REMOTE SENSING AND MODELING IN REGIONAL LAND COVER CHANGE STUDY

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ABSTRACT:

This paper summarises the general pattern of urban land-cover change in the Northeastern Illinois between 1972 and 1997 using Landsat acquired remotely sensed images. The region, centred by the city of Chicago, experienced dramatic land cover change in the past decades. Accompanying the redistribution of population and decentralisation of metropolitan functions are the tremendous growth and development of outlying suburban areas. Comparison of classified land cover data of 1972, 1985, and 1997 demonstrates that urban land expansion dominated the regional pattern of land cover change. Between 1972 and 1985, urban land increased by 14.5%. Urban land increase and suburban sprawl accelerated to about 30% between 1985 and 1997. Within the 25 years between 1972 and 1997, urban land increased about 49%. Most of the suburban land expansion occurred by consumption of agricultural land in the outer-ring and collar counties. About 22% and 20% of agricultural land were converted into other land use in the time periods between 1972 and 1985, and 1985 and 1997, respectively. A 37% decrease of agricultural land was observed from 1972 to 1997. Natural areas, on the other hand, declined 7.6% from 1972 to 1985, and 14.5% from 1985 to 1997. In total, 21% of natural areas were converted into other types of land covers. Many municipalities, particularly in the collar counties of Chicago, have expanded their territory by annexation. The expansion of the municipalities partially reflects the extent and potential of urbanization in the suburban areas.

1. INTRODUCTION

This paper summarises the general pattern of urban land-cover change in the Northeastern Illinois between 1972 and 1997 using Landsat acquired remotely sensed images. The Chicago metropolitan region, like most of the other metropolitan areas in the country, experienced dramatic land cover change in the past decades. Accompanying the redistribution of population and decentralization of metropolitan functions are the tremendous growth and development of outlying suburban areas. An important step towards a regional analysis is to understand the pattern and the quantitative results of urban land change. The objectives of this study are to obtain a quantitative description of the spatial pattern of urban land cover changes; to help in understanding the relations between urban land cover change and its driving factors; and to provide technical protocol and background data for a regional impact study. Eight northeastern Illinois counties, which encompass the city of Chicago, its suburbs and the surroundings, were the study area, including Cook, DuPage, Grundy, Kane, Kendall, Lake, McHenry, and Will counties.

Remote sensing has been broadly applied in land cover mapping and land cover change detection (Green et al., 1994; Clarke and Gaydos, 1998; Vogelmann, et al., 2001; Wang and Moskovits, 2001). Landsat remote sensing images provide a critical data source for this study.

Observation of urban areas over time with Landsat imagery shows where growth has been taking place and helps in evaluation of how different urban planning programs affect population growth and land use. This study applied three scenes of Landsat images to provide a historical Landsat view of the urban land change in the Chicago metropolitan region. Based on the processed Landsat images, the quantitative descriptions of the landscape and interpreted patterns of urban land-cover change were obtained.

2. METHOD

Land cover maps of the region were derived from classification of the Landsat Multispectral Scanner (MSS) imagery data acquired on October 2, 1972 and the Thematic Mapper (TM) data acquired on May 2, 1985 and October 10, 1997. The 1972 MSS data was the first cloud-free Landsat imagery available for the Chicago region. These digital images were geometrically rectified and georeferenced into the Universal Transverse Mercator (UTM) map coordinates. An interpolation process was applied to resample the MSS data into 30-m pixels so that the same spatial resolution was maintained for the MSS and TM imagery data.

This study applied a classification scheme that has eleven (11) land cover categories including forest, woodland, savanna, prairie, wetland, unassociated woody vegetation,

unassociated grassy vegetation, agriculture, urban grass, urban built-up, and open water. Based on the classification scheme, training signatures were identified on the 1997 TM image. These signatures tie characteristic patterns of spectral reflectance to individual types of the above land covers. Intensive ground referencing was conducted to assist in training signature selection. The spatial locations of the training samples were identified using global positioning systems (GPS). The training signatures were then applied to classify the 1997 TM images. To classify the 1972 MSS and 1985 TM, historical land-cover information was obtained from aerial photograph taken at about the same time period, from U.S. Geological Survey topographic maps, and from county land-management records. These references provide information for selection of training signatures on the 1972 MSS and 1985 TM imageries.

The classified Landsat imagery data were recoded into five general categories, *i.e.:* urban land, natural area, unassociated vegetation, agriculture, and open water for the change analysis. Urban land includes all man-made features such as buildings, residential developments, cemeteries, roadways, landfills, quarries, and urban grasses. The natural area includes forests, woodlands, savannas, prairies, shrub lands, and wetlands. Agriculture includes cropland and other types of agricultural practices. The unassociated vegetation represents a mixture of shrubs and trees and abandoned agricultural fields. This category includes both woody and grassy vegetation types and is considered a part of the cultural community. The unassociated woody growth is a mix of shrubs and trees which owe their existence to recent human land use practices. It is so named because its constituent species do not naturally occur together, either historically, or as associates in long-term self-perpetuating communities. The unassociated grassy areas are relatively open fields, which have developed after weedy alien and native herbaceous species colonize barren soils or decimated natural areas. Most unassociated grassy areas occur as re-colonization of plants in the years following the cessation of agricultural cultivation or grazing.

To eliminate the influence by possibly misclassified individual pixels, image processing was applied to filter the classified land cover data. The area of three adjacent pixels was defined as the minimum spatial unit. Therefore, any patches of land cover types that contained less than 3 pixels in size (smaller than 0.5 acres) were eliminated from the change analysis.

Accuracy assessment of land cover classifications indicates that high overall accuracy was achieved for the generalized land cover data. About 90% accuracy was obtained for the 1972 land cover data and about 93% accuracy was obtained for the 1985 and 1997 land cover data. For urban land, about 87% accuracy was achieved.

3. RESULT

3.1 Regional Urban Land Cover Change

Comparison of classified land cover data of 1972, 1985, and 1997 shows that urban land expansion dominated the regional pattern of land cover changes (Table 1). Between 1972 and 1985, urban land increased by 14.5%. Urban land increase and suburban sprawl accelerated to about 30% between 1985 and 1997. Within the 25 years between 1972 and 1997, area classified as urban land increased about 49%.

Most of the suburban land expansion occurred by consumption of agricultural land in the outer-ring and collar counties. About 22% and 20% of agricultural land were converted into other land use in the time periods between 1972 and 1985, and 1985
and 1997, respectively. A 37% decrease of agricultural land was observed from 1972 to 1997. Natural areas, on the other hand, declined 7.6% from 1972 to 1985, and 14.5% from 1985 to 1997. In total, 21% of natural areas were converted into other types of land covers in the 25 years.
It was noticed that the area of unassociated vegetation almost doubled in size during the 25 years. This increase reflects degradation of natural lands in the absence of appropriate management and ecological restoration. It has to be pointed out, however, that the 1972 land cover data was derived from classification of Landsat MSS data. The coarser spatial resolution of the original MSS data made the identification of unassociated vegetation difficult. The 1985 and 1997 land cover data were obtained from classification of Landsat TM. High spatial resolution and richer spectral bandwidths of the TM data made the classification more accurate than that from 1972 MSS.

	1972–1985 (hectares)	1985-1997 (hectares)	1972–1997 (hectares)
Urban Land	+33,011 (14.5%)	+78,114 (30%)	+11,1125 (48.85%)
Natural Area	-17,251 (7.6%)	-30,735 (14.65%)	-47,986 (21.13%)
Agriculture	-130,658 (21.8%)	-93,267 (19.89%)	-223,925 (37.35%)
Unassociated Vegetation	+118,711 (147.2%)	+45,361 (22.75%)	+164,072 (203.45%)

Table 1. Land cover change in metropolitan Chicago region between 1972 and 1997.

3.2 Spatial Pattern of Urban Land Cover Change

Distance from downtown Chicago is an important factor controlling the region's landscape change. A half-ring pattern is clearly observable from both Landsat images and the derivatives of land cover maps. To quantify the spatial pattern of urban land distribution and the changes,

the region was divided into five concentric zones. This zones separated the region into 0-15 km (Zone I), 15-30 km (Zone II), 30-45 km (Zone III), 45-65 km (Zone IV), and > 65 km (Zone V) areas measured from the center of Chicago (Figure 1). The proportion of land converted into urban land use in different zones was compared by calculating the percentage of increase and density of change of the urban land (Table 2).

The result indicates that Zone III, the area between 30 km and 45 km from downtown Chicago, had the highest change density (11.54 ha./km^2) and a high rate of urban land increase (62%) between 1985 and 1997. Zone IV experienced about 76% urban land increase and ranked second in change density (7.26 ha./km^2). This pattern agreed well with the facts that many suburban developments fell into these two zones. The two zones contain many residential and commercial development sites in the northwest Cook County, the southern part of Lake and McHenry counties, most of DuPage County, the eastern Kane County, and the northern Will County. About 22% of urban increase in Zone III and 37% in Zone IV were converted from agriculture land.
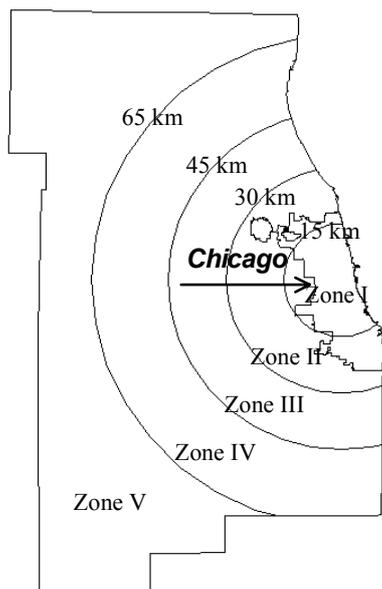
Zone III (30-45 km)	62.01	11.54
Zone IV (45-65 km)	76.11	7.26
Zone V (> 65 km)	52.81	4.04

Table 2. Urban land cover change by distance from downtown Chicago

3.3 Changes in Municipality Boundaries

Many municipalities, particularly in the collar counties, have expanded their territory by annexation in the past 25 years (Figure 2). The expansion of the municipalities partially reflects the extent and potential of urbanization in the suburban areas. As a result of expansion, more planned development has been carried out within these municipalities. To depict the patterns of land expansion in the region, the changes of municipality boundaries were extracted from the census data. The relations between the urban land changes and the expansions of the
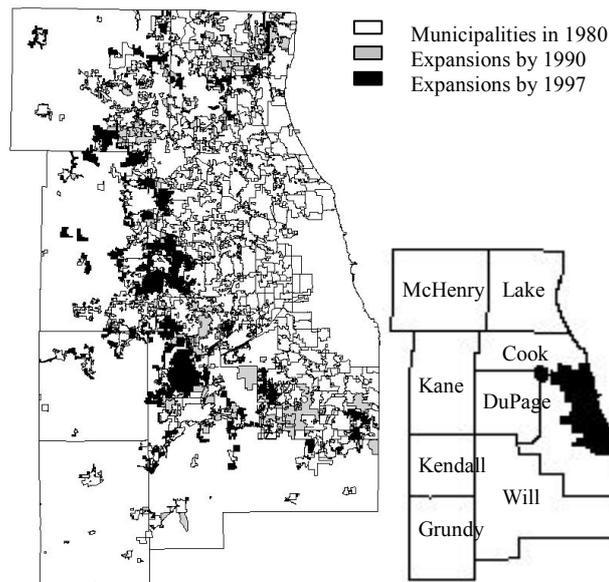

Figure 1. Study area and distance zones.

Figure 2. Changes of municipality boundaries in Chicago area between 1980 and 1997.

Land cover change	Urban Land Change (%) 1985-1997	Change Density (ha./km^2)
Zone I (0-15 km)	2.03	1.63
Zone II (15-20 km)	16.92	6.84

Municipality Name	Area Changed (km^2)	Population Changed	P/A Ratio
Crystal Lake	18.99	6,106	321.54
Long Grove	18.31	2,734	149.32
Naperville	16.36	43,476	2,657.46
Aurora	15.09	18,263	1,210.27
Frankfort	13.49	2,823	209.27
Antioch	11.93	1,686	141.32

Gurnee	11.37	6,536	574.85
Wadsworth	10.95	722	65.94
Bolingbrook	9.48	3,582	377.85
Bartlett	9.08	6,141	676.32
Vernon Hills	8.91	5,492	616.39
Orland Park	8.86	12,675	1,430.59
Crest Hill	8.79	1,747	198.75
Lake in the Hills	8.67	249	28.72
Buffalo Grove	8.43	14,187	1,682.92
Woodridge	7.64	4,037	528.4
Joliet	7.56	-739	-97.75
Waukegan	7.17	1,828	254.95
Lakemoor	7.03	442	62.87

Table 3. Selected municipalities that changed
the most in areas between 1980 and 1990

Municipality Name	Area Changed (km^2)	Population Changed	P/A Ratio
Bolingbrook	20.86	10,469	501.87
Huntley	20.72	576	27.8
Joliet	19.04	9,532	500.63
Naperville	16.71	21,195	1,268.4
Plainfield	14.38	2,783	193.53
Orland Park	13.4	9,937	741.57
Grayslake	12.6	6,982	554.13
Tinley Park	11.22	6,195	552.14
West Chicago	11.2	2,084	186.07
Romeoville	10.82	1,395	128.93
New Lenox	10.38	3,390	326.59
Lake in the Hills	10.11	10,989	1,086.94
Algonquin	10.01	6,326	631.97
Aurora	9.96	16,849	1,691.67
St. Charles	7.89	3,076	389.86
Channahon	7.66	2,074	270.76
Montgomery	6.85	790	115.33
Harvard	6.69	882	131.84

Table 4. Selected municipalities that changed
the most in areas between 1990 and 1997

Municipality Name	Area Changed (km^2)	Population Changed	P/A Ratio
Naperville	33.07	64,671	1,955.58
Bolingbrook	30.34	14,051	463.12
Joliet	26.61	8,793	330.44
Aurora	25.05	35,112	1,401.68
Crystal Lake	23.53	13,590	577.56
Huntley	22.89	1,383	60.42
Orland Park	22.26	22,612	1,015.81

Lake in the Hills	18.78	11,238	598.4
Long Grove	18.11	4,045	223.36
Grayslake	17.38	9,110	524.17
Plainfield	17.15	3,573	208.34
New Lenox	16.53	7,296	441.38
Gurnee	16.41	15,310	932.97
West Chicago	16.32	4,342	266.05
Wadsworth	15.4	1,208	78.44
Frankfort	15.38	5,250	341.35
Romeoville	15.26	-23	-1.51
Algonquin	14.08	12,185	865.41
St. Charles	13.46	8,204	609.51
Antioch	13.26	2,979	224.66

Table 5. Selected municipalities that changed
the most in areas between 1980 and 1997

municipalities was then obtained using multiple year land cover data and the changes of the municipality boundaries. Population changes within the municipalities were extracted as well (Table 3-5).

The results show that municipalities undergoing the greatest expansion lay within and around the areas of Zone III and Zone IV. The changes of the municipality boundaries were more evident between 1990 and 1997 than 1980 and 1990. Between 1980 and 1990 the municipalities of Crystal Lake, Long Grove, Naperville, Aurora, Frankfort, Antioch, Gurnee, and Wadsworth ranked near the top increasing by over 10 km^2 in areas. Crystal Lake ranked first in area increase (about 19 km^2) but ranked only 30th in population increase (6,106). Naperville, on the other hand, ranked third in area expansion (16.36 km^2) but first in population increase (43,476). To reflect the intensity of urban land development, the ratio between population change and the area increase (P/A) was calculated. The P/A ratio served as an indicator for the intensity of urban development. For example, both Naperville and Wadsworth had over 10 km^2 land expansion. Naperville experienced a very intensive urban development (P/A=2657.46/km^2), while Wadsworth had a relatively slower pace in development (P/A=65.94). Therefore, the municipalities with lower P/A ratio should have a greater potential or available land for urban development in the future. The lower P/A ratio also indicates that the area is in a lower density pattern of suburban development rather than an intensified pattern of new urban development.

Bolingbrook ranked 9th in area expansion between 1980 and 1990. However, this municipality ranked the first in area expansion between 1990 and 1997 with 10,469 population increase (Table 4). The second ranked Huntley, on the other hand, had about the same area expansion as the Bolingbrook but its population increased by only 576 during the same time period. The big

difference in P/A ratio between the top ranked two municipalities in area expansion indicated that they were taking different development actions in the time period.

Examination of the changes for the municipalities from 1980 to 1997 shows that Naperville, Aurora, Orland Park, and Gurnee are the top four in P/A ratio (Table 5). Satellite derived land cover maps agreed that the most intensive urban development happened in these areas. The municipalities that ranked high in P/A ratio are mostly located within or beyond Zone IV. The combination of satellite derived land cover maps and the changes of municipalities show that the most intense urban land consumption is occurring in the suburban areas most outlying from the central city.

4. DISCUSSION

This study depicts the land cover change and the pattern within the greater eight-county metropolitan Chicago region during the 25 years between 1972 and 1997. Urban land expansion and suburban sprawl dominated the regional land cover change in this time period. Quantitative comparison and visual maps provide strong evidence of the expansion of suburban sprawl in the region.

This study agreed well with the result derived by other institutions using different methodology and technical approaches. A recent report by the Northeastern Illinois Planning Commission (NIPC) states that developed land in metropolitan Chicago increased 49% between 1970 and 1990, whereas its population grew by 4%. NIPC projected that the population of the region will increase by 25% by the year 2020 (NIPC, 1999). It is certain that suburban sprawl and other urbanization processes will continue there.

Historical Landsat remotely sensed data and the Landsat-7 ETM+ imagery data are critical in development of quantitative analysis models and in simulation of the effects of urban land cover change on regional natural and cultural systems. Based on the research finding from this study, coupled with the population and employment projections made by the census and planning agencies (NIPC, 1998), simulation of the region's land cover change to the year 2020 became possible (Wang and Zhang, 2001). Modeling analysis by integration of driving factors and land cover maps derived from remote sensing provide reliable information to predict the effects of suburban sprawl and the potential impact.

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