

ANALYSIS OF LANDSCAPE DYNAMICS IN SHANGHAI USING LANDSCAPE METRICS: EFFECTS OF SPATIAL RESOLUTIONS

Qian Zhang^{a,b,*}, Yifang Ban^a, Jiyuan Liu^b, Quanqin Sha^b, Yunfeng Hu^{a,b}

Dept. of Urban Planning and Environment, KTH-Royal Institute of Technology, Drottning Kristinas väg30, Stockholm, Sweden - (qianzh, yifang)@infra.kth.se

^bInstitute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, 11A, datum road, anwai, chaoyang district, Beijing, P.R.China - liujy@igsnrr.ac.cn, (shaoqq, huyf)@lreis.ac.cn

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ABSTRACT:

It is increasingly evident that urban sprawl leads to dramatic changes in landscape patterns and thus changes in ecosystem functioning. Analysis of the landscape patterns and their dynamic under urbanization is of great importance for sustainable development, especially in cities with significant changes like Shanghai. The objective of this research is to illustrate the landscape dynamic under the urbanization process in a selected test area of Shanghai in 1991, 1998 and 2007 using multitemporal remote sensing and landscape metrics; and to determine the optimal resolution suitable for this case study. Preliminary results show that it is a quick and executable way to assessing the impact of urban sprawl on landscape dynamic using remote sensing data and landscape matrices; and the optimal resolution for the case study is 10-30 meters.

1. INTRODUCTION

Humanity today is experiencing a dramatic shift to urban living. More than 95% of the net increase in the global population will be in cities of the developing world, which will approach the 80% urbanization level of most industrialized nations today (Grimm *et al.*, 2008). Indubitably, urban sprawl is one of the severe land use/cover change types especially for the developing countries just like China (Chen *et al.*, 2000). Increasing evidence indicates that urban sprawl leads to dramatic changes in landscape pattern and thus changes in ecosystem functions (Turner, 1989; Herold *et al.*, 2003), for examples, the rapid reduce of biodiversity, the shortage of water resources and the heavy deterioration of air quality (Wilson, *et al.*, 2003). Therefore, analyzing the landscape patterns and their dynamic under urbanization is of great importance for sustainable development, especially in cities with significant changes like Shanghai.

Landscape metrics is one of imperative methods for understanding the structure, function and dynamics of landscapes and has a pivotal role to play in finding those solutions and navigating a sustainable urban future (Wu, 2006; Jelinski *et al.*, 2000). At the same time, development of remote sensing and geographic information techniques provides rich data source and powerful spatial analysis methods for the research on landscape metrics.

Past studies focused on the development of different indexes portraying different aspects of landscape, numerous indexes emerged at a time. Software such as Fragstats (McGarigal and Marks, 1995) and APACK (Mladenoff and DeZonia, 2001) is available to researchers world-wide. Since then, more and more research were conducted applying these metrics (Wu & David, 2002; Luck & Wu, 2002; Li *et al.*, 2004; Guo *et al.*, 2007; Zhou *et al.*, 2007; Li *et al.*, 2005) and discussion were made on the

do's and don'ts during the application (Li *et al.*, 2004; Li & Wu, 2004), as well as, the effects of grain (Buyantuyev & Wu, 2007; Meng *et al.*, 2007; Zhang *et al.*, 2007; Tan *et al.*, 2005; Wu, 2004; Qi & Wu, 1996), extent (Xu *et al.*, 2004; Zhao *et al.*, 2007) and land use (Peng *et al.*, 2006) on the landscape metrics analysis (Shao & Wu, 2008). Specific landscape metrics and scale should be selected after careful consideration when it comes to the specific landscape analysis task.

2. STUDY AREA AND DATA

Shanghai is undergoing rapid urban sprawl because of the unprecedented economic and population growth recently (Meng *et al.*, 2007). A 5km*5km study area located in central zone of Shanghai is chosen in this case study (Fig. 1). The major land use classes are residential area, industrial area, commercial area, transportation, infrastructural area (i.e., public facilities), greenbelt, water and unclassified areas. The SPOT images used for land use type interpretation were acquired on 2007-12-31 (pan+xs), 1998-04-16 (pan), 1998-05-27 (xs) and 1991-09-20 (pan).



Figure 1. Location (Left) and SPOT XS Images (R: 1, G: 2, B: 3) in 2007 (Right) of study area

* Corresponding author. Tel.: +46 8 790 7334; Fax: +46 8 790 7343; E-mail: qian.zhang@infra.kth.se

3. METHODS

The methodology for this research is summarized in Figure 2.

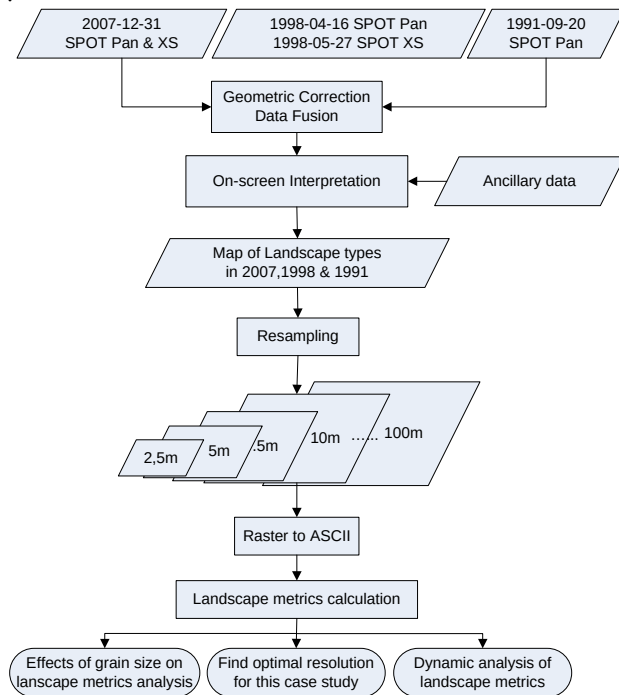


Figure 2. Workflow of this case study

First, the SPOT images from 1991 and 1998 were geocoded to the SPOT images from 2007 using a polynomial approach. Then eight landuse types for 2007, 1998 and 1991 are extracted via on-screen interpretation with the aid of ancillary data (e.g., electronic maps, topographic maps). The overall accuracy of landuse interpretations exceeds 89% based on validation using the random points selected from original images.

Then, the landuse vectors from the above interpretations are transformed to raster using different pixel size, and altogether landuse maps at 13 resolutions (2.5m, 5m, 7.5m, 10m, 20m, 30m, 40m, 50m, 60m, 70m, 80m, 90m, 100m) are generated from original data (Fig. 3). Cell assignment type is set up as MAXIMUM_COMBINED_AREA as far as resampling parameter is concerned. ASCII file is obtained from raster after transform and then as the input of Fragstats (Raster version 3.3). A series of landscape metrics at patch and landscape level are calculated. The 8-neighbors rule for delineating patches is chosen in this case study.

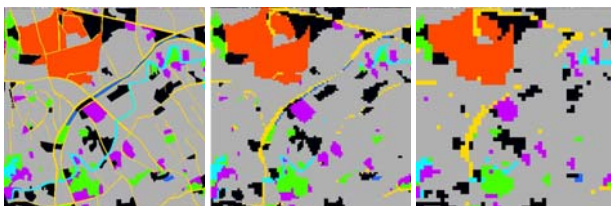


Figure 3. Landuse raster at 2.5m, 50m and 100m resolution in 2007

Landscape metrics at patch and landscape level with different pixel size is analyzed in year 1991, 1998 and 2007 with regard to dynamic information of landscape during 1991, 1998 and 2007, the optimal resolution for this kind of case study as well as the character of landscape dynamics.

4. RESULTS AND DISCUSSION

4.1 Landscape metrics dynamic analysis at landscape level

Several metrics are analyzed but only four typical curves are displayed in the Figure 4. With increasing pixel/grain size, Landscape Patches Index (LPI) shows a monotonically increasing trend, while LSI Landscape Shape Index (LSI) and Shannon's Diversity Index (SHDI) shows a consistently declining trend either laggedly or quickly. The only metric that did not show a clear directional changing pattern was Area-Weighted mean Shape Index (SHAPE_AM) within the grain size < 50m, it fluctuates in this range but beyond that it shows a consistent declining trend as well.

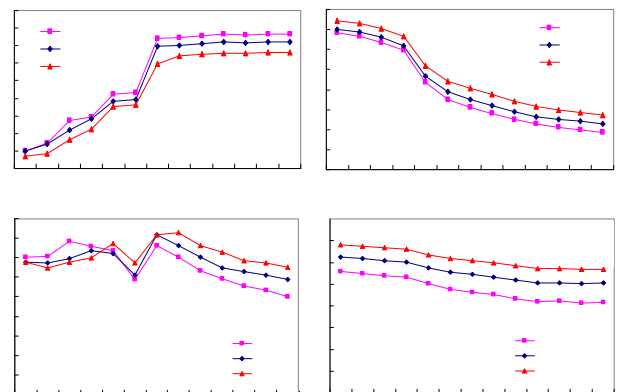


Figure 4. Landscape metrics scalograms in 1991, 1998, 2007 at landscape level

How do these indexes vary in response to different stages of landscape transformation (urbanization in this case)? The distances between lines and the relative positions of individual lines in Figure 4 shows the general response patterns of most landscape metrics to changing pixel size seemed similar among different years, with a few exceptions (e.g. SHAPE_AM and LPI with grain size < 30m). It confirms the conclusions from previous research that these metrics have the character of stability to some extent.

From the viewpoint of time series analysis, from 1991 to 2007, LSI and SHDI becomes lower and lower, it indicates patch becomes more and more regular and aggregative, complexity and fragmentation declines continuously. The change of LPI describes the intensity and frequency of human interference, the wider gap between 1991 and 1998 illustrates that it is a high-speed period of expansion in this study area. Comparing with the previous research results, it seems some conflicts exist to some degree. For example, SHDI increases in the whole Shanghai from 1997 to 2004 (Li, 2007). These conflicts maybe caused by the differences between this study area and the whole Shanghai since the study area is a residential dominant central zone of Shanghai, and large rural-urban fringe and suburbs are

not included in this pilot study, where fragmentation degree is quite high, therefore the decline of the overall SHDI is possible. Further, from the following analysis at patch level, greenbelt becomes fractured while infrastructural and commercial area is more and more aggregated. Generally speaking, major landuse categories are more aggregated in this case study.

4.2 Determination of optimal scale

Obvious critical points (i.e. inflexions) in the above landscape metric scalogram stand for the most suitable scale in landscape pattern analysis. In this case study, most critical points occur within 10-30 meters, that is to say, 10-30m is the width range of some landscape elements, such as roads, branches of rivers, when grain increases over this range, these elements shrink to small patches or are swallowed up by other dominating elements, thus inflexions occur. Satellite images such as SPOT Pan, XS and Landsat TM with 10-30 meter resolution is sufficient for the landscape dynamic research in this study area for the specified time frame.

4.3 Landscape metrics analysis at patch level

Figure 5 shows the changes of area percent of different landuse types with the increase of pixel size. Residential area is excluded here as it is the dominant land use type therefore occupies the majority of area percentage and will leave a narrow gap to the other types if included. Industrial patch swallows up many small patches surrounding them which leads to a continuous increase in area percentage, while other land use types distributed in small patches shrink with the increase of pixel size. When the pixel size unceasingly increases, dominant type will occupy more and more areas.

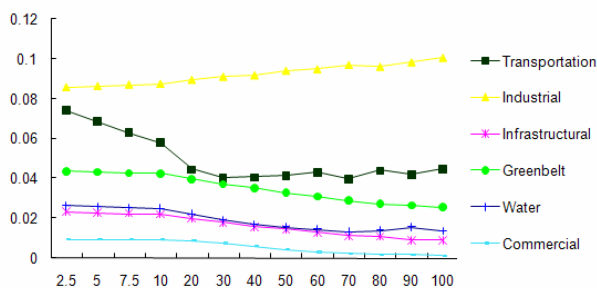


Figure 5. Area percentage of different landuse types with grain size increasing

As shown in Figure 6, some characteristics are observed in the landscape metrics scalograms.

The Number of Patches (NP) and LSI of the greenbelt patches increases over time. It indicates that there are more greenbelt patches in the process of urbanization and the fragmentation degree increases, i.e., the greenbelt patches become increasingly disaggregated.

On the contrary, LSI of infrastructural patches decreases continuously, indicating that the infrastructural patches become more aggregated. Normalized Landscape Shape Index (NLSI) shows similar trend to LSI.

Mean Fractal Dimension Index (FRAC_MN) of most patches has a very slight fluctuation. From 1991 to 2007, several patches class kept their shape and has slight shape changes.

Only greenbelt, infrastructural and commercial area has large variations, the frontal one increases, while the latter two decreases.

In addition, index response curve for different landscape patch type in changing grain size is different, for example, transportation has special patch shape, and is connected each other. When in large pixel size, the large patch break into several some small patches because of the width limit of road. The response of patch type to changing grain size fell into three categories, the first group decreased or increased monotonically, such as LSI; and the second group increased in staircase or single hump, for example, NP; while the third group showed uncertain trend, Contiguity Index (CONTIG_MN) is a case in point.

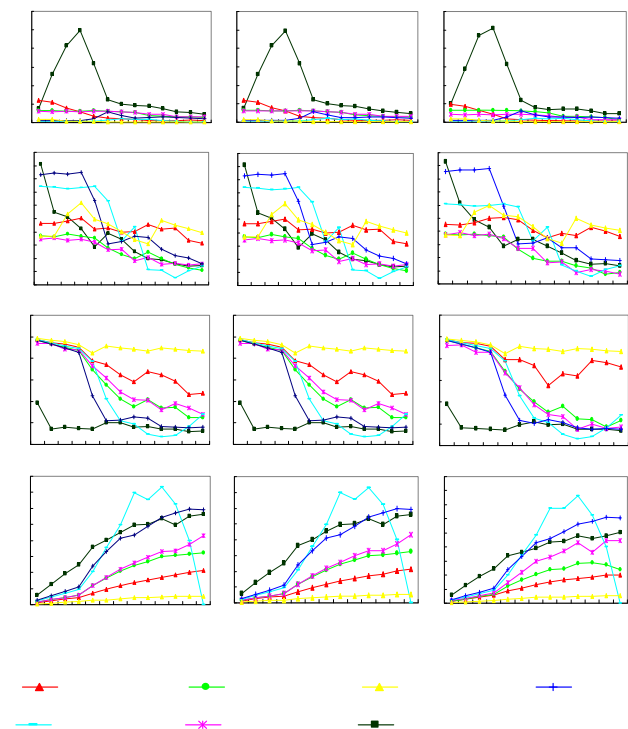


Figure 6. Landscape metrics scalograms in 1991, 1998, 2007 at patch level

5. CONCLUSIONS & FUTURE RESEARCH

Despite the uncertainties in extraction of the land use types, as well as the small extent of the study area used, some meaningful conclusions can be drawn from this research. Preliminary results show that it is a quick and executable way to assess the impact of urban sprawl on landscape pattern using multitemporal remote sensing data and landscape matrices.

Several aspects could be strengthened in the future research: (i) Using true data at different scales instead of resampling data to validate the effects of spatial resolution for analysis of landscape patterns; (ii) Selecting suitable landscape metrics among many available landscape metrics. Comparing different landscape types may help to choose which landscape metrics is more suitable to which kind of landscape; (iii) Whole Shanghai will be as the study area in the future research, to reach

meaningful and comprehensive conclusion; (iv) In-depth analysis should be done in combination with urbanization process; (v) object-based classification will be used as a land use classification method instead of on-screen interpretation, thus will greatly improve the efficiency, shorten the time from imagery to information.

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6. APPENDIX

Index	Formula	Index	Formula
NP (Number of Patches)	NP= Number of patches in the landscape of patch type (class) <i>i</i>	LSI (Landscape Shape Index)	$LSI = \frac{e_i}{\min e_i}$ <i>e_i</i> is total length of edge (or perimeter) of class <i>i</i> , includes all landscape boundary and background edge segments involving class <i>i</i>
FRAC_MN (Mean Fractal Dimension Index)	$FRAC = \frac{2 \ln(25P_{ij})}{\ln a_{ij}}$ <i>P_{ij}</i> is perimeter of patch <i>ij</i> and <i>a_{ij}</i> is area of patch <i>ij</i>	LPI (Largest Patch Index)	$LPI = \frac{\max(a_{ij})}{A} * 100$ <i>a_{ij}</i> = area (m ²) of patch <i>ij</i> . <i>A</i> = total landscape area (m ²)
CONTIG_MN (Contiguity Index)	$CONTIG = \frac{\left[\frac{\sum_{r=1}^z C_{ijr}}{a_{ij}} \right] - 1}{v - 1}$ <i>C_{ijr}</i> is contiguity value for pixel <i>r</i> in patch <i>ij</i> <i>v</i> is sum of the values in a 3-by-3 cell template <i>a_{ij}</i> is area of patch <i>ij</i> in terms of number of cells	NLSI (Normalized Landscape Shape Index)	$NLSI = \frac{e_i - \min e_i}{\max e_i - \min e_i}$ <i>e_i</i> is total length of edge of class <i>i</i> <i>min e_i</i> is min total length of edge of class <i>i</i> <i>max e_i</i> is max total length of edge of class <i>i</i>
SHDI (Shannon's Diversity Index)	$SHDI = - \sum_{i=1}^m P_i \times \log_2 P_i$ <i>P_i</i> is proportion of the landscape occupied by patch type (class) <i>i</i>	SHAPE_AM (Area-Weighted mean Shape Index)	$SHAPE = \frac{P_{ij}}{\min P_{ij}}$ <i>P_{ij}</i> is perimeter of patch <i>ij</i> in terms of number of cell surfaces AM means Area-Weighted Mean

8.1 Formula used in calculating landscape metrics

