MutiTemp-2003, Second International Workshop on the Analysis of Multi-temporal Remote Sensing Images.
July 16-18, 2003. Ispra, Italy.

MULTI-TEMPORAL LANDSAT IMAGE CLASSIFICATION AND CHANGE ANALYSIS OF LAND COVER IN THE TWIN CITIES (MINNESOTA) METROPOLITAN AREA

M.E. BAUER, F. YUAN, K.E. SAWAYA

University of Minnesota
Remote Sensing and Geospatial Analysis Laboratory
1530 Cleveland Avenue North, St. Paul, Minnesota, 55108, USA
Email: mbauer@umn.edu

This paper describes the methods and results of classifications of multi-temporal Landsat TM/ETM+ data of the seven-county Twin Cities Metropolitan Area of Minnesota for 1986, 1991 and 1998. The overall classification accuracies were 95% for the three years, and the change detection accuracy was 88-90%. The classifications showed that the amount of urban or developed land increased from 25.8% to 30.6% of the total area between 1986 and 1998. The results are being used to project future growth patterns, analyze landscape diversity and fragmentation, and examine relationships to factors such as distance to highway. The classifications have provided an economical and accurate way to quantify, map and analyze changes over time in land cover.

1. Introduction

The growth of the size of cities, often at rates exceeding the population growth rate, and the accompanying loss of agricultural lands, forests and wetlands, escalating infrastructure costs, increases in traffic congestion, and degraded environments, is of growing concern to citizens and public agencies responsible for planning and managing growth and development. In Minnesota this concern is manifested in the Smart Growth Twin Cities initiative [2] which examines alternative scenarios for managing growth and making more efficient use of land resources.

Historically, remote sensing in the form of aerial photography has been an important source of land cover and land use information. However, the cost of aerial photography acquisition and interpretation of cover types is prohibitively expensive for large geographic areas. An alternative is to acquire the needed information from digital satellite imagery such as Landsat TM and ETM+.. This approach has several advantages: (1) the synoptic view of the sensor provides coverage of large geographic areas, (2) the digital form of the data lends itself to more efficient analysis and the classified data are compatible with geographic information systems, eliminating the need to digitize interpreted information, and (3) land cover maps can be generated at considerably less cost than by other methods (albeit at 30-meter spatial resolution).

This paper describes the methods and results of classifications of multi-temporal Landsat TM/ETM+ data covering the seven-county Twin Cities Metropolitan Area (TCMA) for three times between 1986 and 1998, and builds on the preliminary results reported by Sawaya et al. [4]. Post-classification change detection has enabled quantification and analysis of changes in land cover over time.

2. Methods

2.1 Description of Study Area

The study area is the seven-county Twin Cities Metropolitan Area (TCMA) of Minnesota, an area of approximately 7700 km^2. The area includes a diversity of land cover classes interspersed with over 900 lakes and transected by the Mississippi, Minnesota, and St. Croix rivers. High and low density urban development characterizes the central portion with more than 100 cities and towns surrounding the core cities of Minneapolis and St. Paul. Several rural land uses, including agricultural fields, grasslands, wetlands and forests, are dispersed across the surrounding landscape. In 2000 the population of the TCMA was 2.6 million. The population increased at a rate of 16.9% between 1990 and 2000 with much of the growth occurring in the suburbs surrounding Minneapolis and St. Paul. The diversity of land cover types and uses, combined with the urbanization of the TCMA, makes it a near ideal area to develop and evaluate the potential of Landsat data for monitoring land change dynamics.

2.2 Multi-temporal Landsat Data Processing and Classification

Multi-temporal Landsat TM/ETM+ data acquired on early and mid to late summer dates in 1986, 1991, and 1998 have been used to classify level I and II land cover. Processing and classification of data for 2002 which will extend the temporal series is currently underway. We have found that the combination of early summer (late May or early June) with mid to late summer (August or early September) images provides the highest classification accuracy. In the early images fields planted to annual crops (e.g., corn and soybean) respond as bare soil and are distinguishable from forests which are already fully leafed out. When only a summer image is used, forests and some crops, especially corn, are spectrally similar. Conversely, the later summer image is needed to separate those same crop fields from urban areas with significant amounts of impervious surfaces that are spectrally similar to bare soil.

The Landsat images were rectified to the UTM projection system using 60-70 ground control points, typically highway intersections, with RMS errors of 0.2-03 pixels, or about 7.5 meters. The land cover classification system included the following level 1 classes: agriculture, cultivated grass, extraction, forest, urban, water, and wetland. Except for the extraction class, samples of each class were clustered into 5-15 classes following the procedures for “guided clustering” described by Bauer et al. [1]. The statistics describing each sub-class were then input to a maximum likelihood classifier. Following classification, the sub-classes were recoded to the level 1 classes. The extraction class was delineated manually using a map provided by the Metropolitan Council. A post-classification rule-based procedure was used to separate urban impervious surface areas that were confused with bare soil in the rural areas, and a 3 x 3 majority filter was used to re-code isolated pixels classified differently than the majority class of the window.

2.3 Change Detection and Analysis

Following classification of imagery from the individual years, a post-classification, approach of subtracting the classification maps, 1998 – 1991 and 1991 – 1986, was applied. This is perhaps the most common approach to change detection and has been successfully used by Yang and Lo [5] to detect land changes in the Atlanta, Georgia area. An advantage of the approach is that provides “from-to” change information.

As part of our analysis we have compared area estimates from the Landsat classifications and change maps to estimates from other inventories, particularly the U.S. Dept. of Agriculture’s Natural Resources Inventory (NRI). The change detection maps have also been compared to high resolution, IKONOS, satellite imagery acquired in 2000 and to 1991 and 1998 parcel maps in a GIS data base. The parcel map data base included comparisons to 59,000 pixels in 859 polygons distributed over the metropolitan area.

3. Results and Discussion

3.1 Classification and Change Detection Accuracy

The overall accuracies were 95.2, 94.6 and 95.9% for 1986, 1991, and 1998, respectively, with Kappa statistics of 94.0, 93.2 and 94.9%. User’s accuracy of individual classes ranged from 85 to 98% and producer’s accuracy ranged from 87 to 99%.

The simplest approximation of change detection accuracy can be found by multiplying the classification accuracies of the individual years [6]. By this measure, the overall accuracy of the change detection in our study equals 88.4% for 1991-98 and 88.7% for 1986-91. Comparison of the Landsat map of changes from rural to urban to the GIS parcel data base for 1991 and 1998 indicates that 90.4% of the parcels classified as change areas were, in fact, in areas undergoing development and urbanization. An additional indicator of accuracy was the overlay of the Landsat change map onto IKONOS imagery which shows, for example, housing developments and shopping centers. Although qualitative, with very few exceptions the areas identified as change from agriculture and rural to urban between 1991 and 1998 were urban developments.

3.2 Comparison of Landsat and NRI Estimates

A second method for evaluating Landsat classification accuracy was by comparison to other inventories such as the Natural Resources Inventory, an inventory conducted by the U.S. Dept. of Agriculture every five years. Results of this comparison results are shown in Table 1. The general landscape trends are very similar in both sets of data with both showing increased amounts of urbanization in the TCMA. Differences between the two are attributed to the varying dates between the two survey methods, as well as to Landsat classification error and sampling error in the NRI estimates. While the area estimates of both surveys are similar, the Landsat method has the clear advantage of also providing maps of “what is where.”

Table 1. Comparison of area estimates from Landsat classification and NRI.

Source - Year	% Urban	% Forest & Wetland	% Agriculture	% Water
Landsat –1991	27.4	22.2	44.4	6.0
NRI – 1992	27.7	21.7	44.4	6.1
Landsat –1998	31.9	21.0	41.1	5.9
NRI – 1997	34.0	19.2	40.6	6.2

3.3 Post-classification Change Detection

A map of the major land cover types and the changes from rural to urban or developed uses is shown in Figure 1. The majority of the changes are at the periphery of the major cities of Minneapolis and St. Paul, and the first ring of suburbs. Figure 1 illustrates one of the major advantages of satellite data classification: a map of where land cover change has occurred.

There are several ways to quantify the land cover change results. One basic method is to tabulate the totals for each land use cover type and examine the trends between the years. Table 2 lists the change statistics from 1991 to 1998; due to the brevity of this paper only the 1991 and 1998 results are included. Values in the table were sorted by area and listed in descending order. Agriculture, urban and forest are the three major land covers and the changes in their proportions represent the most significant changes. Urban growth is the most important change. From 1991 to 1998, urban land increased by 4.3%, or 33,296 hectares, while agriculture land decreased 25,704 hectares, forest land decreased 4,876 hectares, and wetland decreased 4,109 hectares.

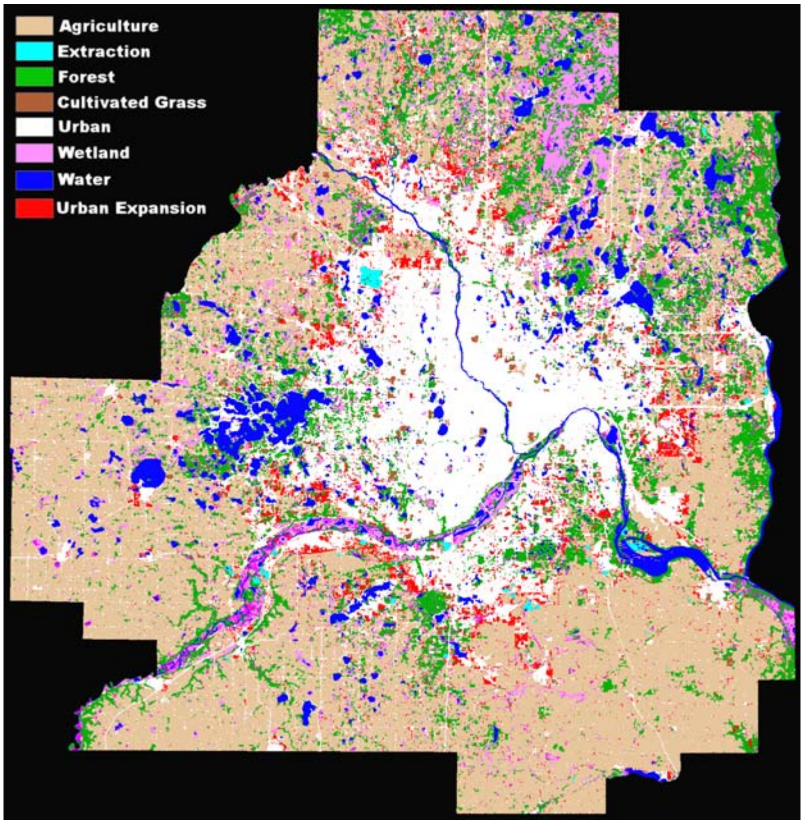

Figure 1. Urban growth from 1991 to 1998. The locations of the 34,884 hectares of undeveloped land uses that were converted into urban uses between 1991 and 1998 are highlighted in red.

A matrix of land cover change from 1991 to 1998 was also created (Table 3). The table demonstrates the kind of land cover changes, namely “from-to” information, that occurred during this period. As indicated, the majority of new urban land was converted from agricultural areas. In the eight-year period, 25,955 hectares of agricultural land, equaling 7.6% of the agriculture land in 1991, were transformed to urban uses. This means that 78% of the 33,296 hectares of total urban land growth was converted from agricultural land. Although Figure 1 only maps the rural changes (agriculture, forest, wetland) to urban or developed, other, more specific changes can also be mapped.

Table 2. Land cover changes from 1991 to 1998.

Land Cover	**1991**		**1998**		**Change**	
	Area (ha)	**%**	**Area (ha)**	**%**	**Area (ha)**	**%**
Agriculture	341,658	44.4	315,955	41.1	-25,704	-3.3
Urban	202,073	26.3	235,370	30.6	33,296	4.3
Forest	110,932	14.4	106,056	13.8	-4,876	-0.6
Wetland	59,987	7.8	55,878	7.3	-4,109	-0.5
Water	45,943	6.0	45,746	5.9	-196	-0.1
Cult. Grass	6,441	0.8	7,706	1.0	1,265	0.2
Extraction	2,419	0.3	2,743	0.4	323	0.1

Table 3. Matrix of changes (hectares) in land cover from 1991 to 1998.

1991	**1998**							**1991 Total**
	Agric.	**Urban**	**Forest**	**Wet.**	**Water**	**Grass**	**Extr.**	
Agric.	**308,594**	25,955	521	5,020	3	1,279	286	341,658
Urban	330	**196,309**	3,482	692	4	1,203	52	202,072
Forest	958	8,453	**96,258**	4,522	8	630	101	110,930
Wet.	5,763	2,937	5,221	**43,767**	2,028	251	19	59,986
Water	.2	315	98	1,760	**43,767**	0	68	45,943
Grass	292	1,230	463	113	1	**4,337**	4	6,440
Extr.	16	169	12	3	2	6	**2,213**	2,421
1998 Total	315,955	235,368	106,055	55,877	45,746	7,706	2,743	**769,450**

We are now examining some of the effects and relationships of urban growth, as determined from the Landsat-derived change maps, to other parameters and factors. One is the relationship to population growth. In contrast to many metropolitan areas the growth rate in urban area from 1991 to 1998 is similar to the increase in population. In other words, there is relatively less "sprawl" in the TCMA. Another finding is that there is, not surprisingly, a strong relationship between new development and proximity to highways. Almost half (48%) of the development detected in our classifications occurred within 2 km of highways, and 25% was between 2 and 4 km.

We have also been investigating the changes in landscape diversity and fragmentation as a function of time from 1986 to 1998 using the Landsat classifications and landscape metrics. Landscape diversity has remained relatively stable, but fragmentation, especially of agriculture and forests, has increased significantly during this period. On the other hand, most of the increase in developed area has occurred inside of the Metropolitan Urban Service Area, in accordance with the land use policies developed for the region.

Land cover/use classification maps can also be inputs to models to simulate or predict future growth patterns. We have implemented the Land Transformation Model (LTM), a neural network model. LTM uses population growth, transportation factors, proximity or density of important landscape features such as rivers, lakes, recreational sites, and high-quality vantage points as inputs to predict land use change [3]. The model uses GIS, artificial neural network routines, and customized geospatial tools with land use data from at least two time periods being a key input. Information derived from historical land use change is one of the most important factors used to forecast future trends and patterns. The model can also be used to help understand what factors are most important to land use change.

4. Conclusions

Information from satellite remote sensing can play a useful role in understanding the nature of changes in land cover/use, where they are occurring, and projecting possible or likely future changes. Such information is essential to planning for development and preserving our natural resources and environment, and is needed by urban planners and citizens. Satellite remote sensing approaches provide a cost-effective alternative when more information is needed, but budgets are declining.

Our continuing work includes adding additional years, both before and after the dates reported here, of Landsat data and classifications to the temporal series. In addition, we have developed the methodology to accurately classify percent impervious surface area which represents an alternative way of looking at urban growth.

Acknowledgements

The support of the Upper Great Lakes Regional Earth Science Applications Center (NASA grant NAG13-99002) and the University of Minnesota Agricultural Experiment Station (project 42-037) is gratefully acknowledged.

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