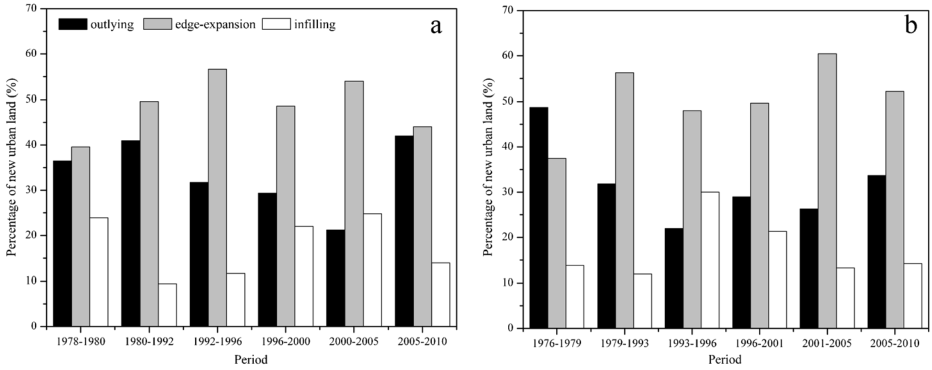

Fig. 4 The composition (%) of three urban expansion types for newly developed urban area in Chengdu (**a**) and Chongqing (**b**) among two neighboring periods

To further our understanding of spatial changes of three urban growth types, the spatial distribution map of three types among two neighboring periods were produced for both cities (Fig. 5). A multinuclear growth pattern was found in Chengdu whereas most of the new urban

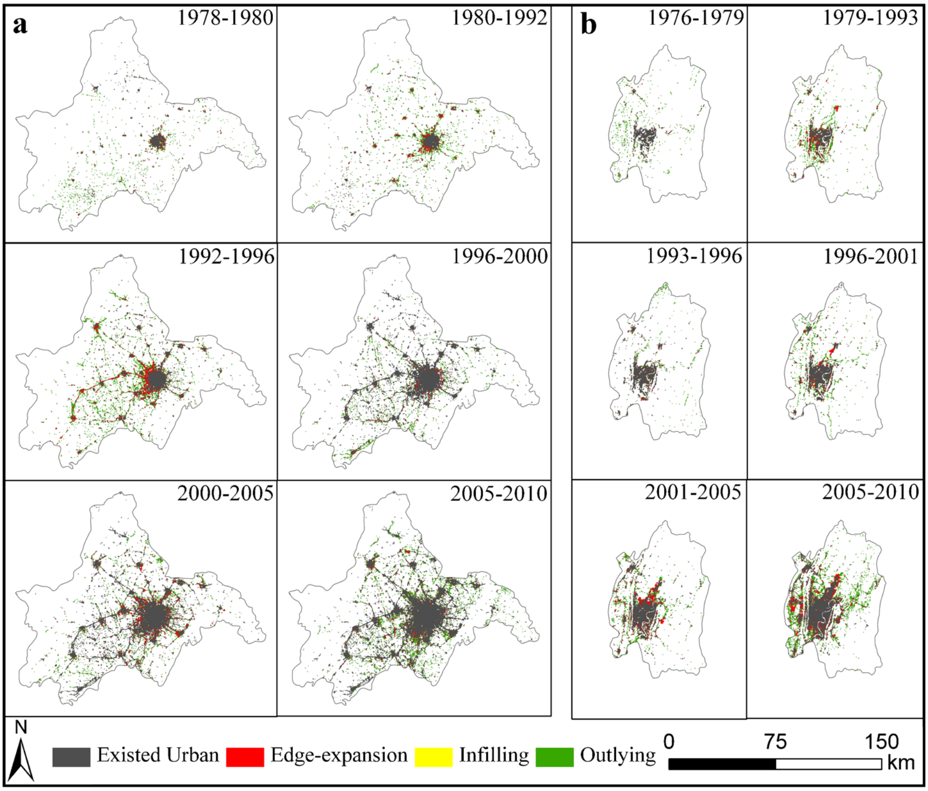

Fig. 5 Spatial distribution of three urban expansion types for newly developed urban area in Chengdu (**a**) and Chongqing (**b**) during the study period

land in Chongqing was developed around the initial urban area which was distributed in the intersection of two rivers in the region. As the primary growth type, edge-expansion mainly occurred towards the west and south of the existed urban land and formed a ring-growth pattern in Chengdu. Unlike the situation in Chengdu, edge-expansion growth was a south–north sprawl in Chongqing, and most of them comprised the main urban land at the south of Jialing River. The outlying growth in Chengdu mainly appeared in the plain area, west of main urban area. In Chongqing, the outlying urban growth mainly occurred around the main urban area till 2005 when it started to sprawl along with two rivers as well as toward the southwestern area. During the entire study period, infilling growth which was unremarkable in the map diatributed among the main urban area to integrate urban patches for both cities.

Distribution of urbanization intensity

Urbanization intensity index (UII) maps ranging from very low to very high for two cities were generated based on 2 km×2 km grid windows across the whole study areas (Fig. 6). Results revealed the similar trend during the entire period for both Chengdu and Chongqing that the areas were more adjacent to urban core were associated with higher growth intensity, as indicated by puce grids (high and very high intensity). In Chengdu the main urban growth occurred in the places around the urban core forming a pattern called "one city with multiple satellite towns" which was ever evidenced by Schneider et al. (2005), and the new urban especially spread toward the plain region, west of Chengdu. Whilst a totally different spatial pattern showed in Chongqing that urban growth with high (contained very high) intensity started from both sides of Jialing River between two mountains, Tongluoshan and Zhongliangshan, and then sprawled toward south and north.

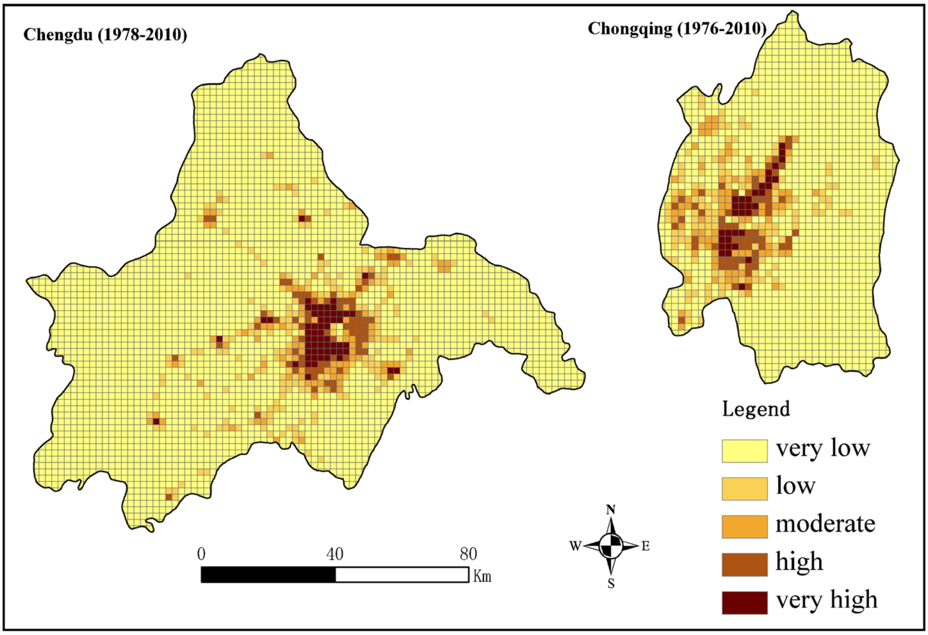

Fig. 6 Spatial distributions of urbanization intensity index (UII) for Chengdu and Chongqing during the study period

Landscape metrics changes

Changes in the entire landscape during urbanization

Under the impacts of accelerating urbanization over the past three decades, the landscape in both cities became fragmented as indicated by the decrease of MPS and increase of PD, and the magnitude of fragmentation was higher in Chengdu before 2004 and reversed afterwards (Fig. 7a, b). The values of CONTAG for both cities declined during the entire study period which gave another evidence for the fragmentation of the whole landscape in our study areas (Fig. 7c). With more human disturbance the entire landscapes in Chengdu and Chongqing became more evenly distributed among different land use types which can be seen by the increase of SHDI, especially for Chengdu whose value of SHDI became higher than Chongqing after the early 1990s (Fig. 7d).

To understand the change of the shape of the entire landscape in Chengdu and Chongqing, we calculated two indices, MPFD and LSI (Fig. 7e, f). MPFD increased firstly and then decreased for both cities, and this trend was especially obvious for Chongqing. However, the peak values occurred around different years for two cities, 1992 year for Chengdu and 2000 year for Chongqing. LSI showed an linear growth for Chengdu while an unimodal trend was

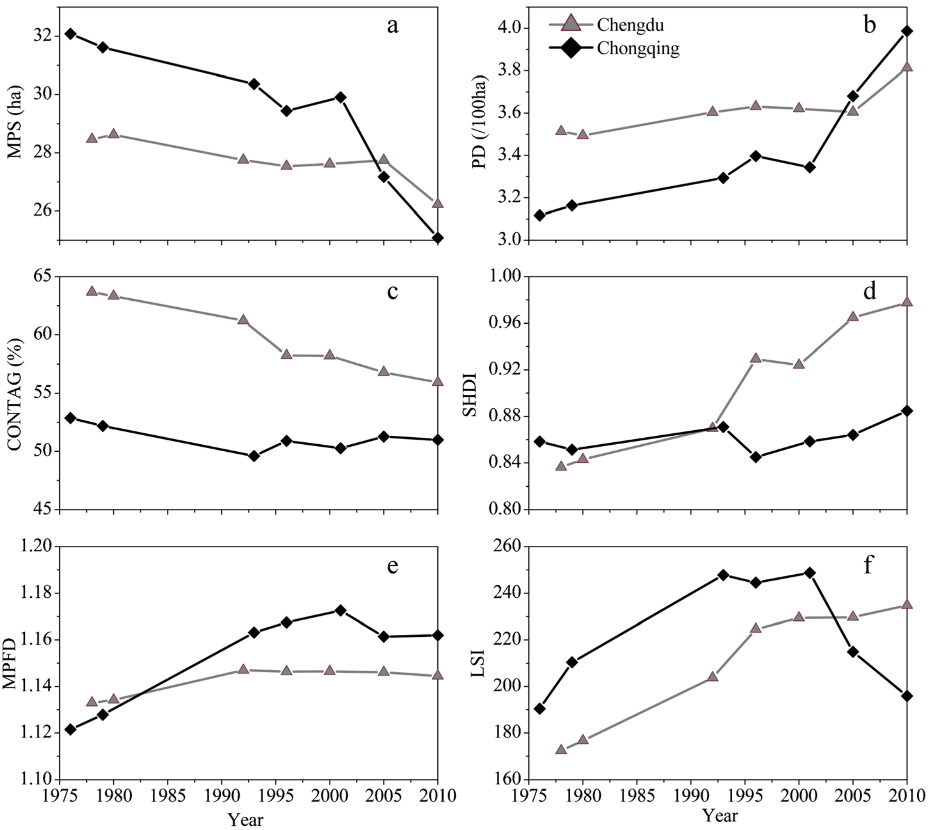

Fig. 7 Temporal patterns of six landscape metrics for whole landscape in Chengdu and Chongqing. **a** MPS, **b** PD, **c** CONTAG, **d** SHDI, **e** MPFD, **f** LSI

observed in Chongqing, suggesting the patches in the landscape become more irregular over the whole study period for Chengdu but become irregular first and then inerratic for Chongqing.

Changes in urban land

Six class-level landscape metrics were calculated to investigate the temporal patterns of urban land changes for both cities over the past three decades. Almost every metrics changed similarly for Chengdu and Chongqing. NP, PD, and ED increased steadily first and then showed an explosive growth for both cities, indicating an increasing level of fragmentation of urban land (Fig. 8a, b, c). Except for a decrease in period 1976–1979 for Chongqing, MPS almost exhibited a similarly linear increasing curve until a drop in 2005 for both cities, revealing that the average value of urban land patch size started to become smaller after a long-term growth (Fig. 8d). LPI increased exponentially for Chengdu and Chongqing during the entire study period emphasizing an increasing urban growth in the urban core (Fig. 8e). For both cities, MPFD decreased in the period before 1980, and then kept a relatively steady increase, and the values of MPFD in Chongqing were always larger than those in Chengdu during the whole period (Fig. 8f).

Discussion

General trends of urbanization in two cities

Both Chengdu and Chongqing have experienced a rapid urbanization over the past three decades (Fig. 2). The areas of urban land became 9.8 and 6.3 times larger than the initial for Chengdu and Chongqing, respectively. The newly developed urban land of both cities was primarily converted from the cropland and green land, with a respective contributing rate of 76.1 and 23.2 % for Chengdu and 67.3 and 31.8 % for Chongqing. This is consistent with the results of many previous studies that urban areas expanded at the cost of agricultural land and natural lands (e.g., Zhao et al. 2006). A relatively slow urbanization was observed in both

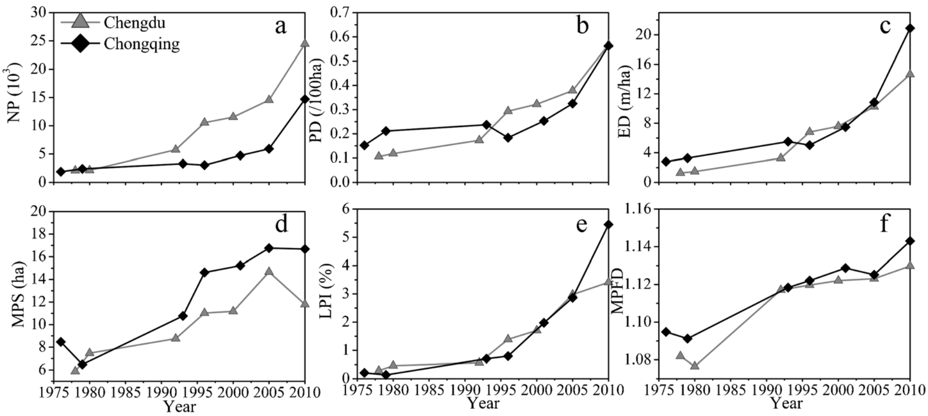

Fig. 8 Temporal patterns of six landscape metrics for urban land in Chengdu and Chongqing. **a** NP, **b** PD, **c** ED, **d** MPS, **e** LPI, **f** MPFD

cities before the 1990s, which might relate to China's urban development mode that the east coastal cities developed more earlier than those in-land ones, especially the cities in western China (Ji et al. 2001). The "Go West" program in China was initiated in the 1990s. As a result, the capital of the most populous province (i.e., Sichuan) in Western China, Chengdu began to take the lead in an explosive growth since 1992 (Schneider et al. 2005). In contrast, a very significant acceleration of urbanization in Chongqing had not occurred until 1996 which was possibly driven by the establishment of Chongqing municipality in 1997 when a series of significant and preferential investment brought from the central and local government (Han and Wang 2001; Long et al. 2008), resulting in a larger growth rate of urban land in Chongqing than that in Chengdu afterwards.

Spatially-explicit patterns of urban growth in two cities

A scattered new urban land in the initial periods (before the early 1990s) for Chengdu and Chongqing rapidly fragmented the landscape, which was corresponded to the second largest (1980–1992) and the largest (1976–1979) contribution of outlying type in Chengdu and Chongqing, respectively (Figs. 4 and 5). This might be mainly attributed to the start of the "Reform and Opening-up" policy as well as the availability of vast undeveloped non-urban land. As the urbanization proceeded, the main urban sprawl moved to the urban core along the ring roads, the middle of our study area (including satellite towns in Chengdu), with an increasing contribution of edge-expansion, which was similar to the situation in Beijing (Xie et al. 2007). In addition, fresh roads connecting main urban and satellite towns were created, as indicated by more linelike new built-up land appearing in Chengdu during 1992–2000, similar finding was observed in Guangzhou by Sun et al. (2013). Fragmentation of landscapes in both cities was increased by the urban expansion along both sides of roads around (in Chengdu) or across the old urban regions (in Chongqing) (Han and Wang 2001). With the "Go West" program established in the 1990s, more industrial parks and infrastructures were built in Chengdu which resulted in a persistent increasing infilling growth till 2005. However, it was the outlying rather than the infilling growth in Chongqing during the same period that experienced the persistent increase, which was possibly because of the different stages of urban development where these two cities were in. Urbanization process in Chongqing started later than Chengdu, and it was likely that Chongqing tended to spend more effort to gain a short-term development through outlying growth during that period (Cai et al. 2012).

Previous studies have found that topography condition was a critical factor affecting urban growth (Fang and Liu 2009; Maimaitiming et al. 2010), which was also observed in the urbanization process of our studied cities, especially in Chongqing (Fig. 2). Chengdu, as a capital city in Sichuan plain, its prominent increasing of urban growth occurred in rings and spread out towards the west and south after 1992 for not only the main urban region but also the satellite towns around, because of the existence of mountains in the east of urban core. In contrast, as a mountainous city situated in the intersection region of two large rivers, constrained by two mountains, urban lands in Chongqing were sprawling along the rivers and formed a scattered multinuclear growth pattern in the areas between two mountains, which was extremely different from Chengdu (Fig. 2).

A common trend of increasing outlying growth distributed far away from the old urban areas was found for Chengdu and Chongqing during the period 2005–2010 (Figs. 4 and 5), which might be attributed to the new policy of "Urban–rural Integrated Reform" established in recent years (Long et al. 2008), as well as the fact that the old urban areas were sufficiently urbanized and further urbanization had to explore new land. This new round increasing of outlying growth may lead to a new era of urbanization.

Spatiotemporal changes of landscape pattern in response to urbanization

As urbanization proceeds rapidly over the past three decades, the degree of fragmentation and discreteness of landscape at the levels of both entire landscape and urban land have been aggravated for both Chengdu and Chongqing, which was evidenced by an increase in PD, ED, and structural complexity (identified by the MPFD) although the magnitude of these changes varied with city. This finding is consistent with the results of many previous studies implemented in other regions that urbanization tends to have a similar impact on landscape metrics, which is generally independent on the scale of cities (Weng 2007; Wu et al. 2011; Angel et al. 2012).

Dietzel et al. (2005) proposed a hypothesis of general urbanization process that an integrated cycle of urban expansion always consists of two distinct phases, diffusion and coalescence, and temporal patterns of several landscape metrics can be used to test the hypothesis. For example, the area of urban land will consistently increase no matter which phase the city steps on; High urban PD reflects the dominance of the diffusion process and once the coalescence begins the PD will decrease. An ever-increasing ED will be found in the diffusion phase and will reach the peak because of the arrival of coalescence process (Dietzel et al. 2005). Two peak values of CONTAG will occur at the start of diffusion and the end of coalescence and one least value will be found in the between (Wu et al. 2011). Using landscape metrics, Dietzel et al. (2005) and Wu et al. (2011) have corroborated this hypothesis of general urbanization process in the Houston metropolitan area, and Phoenix of the state of Arizona and Las Vegas of the state of Nevada, USA, respectively.

A consistent increase in urban land area (Fig. 3a), a general continuous increase in both PD and ED of urban land (Fig. 8b, c), and a monotonic decrease in CONTAG for both Chengdu and Chongqing over the past three decades (Fig. 7c) were observed in this study, which might suggest that the urbanization in these two cities were still in the early stage dominated by the diffusion process according to above-mentioned testable temporal patterns of landscape metrics for the hypothesis of general urbanization process. This was further supported by the fact that the contribution of infilling type to the newly developed urban land was the least one (averaged as 17.6 and 17.4 %, respectively for Chengdu and Chongqing) while outlying type accounted for an averaged value of 33.6 and 31.9 % during the entire study period (Fig. 4). In addition, Chengdu and Chongqing underwent similar changes of landscape patterns despite their different socioeconomic situation and topographic condition (Schneider et al. 2005; Mu et al. 2008).

Conclusions

Using both remote sensing data and landscape metrics, we illustrated the spatiotemporal patterns of urbanization in Chengdu and Chongqing over the past three decades. Results not only showed a dramatic growth in urban land but also an increasing fragmentation and complexity of landscape in both cities. Urban land became 9.8 and 6.3 times larger than the initial for Chengdu and Chongqing, with a respective annual urban growth rate (AGR) of 7.7 and 6.0 % over the past three decades, respectively. Although the AGR of urban land in Chengdu for whole period was a little higher than that in Chongqing, this value after Turning Point (TP) year in Chongqing become almost twice as that in Chengdu.

Spatially-explicit patterns of urban growth in two cities were identified. As the major urban growth type, edge-expansion accounted for more than 40 % of total three types (i.e., edge-expansion, infilling, and outlying) during the whole study period for both cities. Newly developed urban land in Chengdu especially for the main urban area formed a ring-road growth model with one-nuclear, while urban expansion in Chongqing primarily occurred along two rivers with a multinuclear growth model. Landscape metric analyses in this study verified the theory of urbanization process, diffusion and coalescence phases proposed by Dietzel et al. (2005). According to this theory, we found that Chengdu and Chongqing had been undergoing the stage of diffusion and just exhibited a symptom of the coalescence process. Many precious researches have found that whether a city is more disperse (diffusion) or more compact (coalescence) has important implications for the management of natural resources, energy demands, and infrastructure supported. Therefore, understanding which phrase Chengdu and Chongqing were situated at would be helpful for urban management there.

This study demonstrated the advantages of integrating remote sensing data with landscape metric to characterize spatial and temporal patterns of urbanization. Similarity and differences of general trends of urbanization and spatially-explicit urban growth patterns in Chengdu and Chongqing might provide insights for future efforts on a comprehensive understanding of urbanization in western China or whole China. More detailed researches in the near future can be tailored to explore the drivers, and ecological and environmental consequences of urbanization.

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