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Article

Change in vegetation cover and land use in *Morelos*, Mexico, from 2000 to 2009

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Abstract:

Studies related to the progressive changes in vegetation cover and land-use are an important component in environmental research, since they allow the evaluation of the spatio-temporal trends of such processes as deforestation and environmental degradation, caused by human activities. In the present study, land-cover and land-use change in the State of *Morelos* during the period 2000-2009, are described. Fourteen types of vegetation cover and land-use, including water bodies, were identified, all though the latter were no included in the analysis. Agricultural and urban land cover increased 1 373 ha and 189 ha, respectively; whereas the land-cover that undergo the greatest transformations are the forests, with 858 ha, and tropical dry forests, with 1 841 ha. The dynamics of change are complex, its main drivers being socio-environmental factors and land tenure. LANDSAT multispectral satellite data were used, with ESRI ARCMAP 10 software, to map and analyze the land-use change between the years 2000 and 2009. The supervised classification technique was used, based on the maximum likelihood algorithm. Information on the vegetation cover and land-use, and the identification of alternatives for their optimal use, obtained through the use of remote sensing and geographic information systems, are essential for the selection, planning and execution of land management plans, as well as for the development, conservation and use of natural resources required to satisfy the growing demand for basic needs and for human welfare.

Key words: Vegetation cover, land use planning, remote sensing, geographic information systems, land tenure, land use.

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Introduction

Land cover and use

Land is one of the most important natural resources, on which life and various development activities depend (George *et al*., 2016). The changes in land-cover and land-use are the result of socio-economic activities and environmental factors (Overmars *et al.*, 2005). Human activities have a significant impact on biodiversity worldwide, on global and local climate, biogeochemical cycles, on soil quality and degradation, hydrology, and finally on food safety and human well-being (Trimble *et al*., 2000; Foody, 2002); furthermore, they affect the ability of biological systems to meet the increasing demand for natural resources (Tran *et al.*, 2015). However, the effects of land-use change - are not all negative, as some are associated with an increase in food and fiber yield, having a positive impact on human health, wealth and well-being (Lambin and Geist 2006). The documentation of the land-cover and land-use changes are necessary in order to understand the underlying driving forces, their consequences, especially in the context of global climate change, rapid population growth and the ever increasing demands for environmental sustainabilitye.

The use of *Landsat Thematic Mapper* (TM) images in research on land-use change in Mexico is very robust and frequent. Studies have been carried out in central *Chihuahua* (Alatorre *et al.*, 2015), *Hidalgo* (Sierra-Soler *et al*., 2015), *Jalisco* (Morales-Barquero *et al*., 2015), *Michoacán* (Ordóñez *et al*., 2008; Mas and González, 2015), *Yucatán* (Colditz *et al*., 2015), the State of Mexico (Galicia and García-Romero, 2007; Zepeda *et al*., 2012), *Morelos* (Trejo and Hernández, 1996; Vega *et al*., 2008), *Chiapas* (Flamenco-Sandoval *et al*., 2007), and Tabasco (Guerra and Ochoa, 2006), among others.

The objectives of this research are: to develop land-cover and land-use maps in order to analyze the changes detected over a period of 9 years in *Morelos*, Mexico, using *Landsat* TM images of the years 2000 and 2009, and to analyze the changes in the vegetation cover and land-use in order to identify the areas with the highest impact.

Materials and Methods

Study area

The State of *Morelos* is located between the parallels 18°20´ and 19°07´ N and the meridians 98°37´ and 99°30´ W (Figure 1). It has a surface of 4 889 m^2 and at the altitude ranges from 700 to over 5 000 m. The climate varies from warm subhumid to semi-cold (García, 1988). The State of *Morelos* contributes a total of 3 661 plant species, which renders it the sixth state with the greatest species richness, after *Veracruz*, *Michoacán*, *Chiapas*, *Puebla* and *Oaxaca* (Programa de Ordenamiento Ecológico Regional del Estado de Morelos, 2013).

Ubicación de Morelos en México = Location of *Morelos* in Mexico.

Figure 1. Location of the study area in the Mexican Republic.

Morelos has a significant amount of forests and rainforests that are increasingly endangered. In Mexico, the vegetation-type most affected by agricultural activities are the temperate forests and the low deciduous forests (Challenger, 1998; Cervantes *et al.*, 2001); corn is the most widespread crop (Challenger, 1998).

The State of *Morelos* has 1 903 811 inhabitants, who amount to 1.6 % of the overall Mexican population; 84 % of the population is urban, and the remaining 16% is rural. 2.71 % of the economic activities correspond to the primary sector; 31.5 %, to the secondary sector, and 65.71 % to the tertiary sector (INEGI, 2015).

Collection of land-use data and land-cover maps

The LANDSAT satellite data sets with low cloudiness percentages (geocoded with UTM and spheroid projection, and WGS 1984 data, 14 Northern Area) with a 30 m spatial resolution for two different years (February 2000 and 2009) were downloaded from the USGS Earth Explorer website (http: // earthexplorer.usgs.gov/). Images of the years 2000 and 2009 were used because they exhibited the lowest percentages of cloudiness, compared to other images of the decade (2000-2010).

Remote sensing data sets (aerial or satellite images) are often be used to determine land-use through observations of the land-cover (Brown *et al*., 2000; Karl and Maurer, 2010). Information on land-use based on remote sensing data can be obtained through visual interpretation. However, this is limited to a single band or to a three-band color composition (RGB); likewise, the manual digitalization of land use patches is very tedious and subjective (Bolstad *et al.*, 1990). Therefore, automatic remote-sensing based classification of the land use allotment in large areas is more accurate. ArcGIS Spatial Analyst features a complete set of tools to carry out supervised and unsupervised classification processes.

Methodology

The satellite images were subjected to pre-processing algorithms and standard processing in order to correct geometric, atmospheric and topographic errors. The raw reflectance spectral data registered in the various bands that make up the images, as well as the combinations of different bands (spectral vegetation indices), were drawn from the images and spatially connected with the data of the available biophysical variables (figures 2 and 3).

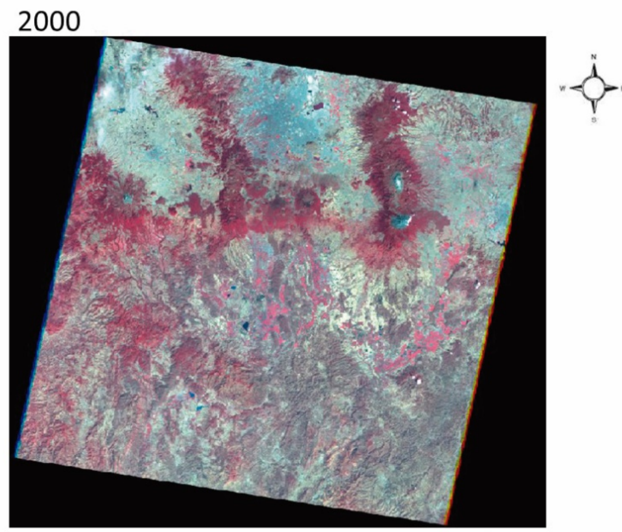


Figure 2. View in the year 2000.

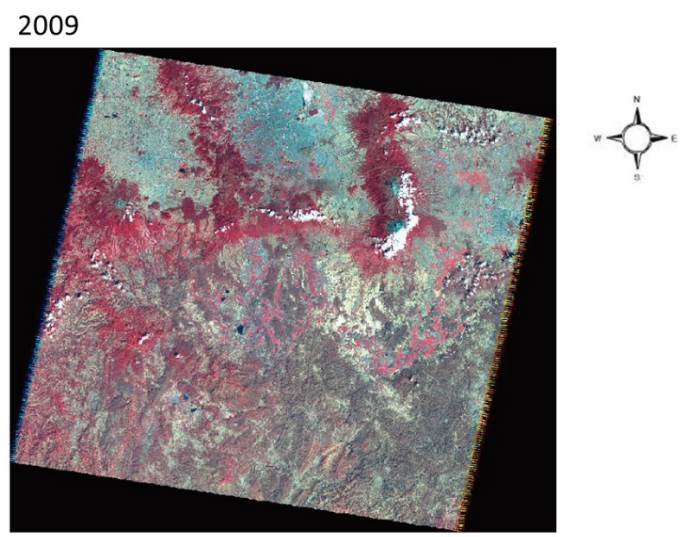


Figure 3 View in the year 2009.

Sections corresponding to the administrative boundaries of the State of *Morelos* were obtained for subsequent comparison (figures 4 and 5).

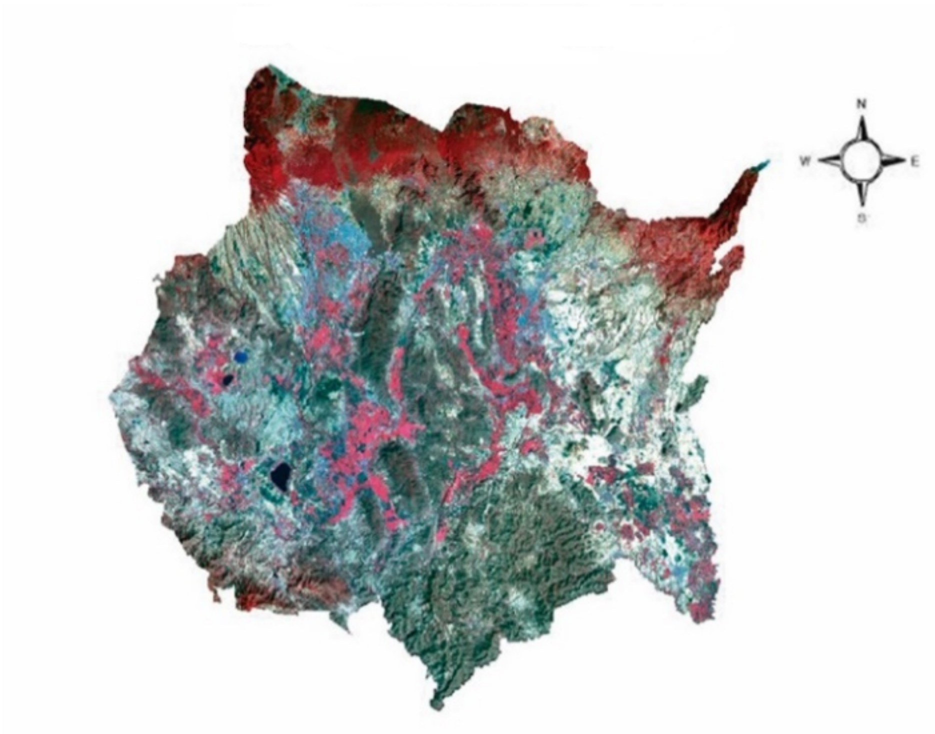


Figure 4. View of 2000 section with administrative boundaries of the State of *Morelos*.

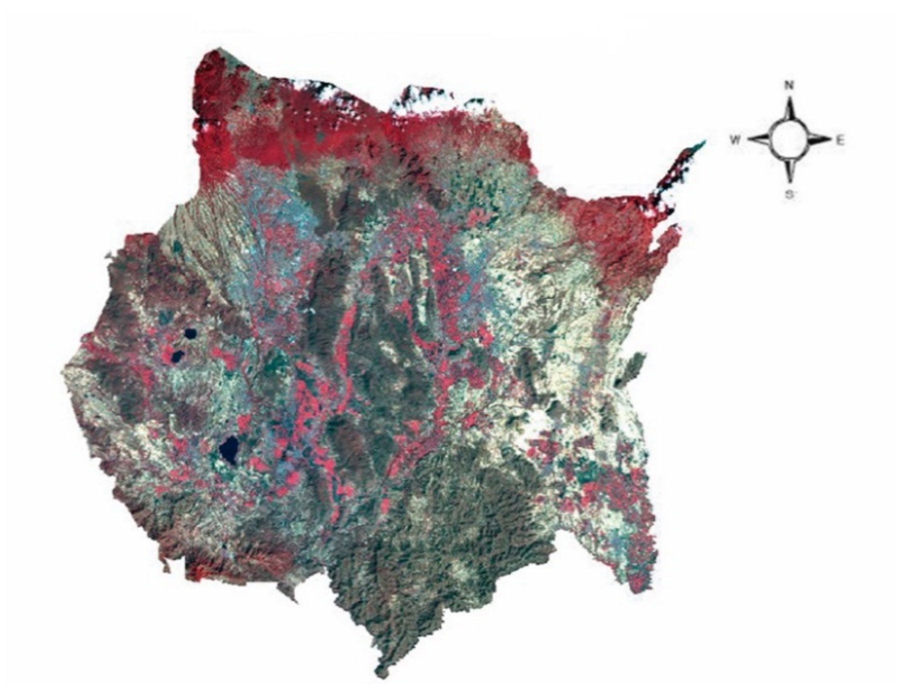


Figure 5. View of 2009 section with administrative boundaries of the State of *Morelos*.

Fourteen distinct classes of vegetation cover and land-use were identified (Trejo and Hernández, 1996):

1) Temperate forests including mixed conifer associations (PF) of *Pinus* spp. and *Abies* spp.
2) Oak forests, communities made up of *Quercus* spp.
3) Low deciduous forests formed by communities of *Bursera* spp. and *Conzattia multiflora* (B.L. Rob.) Standl.
4) Degraded forests grouping oak and conifer forests.
5) Rosetophile scrub species combined with *Brahea dulcis* (Kunth) Mart., *Dodonaea viscosa* (L.) Jacq.
6) Mesophilic forest: grows at an altitude of 1 800 to 1 950 m; the observed tree species were: *Ardisia compressa* Kunth, *Eugenia crenularis* Lundell, *Garrya longifolia* Rose, *Guarea glabra* Vahl, *Meliosma dentata* (Liebm.) Urban, *Myrsine juergensenii* (Mez) Ricketson & Pipoly and *Fraxinus uhdei* (Wenz.) Lingelsh.
7) Irrigated agriculture of sugar cane, rice and flower crops.
8) Rain-fed agriculture: subsistence agriculture, mainly corn, beans, squash.
9) Areas without apparent vegetation: areas devoid of vegetal cover.
10) Urban areas or urban cover: human settlements.
11) Riparian vegetation dominated by willows (*Salix humboldtiana* Willd. *y Salix bonplandiana* Kunth) and amate trees (*Ficus cotinifolia* Kunth).
12) Natural pastures: areas covered with grass or with herbaceous vegetation for grazing.
13) Secondary vegetation.
14) Water bodies: lakes, rivers, dams. Not included in the analysis.

A first map with an unsupervised classification was generated (Richards, 1986) using *Arcgis*10, from an iso-cluster algorithm of the 2009 image, which served as a basis for the in-field identification of vegetation types and their corresponding land-use. A 500 × 500 grid was superimposed, each line corresponding with UTM coordinates. The field work was carried out during the months of February and March; 93 sites were sampled in order to cover all the land-use categories. Each training site was outlined in the images with polygons encompassing multiple pixels (Tran *et al.*, 2015).

Based on the information gathered in field, the images were reclassified using the maximum likelihood algorithm in Arcgis10. Once the maps of the classified images were obtained, a confusion matrix was built for each map (2000 and 2009) in order to assess the accuracy of the grouping and the fidelity with which the classification represents the in-field observations. Once the confusion matrices were developed, the overall accuracy and the Kappa indices of both images were evaluated.

The image classification process consists in allocating the pixels of a reticulated image to predetermined land-cover classes. The basic approach to image classification is through visual interpretation, taking into account the hue, texture, size, shape and association (Lillesand *et al.,* 2004; Serra *et al*., 2008; Qasim *et al*., 2011).

For the present study, the supervised classification utilized a maximum likelihood classification (MLC), which was selected because it has the capacity to incorporate the statistics of the training samples before allocating the land-cover to each pixel. The MLC is a parametric classifier that assumes a normal distribution of the data of the individual classes. It assesses the variance and the covariance of the spectral response patterns when classifying an unknown pixel (Nguyen *et al.*, 2012). The MCL requires sufficient training spectral data samples for each class in order to accurately assess the statistics required by the classification algorithm. The supervised classification was carried out using the spectral signature files for the 13 classes.

Accuracy assessment

The accuracy of a classification process refers to the degree of agreement between the classes of the image and a reference data set (Congalton and Green, 1999). In order to make a quantitative assessment, a diffuse error matrix, —i.e. a quadratic arrangement of numbers ordered in columns and rows— was constructed (Congalton and Green, 2009; Lunetta and Lyon, 2004). The columns correspond to the reference set, and the rows are the classes generated in the course of classification process. The error matrix was constructed based on the results of the classification, and the reference data were those taken from the in-field sampling.

In addition, the total accuracy of a classification can be assessed through a Kappa agreement index (K), a discrete multivariate technique that statistically determines whether or not an error matrix is significantly different from another. It is a measure of correspondence between the classification and reference data set, in relation to the accuracy of a randomly generated classification (Congalton and Green 1999; Richards and Jia 1999; Congalton, 2004).

Change analysis

A change analysis of the "post-classification" type was performed (Chuvieco, 2000). Also, a change matrix was generated indicating the dynamics of the land-use and the vegetation cover change in the analyzed period. Furthermore, the deforestation rate was estimated for the period of interest through a variation in the formula cited by Palacio-Prieto *et al.* (2004):

$$DR = \left(\left(\left(\frac{S2}{S1}\right)^{\frac{1}{n}}\right) - 1\right) * 100$$

Where:

DR = Annual deforestation rate expressed as a percentage

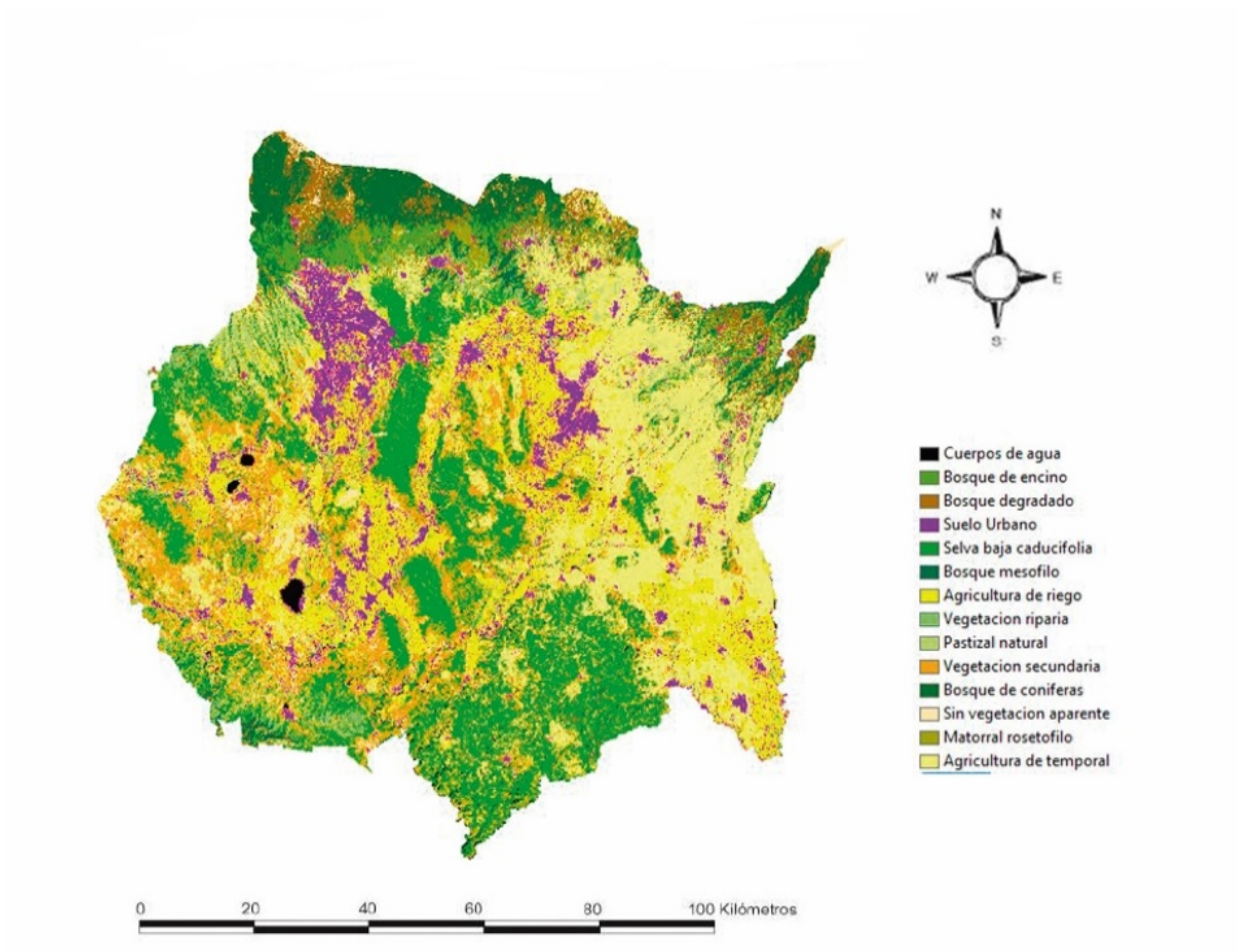
S2 = Forested area in the final year

S1 = Forested area in the initial year

n = Number of years of the analysis period

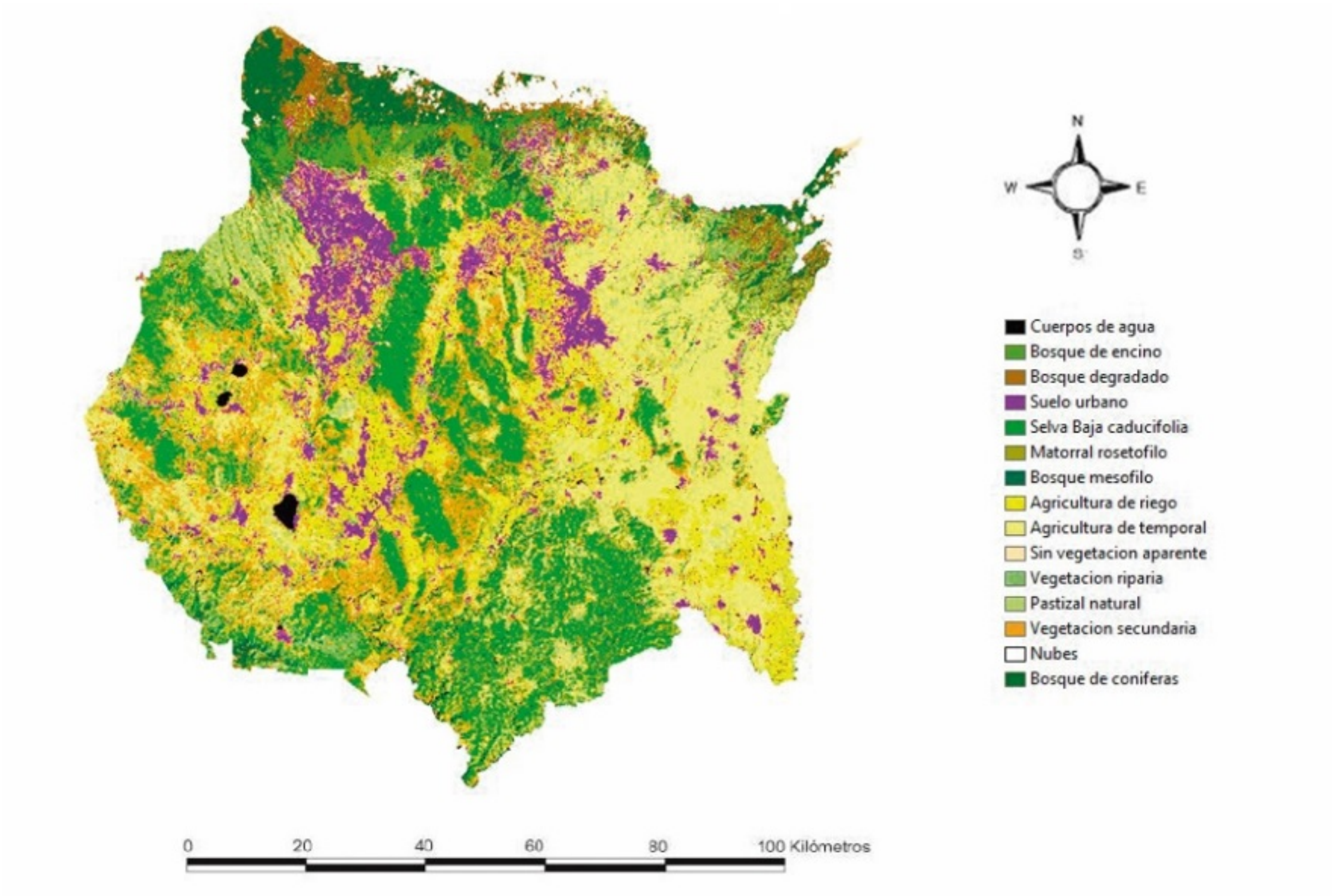
Results

The classified images obtained after the pre-processing and the supervised classification show the land-use and the land-cover in *Morelos* (figures 6 and 7). The 2000 and 2009 images represent 14 classes according to the presence of clouds in the northern area of the state. The work by Trejo and Hernández (1996) was used as a supporting criterion for defining the land use categories.



Cuerpos de agua = Water bodies; *Bosque de encino* = Oak forest; *Bosque degradado* = Degraded forests; *Suelo urbano* = Urban soil; *Selva baja caducifolia* = Low deciduos forest; *Bosque mesófilo* = Mesophilic forest; *Agricultura de riego* = Irrigated agriculture; *Vegetación riparia* = Riparian vegetation; *Pastizal natural* = Natural pastures; *Vegetación secundaria* = Secondary vegetation; *Bosque de coníferas* = Conifer forest; *Sin vegetación aparente* = Without apparent vegetation; *Matorral rosetófilo* = Rosetophile scrub; *Agricultura de temporal* = Rain-fed agricultura.

Figure 6. Map of land-use categories in the State of *Morelos* in 2000.



Cuerpos de agua = Water bodies*; Bosque de encino* = Oak forest*; Bosque degradado* = Degraded forests*; Suelo urbano* = Urban soil*; Selva baja caducifolia* = Low deciduos forest*; Matorral rosetófilo* = Rosetophile scrub*; Bosque mesófilo* = Mesophilic forest*; Agricultura de riego* = Irrigated agriculture*; Agricultura de temporal* = Rain-fed agricultura; *Vegetación riparia* = Riparian vegetation*; Pastizal natural* = Natural pastures*; Vegetación secundaria* = Secondary vegetation*; Nubes* = Clouds; *Bosque de coníferas* = Conifer forest

Figure 7. Map of land-use categories in the State of *Morelos* in 2009.

In order to validate the maps, all the classifications were assessed. There was a global accuracy of 83.5 % for the year 2000, and of 75 % for 2009. The Kappa indices (Table 1) were 0.80 and 0.71 for the 2000 and 2009 classifications, respectively. According to Viera and Garret (2005), a Kappa index with values ranging between 0.70 and 0.81 indicates an acceptable accuracy; hence, the generated maps approach come close to the actual conditions.

Table1. Validation of the classifications in the 2000 and 2009 maps.

Classifications	Validation	
	G	K
2000	0.83	0.80
2009	0.75	0.71

In the year 2000, the most problematic classes, with a users' accuracy ranging from 41.8 % to 81.7 %, were the rosetophile scrub, the mesophilic forests, the riparian vegetation, the natural pastures, the secondary vegetation and the degraded forests (Table 2). The rosetophile scrub and secondary vegetation were the categories with the largest number of omission errors and the highest error rates. The rosetophile scrub was mistaken for secondary vegetation and degraded forests; whereas the secondary vegetation was also mistaken for degraded forests (Table 2).

Table 2. Producer (PROD) and user (USER) values with assessment statistics of the accuracy of the vegetal cover and land use categories for the years 2000 and 2009.

Land Use Cat.		WB	OF	DF	LDF	RS	MF	IA	RFA	WV	US	RV	NP	SV	CF
2000	PROD	92.2	89.2	59.3	99.3	38.9	51.2	99.9	95.3	89.0	98.7	55.6	53.4	43.6	88.1
	USER	92.7	77.3	65.1	89.6	79.0	81.7	93.7	92.8	68.4	75.1	41.8	59.5	47.5	75.1
2009	PROD	91.5	87.0	41.2	84.9	90.5	79.1	70.2	67.3	96.9	86.4	62.8	94.8	39.2	88.6
	USER	90.5	79.5	68.3	80.2	53.3	23.8	73.9	87.6	19.2	79.2	17.9	57.0	42.8	86.6

WB = Water bodies; OF = Oak forest; DF = Degradaded forest; LDF = Low deciduous forest; RS = Rosetophile scrub; MF = Mesophilic forest; IA = Irrigated agriculture; RFA = Rain-fed agriculture; WV = Without apparent vegetation;

US = Urban soil; RV = Riparian vegetation; NP = Natural pasture; SV = Secondary vegetation; CF = Conifer forest.

In the year 2009, the degraded forests, the riparian vegetation and the secondary vegetation exhibited problematic values, with the users' accuracy ranging between 17.9 % and 68.3 %. The secondary vegetation and the degraded forest had higher error rates; the secondary vegetation was mistaken for riparian vegetation and for low deciduous forests, while the degraded forests were mistaken for conifer forests. These and the secondary vegetation exhibited the largest number of omission errors (Table 2).

Table 3 shows the estimated surfaces for each vegetation cover category and each land use category in the years 2000 and 2009.

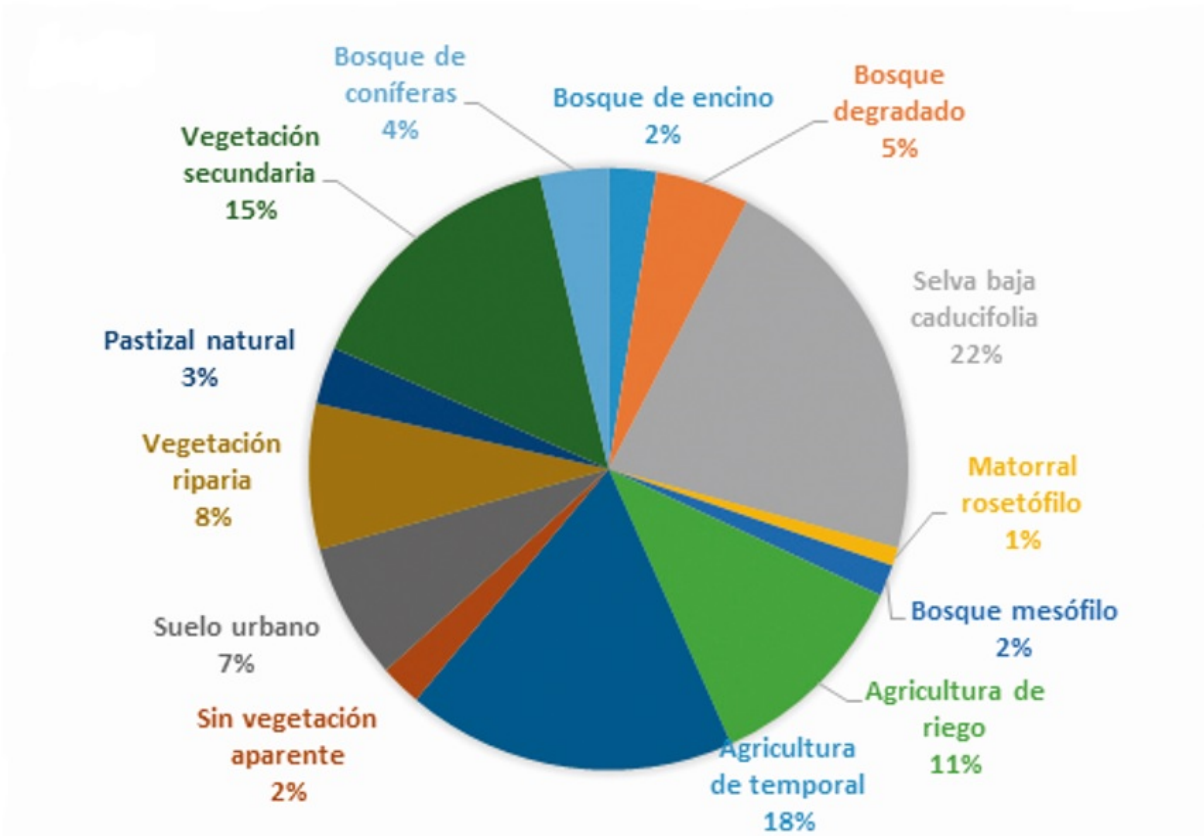
Table 3. Surface area by vegetation cover and land use class in hectares (ha).

Vegetation cover and land use	Abbrv	2000 (ha)	2009 (ha)	Average annual variation rate (ha)
Oak forest	OF	12 493.41	9 787.08	300.70
Degraded forest	DF	24 493.09	19 474.92	557.57
Low deciduous forest	LDF	104 770.11	88 193.87	1841.80
Rosetophile scrub	RS	4 698.11	9 310.52	-512.49
Mesophilic forest	MF	8 247.80	8 383.95	-15.13
Irrigated agriculture	IA	55 343.10	61 273.01	-658.88
Rain-fed agriculture	RFA	86 319.13	92 748.81	-714.41
Without apparent vegetation	WV	10 798.44	9 565.55	136.99
Urban soil	US	35 704.19	37 407.79	-189.29
Riparian vegetation	RV	37 878.68	38 128.52	-27.76
Natural pasture	NP	14 883.24	20 714.44	-647.91
Secondary vegetation	SV	71 416.01	71 390.96	2.78
Conifer forest	CF	17 922.99	12 208.46	634.95
Total		484 968.30	478 587.88	

Abbrv = Abbreviation; OF = Oak forest; DF = Degradaded forest; LDC = Low deciduous forest; RS = Rosetophile scrub; MF = Mesophilic forest; IA = Irrigated agriculture; RFA = Rain-fed agriculture; WV = Without apparent vegetation; US = Urban soil; RV = Riparian vegetation; NP = Natural pasture; SV = Secondary vegetation; CF = Conifer forest.

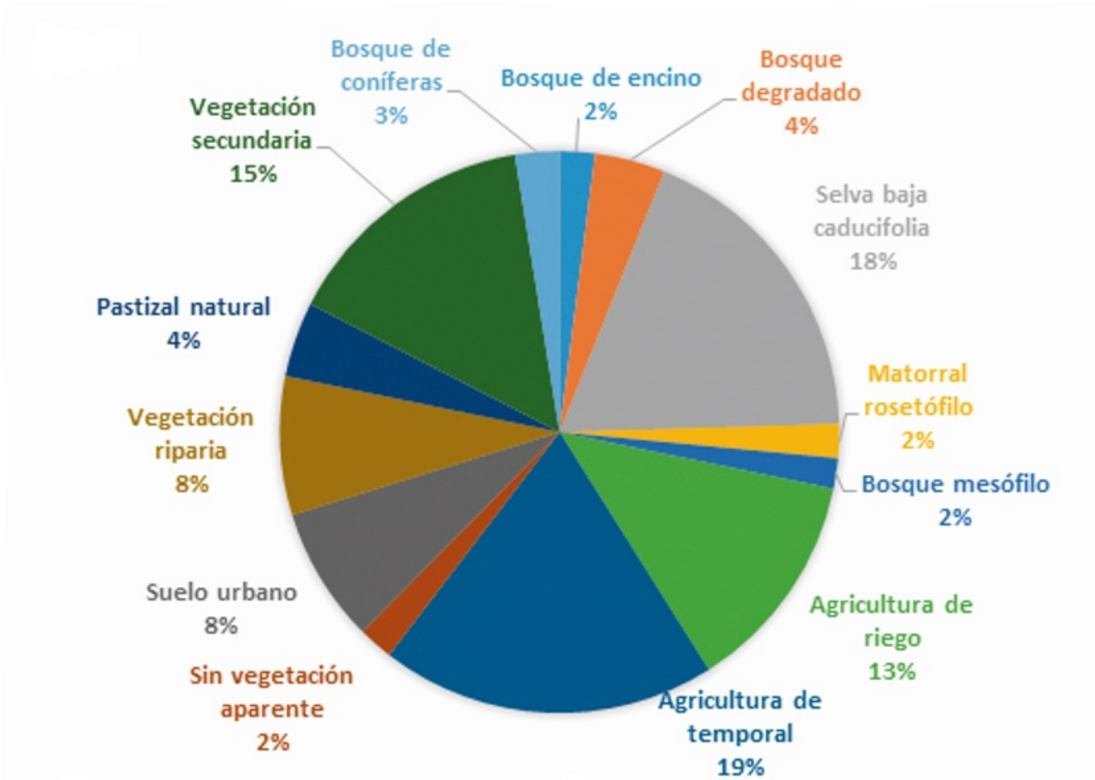
The vegetation cover that evidence a reduction in the corresponding period are the low deciduous forests with a mean annual rate of 1 841.8 ha, the degraded forest with 557.58 ha, the oak forests with 300.70 ha, and the area without apparent vegetation with 137 ha. The land uses that registered an increase are the rain-fed agriculture, with a mean annual rate of 714.41 ha, followed by the irrigation agriculture with 658.88 ha, natural pastures with 647.91 ha, rosetophile scrub with 512.49 ha, and urban land with 189.29 ha (Table 3).

In the two years, the prevalent land-use in the State of *Morelos*, in terms of the total percentage of surface area they occupy, corresponded to the low deciduous forests (figures 8 and 9), followed by the rain-fed agriculture, the secondary vegetation and irrigation agriculture; and lastly, by the riparian vegetation and urban land. The agriculture is the class of land use with the highest degree of transformation, with 28.97 % of the total for the year 2000, and 31.5 % for the year 2009.



Bosque de encino = Oak forest; *Bosque degradado* = Degradaded forest; *Selva baja caducifolia* = Low deciduous forest; *Matorral rosetófilo* = Rosetophile scrub; *Bosque mesófilo* = Mesophilic forest; *Agricultura de riego* = Irrigated agriculture; *Agricultura de temporal* = Rain-fed agriculture; *Sin vegetación aparente* = Without apparent vegetation; *Suelo urbano* = Urban soil; *Vegetación riaparia* = Riparian vegetation; *Pastizal natural* = Natural pasture; *Vegetación secundaria* = Secondary vegetation; *Bosque de coníferas* = Conifer forest.

Figure 8. Percentage of each land-use category in the State of *Morelos* in the year 2000.



Bosque de encino = Oak forest; *Bosque degradado* = Degradaded forest; *Selva baja caducifolia* = Low deciduous forest; *Matorral rosetófilo* = Rosetophile scrub; *Bosque mesófilo* = Mesophilic forest; *Agricultura de riego* = Irrigated agriculture; *Agricultura de temporal* = Rain-fed agriculture; *Sin vegetación aparente* = Without apparent vegetation; *Suelo urbano* = Urban soil; *Vegetación riaparia* = Riparian vegetation; *Pastizal natural* = Natural pasture; *Vegetación secundaria* = Secondary vegetation; *Bosque de coníferas* = Conifer forest.

Figure 9. Percentage of each land-use category in the State of *Morelos* in the year 2009.

The dynamics registered in the 2000-2009 period show that the most vulnerable vegetation class, in terms of surface area reduction, is the low deciduous forest. Furthermore, a significant change occurs in conifer forests and in degraded forests (figures 8 and 9). On the other hand, irrigation agriculture and rain-fed agriculture register an increase of 1 373 ha, as does urban land, with 189 ha.

Conclusions

In the State of *Morelos*, agricultural activities played a major role during the 2000-2009 period, when they exhibited a significant growth. This is understandable from the point of view of the economy, as it represents a short-term source of income for the population. However, its intensity has brought about a loss of natural cover (forests and rainforests) that may have an impact on the fertility and erosion of the land. On the other hand, there is an important transition from forests and rainforests to disturbed vegetation, and from this to pastures and agricultural lands, reflecting the ecological succession experienced by the natural vegetation.

The results show a significant increase in irrigation agriculture (11 % in 2000; 13 % in 2009) and in rain-fed agriculture (18 % in 2000, and 19 % in 2009) at the expense of low deciduous forests, which decreased from 22 % in 2000, to 18 % in 2009. The urban surface exhibited a significant growth. This suggests that the driving forces of the reduction of the area occupied by low deciduous forests in the state of *Morelos* are related to the economic profits generated by agricultural activities, as well as to the growth of urban areas. The results also evidence the fact that public policies in relation to the preservation and management of forests are channeled toward the north of the state (to the *Chichinautzin* mountain chain), having insufficient coverage of those regions where the low deciduous forests are prevalent.

The use and incorporation of new tools, such as the geographic information systems (GIS) and remote sensing, allow the estimation of the magnitude of the changes associated to differential processes of change of the vegetation cover and land-use, as well as accurately assessing the growth of anthropic activities at the expense of the existing natural vegetation.

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Conflict of interests

Dr. María Cecilia del Carmen Nieto de Pascual Pola, PhD, declares that she did not participate in any of the activities involved in the editorial process of the present document.

Contribution by author

Jorge Escandón Calderón: development of the research Project, structure and in-field collation of the different vegetation covers and land uses; José Antonio Benjamín Ordóñez Díaz: analysis of the results and editing of the manuscript; María Cecilia del Carmen Nieto de Pascual Pola: revision of the manuscript; María de Jesús Ordóñez Díaz: interpretation of the results and revision of the manuscript.