

ESTIMATION OF SUB-PIXEL IMPERVIOUS SURFACES USING LANDSAT AND ASTER IMAGERY FOR ASSESSING URBAN GROWTH

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ABSTRACT:

Urban development has expanded rapidly in the Las Vegas, Nevada metropolitan area over the last fifty years. Associated with this growth trend has been the transformation of the landscape from natural cover types to increasingly impervious urban land. To map urban extent and its change over time, an innovative approach is employed that determines sub-pixel impervious surfaces from high-resolution digital orthophoto quarter quadrangles (DOQQs) and satellite remotely sensed data. Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper plus (ETM+) data were used as primary imagery sources to estimate urban imperviousness variation from 1984 to 2002 in Las Vegas. Data collected from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) system were also used to map imperviousness in Las Vegas. The 4 spectral bands of visible and near-infrared (VNIR) and 6 spectral bands of short-wave infrared (SWIR) carried by ASTER provided additional information that improved the accuracy of a regression model in distinguishing impervious surfaces from sandy soil and surficial lithologic material. Results were compared with ground measurements for selected sample sites in Las Vegas. The spatial and temporal characteristics of imperviousness in Las Vegas were analyzed to obtain urban development intensities and trends. Results indicate that sub-pixel imperviousness serves as a good indicator of urban composition and development intensity, and provides an efficient means for documenting these changes.

INTRODUCTION

In 1900, the Census Bureau determined that just over 39 percent of the US population resided in urban areas. By 2000, the percentage of the population living in urban environments had more than doubled to 79 percent (<http://factfinder.census.gov/>), and this trend is expected to continue. A major affect associated with this urbanization trend has been the transformation of the landscape from natural cover types such as forests, grasslands, and wetlands to increasingly impervious surfaces composed of paved roads, buildings, parking lots, and sidewalks. This urban revolution has significant environmental impacts at local and regional scales including climate modification by altering sensible and latent heat fluxes of urban surfaces and changing precipitation patterns and intensity (Chagnon, 1980). Surfaces that are impervious to water also increase the frequency and intensity of stormwater runoff that can lead to serious flooding (Thomas et al, 2003; Weng, 2001). Decreased infiltration reduces groundwater recharge, lowers water tables, and diminishes groundwater contributions to stream flow (Prisloe et al, 2001). Urban areas are also associated with more intensive land uses and a corresponding increase in non-point source pollutants including heavy metals, nutrients, toxic chemicals, pathogens and debris that are readily transported in stormwater runoff (Rogers et al, 2004).

It's no surprise that the amount of imperviousness within a drainage basin is considered an excellent indicator of the water quality and overall environmental health of the watershed (Arnold and Gibbons, 1996). Stream quality usually starts to degrade when more than 10% of the area of a watershed becomes impervious (Schueler, 1994). Imperviousness provides an objective measurement of the areal extent and intensity of urban development. The present study uses a

combination of multi-temporal remote sensing data sets to identify and map imperviousness trends at the sub-pixel level.

BACKGROUND

The geographic focus of this study is the Las Vegas Valley in southern Nevada, the fastest growing metropolitan area in the country. Between 1990 and 2000, the Las Vegas population grew 83.3% according to the Census Bureau. The metropolitan area encompasses an areal extent of about 1320 km² and for this study includes the cities of Las Vegas, North Las Vegas, and Henderson. The region is characterized by a dry desert climate that supports sparse natural vegetation growing on limestone and gypsum influenced soils. Rapid growth over the past three decades has altered the landscape noticeably, with development pushing further and further up the slopes of the broad Las Vegas Valley between low mountains.

Numerous research efforts have dealt with the use of various kinds of remotely sensed data to quantify urban impervious surfaces. Grey and Luckman (2003) investigated the use of satellite radar interferometry for mapping urban land in South Wales and England. Dougherty et al. (2004) evaluated impervious surface estimates derived from Landsat satellite imagery versus aerial photography for an area in northern Virginia. Weng (2001) employs the integration of Landsat satellite imagery with GIS data to study the effects of urban growth on surface runoff in the Zhujiang Delta of South China. Matthias and Martin (2003) explore the use of ASTER satellite imagery for mapping impervious surface cover for the environs of Bonn and Cologne, Germany. Yang et al. (2003) developed an approach for detecting impervious land cover change using a combination of Landsat satellite data together with high-resolution imagery for part of western Georgia. Thus far, most research conducted on impervious surface mapping pertains to

humid environments. An exception is a recent study by Thomas et al. (2003) in which they discovered that the greatest amount of confusion mapping imperviousness in Scottsdale, AZ was due to lack of adequate spectral contrast between bare ground and pavement. Similar conditions are found in the Las Vegas Valley and could create confusion when trying to map imperviousness there (Figure 1). The current research evaluates the utility of satellite and high-resolution remotely sensed data for mapping impervious surfaces in arid landscapes.



Figure 1. Note the similarity in color between the roofs and barren ground at this eastside Las Vegas location.

METHOD

Many challenges still exist in trying to accurately interpret land use/land cover (LULC) in urban and suburban environments using remote sensing techniques. Urban areas are heterogeneous and most medium resolution urban satellite imagery such as Landsat has pixels representing a mix of different surfaces. Pixels classified as residential may represent 60% impervious surface and 40% pervious (lawn, shrubs, tree canopy, landscaping gravel). Remote sensing techniques have recently been developed that specifically address the heterogeneity problem at a sub-pixel level and provide improved accuracy in detecting impervious surfaces (Huang and Townshend, 2003; Yang et al., 2003a; Yang et al., 2003b; Herold, 2003).

The method that deals with the heterogeneity problem associated with urban LULC mapping is known as Sub-pixel Imperviousness Change Detection (SICD). The SICD method uses high-resolution imagery such as digital orthophoto quarter quadrangles (DOQQs) as a source of training data for discriminating urban land cover heterogeneity, and medium resolution Landsat imagery to extrapolate imperviousness over large regions. The technique has been implemented by the Multi-Resolution Land Characteristics Consortium (MRLC) as a standard procedure for the production of an imperviousness data layer as part of the National Land Cover Database (NLCD 2001) and is also being used in several USGS research projects (Homer et al., 2004; Xian and Crane, 2004).

The process of generating impervious surfaces and related change detection data sets involves the following steps: 1) development of training/validation data, 2) selection of predictive variables and initial regression tree modelling and assessment, 3) final spatial modeling and mapping, and 4) imperviousness change detection and interpretation.

Eight digital orthophoto quarter quadrangles (DOQQs) generated by the USGS in 2003 provided representative coverage of the Las Vegas metropolitan area. Each DOQQ was

comprised of three spectral bands: green, red, and near infrared, with a nominal spatial resolution of 1-meter. All DOQQ images were used in a Universal Transverse Mercator (UTM) coordinate system and registered to the Landsat imagery used in the study. Ground reference information acquired at 68 field sites was used with the DOQQs to derive training data for a decision tree model and to test for imperviousness mapping. Spectral and spatial characteristics of the DOQQs were useful in capturing differences in building materials, age, surface colors, and spatial orientation in and around the urban regions. Training pixels classified in 1-meter grids from the DOQQs were used to calculate percent impervious surface area (ISA) for each 30-meter Landsat pixel. This resulted in 30-meter resolution raster ISA image as training data sets. Percent ISA serves as an excellent indicator of the spatial extent and intensity of development for the Las Vegas Valley.

Large area sub-pixel percent imperviousness was determined using a regression tree algorithm and satellite imagery. The regression tree conducts a binary recursive partitioning and produces a set of rules and regression models to predict a target variable (percent imperviousness) based on training data. Each rule set defines the conditions under which a multivariate linear regression model is established for prediction (Breiman *et al.*, 1984). In the partitioning process, each split is made such that the model's combined residual error for the two subsets is significantly lower than the residual error of the single best model (Huang and Townshend, 2003). The main advantage of the regression tree algorithm is that it can account for a non-linear relationship between predictive and target variables, and allows both continuous and discrete variables to be used as input (predictive) data. The predicted percent impervious surface attributed to each pixel was evaluated using independent test data. Ideally, the test data should be collected from fieldwork based on a statistical sampling design. Due to time and resource constraints, 1-meter spatial resolution DOQQs were selected as the best option for providing the spatial resolution needed to accurately determine impervious surfaces in the study area. Impervious estimates derived from the 1-meter DOQQs were used for model evaluation. To ensure validity of the assessment, all test data (pixels) were selected randomly and independently from the training dataset.

Landsat TM images from 1984, 1986, and 1992, and an ETM+ image from 2002 for path 39 and row 35 covering the Las Vegas region were used in this study. All images were processed by the U.S. Geological Survey (USGS) National Center for Earth Resources Observation and Science (EROS) to correct radiometric and geometric distortions to level 1G products. Possible geolocation errors due to terrain effects were corrected using 1-arc second data from the National Elevation Dataset (NED). All images were rectified to a common UTM coordinate system. Bands 1 through 5 and 7 were utilized at a spatial resolution of 30-meters. The thermal bands had their original pixel sizes of 120-meters for TM and 60-meters for ETM+ resampled to 30-meters using the nearest neighbour algorithm to match the pixel size of the other spectral bands. Slope data was also incorporated into the regression tree model.

In addition, an Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) image from 2002 was acquired for the study area. The ASTER image is comprised of 3 bands in the VNIR portion of the spectrum having 15-meter spatial resolution, 6 bands in the SWIR having 30-meter resolution, and 5 bands in the TIR region of 90-meter

resolution. All bands were resampled to 15-meters using the nearest neighbour algorithm to provide a consistent pixel size. This study used all of the ASTER bands and they were processed to correct radiometric and geometric distortions and registered to the Landsat images so that all remotely sensed data sets were in the same UTM coordinate system.

RESULTS

Inspection of the resulting imperviousness maps showed that the 10% threshold captured almost all of the developed land surface including low, medium, and high-density residential areas, as well as commercial, industrial, and the central business district (CBD). Therefore, pixels were classified urban when the ISA was equal to or greater than 10%, and pixels having less than 10% ISA were classified as non-urban.

ISAs were calculated for the Las Vegas region using Landsat imagery from 1984, 1986, 1992, and 2002, as well as from the 2002 ASTER scene. The areal extent of the 10% or greater imperviousness category (urban) measured 344 km² in 1984 and by 2002 had increased to 682 km² as determined from the Landsat imagery (Table 1). An interesting comparison of the

YEAR	1984 L5	1986 L5	1992 L5	2002 L7	2002 ASTER
AREA km ²	344	356	442	682	668

Table 1. Change in extent of the Las Vegas urban area.

extents of the urban areas determined from Landsat 7 and the ASTER imagery reveals a smaller area calculated from ASTER. The smaller ASTER figure may be attributed to a reduction in spectral confusion associated with 15-meter pixels versus the 30-meter pixels of Landsat 7. Another factor to consider is the ASTER image was collected on February 11, 2002, whereas the Landsat 7 scene was acquired June 10, 2002, and some of the difference may result from new development. A more detailed presentation of counts of 30-meter pixels by percent imperviousness category and by year are shown in Table 2. Perusal of the table reveals higher pixel counts from Landsat 7 in the 20% to 59% range, while ASTER provides higher pixel counts in the 60% to 100% range. These relationships are apparent in Figures 2 and 3 that portray percent imperviousness from Landsat 7 and ASTER respectively.

CONCLUSIONS

This research has shown that the Sub-pixel Imperviousness Change Detection method is well suited to mapping urban development in arid environments. Satellite remotely sensed data has provided an efficient means for characterizing the extent and intensity of urban growth in the Las Vegas Valley. The resulting maps of impervious surfaces for different dates (Figures 1, 2, and 3) emphasize the urban morphology of the region. These impervious surface data sets will be used in the SLEUTH urban growth model to forecast future change in imperviousness extent and density out to 2025. Results of the model runs will be used to study stormwater flows in relation to imperviousness and the capacity of the regions storm drains.

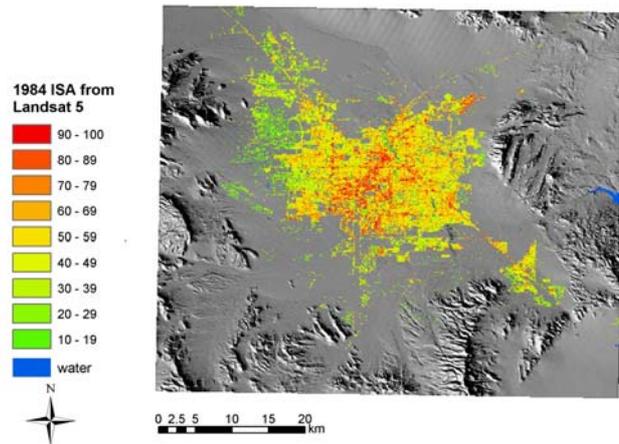


Figure 1. Percent imperviousness from Landsat 5, 1984.

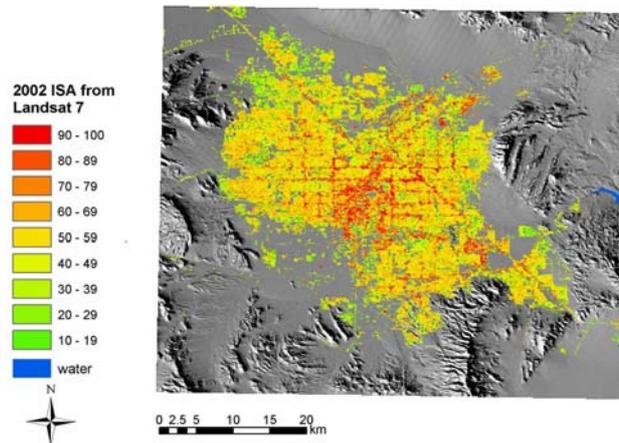


Figure 2. Percent imperviousness from Landsat 7, 2002.

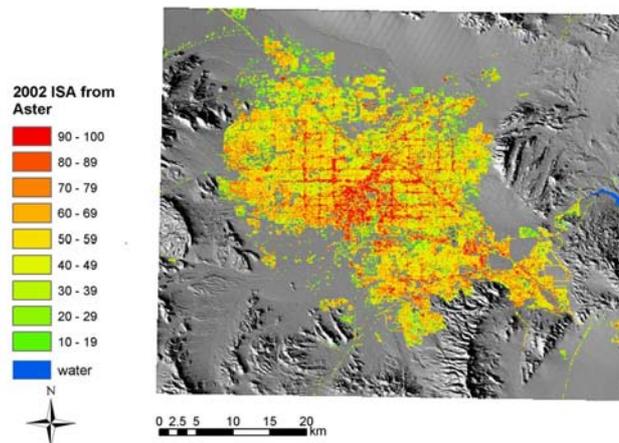


Figure 3. Percent imperviousness from ASTER, 2002.

Year	10-19%	20-29%	30-39%	40-49%	50-59%	60-69%	70-79%	80-89%	90-100%	Total
L5 1984	34,623	22,640	42,532	79,508	83,654	58,182	27,582	26,457	7,370	382,548
L5 1986	27,139	33,548	53,162	74,232	84,486	59,416	29,402	21,935	11,810	395,130
L5 1992	42,314	43,887	58,519	90,840	103,213	63,073	33,683	31,786	24,084	491,399
L7 2002	43,064	63,299	67,006	109,551	211,985	134,060	53,843	48,822	25,605	757,235
ASTER 2002	56,929	46,586	60,807	103,229	164,640	144,185	83,838	50,559	31,213	741,987

Table 2. Imperviousness by percent by year.

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