Quantifying the Type of Urban Sprawl and Dynamic Changes in Shenzhen

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Abstract. Urban sprawl is a hot topic of global concern with increasing dramatically and impact on ecological environment. But there is not a mature method to explain the detail of process of urban sprawl and dynamic changes. In this paper, the dynamic changes of urban is studied based on 1980, 1988, 1994, 2000 and 2005 five remote sensing images of Shenzhen. It is distinguished three types including infilling, edge-expansion and outlying using six landscape metrics related to character the urban pattern. Combining urban sprawl type and urban pattern makes deepen understanding of urban expansion. The results show that the urban area of Shenzhen increases rapidly with growth rate and it experiences urban sprawl phase. In the early stage, it is at the diffusion period with the outlying area in dominant place in sprawl type and landscape fragmentation aggravation showed by NP, LPI increasing in pattern. With the infilling and edge-expansion area increasing rapidly, the urban sprawl turns into coalescence period with good landscape connectivity and landscape fragmentation remission. The method of combining type of urban sprawl and landscape metrics is useful to determine the time of urban sprawl phase. The results can help urban plan and design.

Key words Urbanization; urban sprawl; land use/land cover; landscape metric; Shenzhen

1. Introduction

Urbanization is defined as rural land is converted to urban land use or other construction sites (Karen et al., 2005). The dynamic process of urbanization has led to fundamental changes with resulting in various impacts on the structures, functions, and dynamics of ecological systems at a wide range of scales (Sun et al., 2012).

Reasonable urban spatial pattern is of great significance to promote the sustainable development of cities. In recent studies, urban landscape index has been combined with remote sensing to explain the urban sprawl and dynamic changes, and another focus of researches is how the urban landscape indicators impact on results when it is applied to the multi-scale and multi-temporal data sets (Sun et al.,2012; Y et al. 2012).

However, there are considerable controversies on the definition of “urban sprawl”. The most universally accepted one is the characteristics of urban sprawl by Ewing. Forman (1995) thought that there were mainly three types in the process of urban sprawl including infilling, edge-expansion and outlying. Infilling means the non-urban area surrounded by urban being converted to urban. Edge-expansion refers to the newly developed urban area spreading out from the fringe of existing urban patches. The outlying growth tends to be distributed at a larger distance from existing developed areas (Sun *et al.*, 2012; Y *et al.* 2012). Technology about quantifying different urban growth types from remote sensing image has not been adequately investigated (Sun *et al*.,2012).

Hoffhine *et al.* (2003) first quantified three urban growth types from Landsat classification imageries. Xu *et al.* (2007) observed that the ratio between the length of common edge and patch perimeter could be used to distinguish them, but no spatial visualization of different urban growth types has been provided. Pham and Yamaguchi (2011) used a percentage of a like adjacency metric to generate the types. Liu *et al.* (2010) proposed Landscape Expansion Index (LEI) with buffer zone analysis. Sun *et al.* developed a quantitative method in order to identify and visualize different types. Each of the types is generated by a specific urban growth process, which may lead to different environmental impact.

In our study, the process of urbanization of Shenzhen is quantified in three types, and some landscape indicators that are relate to the sprawl types are calculated. Combining the type of urban sprawl and the landscape metrics to analyse the urbanization characteristics of Shenzhen between 1980 and 2005 is used.

2. Material and method

2.1. Study area

Economic development of Shenzhen was very slow in the three decades before the reform and opening up. But in 1979, the population and Gross Domestic Product (GDP) of the city have been 31.41 million and 196 million yuan respectively. In august of 1980, Shenzhen special economic zone officially proclaimed.

2.2. Data pre-processing

In our study, five remote sensing images of October 13, 1980(MSS), December 10, 1988(TM), November 8, 1994(TM), November 1, 2000(ETM+) and November 23, 2005(ETM+) are selected. The data pre-processing includes geometric rectification and extraction of study area which base the vector data of Shenzhen.

After the processing of classification, the land use system includes build-up area, arable land, forest, water body, orchard, shrub, wet land, vacant land. Since the focus of this study is urban growth, the classified land use types are further converted into the two classes: urban and non-urban. The rest operation aim at the urban areas only.

2.3. The type of urban sprawl

Based on Hoffhine *et al.* (2003) and Sun *et al.* (2011), a field called T is defined whose value equals the ratio of lc to l, and the lc is the common lengths between new-urban patches and old-urban patches and the l is the perimeter of the corresponding new-urban patches. The value of T is between 0 and 1. If $T>0.5$, it means that at least 50% of the new-urban patches is surrounded by the old-urban patch, and it represents the infilling type (Fig.1(a)); if $0<T<0.5$, the new-urban patches develop from the edge of the old-urban patches, and the common length is less than 50% of its boundary. This type is edge-expansion (Fig.1(b)); if T=0, it means that the new-urban patches have no spatial association with the old-urban patches, and this is outlying type (Fig.1(c)).

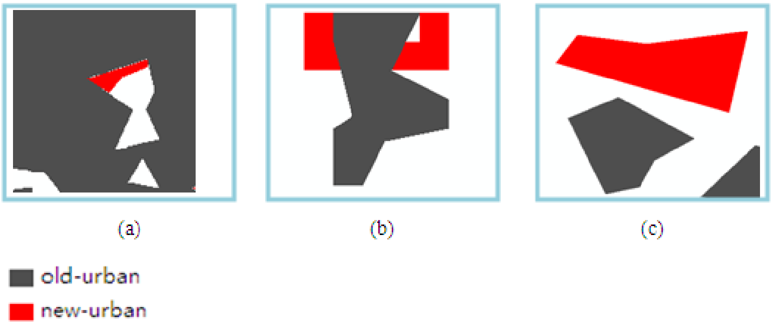

Fig. 1. the three types of urban sprawlAbstract.

2.4. Landscape spatial metrics

In our study, landscape metrics are selected based on the physical meaning of the indicators themselves, as well as its relationship with the type of urban sprawl.

Number of patches (NP) is one of the Area/Density/Edge metrics, and a measure of landscape fragmentation. Largest patch index (LPI) is also one of the Area/Density/Edge metrics, and a measure of patch dominance. Mean Euclidean nearest-neighbor distance (ENN_MN) is a metric of Isolation/Proximity and it describes landscape connectivity. Contagion index (AI) is a physics aggregation index. Mean patch size (AREA_MN) and landscape shape index can describe landscape fragmentation.

The spontaneous growth will result in increase of the number of patches (NP) and decrease of the contagion index (AI). Edge-expansion causes that largest patch index (LPI), mean patch size (AREA_MN) and contagion index (AI) increasing and mean Euclidean nearest-neighbor distance (ENN_MN) decreasing. Infilling will result in largest patch index (LPI), mean patch size (AREA_MN) and contagion index (AI) increasing. They are calculated about five raster data in Shenzhen based on landscape analysis software Fragstats 3.3.

3. Results

3.1. Monitoring urban sprawl area

The Tab.1 shows that the urban area base in 1980 of Shenzhen is only 12.3 km^2. During 1988-1994, the wide urban sprawl area has reached 234.9 km^2 (Tab.1) growing at an average annual rate of 39.15km^2/y. Between 1994 and 2000, the urban sprawl area increased to 268.8km^2 (Tab.1) at an annual rate 44.8km^2/y. The size of sprawl area continues to fall with discrete distribution during 2000-2005. Tab.1 shows that the annual change rate has been rising during study periods.

3.2. Quantifying the urban sprawl type

A series of maps are got who show the type distribution of urban areas changes (Fig.2). And for the detailed characteristics of urbanization, sprawl area of the three types are calculated during each period as the Fig.3 shows.

Table 1. specific urban sprawl area in Shenzhen

Time	Sprawl urban area（km^2）	Annual change rate(km^2/y)
1980	12.3	
1980-1988	163	20.38
1988-1994	234.9	39.15
1994-2000	268.8	44.8
2000-2005	265	53

As Fig.2(a) and Tab.2 show that during 1980-1988, there is no infilling area, and the dominant type is edge-expansion which is collective. The edge-expansion area mainly gathered in the south. The outlying area is discrete distribution in each zone (Fig.2(a)). Comparing to last time period, the area distribution of outlying type decreases slightly between 1988 and 1994(Fig.2(b)). The infilling and edge-expansion area both increase (Fig.3). The edge-expansion type is dominant and the outlying area is discrete as usual (Fig.2(b) and Fig.3). On the contrary, the rest of two types are gathered. As we can see in the Fig.2(b), the coalescence of urban area of the south Shenzhen is happening. The infilling area is the largest one (Fig.3). The outlying area appeared always in a small area of shape (Fig.2). Between 2000 and 2005, the urban area continues growing (Fig.3). The infilling area is still dominant and larger than the last period, whereas the rest two types both decreased (Fig.3). Shenzhen is merging to a whole large urban (Fig.2(d)).

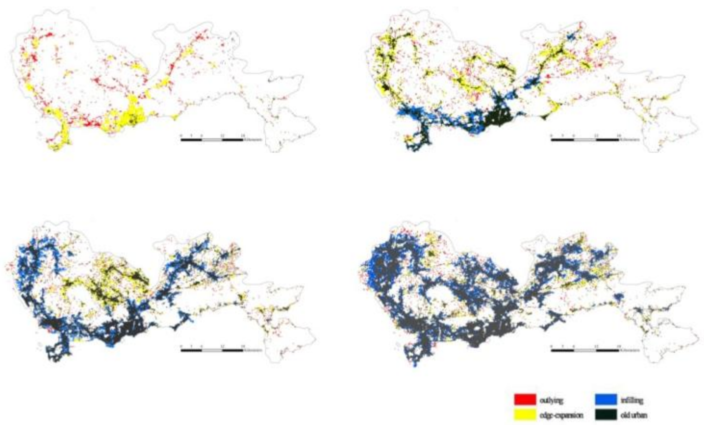

Fig. 2. spatial distribution of three sprawl types in Shenzhen during 1980-1988, 1988-1994, 1994-2000 and 2000-2005 four periods respectively

3.3. Changes in the spatial pattern of the whole landscape

The spatial metrics can show the spatial pattern during urbanization. The resolution of 30m×30m is only selected which is certified as the finest one by Wu et al.(2010).The spatial metrics changing graph in Tab.2show the characteristic of the urban growth dynamics patterns.

LST rises steadily during 1980-2000 and decreases slightly after 2000(Tab.2). LPI and AREA_MN increase exponentially during urbanization (Tab.2). AI increases steadily for the two stages of the boundary in 1988(Tab.2). With the emergence of the new urban center, urban patches merge and boundaries of urban areas dissolve gradually.

Table 2. the trend of three types area in each period

Time	LPI	LST	NP	AREA_MN	ENN_MN	AI
LPI	5.6226	18.6107	291	4.5875	797.2751	85.3953
1988	29.4629	31.837	723	23.5697	401.5861	92.891
1994	40.4032	47.2713	1136	33.1193	287.1715	93.7575
2000	50.3377	43.1191	1145	49.9471	262.1326	94.7072
2005	68.5713	41.5652	922	77.3067	288.5362	95.4362

4. Discussion

4.1. Characteristics of urban sprawl type

Fig.4 shows patch percents of three expansion types during Shenzhen urban growth. The phenomenon shows that the process of edge-expansion growth indicates the area rising weather the number of urban patch increasing or decreasing, whereas if the patches of outlying and infilling growth types rise, the urban area for the two types increase.

The urban growth of Shenzhen verifies the hypothesis postulated by Dietael et al.(2005). Between 1980 and 1988, the patch percent of outlying was 90% (Fig.4). In this period, the urban is in course of diffusion. However, the patch percent of edge-expansion is 10% (Fig.4). During the second period, there are infilling patches and the patch percent of outlying is still the biggest (Fig.4). During the rest periods, the patch percents of outlying are dominant (Fig.4), but the area sprawl is mainly edge-expansion and infilling especially infilling type whose patch percent is the least but area is the largest. The urban are alternating from diffusion to coalescence.

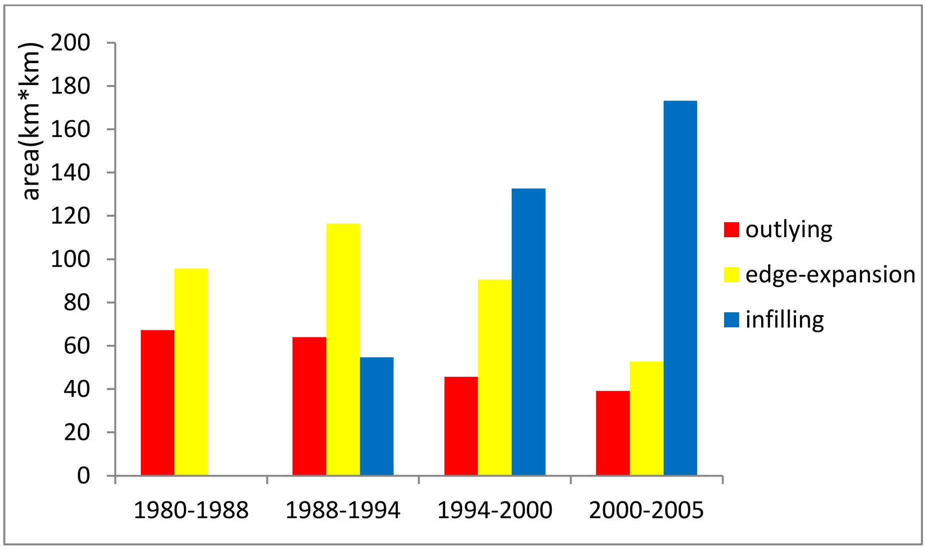

Fig. 3. the trend of three types area in each period

4.2. Dynamic changing of urban growth types along with landscape pattern

During 1980-1994, the rising of NP is very fast, and this is consistent with outlying patches increasing. The LPI and AREA_MN are also rising, and this is due to edge-expansion area sprawling. The change of LST, ENN_MN and AI indicates landscape fragmentation. However, the AI turns changing at 1988 when the infilling type grows, so the AI is relate to infilling growth.

During 1994-2000, the trends of LST, NP and ENN_MN change more slowly, while the infilling area is increasing faster. So it means the landscape fragmentation ease and the urban area become less dispersed in this period.

Between 2000 and 2005, the slope of LPI and AREA_MN are greater. The LST and NP are decreasing which show that the urban is experiencing coalescence. The ENN_MN increases slightly, and this indicates the aggregation of urban patches.

Shenzhen sprawl rapidly relates to policy of government and its own conditions in many respects. Our research provides the foundation for understanding the development of city driving force and impact on the environment.

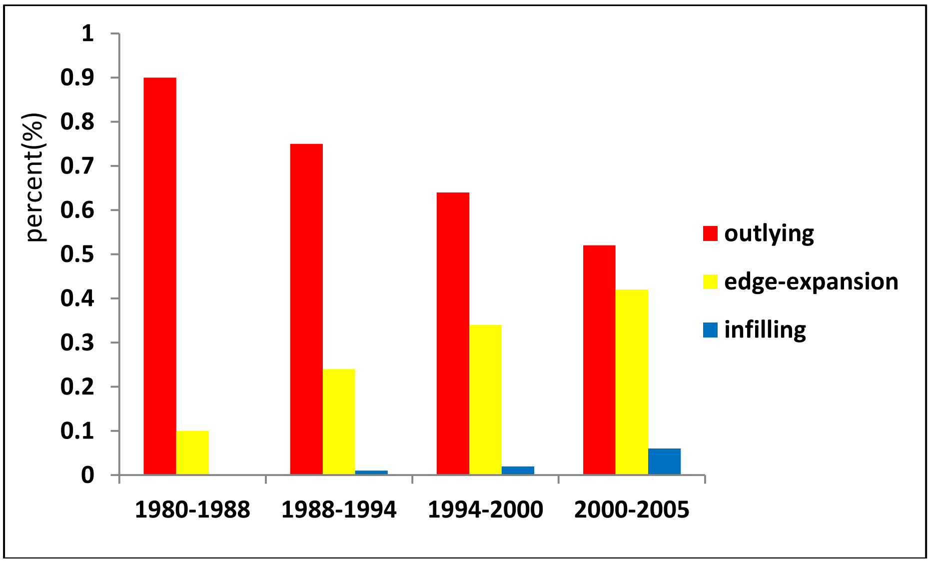

Fig. 4. patch percents of three types during Shenzhen urban growth

5. Conclusion

In our study, the type of urban sprawl is quantified and the dynamic changes of urban pattern is analysed. The method of distinguishing the types of urban sprawl is effective and Landscape metrics verified it. Combination the urban sprawl type with landscape metrics produces stronger persuasion.

At the early stage of urbanization, Shenzhen is experiencing diffusion with dispersion urban area. The area of outlying is large and there is little infilling area. With the gradually decreasing outlying area and increasing rapidly infilling area, the urban turns into coalescence stage. And it is consistent with trend of landscape metrics. The fragmentation of the urban landscape is serious at diffusion stage, while in the stage of coalescence, the urban patches gather gradually to be more compact.

In the future research, we hope to study couple urban growth phases and find the regular spatial distribution of patches of different sprawl types. The results may play an important role in urban planning and designing in Shenzhen.

Acknowledgements

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