ASSESSING URBAN GROWTH AND ENVIRONMENTAL CHANGE USING REMOTELY SENSED DATA

George Z. Xian
SAIC Under Contract to USGS EROS
Sioux Falls, SD 57198
xian@usgs.gov

Mike Crane
U.S. Geological Survey
Sioux Falls, SD 57198
mpcrane@usgs.gov

Cory McMahon
SAIC Under Contract to USGS EROS
Sioux Falls, SD 57198
cmcmahon@usgs.gov

ABSTRACT

Urban development has expanded rapidly in Las Vegas, Nevada, over the last fifty years. By the year 2003, nearly one million people resided in the Las Vegas metropolitan area that includes the cities of Las Vegas, Henderson, North Las Vegas, and Boulder City. A major affect associated with this population trend is the transformation of the landscape from natural cover types to increasingly impervious urban land. This research utilizes an innovative approach for mapping urban extent and its temporal changes by determining impervious surface areas from Landsat satellite remotely sensed data in conjunction with digital orthophotography. Sub-pixel percentages of imperviousness are mapped from the 1980s to 2000s for the Las Vegas metropolitan area. Results indicate that places having a significant increase in impervious surface are primarily within areas of existing urban land cover/use. Analysis suggests that spatial and temporal changes in impervious surface are useful indicators of spatial extent, intensity, and potentially the types of urban land cover/use change. Also, multi-temporal Normalized Difference Vegetation Index (NDVI) satellite data and surface radiant temperatures are examined to understand changes in urban vegetation, urban thermal patterns, and their important influences on the urban environment of the region.

Key Words: Urban, Imperviousness, Remote sensing, environment

INTRODUCTION

Urban development in the United States is usually associated with converting land for residential and commercial uses. This form of development generally raises concern about environmental and quality-of-life impacts of land cover and land use (LCLU) change in urban and suburban areas. An important result of urbanization is the change of land cover types from natural to anthropogenic impervious surfaces. Impervious surface area (ISA) is usually defined as roofs, roads, parking lots, driveways, and sidewalks. ISA is considered a key indicator of environmental quality and can be used to address complex urban environmental issues, particularly those related to the health of urban watersheds (Schuler, 1994) and as an indicator of non-point source pollution or polluted runoff (Arnold and Gibbons, 1996; CWP, 2003).

Percent ISA varies with land use (Arnold and Gibbons, 1996; Ji *et al*., 1999; Ward *et al*., 2000). In residential areas, ISA can range from 20% to more than 65% depending on zoning density. In area of high density commercial development, the percent ISA may exceed 95%. ISA data obtained from historical Landsat imagery has proven to be a useful source for defining urban extent in urban growth modeling (Jantz *et al.*, 2003; Xian and Crane, 2005). Studies have shown that a threshold of 10% ISA captures most developed urban land, including low-density residential areas (Schuler, 1994; Arnold and Gibbons, 1996). In combination with land use information and an urban growth model, Carlson (2004) used Landsat data derived ISA to simulate runoff and urban sprawl. Jennings *et al.* (2004) reported that urban development gradients in watersheds have apparent linear relationship with total percent impervious area when they built linear models to obtain ISA information from National Land Cover Data 92 (NLCD92). Xian and Crane (2005) used three ISA threshold values: 10-40% for low development density, 41-60% for medium development density, and 61-100% for high development density to investigate urban growth in the Tampa Bay watershed. The percent ISA was demonstrated to be useful for quantitatively describing urban LCLU categories and densities, as well as spatial changes, in the watershed.

To deal explicitly with the urban LCLU heterogeneity problem at a sub-pixel level, the Sub-pixel Imperviousness Change Detection (SICD) method provides quantifiable measurements for detecting change (Yang, *et al*., 2003; Xian, *et al*., 2005). The SICD method uses high-resolution imagery as a source of training data for representing urban land-cover heterogeneity, and medium-resolution Landsat imagery to extrapolate imperviousness over large spatial areas. This method has been applied to monitor and detect multi-spatial and temporal urban LCLU changes in Georgia (Yang, *et al*., 2003) and the Tampa Bay watershed of Florida (Xian, *et al*., 2005; Xian and Crane, 2005).

This study investigates urban LCLU change in the Las Vegas valley, Nevada, from 1984 to 2002 through sub-pixel impervious surface estimation. One unique landscape characteristic of this area is that urban and rural lands can be misclassified because surrounding bare sandy soils, gravel, and rocks exhibit spectral signatures similar to ISA reflectance values. Remote sensing data from Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) were used as the primary sources for estimating sub-pixel ISA distribution. General ISA features and associated urban LCLU characteristics were also analyzed.

STUDY AREA

The Las Vegas valley is located in southern Nevada and encompasses about 1320 km^2, including the cities of Las Vegas, Henderson, North Las Vegas, and Boulder City. The area is characterized by a desert climate that is extremely hot and dry in summer and relatively cool and wet in winter. Vegetation is not very abundant in Las Vegas; therefore, landscaping gravel and the bare alluvial soils of the region appear similar to concrete. Fig. 1 shows the landscape complexity in Las Vegas—different urban land uses and development densities associated with surrounding gravels in rural areas. The region has experienced remarkable growth over the past fifty years. The population of Clark County has increased from 48,589 in 1950 to 741,459 in 1990 and 1,375,765 in 2000 according to historical census data (Clark County, 2005). Population in the Las Vegas valley urban area reached 1,685,197 in 2004. Associated with this population increase is the growth of housing development in the area. Housing units reached 537,893 in 2000. Single family detached housing and apartments were 53.3% and 27.6% of total housing units, respectively, resulting in approximately 80% of housing units falling in those two categories.

METHODS AND DATA

To estimate spatial and temporal ISA variations for the Las Vegas area, an improved integrated sub-pixel imperviousness assessment model (SIAM) was implemented. SIAM first requires accurate ISA training datasets obtained from high-resolution imagery. Medium-resolution satellite imagery and derived information such as NDVI, together with geographic information such as slope, are then used to build regression models for extrapolating imperviousness over large spatial areas. The procedures for SIAM implementation are illustrated in Fig.2.

To create the training datasets for mapping temporal and spatial urban development in Las Vegas valley, one-foot resolution digital orthophoto quarter quadrangles (DOQQs) were selected for each of eight different locations. The high-resolution DOQQs were first analyzed and classified into urban and non-urban land use. The classification result was then rescaled to 1 m resolution for calculating percent imperviousness using the NLCD Mapping tool that allows Cubist (http://www.rulequest.com) to interface with ERDAS Imagine. The resultant percent ISA data were then scaled to 30 m resolution using nearest neighbor resample method for the development of training and validation data in the regression tree modeling.

Large area mapping of ISA was performed using five Landsat scenes for path 39, row 35. These consisted of Landsat TM scenes for 1984, 1986, 1992 and 1996, plus a Landsat ETM+ scene for 2002. All images were preprocessed by the U.S. Geological Survey (USGS) National Center for Earth Resources Observation and Science (EROS) to correct radiometric and geometric distortions in the images. All images were rectified to a common Universal Transverse Mercator coordinate system. Bands 1 through 5 and 7 were utilized at a spatial resolution of 30 m. The thermal bands had their original pixel sizes of 120 m for TM and 60m for ETM+ images resampled to 30 m using the nearest neighbor algorithm to match the pixel size of the other spectral bands. These corrections resulted in digital number (DN) images that are measures of at-satellite radiance. To correct the potential bias caused by the sensor differences and their calibration, the digital number of Landsat 5 TM (DN5) was converted to a pseudo Landsat 7 ETM+ DN (DN7) using calibration coefficients developed by Vogelmann *et al*. (2001). The coefficients were derived from an analysis of tandem sets of Landsat 5 and Landsat 7 data collected over the central United States. This conversion was made to take advantage of the superior radiometric calibration of the ETM+. The conversion equation is $DN7 = DN5 * slope + intercept.$ The slope and intercept values vary with bands. DNs in each band were converted first to at-satellite radiance and then to at-satellite reflectance (Landsat Project Science Office, 2002). Reflectance values from the visible (ρ_1) and near-infrared (ρ_2) bands of Landsat images were used to compute NDVI values using the formula NDVI = $(\rho_2 - \rho_1) / (\rho_2 + \rho_1)$. Large area ISA was mapped using Landsat reflectance, NDVI derived from reflectance bands, thermal band, and slope information.

Figure 1. Las Vegas is characterized by a variety of landscape types including urban and suburban residential housing, alluvial soils with scattered desert shrubs and grass.

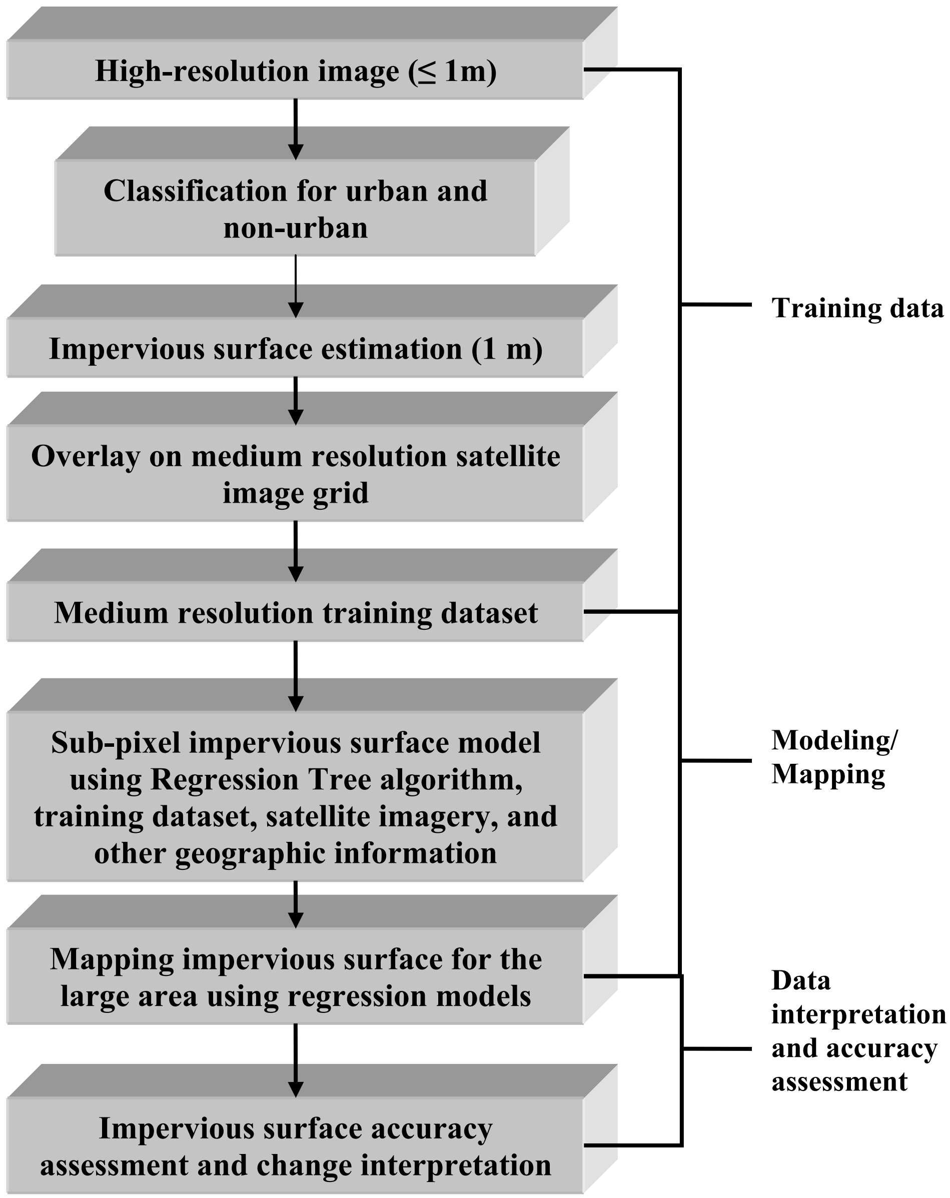

Figure 2. Implementations of SIAM for estimation of sub-pixel impervious surface using remote sensing data and regression tree algorithm.

RESULTS

Previous work (Xian and Crane, 2005) determined that the 10 percent ISA threshold captured almost all developed land including low, medium, and high-density residential as well as business areas for the Tampa Bay watershed. The same threshold value has been used for the Las Vegas investigation. Pixels were classified as urban when the ISA was equal to or greater than 10 percent, whereas pixels of less than 10 percent were classified as non-urban.

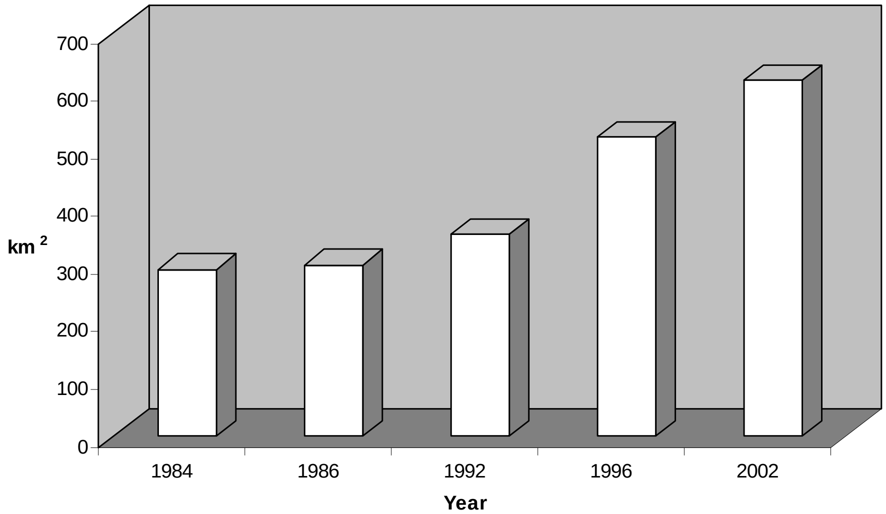

Figure 3. Total urban land cover in the Las Vegas valley from 1984 to 2002 measured from sub-pixel ISA map using a 10% ISA threshold. Landsat imagery is the primary data source.

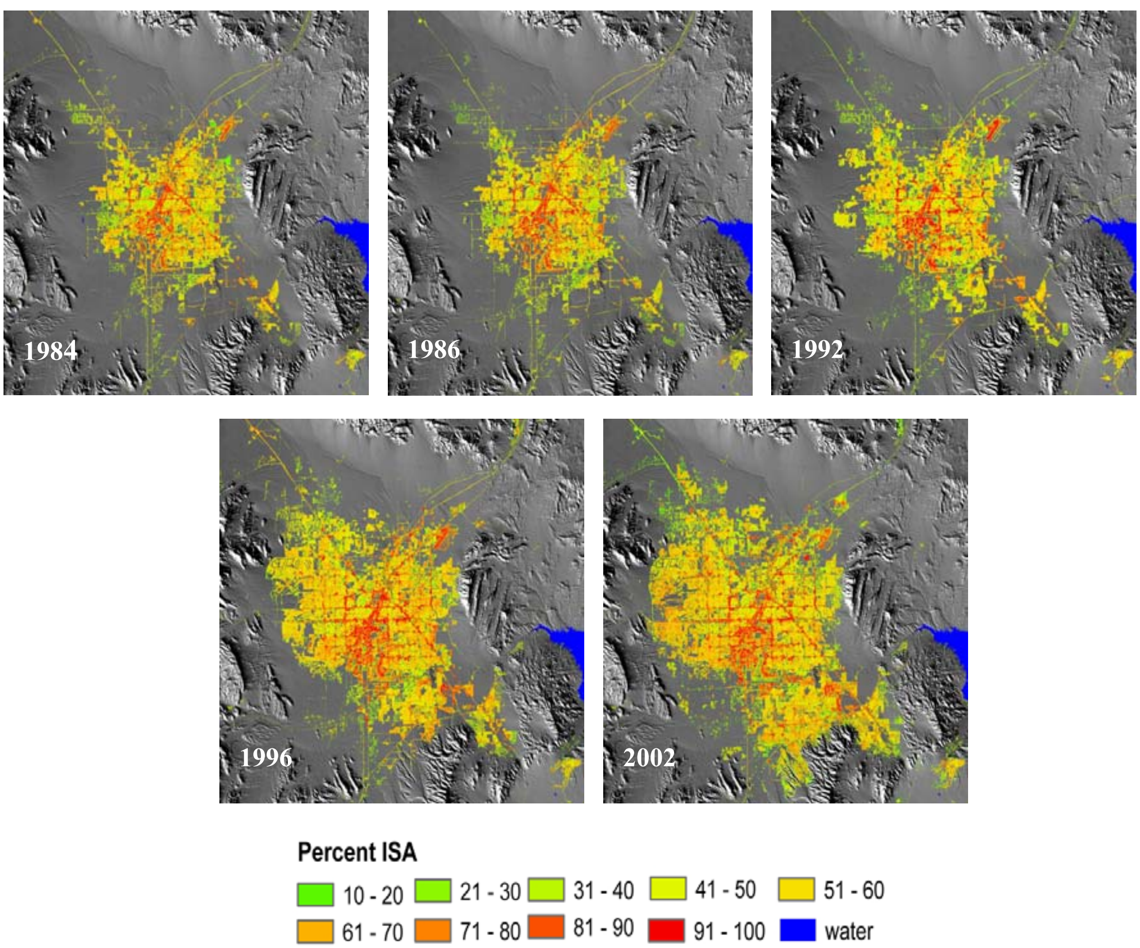

Figure 4. Distribution of ISA in Las Vegas from 1984 to 2002.
All figures were obtained from Landsat 30 m resolution imagery.

ISAs estimation from Landsat TM/ETM+

Large area ISA was mapped using a variety of Landsat satellite data that included reflectance bands, thermal bands, NDVI derived from reflectance bands, and slope information. The thermal band imagery was helpful in eliminating non-impervious areas, especially at the urban fringe. NDVI helped to distinguish urban residential land use from rural land because most trees and lawns are associated with the urban areas. A slope layer eliminated spectral misclassifications in the mountainous areas surrounding Las Vegas because the urban areas are found in the valleys and on the lower alluvial flanks of the mountains.

Multi-year spatial extents of ISA in the Las Vegas valley are displayed in Fig.3. The areal extent of urban land was approximately 290 km^2 in 1984, and increased to about 620 km^2 in 2002, representing an increase of 113%. Spatial and temporal variations of ISA for the Las Vegas valley from 1984 to 2002 are shown in Fig. 4. Urban land use expanded in almost all directions in the valley. During the 1980s and early 1990s, most high percent ISAs were located in the downtown and Las Vegas strip areas. More recently, high percent ISAs have expanded to the southeast and northwest portions of Las Vegas.

Urban vegetation change measured by NDVI

NDVI is a surrogate for the amount of vegetation cover for photosynthetic potential. The natural landscape of the study area is characterized by sparse desert vegetation. However, a relatively dense vegetation canopy is associated with the urban area and can be seen in most residential areas. Therefore, vegetation is a good indicator of urban LCLU and areas of urban ecosystem change. Two-date Landsat imagery was used to obtain NDVI values for 1984 and 2002. As can be seen in Fig. 5, higher NDVI values represent greater vegetation canopy coverage, and as urban land has increased, so has the vegetation canopy.

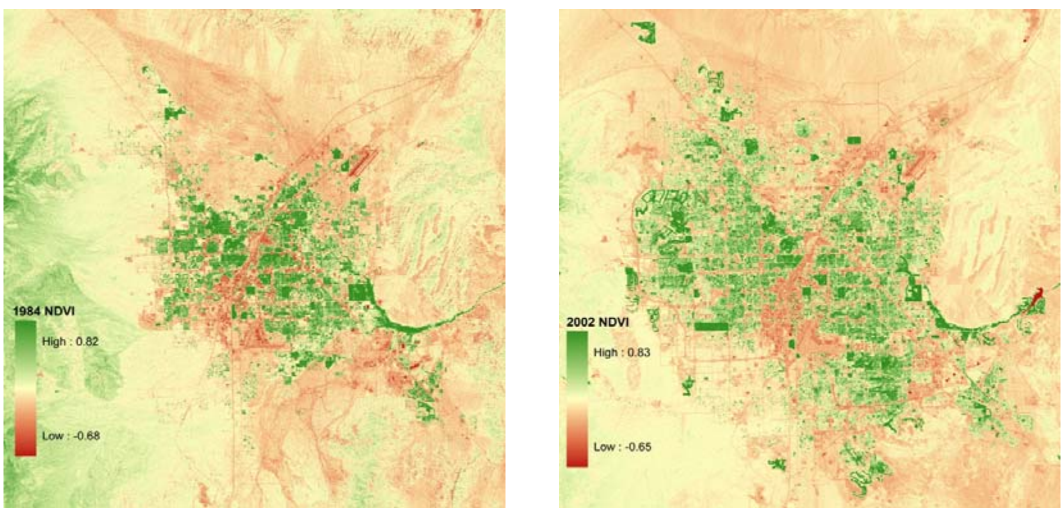

Figure 5. Landsat NDVI images for 1984 (upper) and 2002 (lower) depict the developed areas of Las Vegas in green. Comparison of the two images clearly shows areas of new development.

Urban thermal features

To explore urban thermal features associated with urban development in the valley, radiance values from TM band 6 and ETM+ band 6L, saturating at 347.5 K, were transformed to radiant surface temperature values for the Las Vegas valley. The thermal band was first converted from *DN* to at-satellite radiance and then to effective at-satellite temperature (T_b). To isolate only the land thermal features in each image, water was masked out prior to T_b estimation. After the water pixels were removed, temperatures for the remaining pixels were re-mapped according to each ISA group. Temperature histograms were created for each T_b map. Some extremely high and low temperatures associated with ISA had been retained, e.g., low temperatures caused by shadows in high-density urban areas and high temperatures caused by image noise. The final radiant surface temperature map (Fig.6) was produced by removing pixels with a temperature two standard deviations (2σ) from the mean. The mean T_b shows that high density urban area contains the highest temperature, while medium and low density urban areas possess relatively low temperatures.

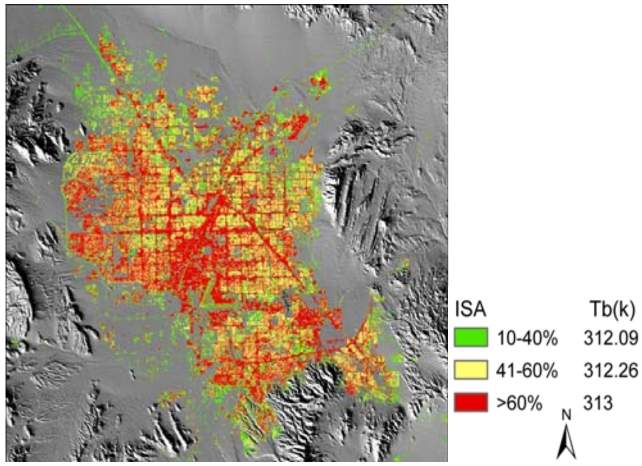

Figure 6. Urban ISA and associated mean T_b in 2002. The high density ISA corresponds to high mean T_b. The values of T_b in medium and low density urban areas are relative low.

ACCURACY ASSESSMENT

The regression tree model used for large area ISA estimation utilized two parameters to measure the model prediction accuracy—average error and the correlation coefficient (R). Table 1 presents these parameters of the regression tree models in each ISA measuring year. Both average error and correlation coefficient show that modeling results from Landsat ETM+ imagery are better than those from Landsat TM imagery.

To perform accuracy assessment using "true" ISA data, root-mean-square error (RMSE) and relative accuracy (RA) were utilized. RMSE and RA are defined as:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(\hat{U}_i - U_i)^2}{N}} \tag{1}$$

$$RA = \frac{100}{N}\sum_{i=1}^{N}\left(1 - \frac{|\hat{U}_i - U_i|}{U_i}\right) \tag{2}$$

where $\hat{U}_i$ is the modeled ISA for sample *i*; U_i is the true ISA digitized from DOQQs for sample *i*; *N* is the total number of samples. For the whole study areas, six random sample locations were generated with the ERDAS Imagine accuracy assessment module. Six colored 1-food resolution DOQQs acquired in 2003 were utilized as ground truth reference for assessing the accuracy of model estimation. A 5x5 sampling unit was used to reduce the impacts of geometric errors associated with DOQQs and satellite images. For each sample pixel, the corresponding true impervious surface was digitized through interpreting DOQQ images and the area of imperviousness was measured from digitized map for each selected pixel. In the 5x5 sample unit, areas of interests (AOIs) were outlined following the boundaries of interpreted impervious surfaces. The area of each AOI was determined by using AOI property functions. The true fraction of ISA in each sample pixel was calculated through dividing the total areas of AOI by each pixel area: 30m x 30m for Landsat results.

Table 1. Regression tree mapping accuracy

year	1984	1986	1992	1996	2002
R for training data	0.84	0.83	0.84	0.82	0.85
Relative error for training data	0.33	0.33	0.34	0.39	0.34
R for testing data	0.83	0.83	0.84	0.82	0.85
Relative error for testing data	0.35	0.34	0.34	0.38	0.34

Table 2. Percent ISA for each sample site and accuracy

Sample site	1	2	3	4	5	6
DOQQ ISA%	92	65	61	55	55	46
Modeling ISA% from Landsat	75	60	58	54	45	47
RA	78.6	83.5	80.8	75.2	68.4	64.4
MEAN RA			75.13			
RMSE	24.2	12.36	13.84	14.68	18.39	17.59
MEAN RMSE			16.85			

The RMSE and RA value for each sample site are given in Table 2. The modeled ISAs exhibit relatively lower accuracy in low percent imperviousness areas than in high percent ISA areas. The overall mean RA and mean RMSE for modeled ISA from Landsat imagery are 75.13% and 16.85, respectively.

CONCLUSIONS

This research has investigated the mapping of urban development in the environs of the Las Vegas valley by modeling anthropogenic impervious surface using SIAM. Quantification of sub-pixel percent imperviousness over time using satellite remote sensing information provided a good estimate of urban LCLU change. Sub-pixel percent imperviousness mapping also provided information on the spatial extent and intensity of urban LCLU change through different percent ISA threshold values. This approach provided considerable flexibility in capturing the heterogeneity of urban land-cover characteristics.

Information about the intensity of urban land-cover change provided by percent imperviousness can help infer types of land-use change in conjunction with previous land-use information. The availability of multi-decade remote sensing information provides an important source for monitoring and assessing urban growth and its influences on the environment and ecosystem. Products produced by SIAM enable users to define and interpret land-cover and land-use change based on different threshold values. The impervious condition of the Las Vegas valley has experienced considerable change, especially in medium to high urban density areas from 1984 to 2002. Areas of imperviousness greater than 10 percent covered about 620 km^2 in 2002. The overall growth rate in imperviousness and urban land use is almost 20 km^2 per year. Associated with these developments is increasing vegetation canopy coverage within the urban area. The mean T_b shows that the high density urban areas of Las Vegas have a temperature value approximately one degree higher than that of medium and low density urban areas. The rapidly developing landscape of the Las Vegas region has created a tremendous challenge for local developers and planners to keep-up with demand.

ACKNOWLEDGEMENTS

This research was performed under U.S. Geological Survey contract 03CRCN0001. We thank Drs. David Meyer and Chandra Giri for carefully reviewing this manuscript.

REFERENCES

Arnold, C. A., Jr., and Gibbons, C. J. (1996). Impervious surface coverage: the emergence of a key urban environmental indicator. *Journal of the American Planning Association*, *62*(2): 243-258.

Carlson, T.N. (2004). Analysis and prediction of surface runoff in an urbanization watershed using satellite imagery. Journal of The American water resources association, 40(4): 1087-1098.

Clark County (2005). Comprehensive Planning, Clark County, Nevada, URL: http://www.co.clark.nv.us/Comprehensive-planning.

CWP (Center for Watershed Protection) (2003). *Impacts of Impervious Cover on Aquatic Systems*, Center for Watershed Protection, Ellicott City, Maryland, 368p.

Landsat Project Science Office (2002). Landsat 7 Science Data User's Handbook. URL: http://ltpwww.gsfc.nasa.gov/IAS/handbook/handbook_toc.html.

Jantz, C.A., Goetz, S.J., and Shelley, M.K. (2003). Using the SLEUTH urban growth model to simulate the impacts of future policy scenarios on urban land use in the Baltimore-Washington metropolitan area. *Environment and Planning B: Planning and Design.* 30: 251-271.

Jennings, D.B., Taylor, S., and Ebert, D.W. (2004). A modeling approach for estimating watershed impervious surface area from National Land Cover Data 1992. *Photogrammetric Engineering & Remote Sensing*, 70(11): 7011-1295.

Ji, M. H., and Jensen, J. R. (1999). Effectiveness of subpixel analysis in detecting and quantifying urban imperviousness from Landsat Thematic Mapper imagery. *Geocarto International*, *14*(4): 31-39.

Schueler, T.R. (1994). The importance of imperviousness. *Watershed Protection Techniques*, 1(3):100-111.

Vogelmann, J.E., Helder, D., Morfitt, R., Choate, M.J., Merchant, J.W., and Bulley,H. (2001). Effects of Landsat 5 Thematic Mapper and Landsat 7 Enhanced Thematic Mapper Plus radiometric and geometric calibrations and corrections on landscape characterization. *Remote Sensing of Environment*, 78: 55-70.

Ward, D., Phinn, S.R., and Murry, A.T. (2000). Monitoring growth in rapidly urbanized areas using remotely sensed data. *Professional Geographer*, *52*(3): 371-386.

Xian, G. and Crane., M. (2005). Assessments of urban growth in the Tampa Bay watershed using remote sensing data. *Remote Sensing of Environment,* 97: 203-215.

Xian, G., Yang, L., Klaver, J. M., Hossain, N. (2005). Measuring urban sprawl and extent through multi-temporal imperviousness mapping. *Urban Dynamic Topic Report, USGS Circular* (in press).

Yang, L., Xian, G., Klaver, J. M., and Deal, B. (2003). Urban land-cover change detection through sub-pixel imperviousness mapping using remotely sensed data. *Photogrammetric Engineering & Remote Sensing*, *69*(9): 1003-1010.

.