GRADIENT ANALYSIS OF LANDSCAPE PATTERN SPATIAL-TEMPORAL CHANGES IN BEIJING METROPOLITAN AREA, CHINA

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ABSTRACT:

The gradient based landscape metrics analysis is now widely used to study the landscape pattern change in respond to urbanization. In order to discover the Beijing metropolitan area landscape pattern spatial and temporal change trends during the past 15 years, several landscape metrics are computed along a 96 km long transect crossing Beijing metropolitan area from west to east. Specially, the spatial extent issue was profound examined in the gradient analysis. The temporal land use data sets are derived from three Landsat images got by year 1992, 1999 and 2006. The results show that the metrics varied smoothly and regularly along the land use transect when the window is large, while fluctuated irregularly when the window is small. The spatial and temporal characteristics of the metrics well match the hypothetical framework of spatio-temporal urban sprawl in the form of alternating processes of diffusion and coalescence. Some new trends of the urban sprawl style in Beijing metropolitan area are also detected by gradient landscape metrics analysis.

1. INTRODUCTION

The process of urbanization is a universal phenomenon taking place the world over, and has increasingly become a major issue facing many metropolitan areas. Although a general consensus regarding the definition and impact of urban sprawl has not been achieved (Johnson, 2001), Urban sprawl is often referred to as an extent of metropolitan areas into adjacent rural landscapes that increases traffic problems, depletes local resources, and destroys open space (Peiser, 2001). With the global increase of urbanization, pressure on land availability for urban use will increase. These land cover conversions usually compete with agricultural activities. In areas where urbanization is not controlled, especially in developing countries, the concentration of human presence in residential and industrial settings may lead to an alteration of ecosystems patterns and short of food (Grimm et al., 2000). It is critically important to properly characterize urban sprawl in order to develop a comprehensive understanding of the causes and effects of urbanization processes. Remote sensing and geographic information system (GIS) aided quantitative landscape structure analysis has become a trend in urban sprawl studies.

Landscape structure refers to the spatial relationship among the distribution of energy, materials, and species in relation to the sizes, shapes, numbers, kinds and configurations of the ecosystems; this structure is critical to landscape/ecosystem function and habitat quality (Turner, 1989; Li et al., 2001). Investigating landscape structure and its change is a prerequisite to the study of ecosystem functions and processes, sustainable resource management, and effective land use planning. Urban sprawl is arguably the most dramatic form of land transformation that profoundly influences biological diversity and human life. Quantifying landscape pattern and its change is essential for the monitoring and assessment of ecological consequences of urbanization. Landscape metrics (indices) are numeric measurements that quantify spatial patterning of land cover patches, land cover classes, or entire landscape mosaics of a geographic area. Numerous landscape metrics have been developed to quantify landscape structure and spatial heterogeneity based on landscape composition and configuration (McGarigal and Marks, 1995). This landscape metrics make quantify landscape pattern of urban and its change possible. Many articles have used landscape metrics to analyze the urban sprawl (Herold et al., 2002, 2003; Wei et al., 2006).

Remote sensing provides spatially consistent data sets that cover large areas with both high spatial detail and high temporal frequency. Remote sensing can also provide consistent historical time series data. Batty and Howes emphasized the importance of remote sensing as a ''unique view'' of the spatial and temporal dynamics of the processes of urban growth and land use change. Satellite remote sensing has revolutionized the process of measuring urban land use during the last three decades (Longley and Mesev, 2000). GIS aids in calculating the landscape metrics such as fragmentation, patchiness, porosity, patch density, interspersion and juxtaposition, relative richness, diversity, and dominance in order to characterize landscape properties in terms of structure, function, and change (ivco et al., 2002). Modelling the spatial and temporal dimensions has been an intense subject of discussion and study for philosophy, mathematics, geography and cognitive science (Claramunt and Jiang, 2001).

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The spatial pattern of land use reflects underlying human processes and influences the ecology of urban environment (Redman, 1999; Bastian, 2000). Humans have the ability to greatly modify their environment, which tends to increase landscape fragmentation by generating more and smaller patches. To relate the spatial pattern of urbanization to ecological processes, quantitative spatial analysis methods are needed. Forman and Godron (1986) postulated that patch characteristics exhibit generally predictable patterns along a landscape modification gradient (i.e., natural—managed—cultivated—suburban—urban). Besides the spatial structural of the urban pattern, the temporal characteristics of the landscape always discuss with the spatial domain at the same time. By focusing either on the spatial transects or on the temporal trend alone, studies would fail to address the spatiotemporal dynamics of landscape change in response to urbanization (Weng, 2007). For example, a hypothetical framework of spatio-temporal urban sprawl in the form of alternating processes of diffusion and coalescence was postulated by Dietzel et al. (2005). One systematically effective approach to analyze the effects of urbanization on ecosystems is studying the changes of ecosystem patterns and processes along an urban-to-rural gradient (McDonnell and Pickett, 1990). Since the combined method of urban gradient analysis and landscape metrics in analyzing the changes of landscape pattern introduction by Luck and Wu (2002), it has been widely applied to urban sprawl study (Hahs and McDonnell, 2006; Yu and Ng, 2007; Kong and Nakagoshi, 2006; Weng, 2007). In gradient analysis, a transect line is selected as an axis and a window with fixed size moves on it for landscape metrics calculation. The window size provides the landscape extent for computing the landscape metrics. The landscape scale issue is a long discussion problem because its importance for quantifying landscape. The landscape scale encompasses both extent and grain. For gradient analysis, the extent choice will affect the accuracy. The extent selection of gradient analysis is arbitrary in most study, only little articles mentioned it but not given systematically research (Luck and Wu, 2002).

In this study, three landsat images and a transect crossing the urban core from west to east was select to analyze the landscape pattern of the urban sprawl. We integrated gradient analysis with landscape metrics to quantitatively characterize landscape pattern and its spatio-temporal change. We aimed to address several questions: (1) do there exist mutation of landscape metric on the study transect (the mutation on transect will help us to discriminate landscape spatial change)? (2) whether the urbanization process change its style in study period and this can be detected by using the gradient analysis and landscape metrics combination method? (3) can the experimental data fit hypotheses on landscape structural responses along a human modification gradient and the spatio-temporal diffusion and coalescence framework .

2. METHOD

2.1 Study area and sample design

Beijing city as the capital of china is experiencing rapid development in recent decades. Especially the Beijing Olympic game greatly stimulates the urbanization process of the Beijing metropolitan area. The obvious characteristic of urbanization is that none built-up land use types such as agriculture, forest, water transform to built-up. The total population within the administrative boundary of the city reached 12.17 million in

1997 from 9.45 million in 1984 and the built-up area has extended from 366 km2 in 1984 to 488 km2 in 1997 (State Statistical Bureau of China 1985, 1998), indicating a growth of one third in area and population within the city. The sprawl of Beijing city is mainly presented in three forms: urban core spread; expanding along growth axle; urbanization in urban fringe. These radical change have aroused the concern of many researchers, and enough literature have discussion about urbanization process of Beijing metropolitan area (Chen et al. 2000; He et al. 2006; Xie et al. 2007; He et al. 2008).
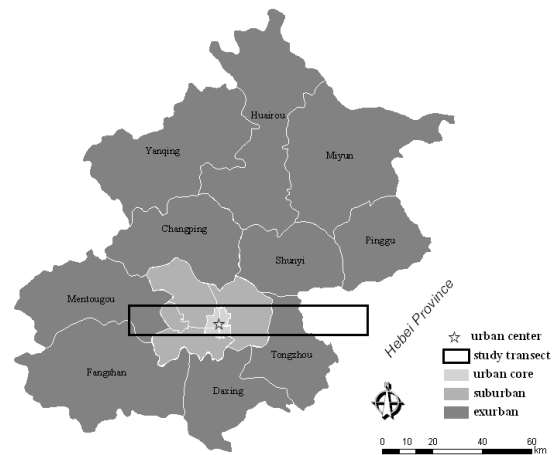

Figure 1. Study area and designed transect

The transect we selected was 96 km long, spanning from one rural area to the urban area and on to the other rural area from west to east crossing the entire Beijing metropolitan area (Figure 1). The urban center represented by Tiananmen Square was about 40 km away from left side along the transect. To preserve the urban expansion continuity, part of the transect extends to Hebei province in eastern. Along the transect, moving window with size 6 km × 6 km was used to cutting the study area into sub landscape. The moving windows for all sizes moved 3 km at each step, to minimize the jumping of landscape along the transect. So there were 31 blocks for window size at 6 km × 6 km.
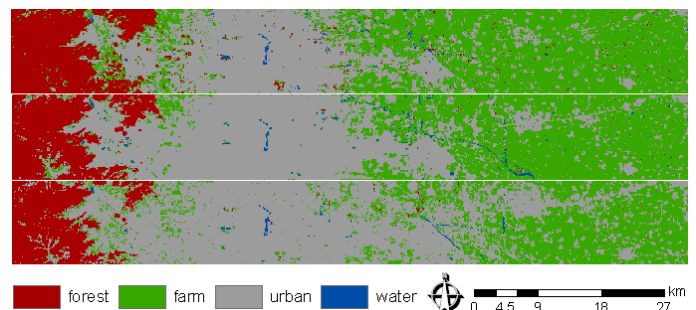
2.2 Data processing

Figure 2. Landuse maps derived from 1992, 1999 and 2006 Landsat images

Three Landsat TM/ETM scenes over Beijing (path 123, row 32) were acquired on 7 September 1992, 1 July 1999, and 24 September 2006 respectively. Four land use types: forest, built-

up, agriculture and water were then recognized using supervising imagery classification for later landscape analysis (Figure 2). The accuracy Land-use map derived from Landsat data decided by classification procedure. The overall accuracies for 1992, 1999 and 2006 are 92.67%, 88.60% and 94.41% respectively.

2.3 Landscape metrics analysis

To detect the spatio-temporal dynamics of landscape pattern for the study transect, landscape metrics were then calculated for each block at the class and landscape levels using the raster version of FRAGSTATS program (Version 3.3). A set of landscape metrics was used for this study, including percentage of landscape (PLAND), Shannon's diversity index (SHDI), patch density (PD), contagion(CONTAG), area coefficient of variation(AREA_CV) and perimeter-area fractal dimension (PAFRAC) . The PLAND and SHDI are indicators of landscape composition while PD, CONTAG, PAFRAC and AREA_CV are indicators of landscape fragmentation. The first metric was used to examine class-level properties while the others were used to examine the landscape-level properties.

3. RESULTS AND DISCUSSION

Figure 3 shows the metrics derived at the window size 6 km × 6 km for year 1992, 1999, 2006. When the curves of metrics go smoother with the window size bigger than 6 km × 6 km, we can see clear ups and downs of the landscape metric curves along the study transect. The ups and downs of curves show good regularity to the landscape pattern. Along the study transect, the landscape experiences the change of a whole rural—suburban—urban—suburban—rural landscape types, and these ups and downs reflect the landscape pattern change along the transect. Obvious mutation points happen on the curves of SHDI, PD, CONTAG, and AREA_CV metrics for all years. The most consistent mutation points for different metrics happened at 12 km and 60 km along the transect and have a bit difference for different year. These mutation points are considered as suburban with extremely high landscape turbulence, and with the urban expansion process, these points move on deviation direction of the city center. The extreme values happened between 30 km and 45 km are considered as urban core which is dominated by onefold impervious patch.

The contagion and Shannon's diversity index are widely used to delineate the urban expansion induced high fragmentation. The contagion gets high value when landscape is simple and low value when landscape is complex. The contagion gets high value at urban core and rural, while gets low value at urban fringe. So when the analysis transect crosses urban area by a whole rural—suburban—urban—suburban—rural stripe, the contagion forms a "W" shape (figure 3d). From contagion curve at 1992, we can see two sharp bottoms. These bottoms and area with low value around them are considered as suburban which reflects high landscape turbulence, and the area between the two bottoms with stable high value are considered as urban core. However, this situation changes on 1999 and 2006 curves, the bottoms get blur and wide, especially the east part of the curves. This is caused by urban expansion pattern style changing from center focus to leapfrog, and the urban fringe occupied large place. Due to natural conditions, the urban expansion mainly happed at east part, so large number of new built-up patches are most happening in east part of the transect. This explains the bottom of the curve change mainly

happened in east part. Comparing the contagion curves for the three years, we can see that the urban core area extended and the suburban area also extended. The Shannon's diversity index (figure 3e) just is opposite to contagion metric, it forms an "M" shape along the transect. From it we can also easily tell where is urban core, where is suburban and where is rural.

The patch density metric (figure 3a) shows high increase at 15 km in west at year 2006, and this area is previous dominated by forest. In east, the patch density values at year 2006 and 1999 are higher than year 1992 between the 55 km and 75 km, which caused by more spot built-up area happened in early agriculture land. The area coefficient of variation metric (figure 3b) at urban fringe from 0 km to 15 km in west increased obviously for these areas got more fragmentation, and three curves of year 1992 and 1999 staggered in urban core area. The perimeter-area fractal dimension metrics range from 1.13 to 1.41 and it is difficult to examine its temporal and spatial pattern (figure 3c).The Percentage of built-up (figure 3f) represents the land-cover ratio occupied by built-up. From the figure 4f, we can see that the newly built-up most happened in east urban fringe ranged from 50 km to 75 km. This is because the west part of the study area is dominant by mountain forest, which stems the urban expansion toward west. The east part is mainly flat agriculture land which is suitable for urban construction.

Comparing the landscape curves getting from three different periods of all metrics, we can see that, temporal change of the landscape mainly happened in east part of the study transect, such as PLAND, SHDI and CONTAG metrics, this reflects that the urban expansion and the built-up increase mainly happened in east part. Comparing the metrics curves temporal change at east part, the curves get gentle and mutation point get bluer, this due to urban expansion style is changing. The urban expansion get looser at east part, different to the early happening near the urban core style, newly built-up often happened far away from the already built-up. This leap-frog development method makes the pattern of suburban looser and area of it is enlarged.
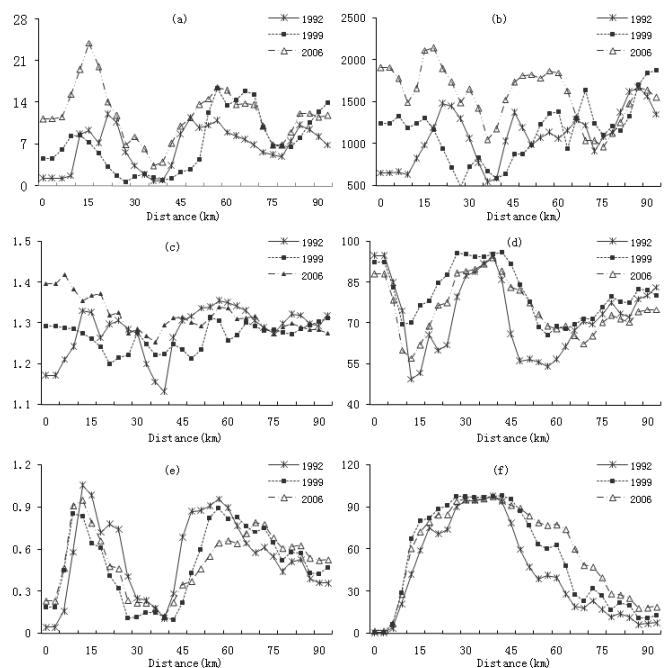
Figure 3. Temporal change along the transect at window size 6km×6km: (a) patch density, (b) area coefficient of variation, (c) perimeter-area fractal dimension, (d) contagion, (e) Shannon's diversity index, (f) Percentage of built-up.

4. CONCLUSION

In this study, we put forward a gradient analysis on the Beijing metropolitan area. A transect cross the city by a whole rural—suburban—urban—suburban—rural landscape stripe was used. To test different landscape metrics ability to delineate the gradient change of landscape along the selected transect, six metrics: percentage of landscape, Shannon's diversity index, patch density, contagion, area coefficient of variation and perimeter-area fractal dimension were selected. We can see that the patch density, contagion and Shannon's diversity index perform better, and metrics sensitive to detail characteristics or sensitive to extents change perform poor. This proves that the metrics selection is also important to gradient analysis.

From the transect based analysis of Beijing city, we can see the urban expansion mainly happened in east part of transect and the expansion style is gradual changing, however, this information just extracts from a single transect cross Beijing city from west to east and other parts expansion information ignored. The transect based analysis can only test one or several directions of the urban expansion, and the prop directions selection is very important. In general, we choose the most rapidly development direction to study. For most city developing process, the urban expansion style cannot be represents by one or two directions. To further understand the urban landscape pattern spatial distribution and its temporal change, new method should be developed to discover two-dimension landscape characteristics of the urban expansion.

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