Applied Remote Sensing Journal

www.academyjournals.net

Original Article

Landsat Satellite Multi-Spectral Image Classification of Land Cover and Land Use Changes for GIS-Based Urbanization Analysis in Irrigation Districts of Lower Rio Grande Valley of Texas

Yanbo HUANG[1]*, Guy FIPPS[2], Ronald E. LACEY[2], and Steven J. THOMSON[1]

[1] *United Department of Agriculture, Agricultural Research Service, Crop Production Systems Research Unit, Stoneville, Mississippi, USA*

[2] *Department of Biological and Agricultural Engineering, Texas A&M University, College Station, Texas, USA*

Received: 23.05.2011 Accepted: 30.06.2011 Published: 16.08.2011

Abstract

The Lower Rio Grande Valley in the south of Texas is experiencing rapid increase of population to bring up urban growth that continues influencing on the irrigation districts in the region. This study evaluated the Landsat satellite multi-spectral imagery to provide information for GIS-based urbanization analysis in irrigation districts. Three image scenes of ETM+ (2003) and TM (1993) multi-spectral image data were used to cover the Hidalgo, Cameron, and Willacy Counties in the Lower Rio Grande Valley. The images were classified in terms of land cover land use categories, and the classified data were overlaid on GIS layout to visualize urbanization in irrigation districts. The accuracy assessment of the image classifications at county level indicated that the overall accuracies were over 75%. For the most concerned classes, irrigated land and urban, all the producer's and user's accuracies in 1993 were over 80%, and all the accuracies in 2003 were over 70%. Based on the image classifications, the land cover land use changes over the ten years in the three counties were estimated. On average, over the ten years, in the three counties, the urbanization increased drastically at 46% while the irrigation land decreased moderately at 7.6%. Specifically in Hidalgo County the urbanization increased 59.7% and irrigated land decreased 10.2%, in Cameron County the urbanization increased 52.8% and irrigated land decreased 6.7%, and in Willacy County the urbanization increased 25.7% and the irrigated land decreased 5.9%. Therefore, in overall, with the increase of urbanization the irrigated land decreases in the region. The urbanization information in the five most urbanized irrigation districts within the region was derived from the county-level image classifications. The information will be helpful for more detailed study to reveal the conflicts between urbanization and irrigation network development.

Keywords: *Urbanization, Landsat, image classification, accuracy assessment*

**Corresponding Author: Yanbo Huang, E-mail: yanbo.huang@ars.usda.gov, Phone: (662)686-5354*

INTRODUCTION

Irrigation is critical to agriculture in the United States. In the past twenty years urbanization in irrigated areas has become one of the major challenges for irrigation districts to develop agricultural production. With rapid social and economic development, the water resource for agriculture is more and more shared by municipal, industrial, and environmental needs in expanded urban areas. Information of urbanization in irrigated areas is needed to create schemes for irrigation districts to balance water demands among alternative uses.

The Lower Rio Grande Valley (LRGV) in the south of Texas is traditionally a farming region with a subtropical climate and the Rio Grande River bordering United States and Mexico. The population in this region has increased significantly in the past two decades with an actual growth about 40 percent from 1990 to 2000, an estimated growth of 36 percent from 2000 to 2010, and a predicted growth of over 30 percent in the next decade (DISC, 2002). With the trend of population increase the LRGV becomes one of the regions with most rapid urbanization in the nation, which has been changing land cover and land use (LCLU) dramatically in this region such that the layout of irrigation districts and water distribution networks has been changing by expansion of urban areas and the irrigation water supply has been reducing by more and more urban use with limited water sources. In order to sustainably develop agriculture in this region, researchers, engineers, and irrigation districts are working together for improving irrigation efficiency and water conservation in the region. To derive urbanization information in the irrigated areas it is necessary to assess historical LCLU changes within the region. With the urbanization analysis irrigation districts will be able to design and implement schemes to be adaptive to rapid urbanization in the areas.

To evaluate the extent of human influence at the landscape level within the LRGV region, it is necessary to quantify LCLU changes in the region. To understand the effects of LCLU changes on different ecological parameters, modeling software packages could be developed to simulate hydrologic and other environmental conditions. A geographical information system (GIS) modeling tool for predicting the impacts of land management practices on water, sediment, and chemical yields has been developed by integration of ArcView (Redlands, California, USA) and Soil and Water Assessment Tool (SWAT) (USDA-ARS, Temple, Texas, USA) (Neitsch et al., 2002; Di Luzio et al., 2002). However, the use of this package needs large areal input data sets in a designated format. Aerial photos could be worked on directly to characterize land cover change. However, this method is laborious and imprecise (Hill et al., 2003).

Remotely sensed data from satellites can provide an alternative source of information on LCLU over large areas (Jensen et al., 2001; Maingi and March, 2001; Zhang et al. 2002). The analysis of the satellite data relies on the classification of the remotely sensed imagery into discrete classes of LCLU (Gong and Howarth, 1992; McDermid et al., 2005; Yuan et al., 2005; Styers et al., 2010). Satellite imagery are available for regional LCLU mapping from different platforms with moderate resolutions, such as ASTER from Japan (15 m spatial resolution for visible and near infrared (VNIR) wavebands), IRS from India (23 m spatial resolution for VNIR wavebands), and Landsat from United States (30 m spatial resolution for VNIR wavebands). Considering the available data, the mapping of the LCLU changes in the LRGV region for urbanization analysis in irrigation districts should be possible with high accuracy potential. This study was to classify the Landsat satellite (NASA, Washington, DC, USA and USGS, Reston, VA, USA) imagery over the LRGV region into discrete classes of LCLU and then overlaid the classified results on GIS layers to provide mapping of urbanization in irrigation districts. In this study the extent of urbanization within the irrigated areas in the LRGV region resulted from LCLU changes over time was of primary interest. The results from this study will help guide and prioritize future modeling initiatives to investigate the effects of urbanization within the LRGV region.

The focus of this study is to classify, quantify, and assess historical land cover changes and the extent of urbanization in the LRGV of Texas between 1993 and 2003. The specific objectives of this research include:

1. Develop and evaluate a method to classify remotely-sensed Landsat satellite imagery to determine LCLU changes within the LRGV region between 1993 and 2003;
2. Conduct GIS-based data analysis of urbanization in irrigation districts within the region based on the Landsat satellite image LCLU classification.

MATERIAL AND METHODS

Study Area

The LRGV is a five-county area (Hidalgo, Cameron, Willacy, Starr and Maverick) located at the southern tip of Texas along the Mexican border. For urbanization study the area covering the first three counties is interested as shown in Fig. 1. In this area there are more than thirty irrigation districts. Some of the districts are close to urban areas, and strongly influenced by urbanization in the adjacent areas.

Landsat Satellite Imagery

Landsat satellites have been collecting images of the Earth's surface for more than thirty years. NASA (National Aeronautics and Space Administration) launched the first Landsat satellite in 1972, and the most recent one, Landsat 7, in 1999. Currently, only the Landsat 5 and 7 are still operating normally. Landsat 7 carries the Enhanced Thematic Mapper Plus (ETM+) sensor with 30m visible and IR (InfraRed) bands, a 60m spatial resolution thermal band, and a 15m panchromatic band. The Thematic Mapper (TM) sensors onboard Landsats 4 and 5 included 30m visible and IR bands, several additional bands in the shortwave infrared (SWIR), and an spatial resolution of 120m for the thermal-IR band.

On May 31, 2003, unusual artifacts began to appear in the image data collected by the ETM+ instrument onboard Landsat 7. The problem was caused by failure of the Scan Line Corrector (SLC), which compensates for the forward motion of the satellite. This caused a problem in using ETM+ image data after May 31, 2003. Therefore, in this study the ETM+ image data in early 2003 has been collected to represent the land cover in the 2000s. Correspondingly, the TM image data in 1993 has been collected to represent the land cover in the 1990s.

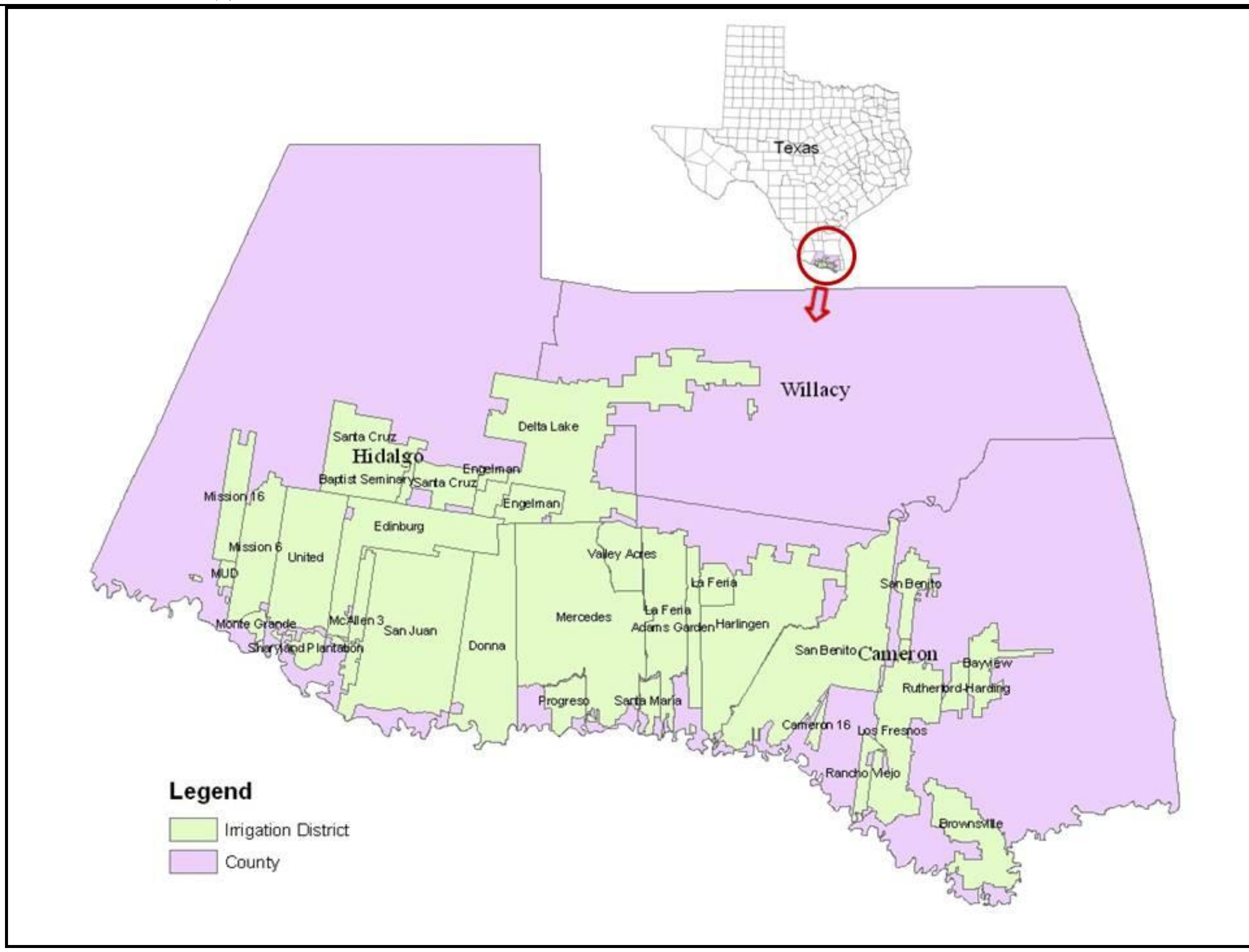

Figure 1 GIS map of the interested area in Lower Rio Grande Valley of Texas.

Image Description

To study the urbanization over the LRGV region, Landsat satellite imagery was used as the data source for estimating LCLU changes in the ten years between 1993 and 2003. During the ten years, the region had experienced a transition from non-drought (1990s) to drought (2000s) periods.

Fig. 2 shows the Landsat satellite footprints over Texas. To cover the interested area in the LRGV, three image scenes are needed. The scene of path 26, row 42 covers the Cameron, Willacy, and eastern Hidalgo Counties. The scene of path 27, row 41 covers north Hidalgo County. The scene of path 27, row 42 covers south Hidalgo County, the most urbanized area in the valley.

The Landsat ETM+ and TM multi-spectral image data were purchased from USGS (United States Geological Survey) through the TexasView Remote Sensing Consortium (Austin, TX, USA), an AmericaView member consortium representing Texas. Figure 3 shows the coverage of the ETM+ images in 2003. The TM images in 1993 have the same coverage. The ETM+ and TM images from the consortium were terrain corrected (similar to orthorectification). They can be directly used for classification and are reliable for GIS analysis.

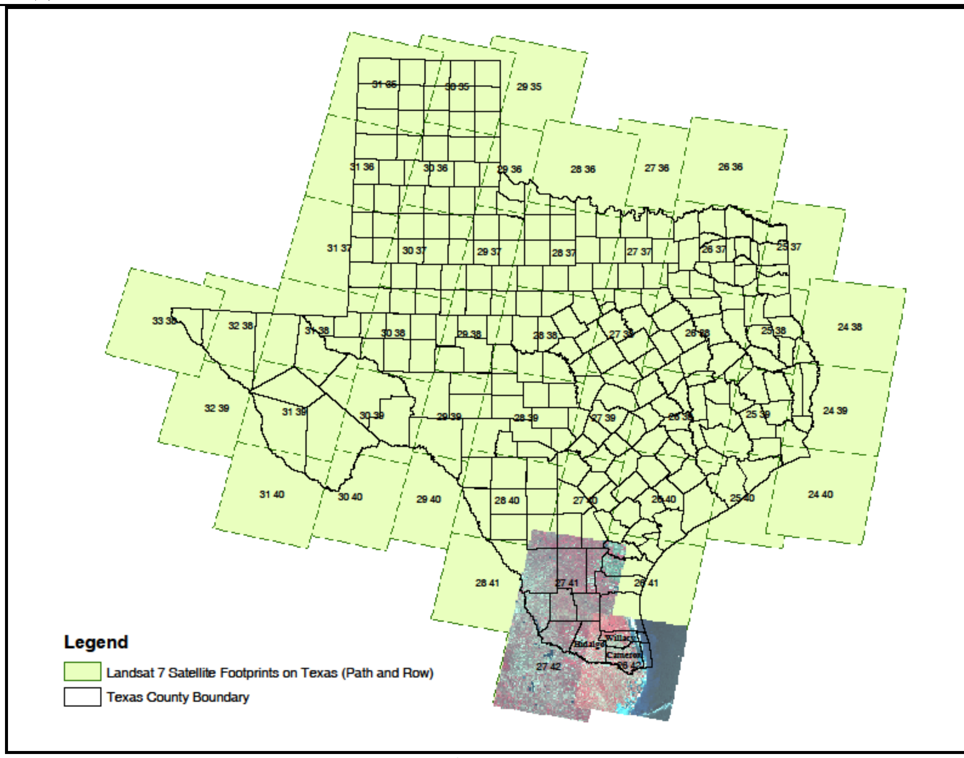

Figure 2 Landsat footprints over Texas

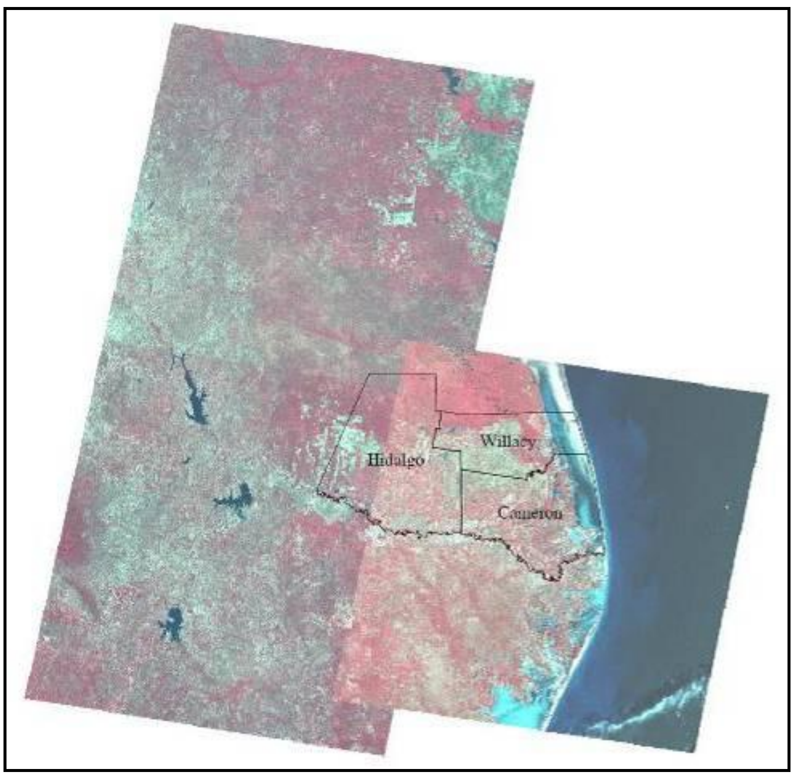

Figure 3 Three ETM+ 2003 image scenes covering the Hidalgo, Cameron, and Willacy Counties in the Lower Rio Grande Valley

Image Processing and Classification

ERDAS Imagine (Leica Geosystems Geospatial Imaging, Atlanta, GA, USA) was used for image processing and classification. The classifications were conducted by separating the images into urban and rural pieces because accurate classification within and around urban areas were difficult. Some zones in urban pieces with unknown classes were further separated into sub pieces to determine the classes in the micro scale. The urban boundaries were determined by the up-to-date geo-referenced 2003 TxDOT (Texas Department of Transportation) shapefiles (http://www.tnris.org) by assuming that the urban areas expanded from 1993 to 2003. The geo-referenced, 1-meter resolution DOQQ (Digital Orthophotoquads) aerial photography were downloaded from TNRIS (Texas Natural Resources Information System) (http://www.tnris.org) and used to further identify the less discernable classes. In the process of classification ArcGIS (ESRI, Redlands, CA, USA) was used interactively with ERDAS to assemble the separately classified image pieces and reclassify them as a whole. Specifically, the tasks in the classification process were conducted as follows sequentially:

1. Convert the image data in visible and IR bands from the original NLAP format to the IMG format compatible to the ERDAS software;
2. Clip the image pieces covering the Hidalgo, Cameron, and Willacy Counties from the original images using ERDAS AOI Tool with GIS shapefiles;
3. Perform ISODATA unsupervised classification on all the clipped image pieces with 50 clusters (more clusters translates to more accuracy but also causes more computing time and post-processing work);
4. Categorize the clusters into five land cover classes: water, barren land, irrigated land, vegetated land, and urban. These classes were adapted from the USGS' Anderson classification system (Anderson et al., 1976). For the zones with unknown classes, the image pieces are further clipped into sub pieces to identify the less discernable classes with the help of DOQQ files;
5. Convert the classified image pieces into GRID format;
6. Reclassify the classified image piece grids with Spatial Analyst in ArcGIS;
7. Merge the reclassified image pieces to produce complete maps for the three counties;
8. Perform GIS analysis in the scale of irrigation districts and even smaller areas by deriving from the classification at county level.

The accuracy of the image classification was assessed based on error matrices (Congalton and Green, 1999) for each classified image, which were generated by comparing the classified classes with the actual classes at the ground points. 100 points were randomly sampled for each LCLU class category per county per year on the DOQQ images as ground verification points. The downloaded DOQQ files were image quarter quads. These quarter quads were mosaiced to cover each county area. In accuracy assessment, overall accuracy, producer's accuracy, user's accuracy, and kappa coefficients were calculated based on the error matrices and kappa analysis was also performed to test if each classification was significantly better than a random classification and if any two classifications were significantly different.

RESULTS

The Landsat 2003 ETM+ and 1993 TM images were classified to quantify the LCLU in the interested area of the LRGV region. Fig. 4, Fig. 5, and Fig. 6 show the classification maps of the LCLU in Hidalgo, Cameron, and Willacy Counties, respectively, in 2003 (overlaid 1993 urban classification showing the urban expansion in the ten years).

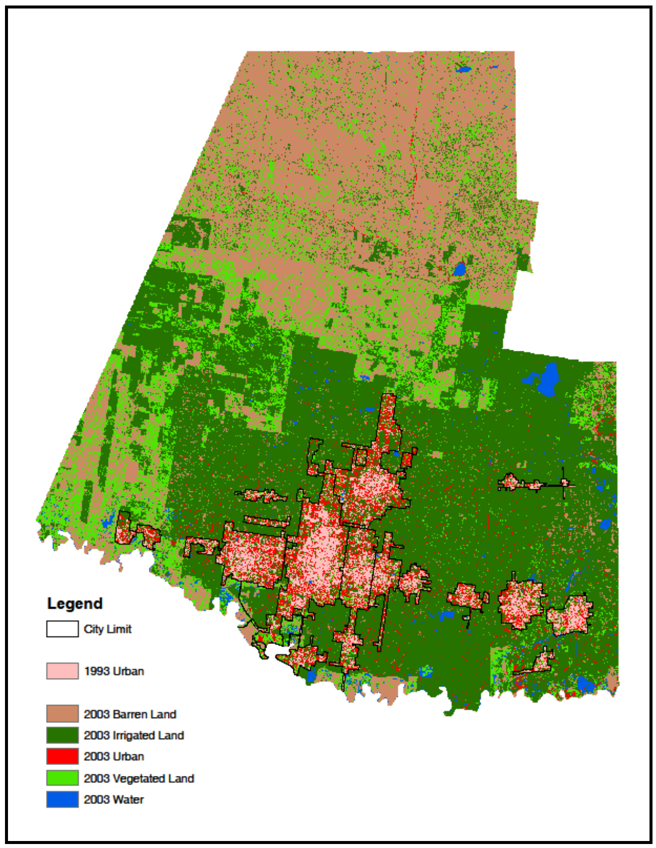

Figure 4 GIS map of 2003 land cover and land use classification in Hidalgo County

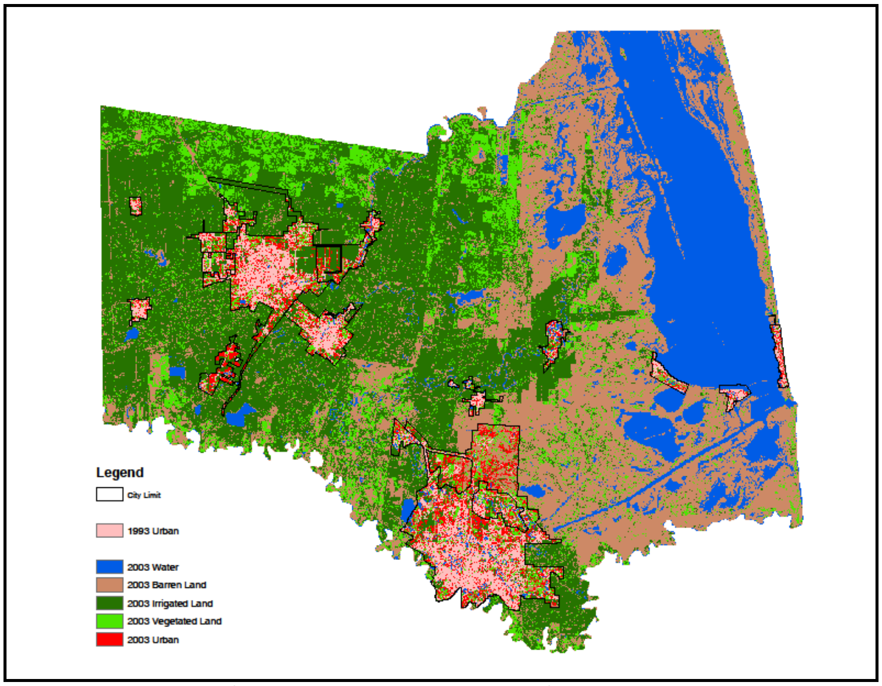

Figure 5 GIS map of 2003 land cover and land use classification in Cameron County

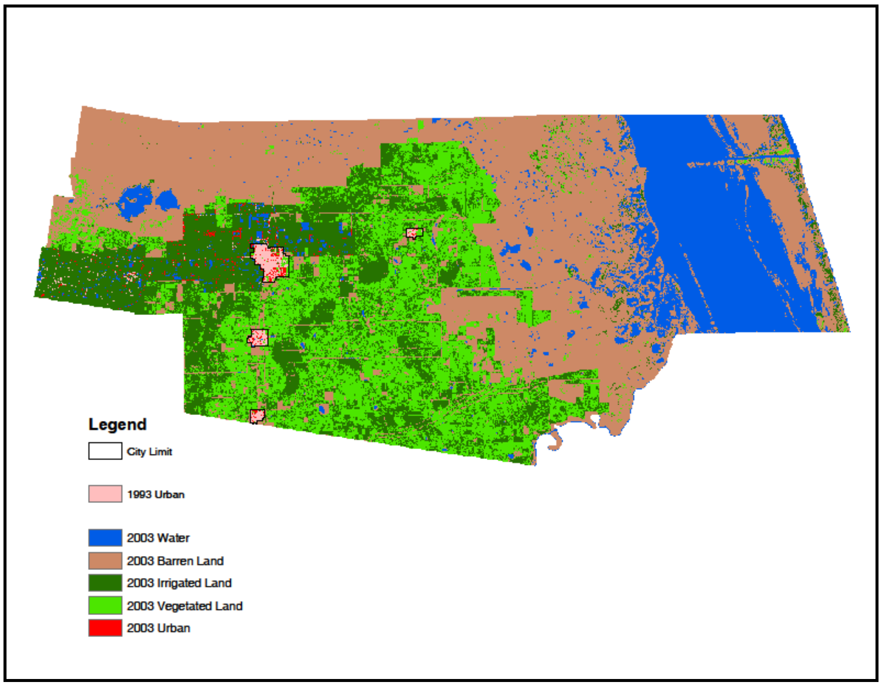

Figure 6 GIS map of 2003 land cover and land use classification in Willacy County

Table 1 summarizes the results of accuracy assessment for the classification images in 1993 and 2003 to cover Hidalgo, Cameron and Willacy counties. For all image classification the overall accuracies were over 75%. For the most concerned classes, irrigated land and urban, all the producer's and user's accuracies in 1993 were over 80%, and all the accuracies in 2003 were over 70%. Kappa data comparison indicated that all the classifications were significantly better than a random classification and that 1993 classifier performed better than the 2003 one.

Table 1 Accuracy assessment results of Landsat 1993 and 2003 image classification.

Year	**County**	**Overall Accuracy (%)**	**Overall Kappa**	**Water**		**Barren Land**		**Irrigated Land**		**Vegetated Land**		**Urban**	
				PA (%)	**UA (%)**	**PA (%)**	**UA (%)**	**PA (%)**	**UA (%)**	**PA (%)**	**UA (%)**	**PA (%)**	**UA (%)**
1993	Hidalgo	89.8	0.873	97.9	93.0	93.6	88.0	88.3	83.0	81.0	98.0	90.6	87.0
	Cameron	89.0	0.863	99.0	99.0	96.3	78.0	81.6	93.0	76.3	87.0	96.7	88.0
	Willacy	86.6	0.833	99.0	97.0	89.6	60.0	82.1	96.0	71.5	93.0	98.9	87.0
2003	Hidalgo	77.4	0.718	100.0	62.0	89.7	70.0	87.4	76.0	54.4	98.0	87.1	81.0
	Cameron	82.4	0.780	96.8	90.0	88.6	70.0	91.6	87.0	61.0	94.0	89.9	71.0
	Willacy	82.4	0.780	100.0	71.0	67.1	49.0	96.9	93.0	62.3	99.0	99.0	100.0

PA – producer's accuracy; UA – user's accuracy

Based on image classification, the LCLU changes were estimated in a ten-year interval from 1993 to 2003 in the Hidalgo, Cameron, and Willacy Counties, respectively, in the LRGV of Texas (Tables 2, 3, and 4). Based on the estimation, over the ten years, Hidalgo County had a significant urbanization increase of 59.7%, but the county had a moderate decrease of irrigated land at 10.2%. Similarly, Cameron County had a significant urbanization increase of 52.8% but a moderate decrease of irrigated land at 6.7% in ten years. Willacy County also had an increase of urbanization at 25.7% while the irrigated land decreased 5.9%. Therefore, the three counties, on the average, had a drastic urbanization increase of 46% and a moderate irrigated land decrease of 7.6%.

Table 2 Land cover land use change estimation in Hidalgo County

Land Cover Category	**1993 Area (km2)**	**2003 Area (km2)**	**Net Change (%)**
Water	71.62	57.34	-19.89
Barren Land	1149.23	1254.27	9.14
Irrigated Land	2155.08	1934.24	-10.25
Vegetated Land	550.94	571.93	3.8
Urban	182.75	291.83	59.69

Table 3 Land cover land use change estimation in Cameron County

Land Cover Category	**1993 Area (km2)**	**2003 Area (km2)**	**Net Change (%)**
Water	547.06	562.68	2.85
Barren Land	894.92	881.09	-1.55
Irrigated Land	1118.27	1043.11	-6.72
Vegetated Land	337.55	343.20	1.67
Urban	130.00	198.63	52.80

Table 4 Land cover land use change estimation in Willacy County

Land Cover Category	**1993 Area (km2)**	**2003 Area (km2)**	**Net Change (%)**
Water	208.18	309.86	48.84
Barren Land	901.24	767.28	-14.86
Irrigated Land	432.28	406.53	-5.96
Vegetated Land	352.77	407.38	15.48
Urban	13.64	17.15	25.68

The image analysis was scaled down to derive the impact of urbanization to the irrigation districts, Tables 5, 6, 7, 8, and 9 are the estimation results of the LCLU cover changes over the ten years in the United, Edinburg, McAllen 3, San Juan, and Harlingen Irrigation Districts within the three-county region. These districts are the most urbanized in the valley. The estimation indicates that in these districts the irrigated lands consistently decreased with the increase of urbanization.

Table 5 Land cover land use change estimation in United Irrigation District

Land Cover Category	1993 Area (km2)	2003 Area (km2)	Net Change (%)
Water	0.77	0.84	9.23
Barren Land	2.24	3.59	60.43
Irrigated Land	123.47	107.31	-13.10
Vegetated Land	3.98	5.96	49.75
Urban	23.33	36.08	54.65

Table 6 Land cover land use change estimation in Edinburg Irrigation District

Land Cover Category	1993 Area (km2)	2003 Area (km2)	Net Change (%)
Water	1.01	1.11	10.38
Barren Land	2.56	2.22	-4.68
Irrigated Land	116.78	92.83	-20.52
Vegetated Land	5.97	8.05	34.74
Urban	31.16	53.05	70.26

Table 7 Land cover land use change estimation in McAllen 3 Irrigation District

Land Cover Category	1993 Area (km2)	2003 Area (km2)	Net Change (%)
Water	0.14	0.14	-1.96
Barren Land	0.71	0.43	-38.85
Irrigated Land	19.47	15.34	-21.20
Vegetated Land	0.98	1.59	62.56
Urban	16.34	20.13	23.20

Table 8 Land cover land use change estimation in San Juan Irrigation District

Land Cover Category	1993 Area (km2)	2003 Area (km2)	Net Change (%)
Water	2.17	2.22	2.28
Barren Land	5.28	3.65	-30.88
Irrigated Land	232.79	200.47	-13.89
Vegetated Land	8.21	12.46	51.84
Urban	46.76	76.40	63.39

Table 9 Land cover land use change estimation in Harlingen Irrigation District

Land Cover Category	1993 Area (km2)	2003 Area (km2)	Net Change (%)
Water	1.77	2.30	30.05
Barren Land	14.47	15.88	9.71
Irrigated Land	156.45	138.42	-11.52
Vegetated Land	23.38	21.04	-10.01
Urban	33.95	52.38	54.28

Fig. 7, Fig. 8, Fig. 9, Fig. 10, and Fig. 11 show the derived image classification maps of the LCLU in the five above-mentioned irrigation districts in 2003 (overlaid 1993 urban classification showing the urban expansion in the ten years). The derivations were based on the image classification at county level.

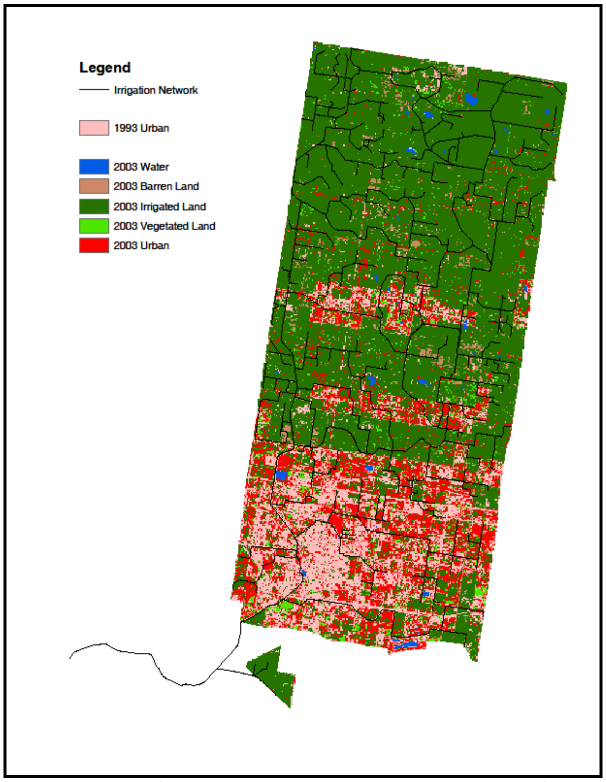

Figure 7 GIS map of derived 2003 land cover and land use classification in United Irrigation District

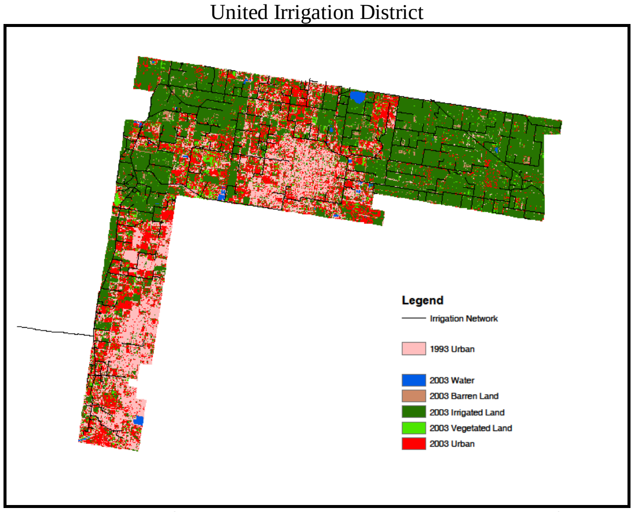

Figure 8 GIS map of derived 2003 land cover and land use classification in Edinburg Irrigation District

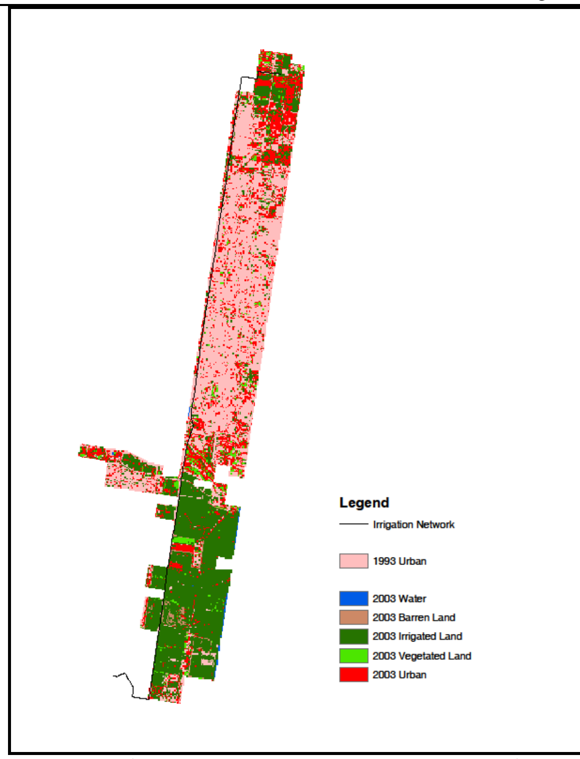

Figure 9 GIS map of derived 2003 land cover and land use classification in McAllen 3 Irrigation District

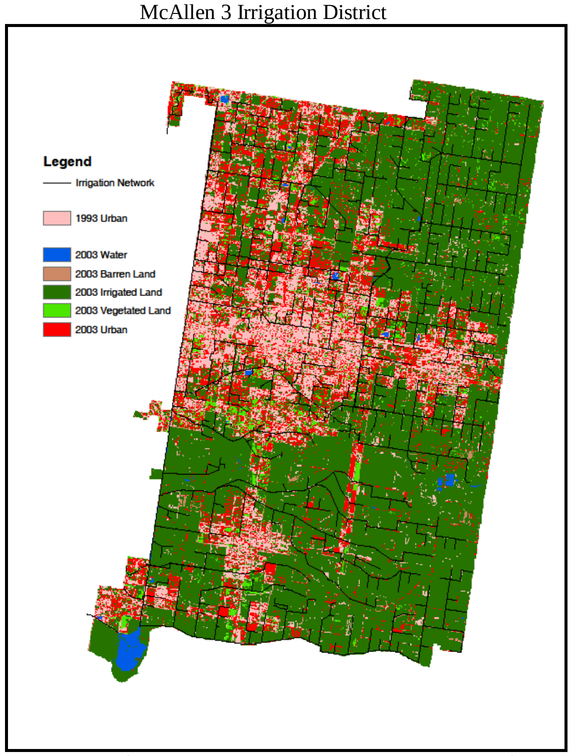

Figure 10 GIS map of derived 2003 land cover and land use classification in San Juan Irrigation District

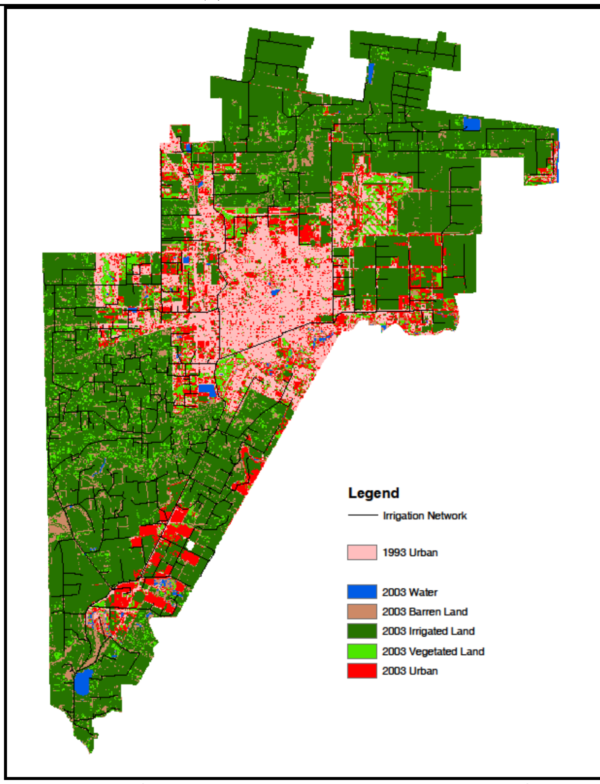

Figure 11 GIS map of derived 2003 land cover and land use classification in Harlingen Irrigation District.

CONCLUSION

This study classified, quantified, and assessed historical LCLU changes and the extent of urbanization in the LRGV of Texas over the ten years between 1993 and 2003 using Landsat satellite imagery. An interactive method between ERDAS and ArcGIS has been developed and evaluated for image classification, and this method attained over 75% overall accuracies for all image classifications at county level. Specifically, for the categories, irrigated land and urban, the producer's and user's accuracies in 1993 were over 80%, and the accuracies in 2003 were over 70%. Based on image classifications, the LCLU changes over the ten years in the Hidalgo, Cameron, and Willacy Counties were estimated, respectively. The estimation indicated that on the average the three counties had a 46% significant urban expansion and a 7.6% irrigated land shrinking in that ten years decrease of 7.6%, and concluded that, in overall, with the increase of urbanization the irrigated land decreases in the region, and this trend will sustain in the next few decades with urbanization. This study provides a method and will help guide and prioritize future modeling initiatives to investigate the effects of urbanization within the LRGV region and other similar regions.

ACKNOWLEDGEMENTS

Would like thank Mr. Jason Weick for his work to organize DOQQ files to assess the accuracies of image classifications. This work was partially funded with support from the Rio Grande Basin Initiative supported by the USDA-Cooperative State Research, Education, and Extension Service and administered by the Texas Water Resources Institute.

DISCLAIMER

Mention of trademark, vendor, or proprietary product does not constitute a guarantee or warranty of the product by the USDA and does not imply its approval to the exclusion of other products that may also be suitable.

REFERENCES

Anderson JR, Hardy EE, Roach JT, Witmer RE, 1976. A land use and land cover classification system for use with remote sensor data. Geographical Survey Professional Paper No. 964. USGS, Washington DC, USA

Congalton RG, Green K, 1998. Assessing the accuracy of remotely sensed data: principles and practices. Lewis Publishers, Inc., Boca Raton, Florida, USA

Di Luzio MR, Srinivasan R, Arnold JG, Neitsch SL. 2002. Soil and Water Assessment Tool, ArcView GIS Interface Manual: Version 2000. Technical Report 192. Texas Water Resources Institute, College Station, Texas, USA

DISC, 2002. Profile of the Rio Grande Valley. In 2002 Labor Market Information Report (http://www.coserve.org/disc/lmi/section_1/section1.html). University of Texas-Pan American. Edinburg, Texas, USA

Gong P, Howarth PJ. 1992. Land-use classification of SPOT HRV data using a cover-frequency Method. International Journal of Remote Sensing 13(8): 1459- 1471

Hill K, Botsford E, Booth DB. 2003. A Rapid Land Cover Classfication Method for Use in Urban Watershed Analsysis. Technical Report 173. University of Washington, Seattle, Washington, USA

Jensen JR, Qiu F, Patterson K. 2001. A neural network image interpretation system to extract rural and urban land use and land cover information from remote sensor data. Geocarto International 16(1): 21- 30

Maingi JK, Marsh SE. 2001. Assessment of environmental impacts of river basin development on the riverine forests of eastern Kenya using multi-temporal satellite data. International Journal of Remote Sensing 22(14): 2701- 2729

McDermid GJ, Franklin SE, LeDrew EF. 2005. Remote sensing for large-area habitat mapping. Progress in Physical Geography 29(4): 449- 474

Neitsch SL, Arnold JG, Kiniry JR, Srinivasan R, Williams JR. 2002. Soil and Water Assessment Tool User's Manual: Version 2000. Technical Report 193. Texas Water Resources Institute, College Station, Texas, USA

Styers DM, Chappelka AH, Marzen LJ, Somers GL. 2010. Developing a land-cover classification to select indicators of forest ecosystem health in a rapidly urbanizing landscape. Landscape and Urban Planning. 94: 158- 165

Yuan F, Sawaya KE, Loeffelholz BC, Bauer ME. 2005. Land cover classification and change analysis of the twin cities (Minnesota) metropolitan area by multitemporal Landsat remote sensing. Remote Sensing of Environment 98(2-3): 317- 328

Zhang Q, Wang J, Peng X, Gong P, Shi P. 2002. Urban built-up land change detection with road density and spectral information from multi-temporal Landsat TM data. International Journal of Remote Sensing 23(15): 3057- 3078