

LANDSCAPE EFFECTS OF URBAN SPRAWL: SPATIAL AND TEMPORAL ANALYSES USING REMOTE SENSING IMAGES AND LANDSCAPE METRICS

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ABSTRACT:

This study intends to identify both general trends and subtle patterns of urban land changes of the past three decades in metropolitan Kansas City area. Landsat images were used to generate time series of land cover data from the early 1970s to the early 2000s. Based on remotely sensed land cover data, landscape metrics were calculated. Both the remotely sensed data and landscape metrics were used to characterize long-term trends and patterns of landscape effects of urban sprawl. Land cover change analyses at the metropolitan, county, and city levels reveal that over the past three decades the significant increase of built-up land in the study area was mainly at the expense of non-forest vegetation cover. The spatial and temporal heterogeneity of land cover changes allowed the identification of the built-up land spread patterns. The landscape metrics were analyzed to quantify the fragmentation of land covers and degrees of urban built-up activities across the study area.

1. INTRODUCTION

Urban sprawl, a consequence of socioeconomic development under certain circumstances, has increasingly become a major issue facing many metropolitan areas. It is critically important to properly characterize urban sprawl in order to develop a comprehensive understanding of the causes and effects of urbanization processes. To address this objective, multi-stage remote sensing images and related landscape metrics were used to generate indicators and measurements of urban land cover changes in the Kansas City metropolitan area, U.S.A. The study had the following objectives: (1) detecting and comparing the variation of urban sprawl trends across the metropolitan, county, and city scales over the past three decades; (2) identifying spatial spread patterns of built-up land expansion from the urban core and associated landscape effects.

2. STUDY AREA

The Kansas City metropolitan area is located in the central United States and centered along the eastern boundary of Kansas and the western boundary of Missouri. The study area covers 8,215.5 square kilometers and includes seven metropolitan counties. Thirteen cities were also included in the study, with at least one city from each county (Figure 1). The topography of the area is generally characterized by rolling hills and open plains. The predominant land cover primarily consists of grassland, cropland, with forests, urban zones and scattered water bodies.

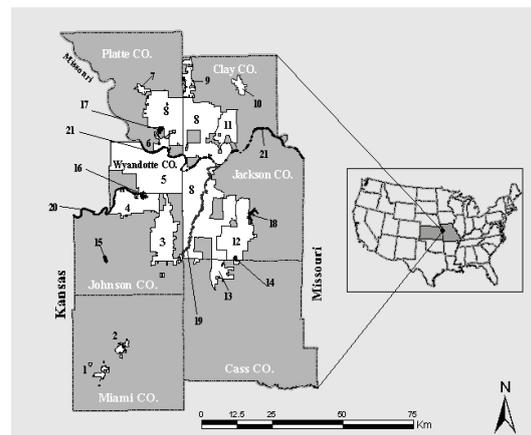


Figure 1. Map of the Metropolitan Kansas City study area. The map depicts seven counties selected for the analysis (Wyandotte, Johnson, and Miami counties on the Kansas side, and Cass, Jackson, Clay and Platte counties on the Missouri side). The map also shows the selected study cities (numbered 1-13), lakes (numbered 14-18), and rivers (numbered 19-21).

The study area witnessed significant population and economic growth in the past century, and especially in the recent decades. Approximately since the 1970s, the metropolitan area has experienced significant population change characterized by its geographic unevenness which varied at the county and city levels. The total metro population increased from 1,273,170 in 1970 to 1,656,014 in 2001 at an annual growth rate of 1.04% (based on the data of U.S. Census Bureau). Relating to population growth, this area also witnessed other accelerated socioeconomic changes over the last decades. The Kansas City metropolitan consumers' budget devoted to transportation increased significantly between 1986 and 1999 at an annual rate of 2.35% (U.S. Bureau of Labor Statistics). This coincides with the remarkable increase in the metropolitan residents' total

daily vehicle miles traveled (DVMT) from 31,705 in 1982 to 66,515 in 2001 at an annual rate of about 5.78% (Texas Transportation Institute, 2003). Along with these socioeconomic changes, the region has experienced significant alterations of its natural landscapes (The Brookings Institution, 2002). However, there is a lack of historical land cover dynamic data at both regional and fine scales, which hinders a comprehensive understanding of the urban sprawl events, which is critical for informed urban planning in the metropolitan.

3. APPROACHES

3.1 Digital Image Classification

Six Landsat images (Path 28/Row 33 for MSS and Path 26/Row 33 for TM and ETM+) covering the Kansas City metropolitan area were obtained for the years 1972, 1979, 1985, 1992, 1999, and 2001 from the U. S. Geological Survey (USGS). The images from mid July to mid August were chosen for better land cover detection during the fast vegetation growth season. The images were classified using the supervised maximum likelihood classification method (Jensen, 2005). For the purpose of characterizing urban sprawl, we identified four major types of land cover: built-up area, forestland, non-forest vegetation, and water body. The "built-up" class depicts residential areas of single houses and apartment buildings, shopping centers, industrial and commercial facilities, highways and major streets, and associated properties and parking lots. The "non-forest vegetation" class includes grasslands, brush land, and cropland.

An accuracy assessment was performed at the metropolitan level. This information was obtained by comparing the classified pixels to the ground reference points in a matrix generated using IMAGINE. The assessment results suggest that the overall producer's and user's accuracies of land cover classifications of the six years were satisfied.

3.2 Across-Scale Land-Cover Data Extraction

Land cover data at the metropolitan level was directly derived from the satellite image classifications. This data set includes area statistics for the four types of land cover (built-up area, forestland, non-forest vegetation, and water body) in the six detection years. To extract land cover data of all the counties and cities in the study area, we subset the classified images of the metropolitan level using the corresponding county and city boundary data sets.

3.3 Built-up Spread Pattern Analysis

To reveal long-term trends in built-up spread patterns over the three decades, we compared the 1972 and 2001 data generated by remote sensing image classifications. A circle of 7.5 km in radius was drawn to delineate the boundary of a metropolitan urban core as we estimated it to be in 1972. Ten concentric buffer rings (4 km wide) were added to the urban core. To measure the magnitude of urban sprawl over the different sectors of the metropolitan area in the last three decades, we delineated North to South (N-S) and East to West (E-W) transects cutting across the center of the depicted urban core. Their axes divide the metropolitan area into four sectors (NW, NE, SW, and SE). We extracted built-up land cover data as well as the built-up patch density and the forest aggregation indices for each buffer ring in each sector from the 1972 and 2001 data sets. We analyzed these data to understand built-up spread effects in the past three decades.

As part of the spatial spread pattern analysis, we performed riparian built-up land change analysis to understand development activities in relation to their proximity to the water areas, a land cover type that may either serve as the "magnet" to attract built-up activities or as the protective zone of waters in the course of urbanization. For this, we conducted spatial buffer analyses in the riparian areas of three major rivers and seven major lakes on classified images. Five buffer zones of width ranging from 80 m to 1.6 km were created around the water bodies with ArcGIS Buffer Wizard tool. The polygons generated by the buffer wizard were used to clip the corresponding classified images utilizing ArcGIS Geoprocessing tool to obtain statistics on built-up land cover in riparian areas of each of the study water bodies.

3.4 Landscape Metrics Generation

Using the remotely sensed land cover data, we calculated selected landscape metrics with the FRAGSTATS software program (McGarigal and Marks, 1995). The metrics include the patch density (PD) index of the built-up land cover as well as the patch density, the largest patch index (LPI), and the aggregation index (AI) of both forestland and non-forest vegetation. The PD equals the number of patches of the corresponding land cover type divided by total area of interest. The LPI at the class level measures the percentage of total land area comprised by the largest patch, showing the dominance of a land cover type. The AI is calculated from a patch adjacency matrix, which quantifies the degree of fragmentation of a land cover type or a landscape. The metrics were generated for each of the selected cities and counties, at the landscape (metropolitan) level, and for each of four directional sectors of the metropolitan area.

4. RESULTS AND ANALYSIS

4.1 Land cover changes at varied spatial scales

	1972	1979	1985	1992	1999	2001
Built-up	8.65	10.38	12.03	15.41	18.69	19.19
Forest	16.36	16.44	16.81	16.58	16.71	17.36
Non-Forest	73.93	71.96	69.06	66.03	62.70	61.24
Water	1.05	1.22	2.10	1.99	1.90	2.21

Table 1. Proportion (%) of land cover types obtained from classified satellite images in the Kansas City Metropolitan area.

The study suggests that over the past three decades, urbanization has significantly modified the land cover of the Kansas City metropolitan area. The built-up land markedly increased, mostly at the expense of the non-forest land, for all the study counties and cities

as well as for the metropolitan area as a whole, while forestland remained relatively unchanged at the metropolitan level (Table 1).

County-level analyses suggest that, similar to the situation at the metropolitan level, there has been a significant trend of steady built-up land cover increase across most of study counties for the six detection years. But, the rates of built-up increases at different counties varied. It appears that the "hot"

or “cold” spots of urban sprawl could be better identified at the county level than at the metropolitan level. The city-level analyses identified sprawling patterns that differ from that detected by the county level analysis. Over the period of study, all the study cities gained built-up land coverage at a greater rate than that of the corresponding counties in which the city is located.

4.2. Built-up spatial spread pattern

Comparative analysis of change in built-up patch density in relation to the spread pattern indicates that the SW and SE sectors of the metropolitan area have been under rapid urban development (Figure 2).

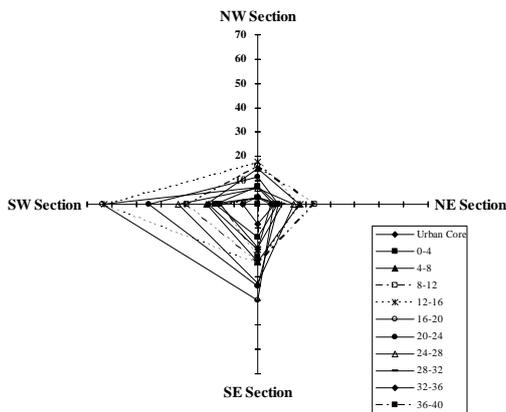


Figure 2. A chart that compares the values of built-up aerial increase (km²) between 1972 and 2001 relative to the four sections of the metropolitan and for the different buffer distances from the urban core. In this chart, the highest built-up activities were located in the SW Section at the distance 12-20 km, and the distance 16-20 km on the SE Section.

The spread analysis also reveals the “fill-in” effects of urban development as spreading away from the urban core.

We used spatial buffering analyses to help understand the dynamics of the built-up addition in the riparian corridors. The results indicate that over the past three decades in the metropolitan area, the proximity of urban developments to the study rivers and lakes varied depending on the location and land ownership surrounding the water body. Generally, all the study water bodies experienced a gradual increase in built-up land at all the buffer distances, which peaked beyond 0.8 km away from the water bodies (Figures 3 & 4). The rate of built-up addition varied among the study water bodies at different distances from the water. Generally, the study lakes experienced higher rates of urban growth than the study rivers as built-up expansion occurred at all the distances to the lakes.

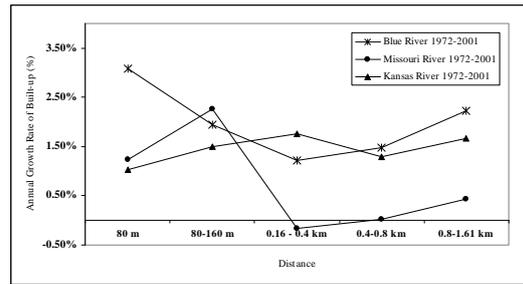


Figure 3. Annual growth rate of added built-up at various buffer distances from the study rivers between 1972 and 2001.

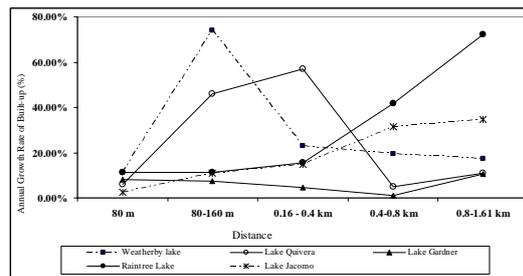


Figure 4. Annual growth rate of added built-up at various buffer distances from the study lakes between 1972 and 2001.

Between 1972 and 2001, Lake Jacomo in Jackson County was subjected to the highest urban development with added 5.35 km² of built-up land at the proximity between 0.8 and 1.61 km, while Lake Gardner, located in the south-west of Johnson County, saw the lowest addition in urban land at all the buffer zones despite the fact that Johnson county is considered a rapidly urbanizing county within the metropolitan. Similarly, among the study rivers, Blue River, which is located in a highly urbanized area within Jackson County, saw the highest aerial built-up addition (12.39 km²) between 0.8-1.61 Km, whereas Kansas River in Johnson County saw the lowest built-up aerial addition (1.13 km²) at 0-80 m distance.

4.3 Landscape Metrics Pattern

The landscape metrics helped identify the landscape effects of urban development in study area. As a general trend at the metropolitan level, non-forest vegetation and forestland covers became more fragmented as a result of the increase of built-up area over the period of study (Figures 5 & 6).

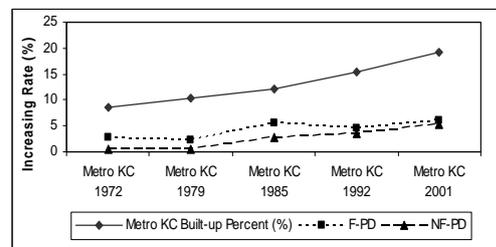


Figure 5. Correlation between built-up area (%) and patch density of non-forest vegetation (NF-PD) and forestland (F-PD). Increased PD values suggest that the non-forest vegetation and the forestland became more fragmented as the result of the growing of the built-up area.

5. CONCLUSIONS

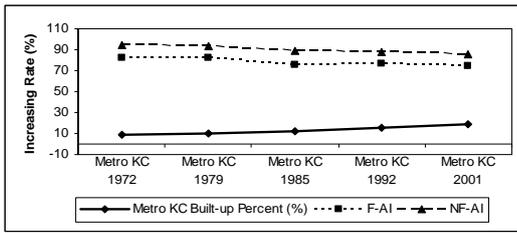


Figure 6. Correlation between built-up area (%) and the aggregation index of non-forest vegetation (NF-AI) and forestland (F-AI). Decreasing AI values indicate more fragmented land covers.

Landscape metrics analysis also indicates that at the metropolitan level large forest areas (patches) were less affected than areas of non-forest vegetation (Figure 7).

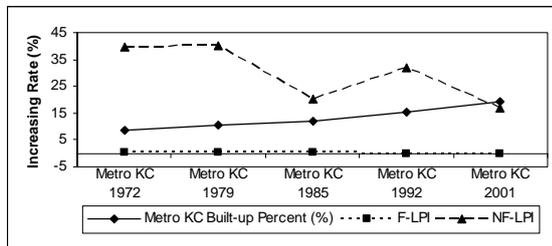


Figure 7. Correlation between the built-up (%) area and non-forest vegetation (NF-LPI) and forestland (F-LPI). Variation of NF-LPI values indicate urban built-up activities affected mainly the non-forestland.

Patch density data analysis suggests that the SW and SE sectors of the metropolitan area are in different stages of urban development. As shown by Figure 8, lower patch density values of built-up area reflect “fill-in” effects of urban development, which usually result in fewer and larger patches. A higher level of and larger variation in built-up area patch density of the SE sector suggests that urbanization in this sector is proceeding more rapidly, resulting in many distinct built-up clusters, while the SW sector has already become an area with large continuous urbanized lands.

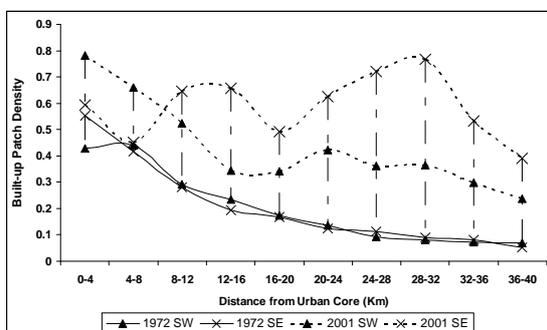


Figure 8. Built-up patch density at different distances (km) from the urban core in the SW and SE sectors of the metropolitan Kansas City.

The study indicates that integrating time series of remotely sensed data with landscape metrics in analysis has helped characterize spatial and temporal patterns of urban sprawl processes. Over the past three decades, urbanization significantly modified landscape of the Kansas City metropolitan area. The built-up land cover significantly increased mostly at the expense of the non-forest coverage for all the study counties and cities as well as for the entire metropolitan area while the forestland cover remained relatively unchanged.

The results of built-up spread analysis show that built-up expansion varied significantly with distance spreading away from the urban core. Urbanization processes evolved by adding built-up pockets to already existing urban development zones, and expanded in the areas that previously had fewer developments. As a consequence, the urban pockets that developed at different times had grown and merged into a continuous urban corridor within the past three decades. Urban sprawl was predominantly expanding toward the southwest and southeast sections of the metropolitan.

The buffering analyses on built-up proximity to waters demonstrate that all the study water bodies experienced a gradual increase in built-up land at all the buffer distances. The rate of built-up addition varied among the study water bodies at different distances from the water. The study further indicates that land ownership of the riparian areas surrounding the study lakes may have played an important role that affected the water bodies’ behavior as either a pull or push factor during the course of urbanization.

Landscape metrics as a land quantification tool helped characterize the land fragmentation conditions of both non-forestland and forestland under urban development. Landscape metrics also helped reveal different stages of urban development between different sectors of the metropolitan areas.

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