A Study on the Land-Cover Change Indicators of Taipei Metropolitan Areas

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Abstract. The traditional research of land cover/land use change sets focus on the spatial unit of parcel or grid for analysis and simulation. Since the change of individual land use would be affected by the surrounding land uses, there is another possibility to explore the land use change in terms of spatial pattern. The paper applies indicators of landscape metrics to analyze pattern characteristics of urban structure, and cluster analysis and discriminant analysis to identify the type of spatial pattern. This paper attempts to analyze land use pattern and its changes by metric analysis with patch-corridor-matrix structure. The process includes three phases. The first phase is to explore categories of land use pattern and attributes by cluster analysis. The second phase is to analyze pattern changes with different periods and to identify properties of pattern changes in the whole system. The final phase is to classify the pattern changes and to look for the relation between different patterns. Through analysis of pattern changes, it would be helpful to realize urban development relative to landscape metrics and to offer new thinking other than traditional urban development thinking.

Keywords: land-cover pattern, cluster analysis, pattern changes, landscape metrics

1. Introduction

The topic land use and land cover change has been one of critical issues over the past decades. The crucial issues of land use change include patterns of land cover change, processes of land use change and predictions of land use dynamics. Generally, land use change is not only by single parcel but also by surroundings. However, most previous studies have focused on dynamics, tendencies, and driving forces of land use change in entire regions or single parcels. Recently lots of researches identify neighborhood effects existed in the process of land use change (Verburg et al., 2004; Huang and Chan, 2009; Whitney, 2011). Since the change of individual land use would be affected by the surrounding land uses, there is another possibility to explore the land use change in terms of spatial pattern. Some land use change researchers have attempted to analyse the changes of land use patterns by thinking in terms of ecological landscapes and applying metric analysis and spatial dynamics models (Lin et al., 2008; Yeh and Huang, 2009). Among these tools, landscape metric is a useful approach in landscape ecology for describing landscape characteristics and dynamics through three elementary elements.
These elements formulate a specified structure “patch-corridor-matrix” framework (Forman, 1995) which is similar to a point-line-poly model from traditional architecture and planning theories. Based on the above discussion, this study attempts to approach land use changes by thinking about different scales. We apply the scales for analysis of land use changes based on three base units, including parcel, pattern and system (see as figure 1). In the three changes types, pattern change is used to examine the structural conversion of land use and to observe the dynamics of interval characteristics. Analysis of pattern changes is often conducted by measuring indexes such as landscape metrics, social economic indexes and environmental indexes. Therefore, this study attempts to landscape metrics and other indexes with econometric analysis as cluster analysis and determinant analysis to explore land use pattern types, pattern attributes and pattern changes. Examining land use pattern structure and pattern changes will allow us to better understand the impacts of human behavior on land use and to provide a different planning thinking.

Figure 1. Types of analysis units for land-cover change

2. Study area, research design and methods

This study takes Taipei metropolitan area (TMA) as a case study. Generally, measurements of landscape pattern are based on land cover and specified spatial analysis scale (Ritters et al., 1996). Thus, it considers the changes of land-covers from 1996 to 2006. It applies the traffic analysis zone (TAZ), which is the specified function unit such as community, as the unit of analysis. There are 365 TAZs in TMA. TMA is the crucial political, economic, educational, cultural and administrative region in Taiwan. TMA is located in the northern part of Taiwan. The topography is made up by a basin surrounded by mountains. Over 30% of population of Taiwan resides in the region with less than 7% of the land area of Taiwan. Under the pressure of population growth and urban expansion, satellite cities, primary transport zones and peri-urban areas have become the main areas of urban development in TMA.

This study is composed of three phases, as shown in figure 2. Phase I is land-cover classification and pattern identification. The main tasks are to define the fundamental categories of land cover patterns and to explore their spatial characteristics. The techniques include classification of satellite images and cluster analysis. The SPOT image from 1996 is applied as baseline. Landscape metrics express the spatial characteristics of land cover patterns with specified functions and values. Furthermore, all metrics are normalized to the scores of spatial characteristics for the sake of consistency. Cluster analysis method K-Means is as the tool to identify the fundamental categories of land cover patterns. After the process, the spatial structure of the baseline emerges in the map. Phase II discriminates land cover pattern categories in the next period, 2006. In the process of discriminant analysis, the discriminant function estimation is based on Fisher’s linear discriminant function. First, this function takes the outputs in phase I as dependent variables and the scores of metrics in 1996 as distinguished variables. Second is to import the dataset of 2006 into these discriminant functions. The discrimination
of new pattern depends on the comparison with the scores of discriminant functions. After the comparison, the results of pattern distribution in 2006 are confirmed. Phase 3 is the analysis of pattern changes. By overlapping analysis, the changes of patterns during 1996 and 2006 are pointed out. Through crossed analysis and landscape metrics, we identify the attributes of changes and locations in the whole TMA.

Figure 2. Procedures of pattern change analysis

3. Description of data and landscape metric indicators

The study applies TAZ as the spatial unit and all data collection is based on this scale. These involve population, transportation, land use, slope, river distribution, etc. The data come from census data, digital maps and SPOT satellite images. This study uses the concept of patch-corridor-matrix as the framework for the variable settings. Following the literature review, eight metrics are set up as standard pattern characteristics of land cover (see table 1). The standard leads to main variables according to traditional urban theory and landscape metrics. For example, in the patch dimension, the metrics PARA, PD, and AI lay emphasis on urban development intensity and shape. The corridor dimension stresses the accessibility of an urban network. Matrix dimension describes land potential and current use.

Table 1. Description of the variables

| Represented Variables | Original Landscape Metrics | Description | Types |
|-----------------------|---------------------------|-------------|-------|
| Perimeter-area ratio to analysis unit (PARA) | Perimeter-Area Ratio (PARA) | Perimeter-area ratio is a simple measure of shape complexity, but without standardization to a simple Euclidean shape (e.g., square) | Patch |
| Net density of built-up area (ND) | Patch Density(PD) | Patch density is a limited, but fundamental, aspect of landscape pattern. Patch density has the same basic utility as the number of patches of an index, except that it expresses the number of patches on a per unit area basis that facilitates comparisons among landscapes of varying size. | |
| Aggregation index of built-up area (AI) | Aggregation index(AI) | Aggregation index is calculated from an adjacency matrix, which shows the frequency with which different pairs of patch types appear side-by-side on the map. Aggregation index takes into account only the adjacencies involving the focal class, not adjacencies with other patch types. | |
| Road connectivity ratio (GMR) | Connectivity Index (y index) | Connectivity refers to the degree to which a landscape facilitates or impedes ecological flows. | Corridor |
| Major road length ratio (LHR) | Length of Corridor | Calculate the interval length of the corridor in every analysis unit. | |
Diversity to land use

**Index (Shannon-Weaver index)**

Shannon's diversity index is a popular measure of diversity in community ecology, applied here to landscapes. Shannon's index is somewhat more sensitive to rare patch types than Simpson's diversity index.

| Industrial area ratio (INR) | Patch 1 area | The area of each patch comprising a landscape mosaic is perhaps the single most important and useful piece of information contained in the landscape. |
|----------------------------|--------------|----------------------------------------------------------------------------------------------------------------------------------|
| Limited area ratio (LMTR)  | Patch 2 area | The area of each patch comprising a landscape mosaic is perhaps the single most important and useful piece of information contained in the landscape. |

### 4. Pattern identification of TMA

#### 4.1. Pattern identification for 1996

To obtain consistent pattern structures in 1996 and 2006, land cover pattern identification is constructed by scores of metrics in 1996. This process of pattern identification involves cluster analysis and grouping of coefficient R. Thereafter, cluster analysis is initially utilized to classify the types of patterns. In an attempt to find out acceptable group numbers, this study computes the grouping coefficient R (Howard and Howard, 1981) among several group counts (table 2). It indicates that five groups could be used as plausible grouping numbers which would minimize the within-cluster sum of squares. Further, in order to reveal the spatial characteristics of each group and investigate pattern kernel factors, the mean of each group with indices and comparatives of mean with each group are presented in table 3. The result obtained by cluster analysis and group coefficient R reveals similarity groups with five statistically significant clusters, namely kernel area (KA), second kernel area (SKA), urban expansion area (UEA), low development area (LDA) and natural area (NA). The entire spatial structure is shown in figure 3. KA is mainly located in central Taipei. SKA is surrounding these areas of KA. UEA is basically located at riverside. The LDA locations basically follow the major road networks and mass rapid transit. The NA is situated around peripheral areas in TMA.

#### 4.2. Pattern discrimination for 2006

In order to further investigate the changes of land cover patterns between 1996 and 2006, discriminant analysis can be used as an appropriate statistical technique to construct a discriminant function for the uniform pattern attributes. Pattern discrimination analysis is divided into two parts. The first part is the construction of discriminant functions. Five homogeneous types of land cover patterns with 8 variables were used to create the canonical discrimination functions (CDFs). When values of the
metrics in 1996 are taken into the discriminant analysis process, five classification functions are yielded, as seen in table 4. All parameters are used to calculate a discriminant score for each analysis unit. The second part is to distinguish the pattern types in the next period. In this part, the values of metrics in 2006 are taken into the discriminant functions described above. Each analysis unit has a set of scores for each type. Through comparison of these scores with each analysis unit, the type of pattern can be distinguished, shown as figure 2 and table 5. In contrast to the structure of 1996, the main structure is centralized without great changes, especially for the locations of the kernel area. However, it is significant change happen in western area.

| Table 4. Coefficients of classification function |
|-----------------------------------------------|
| PARA  | DF1 (KA) | DF2 (SKA) | DF3 (UEA) | DF4 (LDA) | DF5 (NA) |
|-------|----------|----------|----------|----------|----------|
| .289  | 2.379    | .321     | -.129    | 2.490    |
| .625  | 3.270    | -1.947   | -.702    | 2.299    |
| 2.892 | -7.30    | 3.684    | -.635    | -3.219   |
| 1.540 | -9.31    | .336     | -.523    | -.903    |
| 3.099 | -1.572   | 1.332    | -.476    | -2.336   |
| -.168 | -3.97    | 8.525    | -.393    | -1.054   |
| -.146 | -0.02    | -.339    | 1.087    | -1.372   |
| -.624 | -3.24    | -2.03    | .309     | .909     |
| constant | -4.773 | -16.541 | -2.585 | -9.153 |

Fisher's linear discriminant function

5. Discussion of land-cover pattern changes

The details of land cover pattern changes between 1996 and 2006 are shown in figure 3 and table 5 by overlapping two graphs. The figure and table display changes according to a variety of pattern types. In order to simplify classes of pattern changes, it can be divided into two classes based on table 5, including relatively low development areas converted to relatively high development areas (Class I), such as LDA is converted to SKA, and relatively high development areas converted to relatively low development areas (Class II), for example, UEA is converted to LDA.

The red color represents the location of Class I. In contrast, the slightly green color shows where Class II distribution. The white color represents locations without any change. The locations converted of Class I are close to the urban expansion areas and nearby the critical road network. The locations of changes of urban expansion areas are spread along riverside. The locations converted of Class II are located at in western urban expansion area, central Taipei and its periphery. Table 5 shows changes of counts from 1996 to 2006. The total change count is 129 and the ratio is close to 36%. Among all conversions of Class I, the ratio of conversion from SKA to KA is the highest (27.78%) and the counts reach 20. In additional, the ratio of conversion from NA to LDA is secondly high (20.55%) and the counts reach 15. Such a characteristic is also existed in Class II. These results mean that there are some dynamic conversions occurring in the urban centres and urban expansion areas near natural area. These conversions may come from urban renewal or other activities.

| Table 5. Crossed table of land-cover pattern changes from 1996 to 2006 |
|-----------------------------------------------|
| 1996 | 2006 | NA | SKA | UEA | LDA | NA | Total |
|------|------|----|-----|-----|-----|----|-------|
| KA   | Type I | 50(50.51%) | 34(34.34%) | 3(3.03%) | 12(12.12%) | 0 | 99 |
| SKA  | Type I | 20(27.78%) | 48(66.67%) | 2(2.78%) | 2(2.78%) | 0 | 72 |
| UEA  | Type III | 1(5.26%) | 4(21.05%) | 13(68.42%) | 1(5.26%) | 0 | 19 |
| LDA  | Type IV | 8(7.84%) | 3(29.4%) | 9(8.82%) | 69(67.65%) | 13(12.75%) | 102 |
| NA   | Type V | 1(1.37%) | 1(1.37%) | 0 | 15(20.55%) | 56(76.71%) | 73 |
| Total | 80 | 90 | 27 | 99 | 69 | 365 |

Note: light grey represents Class I; Dark grey represents Class II.
6. Conclusion

In this study, a new combination of spatial units and landscape metrics is applied to the discussion of pattern change. Specified land use sets which exist between systems and parcels can be identified through the process of classification with cluster analysis and exploration of pattern changes. Five categories of TAZs are identified from the 1996 metric by which the distributions of TAZs of 2006 are derived. The matrix of the pattern changes of TMA reveals important information. The result points out that most of converted areas are located in peri-urban areas. This article integrates metric analysis, cluster analysis and discriminant analysis to build a set of land cover pattern categories based on TAZ scale. Though these attributes from the metrics do not correspond exactly with types of land use, however, this approach can verify the characteristics of development in these areas and future development modes. Such discrepancies in land cover patterns will be helpful to the understanding of the spatial structure of land cover patterns.

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