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Shoreline evolution of Valencia Lake and land use and land cover changes in Zamora municipality, Aragua state, Venezuela, period 1986-2016.

Abraham COIMAN

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Shoreline evolution of Valencia Lake and land use and land cover changes in Zamora municipality, Aragua state, Venezuela, period 1986-2016.

Abraham Coiman 

Independent researcher, Turmero 0211, Aragua, Venezuela.

E-mail: abrahamcoiman@gmail.com

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Abstract

Understanding the current and past state of land use and land cover (LULC) changes in a region is possible through multitemporal remote sensing studies in order to identify patterns of long-term changes. This study was conducted to evaluate the shoreline dynamics of the Valencia lake and the magnitude of LULC changes in Zamora Municipality, Venezuela from 1986 to 2016. Landsat (5/7/8) images were processed and classified through the object-based approach. The image classification assessment was performed through the stratified random sampling and the unbiased accuracy assessment methods over 397 sampling units. We used GIS (Geographical Information System) analysis to estimate the magnitude of LULC changes, ascertain the evolution of the shoreline, and identify areas in conflict with the potential for agricultural use. Our image classification accuracy was 69%. We found that scrublands and farmlands experienced reductions, 13029 ha, and 818 ha respectively, whereas forest, built-up, and water bodies showed increments, 11792 ha, 1482 ha, and 634 ha correspondingly. The lake shoreline underwent more than 50% of its raising during the last two study years (2003-2016). It was also observed during these two years that LULC changes prompted conflicts with other land uses, 82% of the lands affected by the shoreline increment were farmlands with high potential for crop yields, and built-up areas grew at a rate of 81 ha/yr. wherein more than one third were lands with high or moderate potential for agricultural use. Our results show that scrublands and/or grasslands experienced important reductions and to a lesser degree farmlands. On the other hand, other classes experienced remarkable increments: forest, and built-up. An upward trend of the Valencia lake shoreline was determined. Further studies are advisable to determine whether the object-based or the pixel-based classification is more suitable to evaluate LULC changes in our study area.

Keywords: Land Use/ Cover, Multitemporal Remote Sensing, Object-Based Classification, Valencia Lake, Venezuela.

Introduction

The Valencia lake basin spans 3055 km² and is located between the Serranía del Litoral (littoral mountains) and the Serranía del Interior (inland mountains) of the Cordillera de la Costa (coastal mountain range) in the central region of Venezuela. This basin is an endorheic basin that retains water and without outflow to other water bodies like rivers or oceans (Wikipedia, 2017). Approximately 0.3% of the territory in Venezuela is occupied by this basin, but nearly 10 % of the population and 30% of the industrial infrastructure in Venezuela lie within the Valencia lake basin (Fundacite, 1999). The compulsive establishment of manufacturing and raw material processing companies in this basin has been accompanied by a significant urban sprawl.

The abovementioned issues have created enormous environmental pressures in this basin, especially since the industrialization of areas surrounding the Valencia Lake. As a result, urban centers have been expanded without planning; generating significant land use and land cover (LULC) changes. It is important to highlight that the volume of wastewater flowing into the Valencia lake has increased as a consequence of an improvised occupation of the basin's territory, especially in flatlands. For more than fifty years, this wastewater has been discharged into the lake without appropriate treatment and management (Jaimes, 2011). Therefore, the lake water is polluted and is not suitable for human

consumption and recreational or agricultural activities because the lacustrine ecosystem is seriously affected by urban and industrial effluents. Since the mid-twentieth century, this basin has experienced quick population growth, generating scarcity of freshwater. To solve this problem, water from the Pao river (a tributary of the Orinoco river basin) began to be transferred since the late 1970s. In consequence, since the 1980s, the lake level has grown significantly and agricultural and urban areas have been flooded.

In this respect, areas for agricultural use in this basin have dropped due to increments of the lake level and urban and industrial areas (Fundacite, 1999). Between 1982 and 2000, urban areas grew at an average annual rate of 3.3 % and 70 % of this increment affected lands with high potential for agricultural use (Ormeño, 2002). From 1980 to 2000 the annual average rate of area decreases for agricultural use was 790 hectares per year (Ormeño, 2002). Due to the fast development, the Valencia lake basin has undergone, LULC changes have shown dynamic and heterogeneous behavior. Natural covers and urban and agricultural uses have experienced significant changes (Tejada, 2006).

LULC is a topic that is widely discussed and studied by several scientific disciplines. This is mainly due to the fact that unplanned human activities such as illegal logging and burning of forests, mining, agriculture, and

urban expansion, are causing negative effects on the environment (Pontes, 2013; Burak et al., 2004).

Land cover refers to all biotic and abiotic factors of Earth's surface and the underlying subsoil. Land cover change is the conversion from one category to another, implying changes in its condition, for example, changes from agriculture to urban areas, or forest degradation (Giri, 2012; Kaya et al., 20017). Land use can be defined as the way by which human beings use or occupy the territory. This term is related to socioeconomic factors that influence a particular use of the territory (e.g. production, recreation, conservation, etc.). Land use change refers to the substitution of one use for another one due to human activities, for example, a forest can be used as a protected area (e.g. change of use), resulting in a greater number of visitors, which does not imply a change in land cover (Giri, 2012; Gazioğlu et al., 1997; Islam et al., 2016; Mohammadi and Hosseinali, 2019).

LULC changes are caused directly or indirectly by human activities seeking to ensure essential resources. This may have happened for the first time when humans burned vegetation in order to facilitate hunting. Agricultural activities have accelerated this process dramatically, resulting in widespread deforestation and intervention of the Earth's surface. Recently, the industrialization has triggered population growth in urban areas and population depletion in rural areas. This has intensified the use of the most productive lands for agriculture and the marginalization of the less suitable lands (The Encyclopedia of Earth 2010).

Data captured through remote sensing techniques and their analyses provide detailed information for monitoring LULC changes (Rogan and DongMe, 2004). The accessibility of free and low-cost data generated from remote sensing and new image analysis techniques have encouraged the remote-sensing community to generate information for LULC mapping (Mallinis and Georgiadis, 2019). In contrast to traditional methods, LULC mapping using remotely sensed data is faster and cheaper, map products are readily updated. It is straightforward to join remotely sensed data with data derived from GIS, and by using data obtained from remote sensing it is possible to map large areas (Toure, et al., 2018), which is very useful for LULC purposes.

There are a variety of remote sensing techniques producing various results due to the remotely sensed data, environmental conditions, and image processing methods (Berberoglu and Akin, 2009). Mapping accurately land use and land cover using remote sensing techniques requires adequate image classification methods (Ngan Lam, 2008). Image classification is an essential stage during the image analysis that allows users to group pixels of an image into classes or categories representing land covers (Patil, et al., 2012).

New classification methods have been devised to enhance the classification process (Ngan Lam, 2008). New methods such as fuzzy classification, artificial neural network, and object-based classification have been successfully applied (Ngan Lam, 2008). The object-based classification uses the sizes, shapes, textures and spectral features of the regions (Campbell and Wynne, 2011). To extract features, the object-based paradigm makes use of all aspects of remote sensing, especially spectral, spatial, contextual, textural and temporal properties of the features (Navulur, 2007).

The purpose of this work is to evaluate the shoreline dynamic of the Valencia Lake and its LULC changes through geomatics tools, focusing on the Zamora municipality in the Aragua state. These dynamic and LULC changes were assessed by classifying medium resolution satellite imagery using the object-based approach between 1986 and 2016.

The main objective of this work is to evaluate the evolution of the Valencia lake shoreline and LULC changes in Zamora municipality Aragua state from 1986 to 2016. Other objectives are as follows: (i) describe LULC changes in Zamora municipality between 1986 and 2016; (ii) ascertain the evolution of the lake shoreline in the study area from 1986 to 2016; (iii) identify areas in conflict with the potential agricultural land use in the study area between 1986 and 2016.

Study Area

Zamora municipality is located at the middle part of the Aragua state (Figure 1). Its limits are the following: North: Libertador, José Ángel Lamas and Sucre municipalities; South: Guárico state; East: San Sebastián and José Félix Ribas municipalities; West: Carabobo state (Figure 2).

Zamora municipality is in the Aragua state in Venezuela and spans an area of 68424 hectares. The western portion of this municipality lies in the Valencia lake basin where important urban centers are located: Villa de Cura (capital city), Tocorón and San Francisco de Asís. On the other hand, the eastern area of this municipality that makes up the Guárico river basin is predominantly hilly and has not urban development. This work is based on the LULC changes that occurred in this territory.

Almost all the Zamora municipality territory has a tropical savanna climate. The predominant vegetation is savanna, with some features of premontane forests. The most important economic activities of this municipality are mining, agriculture, and industries. Its relief is formed by the Serranía del Interior (inland mountains), which in geological terms is a recent mountainous block. Open or natural paths such as Villa de Cura allow the communication between the Valencia lake basin, the Aragua valleys and the Guariqueños Plains (Wikipedia, 2016).

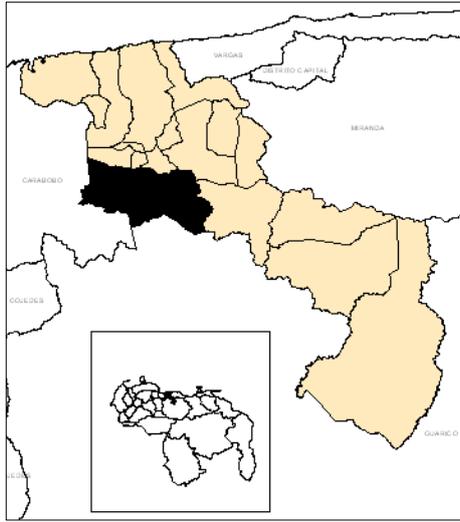


Figure 1. Study Area



Figure 2. Study Area Boundaries

Materials and Methods

Datasets

Cartographic information was reviewed in order to obtain geospatial data and information related to the study area. In this regard, vector and raster datasets of the Aragua state administrative areas, land use classifications, topography, among others, were selected and used. These datasets were mainly obtained from the Ministry of Environment, the Faculty of Agronomy UCV (Universidad Central de Venezuela) and the regional government.

Landsat 5, 7 and 8 images were obtained from the Geological Survey of the United States (USGS) through the website <http://earthexplorer.usgs.gov/>. Landsat 5 and 7 thermal infrared band (band 6), and Landsat 8 coastal aerosol (band 1), cirrus (band 9), and infrared thermal bands (band 10, 11) were not taken into account since they are generally used for coastal and aerosol studies, cirrus cloud contaminations and soil moisture (USGS, Table 1. Images used in this study

2015). In order to obtain an even spatial resolution, only Landsat images were used throughout the study periods. Four study periods were defined, for each period an image was selected with the specification presented in Table 1.

Land Use and Land Cover System

The CORINE Land Cover system adapted to Colombia was chosen as the basis for defining LULC change categories. The Colombian CORINE Land Cover project standardized a classification system with hierarchical categories, based on the information provided by Landsat TM images according to local conditions of the territory in Colombia (Instituto de Hidrología, Meteorología y Estudios Ambientales, et al., 2008). The CORINE Land Cover system adapted to Colombia was used in this work because Venezuela and Colombia have similar anthropic footprint patterns as well as common biotic and abiotic features. The Colombian CORINE Land Cover system adapted to this investigation is presented in Table 2.

Study Period	Acquisition / Study Year	Mission/Sensor	Processed Bands
1986-1998	1986	Landsat 5 (TM)	1-6
	1998	Landsat 5 (TM)	1-6
1998-2003	2003	Landsat 7 (ETM+)	1,2,3,4,5,7
2003-2016	2016	Landsat 8 (OLI/TIRS)	2-7

Table 2. CORINE Land Cover Colombia legend adapted to this study

Level 1	Level 2
1. Artificial Surfaces	1.1 Urban fabric
	1.2 Industrial and commercial units
	1.3 Mine and dump sites
2. Agricultural Areas	2.1 Heterogeneous agricultural areas
3. Forest and Semi Natural Areas	3.1 Forests
	3.2 Scrub and/or herbaceous vegetation associations
	3.3 Open spaces with little or no vegetation
4. Water Bodies	4.1 Inland waters

Image Pre-processing

In the image processing step, three operations were performed on each of the selected images: cropping, atmospheric correction, and enhancements. It is important to highlight that when multitemporal studies are carried out, it is necessary to atmospherically correct the images since the scattering is not the same for images acquired on different dates (Chuvieco, 1995; Kaya et al., 2015).

The FLAASH module (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes) of the ENVI 5.1 software was used for image atmospheric correction. The eCognition Developer software was used for image enhancement. Images used in this study were not geometrically corrected because the USGS performs a standard terrain correction (level 1T) with systematic radiometric and geometric accuracy (Rodríguez, 2011).

Image Classification

Landsat image classification was carried out by using the eCognition Developer 8.0 and the object-based approach. The following steps were executed in order to perform the object-based classification (Figure 3). (i) loading land use vectors and image composites into eCognition projects; (ii) definition of parameters used by the Multiresolution Segmentation algorithm; (iii) building class trees from the categories shown in Table 2; (iv) collecting training samples to define parameters of the classification rules. Ten (10) samples were collected per category since each of them must be made up by a number of training sites (at least 5 to 10) that ensure that their spectral properties are represented (Campbell and Wynne 2011); (v) definition of classification rules for each coverage classes based on the membership function classifier. The membership function method uses the fuzzy logic approach to classify image objects (Xiaoxiaa, et al., 2004); The

classification rules were based on image composites and vegetation indices like Normalized Difference Vegetation Index (NDVI), Ratio Vegetation Index (RVI), Soil-adjusted Vegetation Index (SAVI), and Difference Vegetation Index (DVI). The classification rule for the Inland waters class was defined from the Land Water Mask (LWM) used by (ICIMOD, 2015); (vi) defining algorithms to classify objects based on classification rules and vector layers. The following algorithms were used: Classification, Assign Classes by Thematic Layer and Assign Class; (vii) image classification assessment through the error matrix (confusion matrix) based on the unbiased accuracy assessment method proposed by (Olofsson, et al., 2013). The classification assessment was only performed on six classes of the 2016 classification results due to the lack of ground truth data for all the classified images. The Copernicus Global Land Cover Layers: CGLS-LC100 collection 2 (Buchhorn, et al., 2019) and the Google Earth Engine Python API were used to capture ground truth samples. 397 random sample points were selected within the strata or classes using the stratified random sampling method and the NOAA Biogeography Branch's Sampling Design Tool for ArcGIS (NCCOS, 2017).

Image post-classification

In the post-classification phase, all the classified objects were processed in order to generate vector layers that were used in subsequent stages of spatial analysis. The objects were merged with the Merge Region algorithm of eCognition and then exported as shapefile layers. Vector layers were adapted to the minimum mapping unit (MMU) that was set at 25 ha which is equivalent to $\frac{1}{4}$ cm² at a 1: 100000 scale. Finally, shapefile layers were reduced to the Zamora municipality extent through a cutting operation.

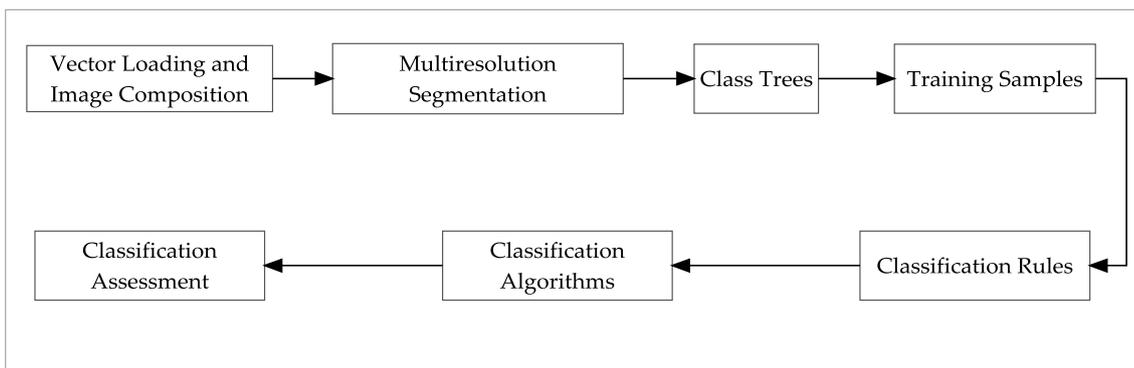


Figure 3. Steps executed to carried out the object-based classification.

Evolution of the lake shoreline, and the agricultural and urban use

To calculate the evolution of the lake shoreline, the area occupied by the lake was extracted from each study year shown in Table 1. Layers of consecutive years were joined to obtain polygons containing data about the variation of the lake surface for each period of study depicted in Table 1. This task was carried out through ArcGIS Desktop 10.1. The FID field of the resulting

attributive table was used to pinpoint growth polygons of the lake. To calculate the lake shoreline level of each study year, the above-mentioned polygons were transformed into polylines from which the lacustrine shoreline was obtained. Then, a 10 m buffer was calculated that was used to extract the portion of the MDE-SISDELAV (Sistema de Información de Suelos de la Depresión del Lago de Valencia) and the shoreline mean elevation of each study year.

To obtain agricultural use and urban use areas, a procedure similar to the above-mentioned was used. For each study year, areas of agricultural and urban use were selected and converted into new layers. Then, layers of consecutive study years were joined in order to obtain polygons containing the variation of the agricultural and urban areas by period of study. The FID attribute was equally used to determine areas that increased or decreased.

Identification of areas in conflict with potential agricultural land use

The identification of areas in conflict with potential agricultural land use was carried out on the following classes: Inland waters (lake), Heterogeneous agricultural areas and Urban fabric. To do that, the following layers were processed: increment of the lake area, raise and shrink of agricultural and urban use, and potential land use from SISDELAV data. QGIS 2.18 was used to clip the SISDELAV data using the corresponding increment and decrement polygon. This procedure allowed obtaining the data to quantify and characterize the potential agricultural land use affected by the evolution of the lake shoreline, the increase and/or decrease of agricultural areas and the urban expansion in Zamora municipality.

Results

Accuracy Assessment

As mentioned previously, the image accuracy assessment was calculated through the unbiased accuracy assessment method. The following statistics are presented: (i) confidence interval, (ii) user accuracy, (ii) producer accuracy, and (iv) overall accuracy. A confidence interval gives a range of values for a certain parameter considering the uncertainty of the example-based estimate (Olofsson, et al., 2013); user accuracy is the probability of commission error while producer accuracy is the probability of omission error, and the proportion of the area classified correctly is the overall accuracy (Olofsson, et al., 2013). A total of 397 sampling points were used for the accuracy assessment of the year 2016, and the overall accuracy was 69 %. Producer accuracy for all classes ranged from 53 % to 95 %, the user accuracy from 47 % to 84 % and the error (in hectares) of the area estimate for all classes varies from 650 to 2965 (Table 3). Although accuracy assessment between 75-85 % is acceptable (Mubako, et al., 2018), the overall accuracy is slightly below this range, that means, on average, that the chance a pixel will be correctly classified is 69 %. This could be attributed to the difference between the spatial resolution of the reference data (100 m) and the classified data (30 m). The latter explains why the urban and the agricultural classes showed low producer (e.g. omission error) and user (e.g. commission error) accuracy respectively, and wide confidence intervals (Table 3). Despite the limitation of available data for accuracy assessment, the reliability of the classified results is generally acceptable.

Table 3. Unbiased accuracy assessment summary table

Class	Area (hectares)	± 95% CI	User's Accuracy (%)	Producer's Accuracy (%)	Overall Accuracy (%)
Urban fabric	3331.13	1126.88	76.9	50.8	69.09
Inland waters	2892.68	649.47	84.2	93.7	
Forest	22785.60	2731.30	66.7	65.7	
Scrub and/or herbaceous Vegetation associations	34038.40	2964.85	73.7	68.2	
Heterogeneous agricultural areas	3676.75	1144.46	47.7	95.6	

Table 4. Area of LULC categories per year of study

Class/Year	AREA (ha)				Variation 1986-2016
	1986	1998	2003	2016	
Inland waters	2677	2949	2917	3311	634
Open spaces with little or no vegetation	522	2890	4187	388	-134
Heterogeneous agricultural areas	8412	8257	8454	7594	-818
Scrub and/or herbaceous vegetation associations	46451	51811	48861	33422	-13029
Forest	9387	1238	2388	21179	11792
Mine and dump sites	72	107	240	148	76
Industrial and commercial units	145	197	193	142	-3
Urban fabric	758	975	1184	2240	1482
TOTAL	68424	68424	68424	68424	

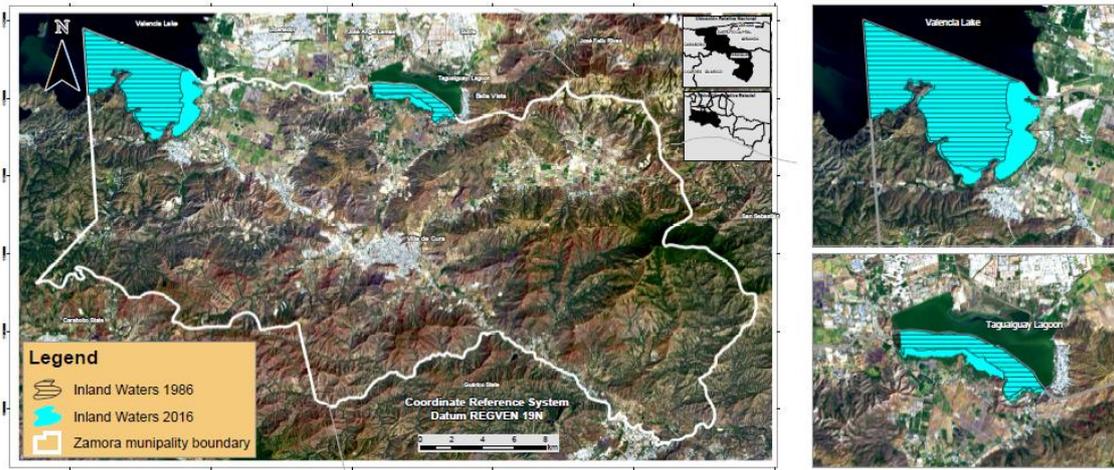


Figure 4. Variation of Inland waters in Zamora Municipality between 1986 and 2016

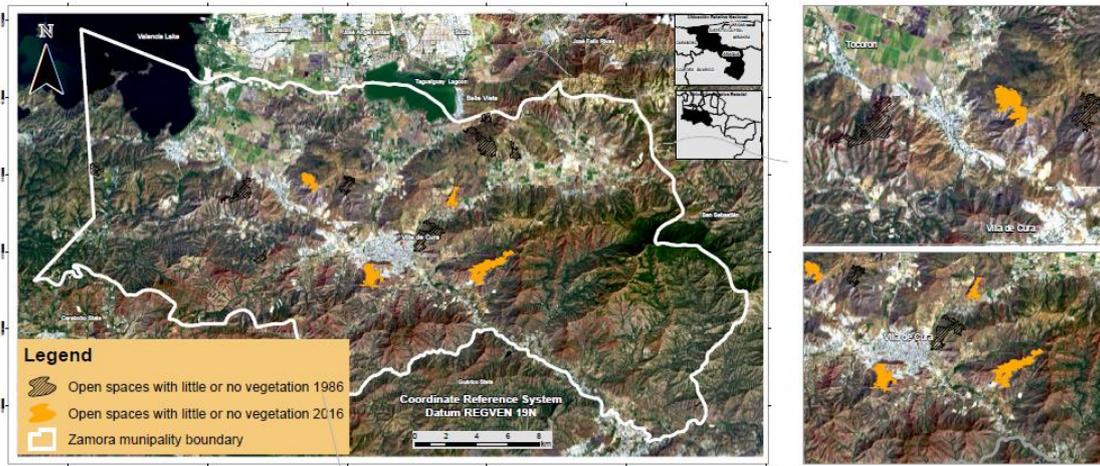


Figure 5. Variation of Open spaces with little or no vegetation in Zamora Municipality, between 1986 and 2016.

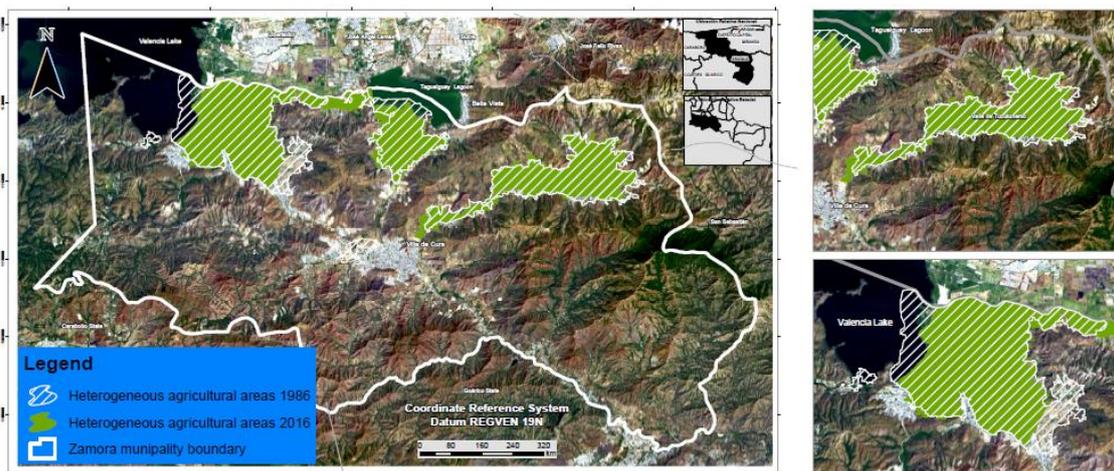


Figure 6. Variation of Heterogeneous agricultural areas in Zamora Municipality, between 1986 and 2016

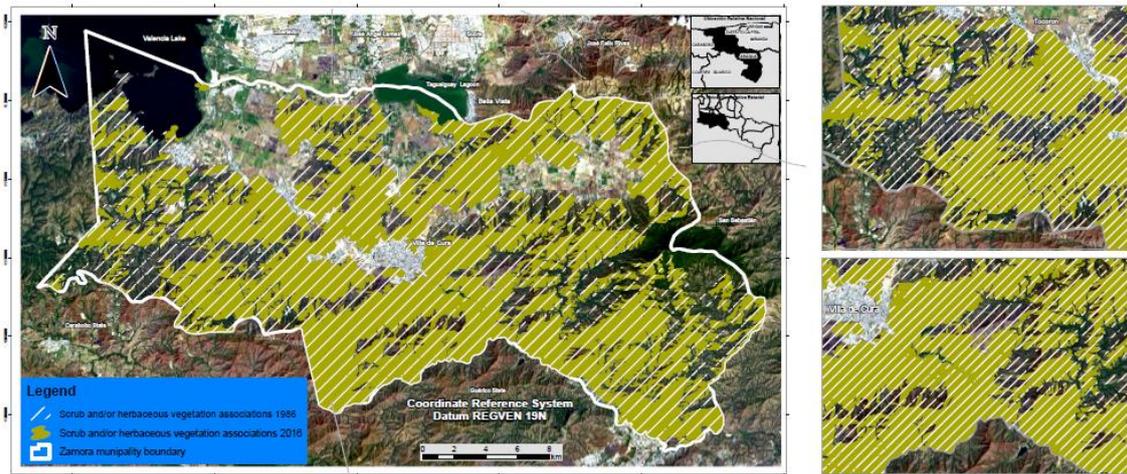


Figure 7. Variation of Scrub and/or herbaceous vegetation associations in Zamora Municipality, between 1986 and 2016

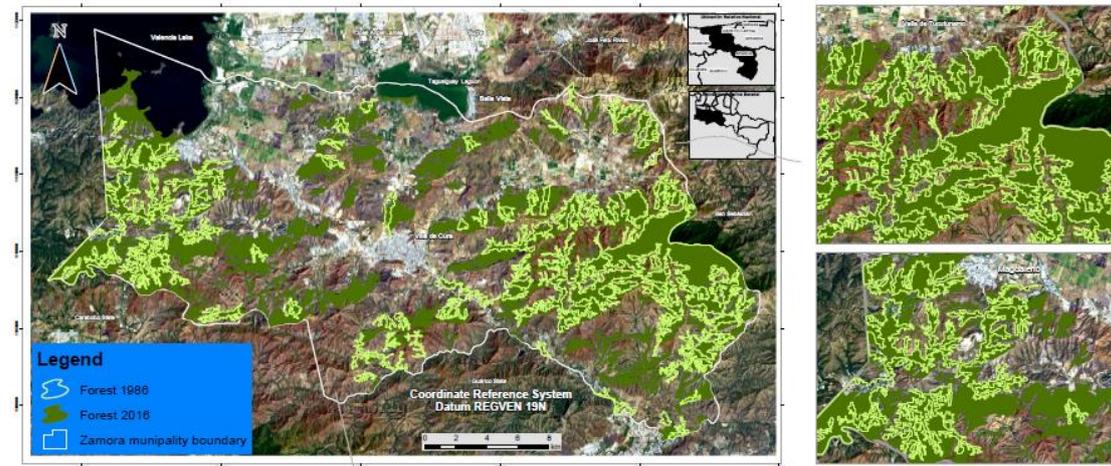


Figure 8. Variation of Forests in Zamora Municipality, between 1986 and 2016.

Land Use and Land Cover Changes

Areas of LULC classes showed a variable behavior between 1986 and 2016. Table 4 shows the area of each class for each study year. Inland waters class showed a constant increase throughout the study years, its variation between 1986 and 2016 was 634 ha (Figure 4, Table 3). The category named Open spaces with little or no vegetation showed a notable decrease in its surface between 1986 and 2016 with a variation of -134 ha (Figure 5, Table 4). The Heterogeneous agricultural areas class showed a downward trend in its surface between 1998 and 2016, the difference in the area occupied by this class between 1986 and 2016 was -818 ha (Figure 6, Table 4).

The area of Scrub and/or herbaceous vegetation associations showed a variable trend with increases between 1986 and 1998 and declines from 1998 to 2016,

its variation was -13029 ha between 1986 and 2016 (Figure 7, Table 4). Forests showed a dramatic decline in more than 8000 hectares of their surface from 1986 to 2003. Between 2003 and 2016 the area occupied by this land cover experienced remarkable increases, the surface variation was 11792 ha from 1986 to 2016 (Figure 8, Table 4).

Mine and dump sites and Industrial and commercial units showed variable behaviors throughout the study years. The area of Mine and dump sites varied 76 ha between 1986 and 2016 (Figure 9, Table 4). Industrial and commercial units decreased by 3 ha in its surface during the above-mentioned period (Figure 10, Table 4). Like inland waters, the Urban fabric class showed a sustained increase in its area between 1986 and 2016, with a variation of 1482 ha (Figure 11, Table 4).

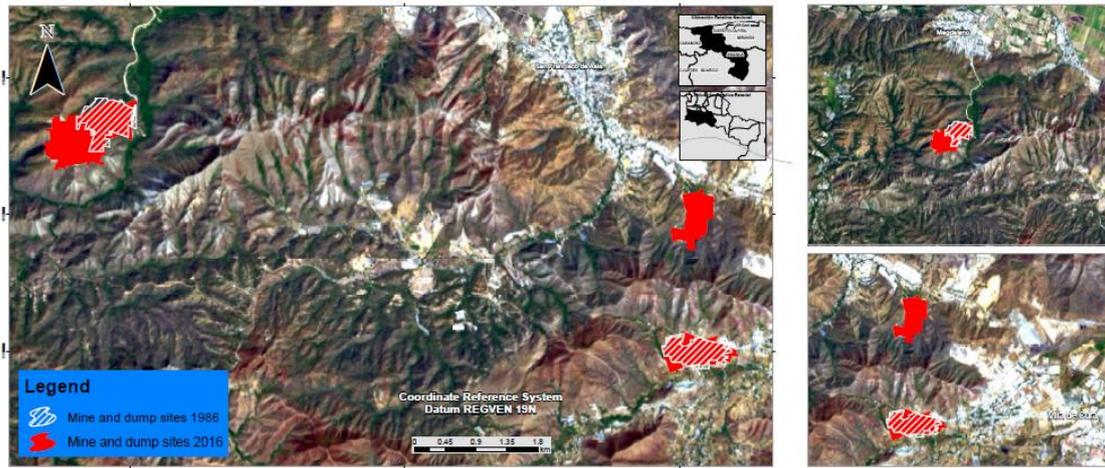


Figure 9. Variation of Mine and dump sites in Zamora Municipality, between 1986 and 2016

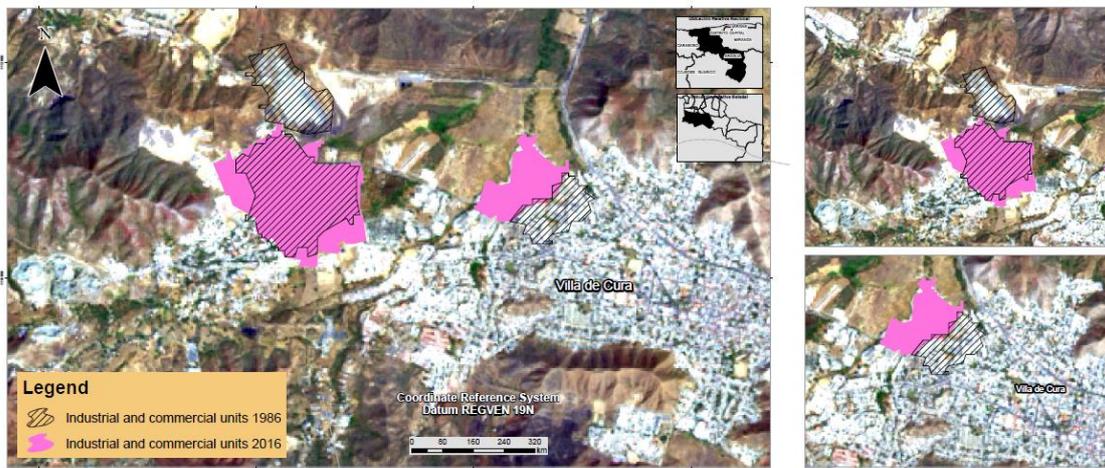


Figure 10. Variation of Industrial and commercial units in Zamora Municipality, between 1986 and 2016

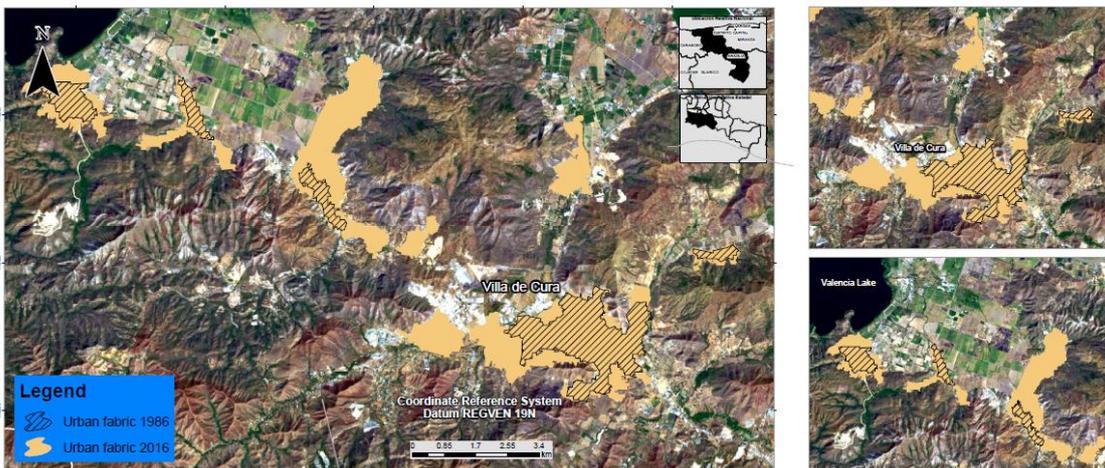


Figure 11. Variation of Urban fabric in Zamora Municipality, between 1986 and 2016

Shoreline growth

Valencia Lake expanded over an area of 544 ha between 1986 and 2016. From 1986 to 1998 the surface of the lake increased by 158 ha, this is equivalent to 29% of the total expansion between 1986 and 2016. From 1998 to 2003 the increase in the area occupied by the lake attained 66 ha, which represents 12% of the increase between 1986 and 2016. The Valencia lake increased its surface in 320 ha (59%) between 2003 and 2016.

The shoreline level of the Valencia lake showed an upward behavior between 1986 and 2016. From 1986 to 1990, this level rose from 387 meters above sea level (masl) to 390 masl, which is equivalent to a variation of 3 m. Between 1998 and 2003 the lake level increased by 7 m with 397 masl for 2003. The level of the lake increased by 25 m between 2003 and 2016 with values of 422 masl for the last year (Figure 12).



Figure 12. Shoreline growth of Valencia lake between 1986 and 2016.

Table 5. Surface variation of the Heterogeneous agricultural areas between study periods

Period	Increase (ha)	Decrease (ha)	Increase (%)	Decrease (%)
1986- 1998	907	1062	46.06	53.94
1998-2003	1051	854	55.17	44.83
2003-2016	642	1502	29.94	70.06
1986-2016	2600	3418	43.20	56.80

Table 6. Potential for agricultural use affected by the shoreline growth

Potential for agricultural use	Period							
	1986-1998		1998-2003		2003-2016		1986-2016	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Total (ha)	%
High	41	26	32	48	264	83	337	62
Moderate	4	3	4	6	15	5	23	4
Low	91	58	19	29	21	7	131	24
Very low	1	1	1	2	6	2	8	1
No data	21	13	10	15	14	4	45	8
Total (ha)	158		66		320		544	

Table 7. Potential for agricultural use affected by the urban growth

Potential for agricultural use	Period							
	1986-1998		1998-2003		2003-2016		1986-2016	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Total (ha)	%
High	19	7	26	11	361	34	406	26
Moderate	13	5	14	6	36	3	63	4
Low	36	13	22	9	75	7	133	8
Very low	92	34	33	13	240	23	365	23
No data	107	40	15	61	341	32	598	38
Total (ha)	267		24		1053		1565	
			5					

Evolution of the urban and agricultural land use

Between 1986 and 2016 urban areas increased by 1482 ha. From 1986 to 1998, urban areas in the Zamora municipality increased by 217 ha, which represents 15% of the increment between 1986 and 2016. Urban areas augmented by 209 ha (14%) between 1998 and 2003. From 2003 to 2016 occurred the greatest expansion of the urban fabric class with an increase of 1056 ha, representing 71% of the growth between 1986 and 2016.

Between 1986 and 2016, agricultural areas showed a downward trend of its surface since the extent of decrease was greater than the extent of increase (Table 5). From 1986 and 2016 Heterogeneous agricultural areas increased by 2600 ha and decreased by 3418 ha. These figures support its tendency towards the shrinking of its surface.

Areas in conflict with the potential agricultural land use

Between 1986 and 2016 the lake shoreline expansion flooded 544 ha. 66% of the affected areas were lands with high and moderate potential for agricultural use, while 25% of the areas were lands with low to very low potential for farming activities. From 1986 to 1998 the shoreline expansion mainly flooded lands with low potential agricultural use (91 ha). Between 1998 and 2003 essentially, 32 ha with high potential for agricultural use were waterlogged, while during the period 2003-2016, 264 ha of land losses with high potential were quantified (Table 6). At the beginning the affectation was low and on soils with a high water table, then, in the period 2003-2016, the affected area was more extensive and mainly on well-drained soils, with high potential agricultural land use.

Defining areas in conflict with urban growth was based on quantifying the potential for agricultural use affected by urban development. In general, during the study period (1986-2016), lands with high potential (406 ha.) and lands with very low potential (365 ha.) for agricultural use were affected by the expansion of urban areas (Table 7). It was not possible to calculate the potential for agricultural use in 38% of the affected area because there was not SISDELAV data. In the beginning, the urban growth overlaid land with low potential for agricultural use, then when engineering limitations constrained the urbanization, lands with high potential for agricultural use were affected (period 2003-2016). Urban shrinking areas (83 ha) for the overall study period (1986-2016) were not included in this analysis.

Heterogeneous agricultural areas showed increases and decreases in its surface during the study period (1986-2016) (Figure 13). From 1986 to 2016 the increase of agricultural areas was carried out mainly on lands with low to very low potential for agricultural use (37%), but there is only 1% of difference in comparison with the other classes of potential for agricultural use (Figure 14). There was no SISDELAV data for 27% of the areas affected by the increase of agricultural areas. Along the overall study period (1986-2016), shrinking of Heterogeneous agricultural areas was made up of land with high to moderate potential for agricultural use (45%), and there was no SISDELAV data for 23% of the areas affected by the decrease of agricultural areas (Figure 15). Similar to (Tejada, 2006), in general, it was possible to determine that between 1986 and 2016, Heterogeneous agricultural areas showed a downward trend made up essentially of land with high to moderate potential for agricultural use.

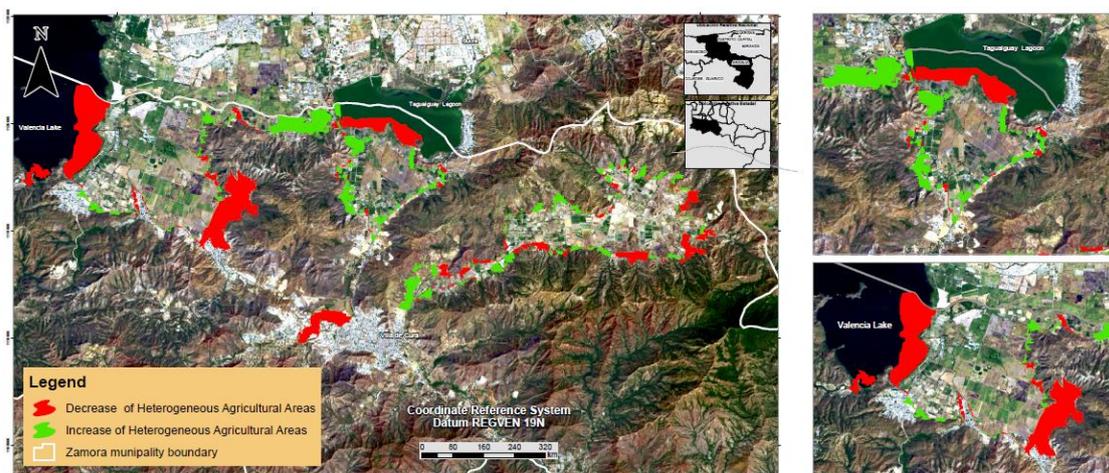


Figure 13. Increase and decrease of Heterogeneous agricultural areas between 1986 and 2016

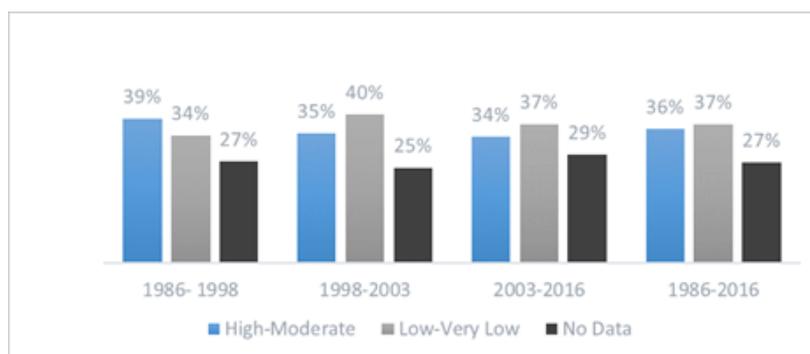


Figure 14. Potential for agricultural use affected by the increase of Heterogeneous agricultural areas between 1986 and 2016

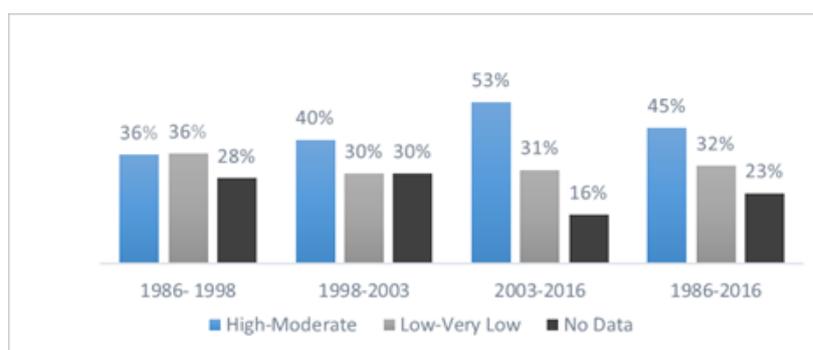


Figure 15. Potential for agricultural use affected by the increase of Heterogeneous agricultural areas between 1986 and 2016

Discussion

We classified Landsat images by using the object-based approach to describe LULC changes in Zamora municipality between 1986 and 2016. We used the image classification results in conjunction with SISDELAV data and feature extraction to determine the evolution of the Valencia Lake shoreline and identify areas in conflict with the potential for agricultural use. In general, we found a variable behavior of the LULC classes during this thirty-year study period. According to our results (Table 4), Inland waters and Urban fabric classes showed a steady increase during the study period. Open spaces with little or no vegetation, Mine and dump sites, and Industrial and commercial units raised between 1986 to 2003 and then dropped in 2016. Heterogeneous agricultural areas and Scrub and/or herbaceous vegetation associations experienced a downward trend in area with peaks and drops. Forest class showed a dramatic decrease from 1986 to 1998 and then a steep growth between 1998 and 2016. Previous studies have found similar results in areas and time-lapses overlapping with our area and period of study. From 1986 to 2001, in the Valencia Lake basin, Ormeño (2002) reported reductions in agricultural lands and increases in urban uses and the Valencia Lake. Inland waters, urban areas, and bare soils experienced increments while other categories such as Forests and agriculture areas showed decreases in Zamora, Liberator, José Angel Lamas and Sucre municipalities between 1986 and 2001 (Tejada, 2006).

We assessed the image accuracy through the unbiased accuracy assessment method and the CGLS-LC100 as a reference dataset. The overall accuracy was 69%, which means that on average the chance a pixel will be correctly classified is 69%. Our best user's accuracy was 84% (Inland waters) and the best producer's accuracy was 95.6% (Heterogeneous agricultural areas). On the other hand, the worst user's accuracy was 47.7% (Heterogeneous agricultural areas) and the worst producer's accuracy was 50.8% (Urban fabric) (Table 3). It has been reported overall accuracy over 80% when using object-based approach to classify Landsat imagery (Oruc, et al., 2004, Kindu, et al., 2013, Estoque, et al., 2015, Poursanidis, et al., 2015). However, we would like to point out that our overall accuracy was slightly below 75-85% which is the acceptable range of this metric (Mubako, et al., 2018). This could stem from two issues: first, the difference between the spatial resolution of the reference data (100 m) and the classified data (30 m) could affect sampling results. When using medium to high-resolution imagery as reference data, we can only extract a small amount of the landscape variability because our pixels are small and therefore the area covered by the sample units are small too (Congalton and Green, 2019), on the contrary, we extract a large amount of the landscape variability with low-resolution imagery because the sample units overlap more surface. In our case, it is possible that a sample unit containing a given class we classified using Landsat data, was identified as a more general or predominant class on CGLS-LC100 data due to differences in pixel size between both datasets. Second, we had to visually

interpret Landsat image composites to extract urban and agricultural areas. Errors could therefore arise during the interpretation process due to the interpreter skills (Congalton and Green, 2019). Inaccurate visual interpretations could undermine user's and producer's accuracy of both Heterogeneous agricultural areas and Urban fabric categories respectively. More research is required on assessing object-based classification using images with different spatial resolutions in our study area. Also, it would be interesting to investigate whether it is possible to achieve high overall accuracy combining Landsat and high-resolution images (Toure, et al., 2018) because object-based classification is mainly used to classify high-resolution imagery (Ma, et al, 2017).

Our results provide compelling evidence for long term increments of the Forest class, especially after 1998. This suggests a secondary succession process characterized by changes in plant communities whereby vegetation has been disturbed but the soil has not been removed (Gibson and Gibson, 2006). From Table 4, and Figures 7 and 8, we can infer that owing to a secondary succession, areas occupied by Scrub and/or herbaceous vegetation in 1986 changed into Forest in 2016. Understanding how forest areas are changing due to local patterns of succession can help planners to visualize how the landscape will change over the next years (Perman and Milder, 2004), especially in the Valencia Lake basin. In the same way, we found evidence that urban areas exhibited an upward trend during the study period. In the beginning, the urban growth overlaid land with low potential for agricultural use, then when engineering limitations constrained the urbanization, lands with high potential for agricultural use were affected (period 2003-2016) (Table 7). This finding about urban growth are explain by the fact that built-up areas in the Valencia Lake basin have been populated untidily around urban centers and towards unsuitable areas for urbanization (de La Rosa, 2009; Jaimes, 2011). These insights should alert urban planners in the region because as a result of urban sprawl, prime farmlands can be negatively affected, resulting in irreversible change of forest and agricultural lands into urban areas (Doygun, 2009). It is crucial to understand how urban expansion and agricultural land use interact because it allows to formulate land use planning polices and plans to balance the pressure of urban growth on farmlands (Jiang, et al., 2013). Although our findings were aligned with other author's claims about the relationship between urban growth and farmland, SISDELAV data only covered 61% of our study area (Table 7). Future works should, therefore, produce the missing data in order to account for the potential for agricultural use affected by the urban growth in the entire study area.

In this study, we determined the evolution of the Valencia Lake shoreline from 1986 to 2016 in Zamora municipality using the DEM of SISDELAV data and classification results of Landsat images. The overall results indicate that the lake spread out into 544 ha and its water level (elevation) rose 35 m. The data confirms an upward trend of the lake level especially for the last study year (2016), and the claim of (Castillo and Jiménez, 2013) who stated that since 2010 the lake level

has grown. These results build on existing evidence of a direct relationship between water importation and water level rising. From 1981 on, the lake level has increased as a direct consequence of water importation (Jaime, 2011) and probably as a consequence of changes in moisture availability (Curtis, et al., 1999). This knowledge has various implications in economic activities in the Valencia Lake basin. The rising of the lake level implies more flooded areas that impacts agricultural activities due to loss of high-quality farmlands, infrastructure for farming activities and perennials crops (Guevara, 2000), this situation is relevant to Zamora municipality because between 1986 and 2016, 63% of the farmlands affected by the shoreline growth were lands with high potential for agricultural use (Table 6). It should be noted that Landsat images were valuables because they allowed us to obtain lake boundaries from which we extracted the shoreline for each year of study. On the other hand, we used a DEM with a spatial resolution (10 m) that constrained the accuracy of the calculated water level for each study year. A more detailed DEM should therefore be used in order to estimate more accurate lake levels.

Conclusions

Evaluating land use and land cover through multitemporal remote sensing allows identifying patterns of long-term changes. Due to the vast amount of historical Landsat data, we can classify images and extract features that are used to create a snapshot of a given time. Successive snapshots are then compared to gain insights into how LULC has evolved over time. Mutitemporal remote sensing capabilities have been used in this study to gain understanding of LULC changes and the Valencia Lake shoreline evolution over a thirty-year period in Zamora municipality. This kind of study is important because it is a source of data and information for conceiving informed plans for land using planning.

The results show that there was a notable reduction of the scrub and/or herbaceous vegetation associations and to a lesser degree the Heterogeneous agricultural areas. On the other hand, other classes experienced remarkable increments in area: Forest, and Urban fabric. These findings are important to understand that LULC dynamics in the study area are related to secondary succession processes favoring forest recovery, and urban sprawl disturbing prime farmlands.

An upward trend of the Valencia Lake shoreline was observed, and for the last two study years (2003-2016) more than 50% of this raising occurred. This trend elicited conflicts with the potential agricultural land use. Lands with high potential for crop yields were affected by the lake shoreline increment. At the beginning the affectation was low and on soils with a high water table, then, in the period 2003-2016, the affected area was more extensive and mainly on well-drained soils with high potential agricultural land use.

In the image classification carried out by the object-based approach, despite its moderate overall accuracy,

built-up areas and vegetated covers were satisfactorily extracted. Notwithstanding the accuracy outputs, it is the first time this approach was applied in the study area to classify images intended for LULC studies. Also, this study does suggest that in the absence of classification rules based on shape, texture, and contextual information of the images, it is possible to separate objects through vegetation indexes and thematic layers like we did in this study.

In future studies, it is advisable to use high-spatial-resolution images in order to improve image classification accuracy. High-resolution data could be very useful to separate objects in built-up areas wherein mid-resolution images tend to be more prone to generate errors. Therefore, high-spatial-resolution images in conjunction with mid-resolution images can be used to determine whether the object-based classification or the pixel-based classification is more suitable to conduct studies of LULC changes in our study area and its surroundings.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at doi:10.5281/zenodo.3978372

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