ANALYSIS OF URBAN LAND USE CHANGE IN THE LAS VEGAS METROPOLITAN AREA USING MULTI-TEMPORAL SATELLITE IMAGERY

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ABSTRACT

Urban development has expanded rapidly in Las Vegas, Nevada, over the last fifty years. To assess urban land use change in the area, a sub-pixel change detection approach has been used to map urban extent and its temporal changes by determining sub-pixel level impervious surface areas from Landsat satellite remote sensing data in conjunction with digital orthophotography. Sub-pixel percentages of imperviousness are mapped from the 1980s to the 2000s for the Las Vegas metropolitan area using a regression tree model. The spatial-temporal distribution of vegetation in the urban area has also been quantified using the same approach. 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 and land use change. Results indicate that areas of 40–60% imperviousness have experienced the largest increase in Las Vegas, suggesting that areas of medium to high development density areas represent the major urban land uses in the region. Urban area fractional vegetation cover has the highest coverage in medium-density urban areas of Las Vegas.

INTRODUCTION

Urban development is usually associated with consuming land in rural areas for residential and commercial land use. As the extent of built-up land increases, development generally raises concerns about impacts of land use and land cover (LULC) change on the environmental and quality-of-life. The relative importance of urban environments to the global population and the monitoring of spatial-temporal changes in large urban/suburban areas are becoming increasingly important (Small, 2001).

An important environmental change of urbanization is the conversion of land cover types from natural to anthropogenic impervious surface areas (ISA), which usually consist of 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). In addition, ISA is an indicator of non-point source pollution or polluted runoff (Arnold and Gibbons, 1996; CWP, 2003), as well as surface runoff (Carlson, 2004). Percent ISA also varies with land use (Arnold and Gibbons, 1996; Ji *et al*., 1999; Ward *et al*., 2000). In combination with land use information, Jennings *et al.* (2004) reported that urban development gradients in watersheds have an apparent linear relationship with total percent impervious area when they built linear models to obtain ISA information from National Land Cover Data 92 (NLCD92).

Recent studies indicate that sub-pixel imperviousness change detection provides quantifiable measurements for urban LULC change and can deal explicitly with the urban LULC heterogeneity problem at a sub-pixel level (Yang, *et al*., 2003; Xian and Crane 2005). To estimate spatial and temporal ISA variation in urban areas, an integrated sub-

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pixel imperviousness assessment model (SIAM) has been implemented (Xian, *et al*., 2005). Studies have shown that a threshold of 10% ISA captures most developed urban land, including low-density residential areas, and three ISA threshold ranges—10–40%, 41–60%, and 61–100%—represent low development density, medium development density, and high development density, respectively (Xian and Crane, 2005). Percent ISA was demonstrated to be useful for quantitatively describing urban LULC categories and densities, as well as spatial changes.

As a fundamental component of the urban environment and a biophysical variable, vegetation plays an important role in determining urban environmental conditions and energy fluxes at the land surface (Deardorff, 1978; Landsberg, 1981; Roth *et al*., 1985; Gillies *et al.*, 1997; Owen *et al*., 1998; Small, 2001). The presence of vegetation also influences air quality (Nowak, 2000). Vegetation extent and abundance, and the fraction of vegetation cover in urban and suburban areas have been determined using Landsat imagery through the linear spectral mixing model (Small, 2001) and normalized difference vegetation index (NDVI)-based methods (Chouldhury *et al.*, 1994; Carson and Ripley, 1997). Using NDVI-based methods and Landsat imagery, the fractional vegetation cover in arid and semi-arid regions can also be estimated (Xiao and Moody, 2005).

This study investigated changes in urban spatial extent in the Las Vegas valley, Nevada, from 1984 to 2002 through sub-pixel impervious surface estimation. Sub-pixel level variations of vegetation cover in the Las Vegas urban area in 1996 and 2002 were also studied. The Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) were used as the primary data sources for estimating both sub-pixel ISA distribution and fractional vegetation cover. General ISA features and associated vegetation characteristics were also analyzed for the region.

METHODS

Study Area

The Las Vegas valley is located in southern Nevada and encompasses about 1,320 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. The landscape in Las Vegas is complex—different urban land uses and development densities associated with surrounding gravels in rural areas. Vegetation is not very abundant in the rural area. However, landscaping grass, bushes, and trees exist in most residential and commercial areas. The region has experienced remarkable growth over the past fifty years. The population of Clark County increased from 741,459 in 1990 to 1,375,765 in 2000, according to historical census data (Clark County, 2005). The population in the Las Vegas valley urban area reached 1,685,197 in 2004. Associated with the population increase has been the growth of housing development in the area. Housing units totaled 537,893 in 2000. Single-family detached housing and apartments accounted for 53.3% and 27.6% of total housing units, respectively. Approximately 80% of housing units fall within these two categories.

Sub-pixel ISA Estimation

To estimate spatial and temporal ISA variation for the Las Vegas area, SIAM was used. SIAM requires accurate ISA training data sets 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. To create the training data sets for mapping temporal and spatial urban development in the Las Vegas valley, eight 0.3-m orthoimages were used for selected locations. The high-resolution images were analyzed to classify urban and non-urban land use. The classification results were then rescaled to 1-m resolution for percent imperviousness calculation. Resulting percent ISA data were further rescaled to 30-m resolution for the development of training and validation data in 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) Center for Earth Resources Observation and Science (EROS) to correct radiometric and geometric distortions in the images. Bands 1 through 5 and 7 were used at a spatial resolution of 30 m. The thermal bands had their original pixel sizes of 120 m for TM and 60 m for ETM+ images resampled to 30 m using the nearest neighbor algorithm to match the pixel size of the other spectral bands. Bands 1 through 5 and 7 corrections resulted in digital number (DN) images that measure at-satellite radiance. DNs in each band were converted first to at-satellite radiance and then to at-satellite reflectance (Landsat Project Science Office, 2002). The regression models were built according to the assumption of

$$ISA = f(b_i, slope, NDVI) \quad (1)$$

where b_i is Landsat reflectance bands and thermal band (i = 1 to 7).

Fractional Vegetation Estimation

The land surface in urban areas can be characterized in terms of impervious surface area (A_i), vegetation covered area (A_v), and others such as bare soil and water (A_o). If fractional area is considered, then for any grid, we have

$$1 = (A_i + A_v + A_o)/A \quad (2)$$

where A is the total area of a grid. When satellite imagery is used for sub-pixel level analysis, each unit area is defined within a pixel. Most vegetation canopies in the Las Vegas metropolitan area are associated with artificial landscaping, while a few natural vegetation canopies exist in urban and surrounding rural areas. To understand urban environmental change in the region, estimation of vegetation cover is needed. Various methods could be applied for dealing with fractional vegetation cover. The regression tree algorithms used in SIAM to estimate the continuous variable— percent ISA—at the sub-pixel level are applicable for estimating fractional vegetation. Therefore, the same approach was used to estimate fractional vegetation cover (f_v), which is also a continuous variable, at 30-m pixel resolution. The training data sets for f_v were built from the same high-resolution orthoimagery used for ISA estimation. Two widely used vegetation indices were used to compare the f_v obtained from the regression tree model. One from Wittich and Hansing (1995) uses a normalized method of

$$f_v(n) = \frac{NDVI - NDVI_{\min}}{NDVI_{\max} - NDVI_{\min}} \quad (3)$$

where $NDVI$ is the normalized difference vegetation index obtained from the visible (ρ_{vis}) and near-infrared (ρ_{nir}) bands of Landsat images using the formula $NDVI = (\rho_{nir} - \rho_{vis}) / (\rho_{nir} + \rho_{vis})$; $NDVI_{min}$ and $NDVI_{max}$ correspond to the values of bare soil and a surface with a fractional vegetation cover of 100%, respectively. The other method, from Choudhury *et al.* (1994), is defined as

$$f_v(N) = 1 - \left(\frac{NDVI_{\max} - NDVI}{NDVI_{\max} - NDVI_{\min}}\right)^{0.625} \quad (4)$$

Fractional vegetation covers were calculated from these formulas using 1996 and 2002 Landsat data.

RESULTS

Using the 10% ISA threshold (Xian and Crane, 2005), pixels were classified as urban when ISA was equal to or greater than 10%, whereas pixels of less than 10% were classified as non-urban. With consideration of f_v, pixels in urban areas were treated as a mixture of ISA, vegetation, bare soil, and water. Pixels in rural area were treated as a mixture of vegetation, bare soil, and water.

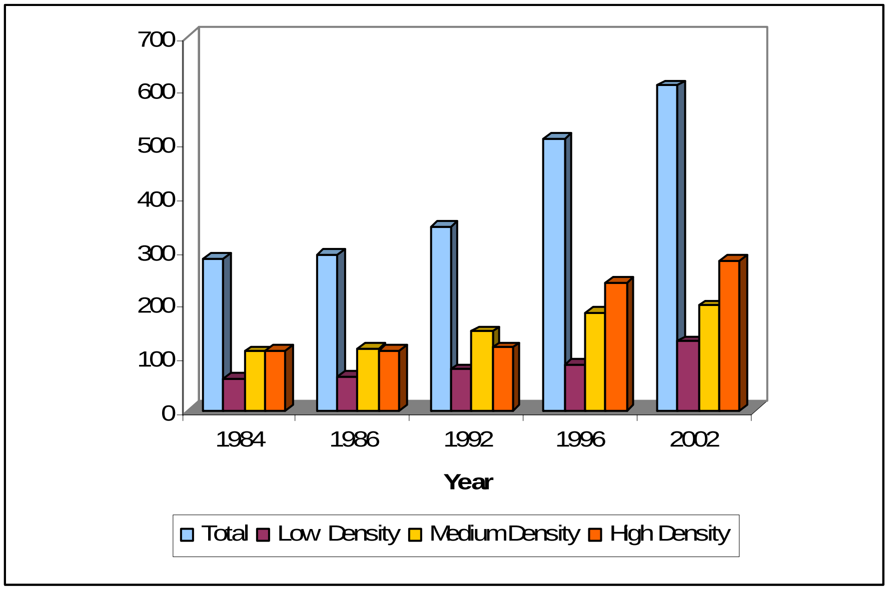

Figure 1. Total urban land cover in the Las Vegas valley from 1984 to 2002, measured from a sub-pixel ISA map using a 10% ISA threshold. The low-density, medium-density, and high-density urban land in each mapping year are also presented.

Large area ISA was mapped using a variety of Landsat satellite data, including both reflectance and thermal bands, NDVI derived from reflectance bands, and slope information. 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 urban areas. A slope layer eliminated spectral misclassifications in the mountainous areas surrounding Las Vegas because 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 Figure 1. The areal extent of urban land measuredapproximately 290 km^2 in 1984 and increased to about 620 km^2 in 2002, representing an increase of 113%. Spatial extents of three categories of urban development density in each mapping year are also listed. Spatial and temporal variations of ISA for the Las Vegas valley from 1984 to 2002 are shown in Figure 2. Urban land use expanded in almost all directions in the valley. During the 1980s and early 1990s, most high percent

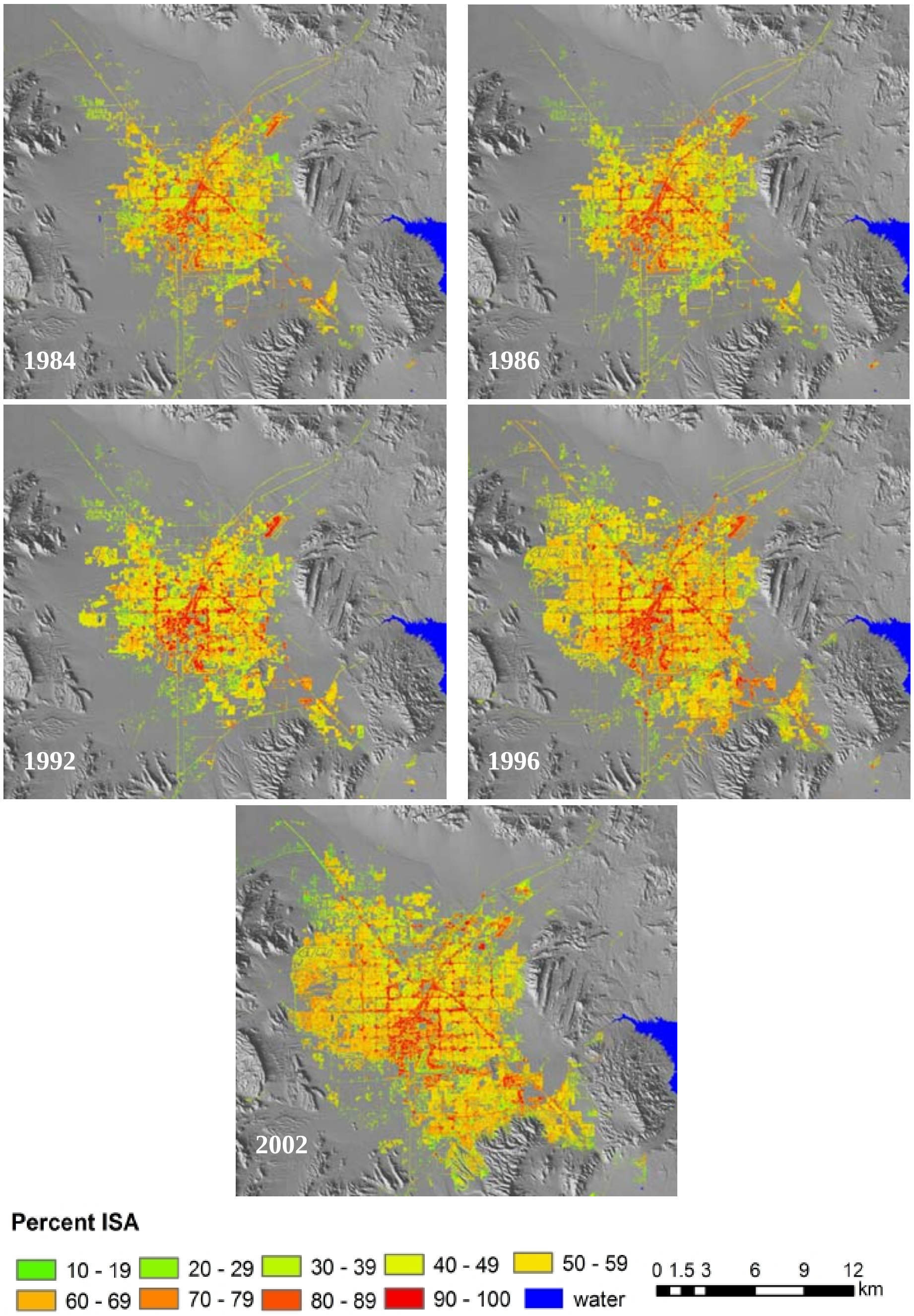

Figure 2. Distribution of ISA in Las Vegas from 1984 to 2002. All figures were obtained from Landsat 30-m resolution imagery.

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.

An accuracy assessment was accomplished by comparing true ISAs obtained from six randomly selected 0.3-m orthoimages, on which a 5-by-5, 30-m grid was digitalized to outline the proportion of true impervious surface for comparison with ISA estimated from Landsat imagery. The overall mean relative accuracy (RA) and mean root-mean-square error (RMSE) for the 2002 modeled ISA from Landsat imagery were 75.13% and 16.85, respectively (Xian *et al*., 2005).

Urban Fractional Vegetation Estimation

Using the sub-pixel level mapping approach, fractional vegetation coverage in each pixel can be mapped for a large spatial area with the same spatial resolution of the satellite imagery. The natural landscape of the study area is characterized by sparse desert vegetation. However, relatively dense vegetation canopies are associated with urban development and can be seen in most residential areas. The same high-resolution orthoimages used for ISA estimation were used for f_v, except that the variables in the training data sets were percent vegetation cover. Landsat images for 1996 and 2002 were used to obtain f_v values, because both images were acquired in mid-June during leaf-on season. As depicteded in Figure 3, larger f_v values represent higher vegetation canopy coverage. The areal extent of the vegetation canopy expanded as the spatial extent of urban land increased. To quantitatively exam the fractional vegetation condition, the proportion of vegetation cover for different land use is defined as

$$VC = \sum (f_{vi} \times N_i)/N \qquad (5)$$

where VC is the proportion of vegetation cover, f_{vi} is the f_v with i percent coverage, N_i is the number of pixels having i percent f_v, N is the total number of pixels for a certain land use category, and i varies from 0 to 100. Table 1 gives VC values for rural area, three categories of urban density and overall urban area in the Las Vegas valley. The VC value for urban area decreased from 10.97% in 1996 to 9.77% in 2002. The largest decrease occurred in the low-density urban areas from 12.80% in 1996 to 9.79% in 2002. However, VC values for medium- and high-density urban areas did not significantly change. Results suggest that the landscaping associated with new, built-up land has less vegetation canopy, especially for low-density areas. The VC value change in rural area also suggests that most urban developments convert natural landscapes having little vegetation canopy into impervious surfaces. The standard deviation for medium-density urban area shows an apparent increase from 1996 (7.27) to 2002 (8.92). Other categories of built-up land do not have apparent change in standard deviation. This indicates that a large variation of fractional vegetation cover is associated with the largest urban growth in the medium density land use category.

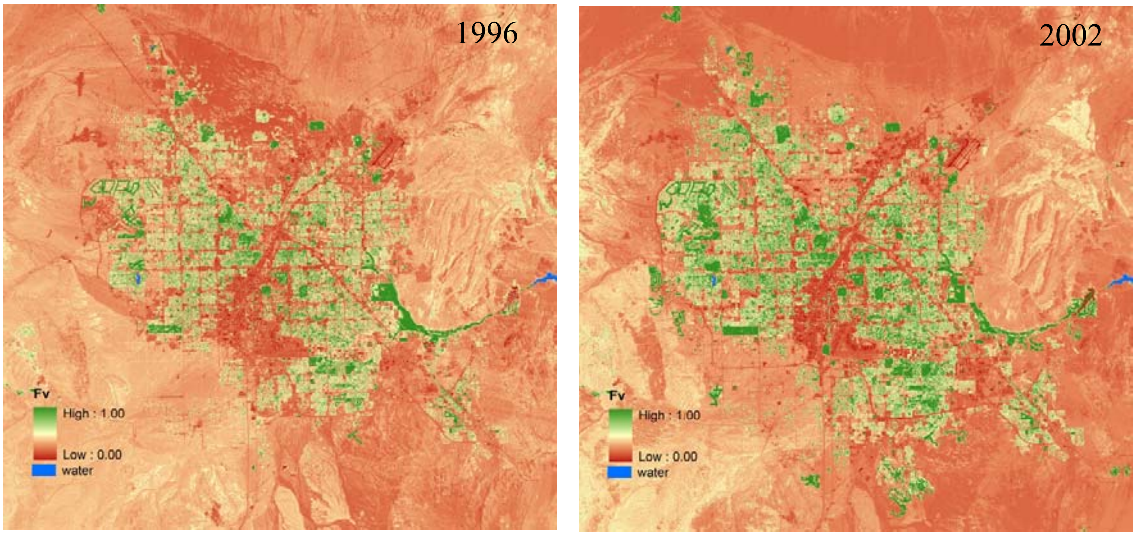

Figure 3. Fractional vegetation cover in 1996 (left) and 2002 (right) depicts the vegetation canopies in developed areas of Las Vegas. Comparison of the two images clearly shows areas of newly planned vegetation associated urban growth.

The fractional vegetation cover can be estimated using other simple methods that use a few bands of information from satellite imagery. Methods described by Equations (3) and (4) that use only NDVI as a variable were used here to calculate vegetation distribution in the valley. By comparing the NDVI-based method results with vegetation cover obtained from the regression tree models, 187 sample points in the Las Vegas valley were randomly selected and plotted against ISA values for these sample sites (Fig. 4). Apparent differences exist in both high- and low-percent imperviousness areas. Both $f_v(n)$ and $f_v(N)$ values overestimated vegetation canopy cover in those areas according to the analysis of high-resolution imagery and the authors' on-site observations, although results for rural and medium-density urban areas were reasonable. Further analysis evaluated the proportion of pixels containing both f_v and ISA. According to Equation (2), the proportion value for any pixel in urban area should follow $(A_i+A_v)/A \leq 1$, or the proportion of those urban and vegetation mixed pixels should be $ISA+f_v \leq 100\%$. Table

2 gives the comparison results for 1996 and 2002. A total of 99.92% and 99.72% of pixels in 1996 and 2002, respectively, met the less than or equal to 100% requirement when adding f_v from the regression tree model together with ISA. However, only 82.08% and 81.45% of pixels in 1996 and 2002, respectively, met the requirement when f_v was calculated from Equation (3). For f_v values calculated from Equation (4), the proportions of pixels satisfying the requirement were 86.87% and 88.85% in 1996, and 2002, respectively. The regression tree modeling result was more reasonable than results obtained from other two NDVI-based methods. NDVI-based methods apparently over-estimated f_v values for this particular geographic environment.

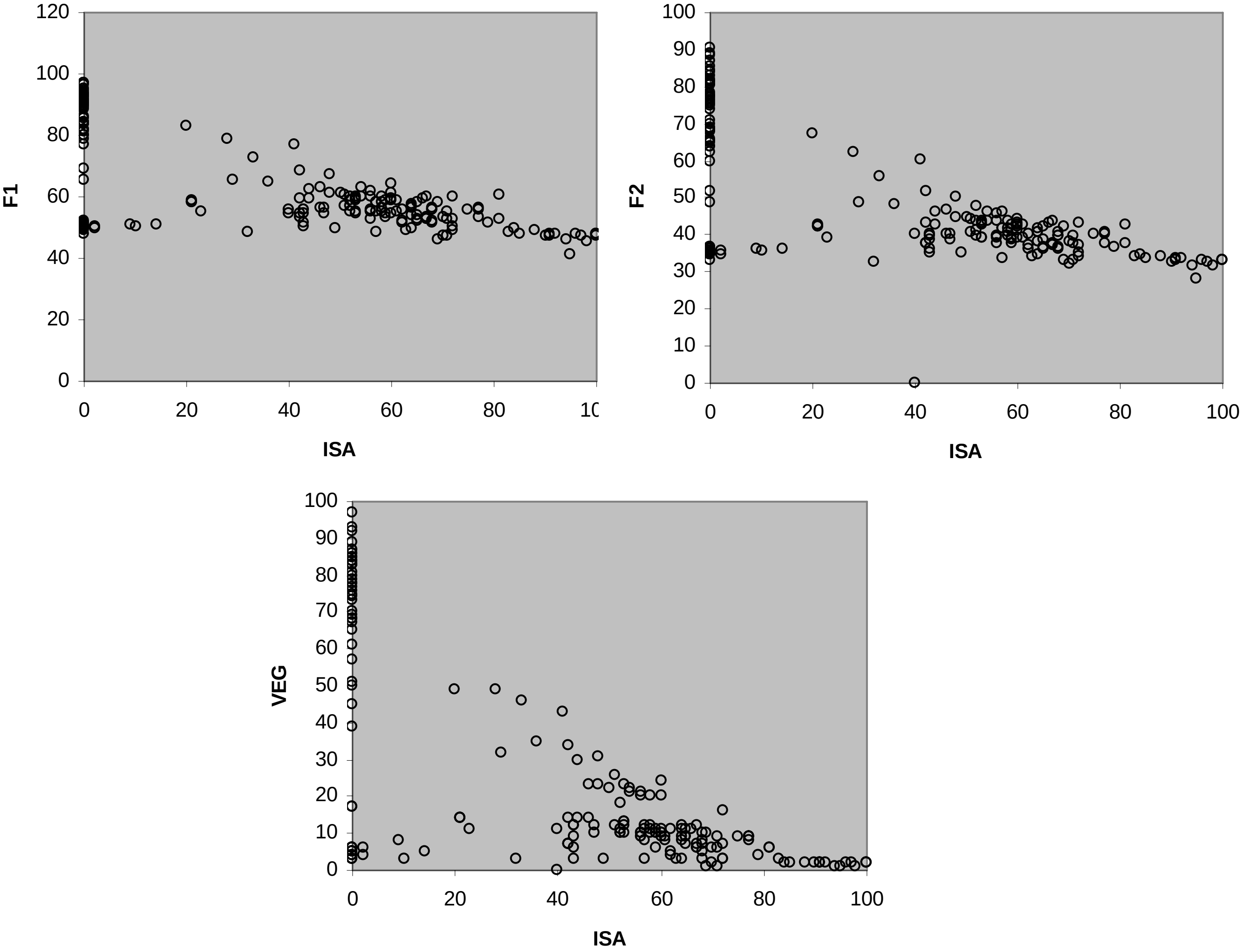

Figure 4. 2002 ISA and fractional vegetation calculated from Equation (2) (upper), Equation (3) (middle), and a regression tree model (lower) for selected sample sites.

Mixed Pixels

Percent ISA and fractional vegetation cover estimations for urban area presented necessary information for evaluating anthropogenic influence on the environment. Most vegetation canopy in urban areas was planted by landscaping. The hot and dry summer desert climate usually restricts vegetation abundance in the area. Detailed information regarding surface biomass characteristics could help in understanding the surface thermal capacity, evaporation, and energy balance in the region. To reveal the balance between anthropogenic impact and natural restriction, selected random samples were re-plotted for mixed pixels that contained imperviousness greater than or equal to 10%. The unmixed pervious pixels were removed from the plot. Figure 5 presents fractional vegetation cover and ISA in 2002 for these samples. For high percent ISA, f_v values were less than 10%. For percent ISA of

40–60, most f_v values were between 10% and 40%. However, in the low percent ISA area, f_v values varied from less than 10% to near 50%. We also examined the mixing ratio (MR) of f_v to ISA, which is expressed as

$$MR = \sum_{i=1}^{N} \frac{fv_i}{ISA_i} / N \tag{6}$$

where f_{vi} and ISA_i are fractional vegetation cover and percent imperviousness for sample site *i,* respectively, and N is the number of samples. The overall MR for these mixed pixel samples is 0.25, which suggests that impervious surface is the majority component for urban pixels.

Table 1. Vegetation coverage in urban and rural areas

		Rural area	Low-density urban	Medium-density urban	High-density urban	Urban area
The proportion of vegetation coverage (%)	1996	7.9	12.80	13.43	6.69	10.97
	2002	6.12	9.79	13.34	6.18	9.77
Standard deviation	1996	7.2	12.18	7.27	4.53	
	2002	9.42	12.12	8.92	4.56	

Table 2. Comparison of different methods

	Regression tree model	$f_v(n)$	$f_v(N)$
1996	99.92	82.08	86.87
2002	99.73	81.45	88.85

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 LULC change. Sub-pixel percent imperviousness mapping also provided information on the spatial extent and intensity of urban LULC change through different percent ISA threshold values. Following a similar approach, SIAM has also been used to estimate an important biomass element—fractional vegetation cover—for the region. This approach provided considerable flexibility in capturing the heterogeneity of urban land-cover characteristics.

The impervious condition of the Las Vegas valley experienced considerable change, especially for medium to high urban density areas from 1984 to 2002. Areas of imperviousness greater than 10% 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.

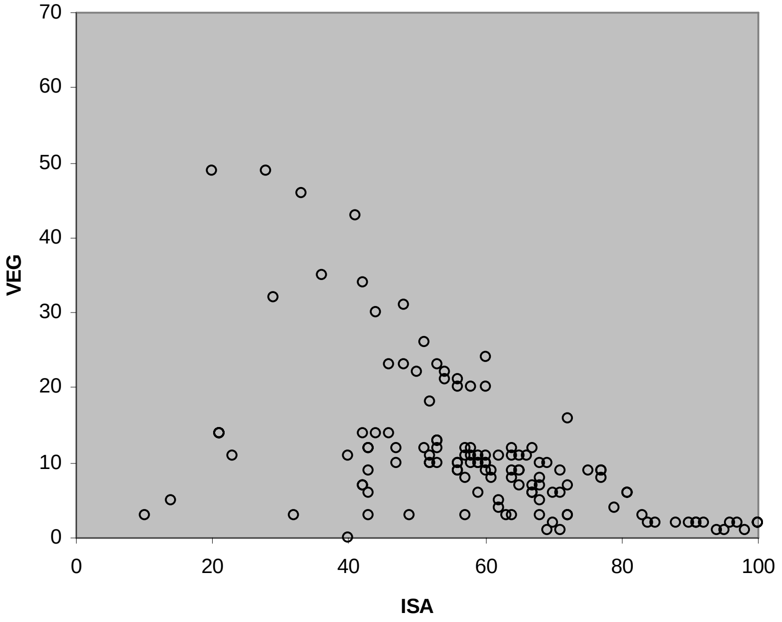

Figure 5. 2002 ISA and fractional vegetation cover calculated from a regression tree model for pixels that have ISA $\geq 10\%$.

Information about the intensity of urban land-cover change provided by percent imperviousness can help infer types of land-use change in conjunction with other land-use information. Fractional vegetation coverage provided information necessary for assessing characteristics of ecosystem structure in urban areas. The availability of multi-decade remote sensing information provides an important source for monitoring and assessing spatial and temporal changes of urban land and associated 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. By comparing f_v variation in the valley, we discovered that vegetation coverage in the urban area changed from 10.97% in 1996 to 9.77% in 2002. However, fractional vegetation cover had the largest value for medium urban development density area in both 1996 (13.43%) and 2002 (13.34%). Analysis of randomly selected samples indicated a 0.25 mixing ratio of vegetation cover and imperviousness in 2002 for mixed pixels in the valley. However, using SIAM to map temporal change in vegetation coverage is restricted because of tremendous seasonal and annual variation in vegetation conditions. It is important that the acquisition time of high-resolution imagery used to create training data should be temporally close to that of Landsat imagery in order to ensure the modeled results will be close to the truth.

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