

MAPPING ATLANTA'S LAND USE/COVER CHANGE AND ITS IMPACT ON THE ENVIRONMENT USING TIME SEQUENTIAL LANDSAT IMAGES

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ABSTRACT

Time sequential Landsat MSS and TM images were used to map land use/cover of the Atlanta metropolitan area for the past 25 years as a component of the NASA-funded Project ATLANTA (ATlanta Land-use ANalysis: Temperature and Air-quality), which has the objective to model the impact of land use/cover change on temperature and air quality in Atlanta. This paper describes a suite of techniques that have been developed to ensure high accuracy of land use/cover classification from these satellite images with varying quality. Post-classification comparison with GIS overlay to map the spatial dynamics of land use/cover change was conducted. A GIS database of land use/cover at the county level was created, which integrates biophysical data (air temperature, rainfall, surface temperature, normalized difference vegetation index) with demographic/socio-economic data from the censuses (population density, housing, per capita income, education). Interrelationships among these data were investigated, and the impact of land use/cover changes on the environment was clearly revealed. The analysis has succeeded in uncovering the socio-economic causes of land use/cover change. Initial findings suggested that an increase in personal income has brought about a corresponding increase in residential development at the expense of forest and cropland, which in turn has brought about an increase in urban heat island effect. Through the use of an animation sequence of the land use/cover maps, the processes of urban development in Atlanta through time were vividly displayed.

1 INTRODUCTION

Project ATLANTA (ATlanta Land Use ANalysis: Temperature and Air quality), funded by NASA, was initiated in 1997 as an interdisciplinary remote sensing study to observe and measure the growth and development of the urban heat island effect over the Atlanta, Georgia metropolitan area in the United States, and its associated impacts. A major research objective of the project is to study how land use/cover changes, from early 1970s to the present, have affected Atlanta's meteorology and air quality. Another objective is to model how potential urban growth patterns will further affect Atlanta's meteorology and air quality in the future. Project ATLANTA is also designed to demonstrate the usefulness of satellite data to planners and policy makers as land use/cover data sources to a GIS database for decision making. The author of this paper is responsible for producing the land use/cover maps of Atlanta for this project.

Because of the need to map the land use/cover of Atlanta as early as possible using satellite images, Landsat MSS data which have been available to the public since July 1972 were used for mapping the land use/cover in the 1970s and early 1980s. To map land use/cover in the late 1980s and 1990s, the much higher resolution Landsat TM data, available since 1982, were used. This mapping project therefore has to deal with old and new Landsat data of variable quality and different spatial resolutions. To be useful, the land use/cover data extracted from these Landsat images should meet the United States Geological Survey mandated minimum level of accuracy of 85 percent in identifying land use/cover categories (Anderson et al., 1976). The main objective of this paper is to describe the approaches developed to ensure high accuracy in the land use/cover data extracted. Another objective is to achieve integration of biophysical and demographic/socio-economic data via land use/cover in a specially created GIS database, so that the people-environment interactions can be revealed.

2 THE STUDY AREA AND ENVIRONMENTAL PROBLEMS

The city of Atlanta in the State of Georgia is one of the fastest growing metropolitan areas in the United States. Being located in the Sun Belt, it has attracted population and investment since the 1970s. Atlanta has now become the premier commercial, industrial, and transportation center of the Southeastern United States. Population has increased 27 percent and 33 per cent respectively for the 1970-80 and 1980-90 periods (Research Atlanta, Inc., 1993). The city has expanded in size through a process known as suburbanization at the expense of forest and cropland (Hartshorn and Muller, 1989). The result is urban sprawl, which has brought havoc to the environment: traffic congestion (people driving longer hours in Atlanta than their counterparts in many other cities in the United States) and rapid loss of valuable forest land (20 hectares/day). The major concern is the degeneration of urban climate and air quality, particularly in regard to elevated temperature and increases in ozone and emissions of volatile organic compounds (VOCs).

3. CHARACTERISTICS OF LANDSAT IMAGES EMPLOYED FOR THE PROJECT

Eleven predominantly cloud-free Landsat images acquired between 1973 and 1998 were used. These consist of eight Landsat MSS images for 1973, 1979, 1983, 1987, 1988, and 1992, and three Landsat TM images for 1987, 1997, and 1998 (Table 1).

Date	Type of Imagery	Landsat No.	Nominal IFOV (m)	Sun Elevation (degree)	Sun Azimuth (degree)	Scene Location	Rectification RMSE (Control Point No.)	Radiometric Normalization
4-13-73	MSS	1	57X79	54.16	129.37	North Atlanta	0.58 (13)	Yes
4-13-73	MSS	1	57X79	54.83	127.39	South Atlanta		
6-11-79	MSS	3	57X79	61.65	105.65	North Atlanta	0.46 (13)	Yes
6-11-79	MSS	3	57X79	61.74	102.77	South Atlanta		
5-9-83	MSS	4	57X79	60.50	117.64	center-shifted*	0.61 (13)	Yes
6-29-87	MSS	5	57X79	61.84	103.71	center-shifted*	0.44 (13)	No
6-29-87	TM	5	28.5X28.5	61.84	103.71	center-shifted*	0.22 (13)	No
5-14-88	MSS	5	57X79	61.61	115.51	center-shifted*	0.51 (12)	reference
4-23-92	MSS	5	57X79	56.00	121.80	center-shifted*	0.47 (15)	Yes
7-29-97	TM	5	28.5X28.5	61.00	106.00	center-shifted*	reference	No
1-2-98	TM	5	28.5X28.5	27.00	150.00	center-shifted*	0.27 (14)	No

*The center of the north scene has been shifted 50%. The scene size is approximately 185X185 km²

Table 1. Characteristics of the satellite data used for land use/cover change mapping in the Atlanta Metropolitan area

The preferred seasons are springs and early summers (April-July) when vegetation is in full bloom. However, the choice of images were constrained by the frequent occurrence of clouds in Atlanta, some of which are associated with thunderstorms.

4. REFERENCE DATA

NASA has specially commissioned thermal infrared images to be acquired over the city of Atlanta for day and night time, using the 15-band Advanced Thermal and Land Applications Sensor (ATLAS) on May 11, 1997. At the same time, color infrared photography at the scale of 1:40,000 was also acquired. This is the main source of reference data for providing ground truths. Another source of data are the contact prints of black-and-white and color aerial photographs

of Atlanta for the period 1986-1988 at the nominal scale of 1:40,000 also. Field surveys were also conducted with a Global Positioning System as needed.

4 IMAGE PRE-PROCESSING

4.1 Geometric Rectification

This was required to register all the images acquired in different years. The 1997 Landsat TM image, which has already been rectified and georeferenced to the UTM coordinate system (Zone 16), NAD83 horizontal datum, and GRS80 ellipsoid by Space Imaging EOSAT, the supplier, was selected as the reference image to which all other images were registered. The accuracy of georeference of the 1997 Tmimage was verified by superimposing the census tract boundaries (DLG file) onto the image. The registration of all other images to the 1997 TM image produced a RMSE of about 0.5 pixel for both MSS and TM images.

4.2 Radiometric Normalization

Radiometric normalization was carried out to eliminate the differences in radiometry among different Landsat images caused by variations in sensors, atmospheric conditions, and sensor-target-illumination geometry. Relative radiometric normalization (RRN) is the preferred method because it does not require *in situ* atmospheric data at the time of satellite overpasses to make the corrections. There are different RRN methods. Choice of the right method depends on the scene characteristics, such as, the pattern of land use/cover distribution, water-land proportion, topographic relief, and similarity between the reference scene and the subject scene. For this project, the method developed by Hall et al. (1991) was used because it meets best the terrain characteristics of Atlanta. This method developed regression equations based on a bright and a dark target to relate a subject image scene to the reference scene. For this project, only the Landsat MSS scenes were radiometrically normalized because the Landsat TM scenes are in excellent radiometric quality. For this project, the 1988 MSS scene was selected as the reference image to which all other MSS images were related. Basically, the following transform coefficients in the regression equation were computed:

$$\text{Slope : } m_k = \frac{(B_{Rk} - D_{Rk})}{(B_{Sk} - D_{Sk})}$$

$$\text{Intercept: } b_k = \frac{(D_{Rk} * B_{Sk} - D_{Sk} * B_{Rk})}{(B_{Sk} - D_{Sk})}$$

where k is the band, D_{Rk} and D_{Sk} are the mean values of dark radiometric control sets of the reference image and the subject image respectively, and B_{Rk} and B_{Sk} are the mean values of bright radiometric control sets of the reference image and the subject image respectively. Using the above transformation coefficients, each subject MSS image was then radiometrically rectified by applying the following equation:

$$S'_k = m_k S_k + b_k$$

Where S_k is the digital number (DN) of band k in image S on date 1, S'_k is the normalized digital number of band k on date 1, m_k is the slope or gain, and b_k is the intercept or offset.

4. IMAGE CLASSIFICATION

4.1 Classification Scheme

Hybrid levels I and II land use/cover categories modified from the USGS scheme (Anderson et al., 1976) were adopted because of the lower spatial resolution of the Landsat MSS image data. Six land use/cover classes were developed: (1) high-density urban use, (2) low-density urban use, (3) cultivated/exposed land, (4) cropland or grassland, (5) forest, and (6) water (Table 2).

4.2 Classification Approach

No.	Classes	Definitions
1	High-Density Urban Use	Approximately 80 to 100 % construction materials, e.g. asphalt, concrete, etc.; typically commercial and industrial buildings with large open roofs as well as large open transportation facilities, e.g. large airports, parking lots, and multilane interstate/state highways; with low percentage of residential development residing in the city cores.
2	Low-Density Urban Use	Approximately 50 to 80 % construction materials; often residential development including most of single/multiple family houses and public rental housing estate as well as local roads and small open (transitional)space as can be always found in a residential area; with certain amount of vegetation cover (up to 20%).
3	Cultivated/exposed land	Areas of sparse vegetation cover (less than 20%) that are likely to change or be converted to other uses in the near future; including clearcuts, all quarry area, cultivated land without crops, and barren rock or sand along river/stream beaches.
4	Cropland or grassland	Characterized by high percentages of grasses, other herbaceous vegetation, and crops; including lands that are regularly mowed for hay and/or grazed by livestock, golf courses and city parks, and regularly tilled and planted cropland.
5	Forest	Including coniferous, deciduous, and mixed forests (90 to 100 %).
6	Water	All areas of open water, generally with greater than 95% cover of water, including streams, rivers, lakes, and reservoirs

Table 2. Land use/cover classes and definitions used in this study.

An unsupervised classification approach was used, which involved two steps:

- (1) Image clustering: Using ERDAS Imagine's ISODATA algorithm to identify spectral clusters from Landsat images. To find the optimum number of clusters, different numbers of classes were tried to determine which would result in a better accuracy in relation to the classification scheme. Sixty clusters were determined to be the best for this project.
- (2) Cluster labeling: With reference to the ground truth data and the false color composite of the Landsat image on display side by side with the cluster image, each cluster was manually interpreted and labeled. Clusters which contained more than one class of land use/cover were specially documented. These clusters would be split by spatial reclassification.
- (3) Spatial reclassification: Boundary errors caused by spectral mixing within a pixel were reduced using a specially designed model filter (3x3 with corner cells disabled). Spectral confusion caused by similarities in spectral value of several land use/cover was corrected with the aid of on-screen digitizing, multiple zooming, area of interest (AOI) functionality, and other relevant GIS tools such as overlay and recode. In this way, spectrally confused clusters were split, each of which was then recoded into the correct land use/cover class.

5. ACCURACY ASSESSMENT

Only the most recent land use/cover map produced (1997/98) was evaluated. A stratified random sample of 488 points were selected on the map so that each class had at least 50 points. These points were checked against the reference data mentioned above. The results are shown in Table 3. The overall accuracy is 90% and kappa is 0.878.

6. CHANGE DETECTION

Six land use/cover maps were produced (Figure 1). Post-classification (or map-to-map) comparison was used to detect changes between any pairs of maps. This method minimizes the problem of normalizing for atmospheric and sensor differences between two dates, and can indicate the nature of

Classified Data	Reference Data							
	1	2	3	4	5	6	Row Total	User Accuracy (%)
1	54	3	3	5	0	0	65	83.31
2	2	57	2	6	6	0	73	78.08
3	0	1	41	8	0	0	50	82
4	0	0	1	96	3	0	100	96
5	0	0	0	3	147	0	150	98
6	0	0	1	0	0	49	50	98
Column Total	56	61	48	118	156	49	488	
Producer's Accuracy (%)	96.43	93.44	85.42	81.36	94.23	100		
Number of Pixels Correctly Classified = 444 Overall Classification Accuracy = 90.10%								
Class Name	Kappa		Class 1 = High-density urban use Class 2 = Low-density urban use Class 3 = Cultivated/exposed land Class 4 = Cropland or grassland Class 5 = Forest Class 6 = Water					
1	0.809							
2	0.75							
3	0.8							
4	0.951							
5	0.976							
6	0.978							
Overall Kappa Index of Agreement = 0.878								

Table 3 Results of accuracy assessment of the 1997/1998 land use/cover map produced from Landat TM data, showing both the confusion matrix and the kappa statistics.

change. Table 4 shows the land use/cover change statistics of Atlanta as extracted from the six land use/cover maps. High-density urban use has increased from 45,423 hectares (4.35%) in 1973 to 86,027 hectares (or 8.24%) in 1997/98 for the 13 urban counties of Atlanta, thus representing an increase of 89.4% in land area. Low-density urban use has increased from 121,448 hectares (or 11.6%) in 1973 to 266,222 hectares (or 25.5%) in 1997/98 or an increase of 119.2% in land area. There has been a significant decline in forest and cropland areas. In 1973, there were 653,729 hectares of forest land (or 62.6%), which declined to 516,987 hectares (or 49.5%) by 1997/98. This represents a decrease of 20.9%. Cropland has declined from 198,146 hectares (or 19%) in 1973 to 132,168 hectares (or 12.7%) in 1997/98, or a decrease of 33.3% in land area. The decline of forest and cropland is clearly the result of accelerated expansion of the city of Atlanta through the process of suburbanization.

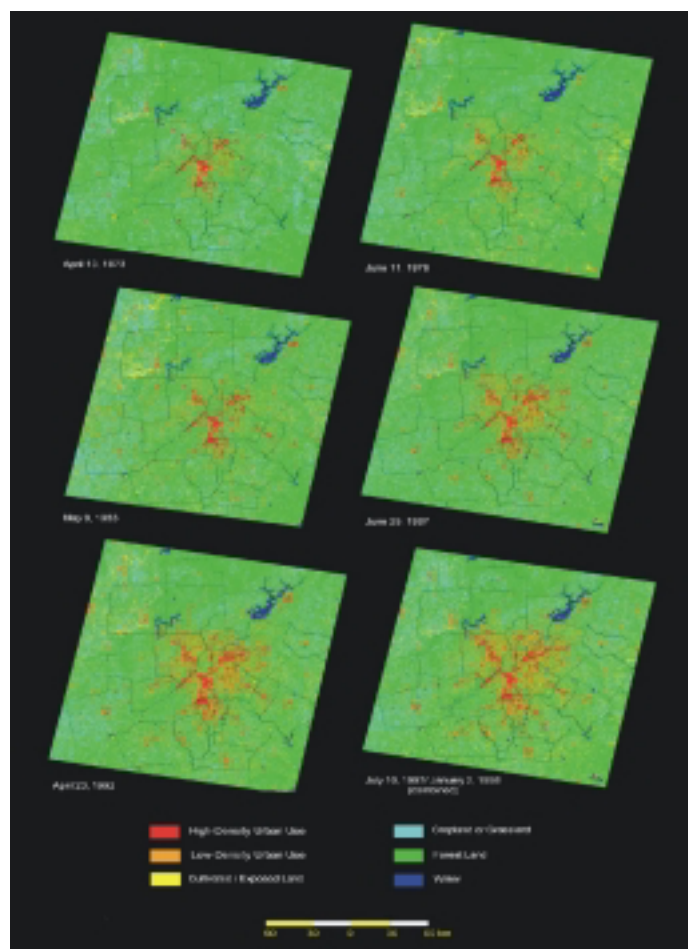


Figure 1. Land use/cover maps of the Atlanta metropolitan area extracted from Landsat images

7. INTEGRATION OF LAND USE/COVER, BIOPHYSICAL, DEMOGRAPHIC, AND SOCIO-ECONOMIC DATA

The time series of land use/cover data of Atlanta as extracted from the maps were stored at the county level as a GIS database. Biophysical data, such as temperature, rainfall, vegetation, and vegetation index, can be stored together with data on population, such as population density, education, housing, and per capita income. Land use/cover change is a

Classification Map		High-density Urban Use	Low-density Urban Use	Cultivated/ Exposed Land	Cropland / Grassland	Forest	Water	Total
4-13-73	hectares	45423	121448	9949	198146	653729	15607	1044303
	percent	4.35	11.63	0.95	18.97	62.60	1.49	100.00
6-11-79	hectares	45672	159082	19914	168748	634896	15985	1044298
	percent	4.37	15.23	1.91	16.16	60.80	1.53	100.00
5-09-83	hectares	61234	171368	20580	161747	613989	15317	1044236
	percent	5.86	16.41	1.97	15.49	58.79	1.47	99.99
6-29-87	hectares	74038	180740	18669	154939	599973	15944	1044303
	percent	7.09	17.31	1.79	14.84	57.45	1.53	100.00
4-23-92	hectares	83987	232009	19655	137428	553746	17477	1044303
	percent	8.04	22.22	1.88	13.16	53.03	1.67	100.00
7-29-97/ 1-02-98	hectares	86027	266222	21552	132168	516987	21347	1044303
	percent	8.24	25.49	2.06	12.66	49.51	2.04	100

Table 4. Land use/cover change for the Atlanta metropolitan area (13 counties) as extracted from a time series of Landsat images, 1973-1998

result of socio-economic change, which in turn affects the physical environment (e.g. the urban heat island effect and more rapid rainwater runoff. ArcView GIS was used to create the GIS database. The data can be further analysed by a statistical package such as SAS.

Initial analysis has shown some interesting results:

- (1) The relationship between change in residential use and change in Normalized Difference Vegetation Index (NDVI) has become stronger in recent years (1992-1997). It revealed that the larger the change in residential use area, the greater will be the decrease in NDVI (i.e. the environment becoming less green).
- (2) The correlation between change in NDVI and change in per capita income is positive and is strengthening in recent years (1987-1992). In other words, the greater change in per capita income is associated with a greater change in NDVI (greenness).
- (3) The correlation between change in residential land use area and change in per capita income is positive, and is also strengthening in recent years (1987-1992). In other words, great increase in residential use area is accompanied by large change in per capita income.

Further development of the GIS database will be carried out, using finer spatial areal unit (census tracts). Land use/cover can be easily updated with new satellite images, notably the Enhanced Thematic Mapper Plus (ETM+) data from Landsat 7, which became available since April 15, 1999. Landsat 7 data includes a 15-metre panchromatic band, making more precise land use/cover mapping and statistics extraction possible.

8. CONCLUSIONS

Time sequential Landsat images allow accurate land use/cover maps and data of Atlanta to be extracted, provided care has been taken to correct problems of radiometric differences caused by variations in sensor quality and sensor-target-illumination geometry, especially for the lower quality Landsat MSS data. The lower spatial resolution have also given rise to spectral confusion, which needs to be corrected using GIS functionality. Land use/cover provides a good link to integrate biophysical and socio-economic data in a GIS database, which reveals interesting relationships.

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