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Article

Dinámica de cambios de uso de suelo y vegetación por actividades antropogénicas en Zaachila, Oaxaca

Dynamics of changes in land use and vegetation due to anthropogenic activities in *Zaachila, Oaxaca*

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Resumen

La importancia de los bosques a nivel mundial es reconocida por los bienes y servicios que ofrecen. Sin embargo, los cambios en el uso de suelo y vegetación han generado modificaciones en los patrones climáticos, inundaciones, degradación de los suelos, pérdida de la biodiversidad, amenazas de las formas de vida y en la integridad cultural de la humanidad. La presente investigación tuvo como objetivo realizar un análisis de la dinámica de cambios de uso de suelo y vegetación a nivel local, con la finalidad de tener bases específicas para el buen manejo de los ecosistemas del municipio San Pablo Cuatro Venados, Zaachila, Oaxaca. Los resultados obtenidos, mostraron que de 1987 a 2020 las áreas de asentamientos humanos han ganado mayor superficie, ya que presentan una tasa positiva de 11.4 %; lo que indica un aumento de 221.6 ha, al igual que la vegetación arbórea que incrementó su superficie en 698.2 ha respecto a la superficie de 1987 (2 596.2 ha). Por otra parte, la vegetación arbustiva perdió 654 ha a favor de áreas con coberturas de pastizal, asentamientos humanos, agricultura y vegetación arbórea. Los cambios en la cobertura arbustiva revelaron un importante reemplazo de esta por zonas destinadas a diversas actividades antrópicas. En el municipio, la tasa de cambio de la cobertura arbórea evidenció un aprovechamiento racional de los recursos forestales, y las zonas con mayor deforestación se ubicaron, principalmente, en áreas cercanas a los centros de población.

Palabras clave: Aprovechamiento forestal, dinámica de cambio, firma espectral, imágenes de satélite, restauración, tasa de cambio.

Abstract

The importance of forests from the goods and services that they provide is recognized worldwide. Nevertheless, changes in land use and vegetation have led to changes in climate patterns, flooding, soil degradation biodiversity, loss and threats to livelihoods and to the cultural integrity of humankind. The objective of this research was to analyze the dynamics of changes in land use and vegetation at the local level, in order to have specific basis for the proper management of ecosystems in the *San Pablo Cuatro Venados* municipality, *Zaachila, Oaxaca*. The objective of this research was to analyze the dynamics of changes in land use and vegetation at the local level, in order to have specific basis for the proper management of ecosystems in the *San Pablo Cuatro Venados* municipality, *Zaachila, Oaxaca*. Results showed that, from 1987 to 2020, human settlements have gained more surface area, having a positive rate of 11.41 %, which means an increment of 221.6 ha; the tree vegetation also increased by 698.2 ha, compared with 1987 (2 596.2 ha). On the other hand, the shrub vegetation lost 654 ha, giving up areas to grassland, human settlements, farming, and tree vegetation covers. The changes in the shrub cover revealed an important replacement of this type of vegetation with areas oriented to anthropic activities. The rate of tree cover change shows rational use of forest resources in the municipality, although the areas with the highest deforestation levels were located mainly close to population centers.

Keywords: Forest use, dynamics of change, spectral signature, satellite images, restoration, rate of change.

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Introduction

Soil is one of the most important natural resources on which the existence of flora and fauna depends, in addition to sustaining some economic development activities for humanity (Segura-Castruita, 2014). In several regions of the world, soil resources have been seriously affected by changes in vegetation cover and land use from anthropogenic activities (Józefowska *et al*., 2020).

The analysis of land use and land cover change allows to infer the effects that these transformations have on ecosystem services, such as groundwater recharge, carbon sequestration, biogeochemical cycles, biodiversity, among others (Ramos-Reyes *et al*., 2016, Franco-Navarro y Godínez-Vidal, 2017). For this reason, they are considered a priority in environmental research for understanding the course of the deterioration of natural resources.

Currently, there is still a lack of studies in Mexico that provide spatial and temporal information that accurately quantifies changes in land cover, land use and deforestation (Mas *et al*., 2017). Despite this, there are some that provide relevant information to understand the dynamics of vegetation cover change, for example: deforestation and its causal factors in the state of *Sinaloa*, Mexico (Monjardín-Armenta *et al*., 2017); land cover and land use change from 2000 to 2009 in the state of *Morelos*, Mexico (Escandón *et al.*, 2018); changes in land cover, land uses, and future scenarios in the coastal region of the state of *Oaxaca*, Mexico (Leija-Loredo *et al*., 2016); the advance of deforestation in Mexico 1976-2007 (Rosete-Vergés *et al.*, 2014), and the analysis of land use changes in the coastal *Comalcalco* municipality, state of *Tabasco*, Mexico (Ramos-Reyes *et al*., 2016), among others.

Bonilla-Moheno *et al.* (2012) point out that local-level investigations of land cover and land use change provide timely information on the main drivers of these modifications; and incorporating into the analysis details of the productive activities in the family environment, as well as in the historical and social context.

The objective of this research was to analyze the dynamics of changes in land use and vegetation at the local level, in order to have specific basis for the proper management of ecosystems in the *San Pablo Cuatro Venados* municipality, *Zaachila, Oaxaca*. Currently, this municipality lacks information offering a perspective on the current state of its forests.

Materials and Methods

Study area

San Pablo Cuatro Venados has an area of 6 086.3 hectares and belongs to the *Zaachila* district in the Central Valleys region of the state of *Oaxaca*. Its geographical position is 16°57' N and 96°56' W; it borders the municipalities of *San Pedro Ixtlahuaca* (to the north), *Cuilapam de Guerrero* (to the east), *Santiago Tlazoyaltepec* (to the west), *Jalapa del Valle* (to the northwest), and *San Miguel Peras* and *Santiago Clavellinas* (to the southwest) (Figure 1).

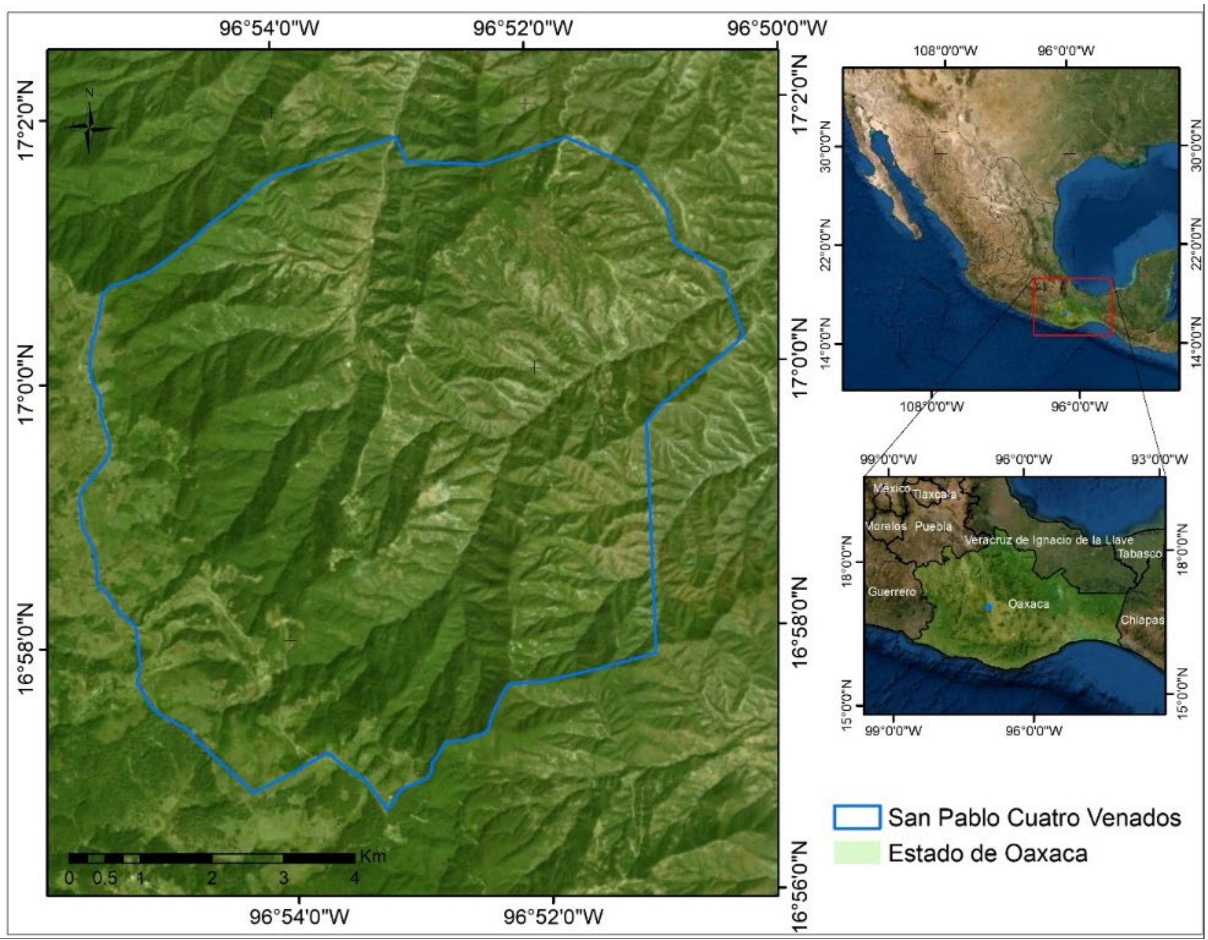

Figure 1. Geographical location of *San Pablo Cuatro Venados* municipality, *Zaachila, Oaxaca*.

As of 2015, the population of the municipality was 1 411 inhabitants (INEGI, 2015). It is located between 1 700 and 2 800 masl. The predominant climate is temperate sub-humid, corresponding to type C(w_1), with an average annual rainfall of 700 to 1 200 mm and an average annual temperature of 17 °C. The predominant soil types are Regosol (47.60 %), Luvisol (21.76 %), Acrisol (19.61 %), and Cambisol (11.03 %) (INEGI, 2005). These characteristics are related to the type of existing vegetation: pine-oak forest (García-Mendoza *et al*., 2004).

Satellite image pre-processing

Landsat 5 TM satellite images were used for 1987 and 2008, and Landsat 8 OLI for 2020 —all corresponding to the month of May—, with a spatial resolution of 30 meters. Images with low percentage of cloud cover and L1T processing levels (geometric and topographic correction) were selected. Landsat 5 images are composed of seven bands: bands 1-3 correspond to the visible spectral range; bands 4, 5 and 7, to infrared; and band 6, to thermal infrared (Fernández-Coppel and Herrero, 2001). Landsat 8 shows 11 bands: bands 1-4 correspond to the visible range; bands 5-7, to infrared; band 8, to the panchromatic range; band 9, to cirrus, and bands 10 and 11, to thermal infrared (Ariza, 2013). The images were obtained free of charge from the https://earthexplorer.usgs.gov/ platform.

They were homogenized by means of an atmospheric correction process carried out with the IDRISI Selva® software, through the ATMOSC module, using the Cost(t) model, which is an improved dark object subtraction model (DOS) (Eastman, 2003). This method allows the elimination of haze and the transformation of Digital Levels (DL) into real values of spectral reflectance of the terrain.

Field reconnaissance for defining land and vegetation uses

With the 2020 satellite image, a visual recognition of the types of land use and vegetation in the study area was carried out; subsequently, a supervised classification was carried out in order to obtain a base map of the area. The vegetation cover was delimited according to the classification of life forms described by Miranda and Hernández (1963), and the classes defined in the INEGI's land use and vegetation cartography series 6 were considered. Six categories were defined: arboreal vegetation (AV), shrub vegetation (SV), grassland (GL), agricultural land (AL), bare soil or without apparent vegetation (BS), and human settlements (HS).

Land use and vegetation were verified by applying stratified random sampling: this method guarantees the sampling of the same number of points per class, without considering the occupied surface (Chuvieco, 1995; Lesschen *et al*., 2005). Based on the above, 120 sites were selected for the study area.

The number of vegetation categories and land uses checked against those observed in the satellite images in a field trip in which the 120 selected sites were compared and the uses that the inhabitants of the municipality give to the vegetation were documented. From these, nine representative sites were chosen for the different categories of use; the central coordinate and the main characteristics of the vegetation covers —such as composition, structure and percentage of tree cover— were recorded and used as a basis for defining the spectral signatures of the different covers present in the terrain (Eastman, 2003).

Image classification method

Land use and vegetation maps were obtained through the supervised classification method, by generating a gallery of spectral signatures with ENVI 5.3™ software. The process involved three stages: first, it was necessary to identify, for each date, the useful bands that highlight vegetation characteristics and soil properties. Bands one through five and band seven were utilized for the years 1987 and 2008, while bands two through seven were selected for 2020. The spectral range of these bands allows to differentiate, mainly, moisture conditions, soil minerals, and vegetation states (Manrique, 1999; Rodríguez-Moreno and Bullock, 2013).

The previous result gave way to the second stage of the supervised classification process, which consisted of creating a gallery of spectral signatures according to the types of covers identified in the field. In the last stage, the supervised classification was performed using the Spectral Angle Mapper algorithm that determines the similarity between two spectra, by calculating the angle between the two signatures, treating them as vectors in a space with dimensionality equal to the number of bands.

Each cover will be allocated according to the similarity of the reflectance values in the spectral intervals of the utilized bands (Eastman, 2003).

The assessment of the classification accuracy was based on the overall accuracy and on the *Kappa* coefficient calculated with the ENVI 5.3 software. For this purpose, the reference was the coordinates and types of covers of the sites validated in the field, which were complemented with a random sample of 10 % of the pixels classified for each category (Chuvieco, 1995; Lesschen *et al*., 2005).

Dynamics and rate of land use and vegetation change

The dynamics of change were determined with the land use and vegetation maps for 1987, 2008 and 2020, using the Land Change Modeler for Ecological Sustainability module of the IDRISI Selva® software. The analysis was carried out in order to observe the dynamics of change in two periods from 1987 to 2008 and from 2008 to 2020, for an overall analysis period of 33 years.

The rate of change was obtained using the equation proposed by FAO (1995):

$$q = \left[(A2/A1)^{(1/n)} - 1\right] * 100$$

Where:

q = Rate of change (%)

A1 = Area occupied by vegetation on date 1/use *i* in the starting year

A2 = Area occupied by vegetation on date 2/use *i* in the most recent year

n = Number of years in the analysis period

Results and Discussion

Land use and vegetation map

The field survey confirmed six categories of land use and vegetation: arboreal vegetation (AV), consisting of pine-oak vegetation; shrub vegetation (SV), consisting of secondary shrub vegetation of pine-oak forest, and shrub vegetation (SV2), consisting of secondary shrub vegetation of pine-oak forest; grassland areas (GL), which also includes herbaceous vegetation to a lesser extent; agricultural land (AL), bare soil or without apparent vegetation (BS), and human settlements (HS).

The accuracy indicators derived from the classification are considered acceptable, as an overall accuracy of 91 %, 89 % and 86 %, was obtained for 2020, 2008 and 1987, respectively; while the *Kappa* coefficient index for 2020 was 0.90, 0.86 for 2008, and 0.84 for 1987. According to Mas *et al.* (2003) and Lesschen *et al*. (2005), the overall accuracy and *Kappa* coefficient value obtained at the three dates are reliable for post-classification studies, such as land use change modeling and deforestation projection, among others.

The land use and vegetation map for 1987 showed arboreal vegetation homogeneously distributed in the central and northern part of the municipality; by 2008, this vegetation was consolidated, occupying a larger area (4 163.1 ha), and by 2020, it lost area and became more concentrated in the western and northern part of the municipality. The persistence of arboreal and shrub vegetation in these areas is mainly due to the topography of the terrain, as they are sites with altitudes of 2 000 to 2 600 m and a slope of more than 40 %. Tenants perceive these areas as inaccessible slopes; in addition, these places retain more humidity, which favors the growth of the shoots (Figure 2).

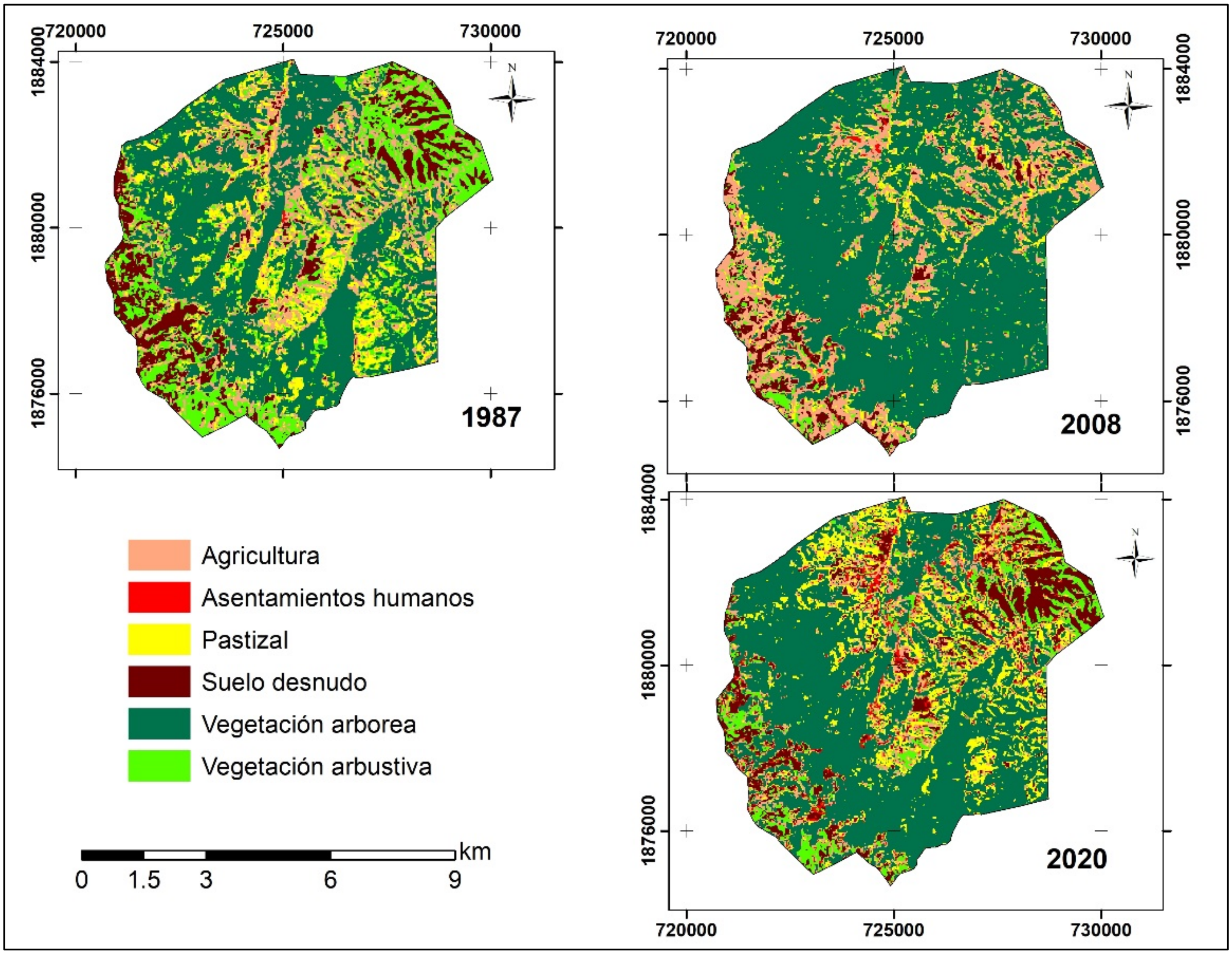

Figure 2. 1987, 2008 and 2020 land use and vegetation map of *San Pablo Cuatro Venados* municipality, *Zaachila, Oaxaca*.

The results are consistent with those cited by Bonilla-Moheno *et al.* (2012), who point out that altitude is one of the main variables explaining deforestation and that there is a negative relationship between the two variables: the higher the altitude, the lower the deforestation.

For 1987, the category with the largest area was arboreal vegetation, with 2 596.2 ha (Table 1), which represented 42.66 % of the total area; and the one that covered the least area was the category of human settlements, with 6.5 ha.

Table 1. Area and rate of change for the 1987-2008, 2008-2020 and 1987-2020 periods.

Land Use and Vegetation Covers	Surface area (ha)			Rate of change (%)[1]		
	1987	2008	2020	1987-2008	2008-2020	1987-2020
Agricultural	924.5	990.1	545.7	0.3	-4.8	-1.6
Human settlements	6.5	29.4	228.1	7.5	18.6	11.4
Grassland	713.2	396.6	888.3	-2.8	7.0	0.7
Bare soil	735.5	290.4	673.4	-4.3	7.3	-0.3
Arboreal vegetation	2 596.2	4 163.1	3 294.4	2.3	-1.9	0.7
Shrub vegetation	1 110.4	216.7	456.4	-7.5	6.4	-2.7

[1]Positive values indicate surface area gain and negative values loss.

As in 1987, in 2008, tree vegetation was the largest area, with an increase of 1 566.8 ha compared to the first date; the second largest cover was agriculture, with 16.3 % (990.1 ha). By 2020, arboreal vegetation decreased considerably in relation to the 2008 area, since only 3 294.4 ha were conserved, while the human settlements category gained the largest area, from 29.4 ha to 228.1 ha.

These results are mainly due to sociodemographic factors. In the 1980s and early 1990s there was a process of emigration of the local population to some of the cities (Mexico City, *Oaxaca*); other states, such as the State of Mexico and *Puebla*, as well as abroad (Conapo, 2014), which led to the abandonment of agricultural and pasture lands. However, by the middle of the year 2000, the urban area and the number of inhabitants began to increase, as the number of emigrants decreased and people —even entire families— who had emigrated began to return: a phenomenon that triggered the opening of land for human settlements and grazing. Velázquez *et al.* (2010) document similar results; they point out that emigration leads to the abandonment and recovery of cultivation and grazing areas. For their part, Torres-Rojo *et al.* (2016) indicate that the presence of a larger number of individuals not originating from a geographic unit causes the change of forest use to other uses.

Analysis of the dynamics and rate of change

The dynamics and rate of change (Figure 3 and Table 1) showed that from 1987 to 2008, arboreal vegetation gained area, with a positive rate of 2.3 %; the land covers that ceded territory to it were: grassland (550 ha), shrub vegetation (474 ha) and agricultural areas (467 ha). This is attributed to the migration of peasants to the cities and to the fact that, historically, there have been conflicts over land ownership. The delimitation of the area that corresponds to the municipality was established recently, a situation that led to the restriction of access to the conflict zones, which led to the abandonment of these areas.

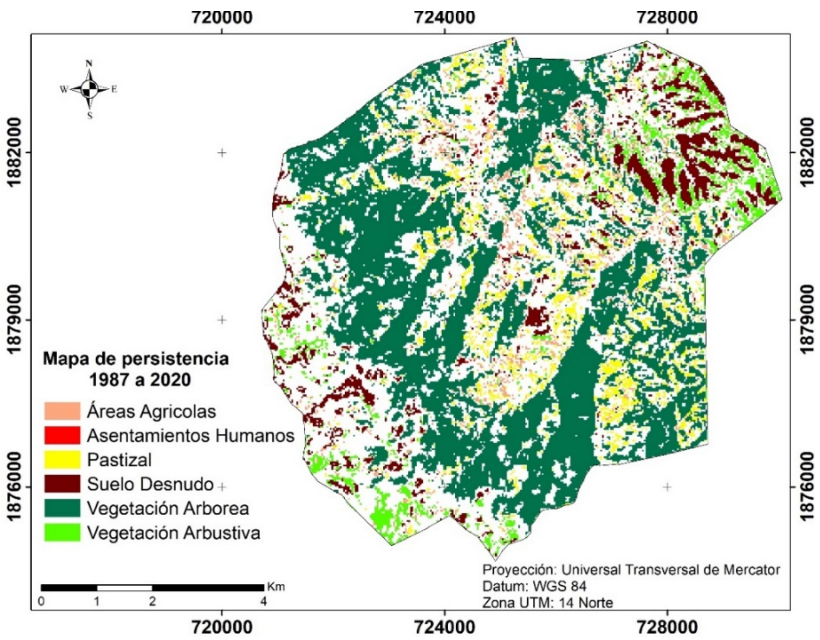

Figure 3. Land use and vegetation land cover persistence map for the 1987-2020 period.

During the second period (2008 to 2020), arboreal vegetation was strongly affected, its rate was negative (-1.9 %); it lost cover to grassland (584 ha), and to shrub vegetation (97 ha); bare soil gained 76 ha; agriculture, 68 ha, and human settlements, 32 ha. Likewise, in this period, the human settlements category had the highest growth rate, of 18.6 %.

In the last 33 years (1987-2020), the municipality of *San Pablo Cuatro Venados* has exhibited strong transformations due to anthropic activities; thus, its rate of change, of 11.4 %, showed that the area occupied by human settlements has increased. Shrub vegetation was the most affected, exhibiting a rate of -2.7 %; although arboreal vegetation showed a positive rate of 0.7 %, in the last 12 years there has been considerable deforestation, and the areas surrounding human settlements were the most affected.

The above results can be explained by the following factors:

1) Population increase: in the analysis conducted by Conapo (2016) it was indicated that from 1990 to 1995 the population increased by 54 people, from 1995 to 2005 it decreased by 67 individuals, and for the 2005-2015 period, the number of inhabitants increased by 144 people; this condition forced the opening of land for agricultural, livestock and housing use.
2) Poverty and degree of marginalization: the state of *Oaxaca* ranks first in the country in terms of social backwardness (Coneval, 2015). In the period from 1990 to 2010, Conapo (2016) placed the municipality with a very high degree of marginalization; by 2015, it moved to a high degree of marginalization. The population's dependence on forest resources for subsistence is significant. In this regard, Ellis *et al.* (2016) suggest that the main cause of deforestation in *San Pablo Cuatro Venados, Zaachila, Oaxaca* is the use of firewood for self-consumption; this explains that the main losses of arboreal and shrub vegetation occurred in the vicinity of human settlements. Within this context, Ochoa-Gaona and González-Espinosa (2000) point out that the disturbance of

forests by selective extraction for firewood or charcoal intensifies the transition to crop or livestock areas.

3) Proximity to human settlements: for communities located in or near forests, these represent an important source of employment, income and subsistence (Chapela, 2012; Osorio *et al*., 2015). In the present study, it was observed that the population of the municipality of *San Pablo Cuatro Venados* is highly dependent on various forest resources, among them: the use of firewood, timber for construction, medicinal and ornamental plants, and edible mushrooms.
4) Forest fires: based on what was expressed by the inhabitants of the municipality, recurrent forest fires have occurred in the study area, affecting mainly the areas of secondary pine-oak vegetation. In this regard, Manson *et al.* (2009) report that recurrent anthropogenic fires consume young trees and prevent regeneration, the trees being replaced by grasses, pastures, and bushes.

Since *ejidos* and communities own 80 % of the temperate and tropical forests in the state of *Oaxaca*, the promotion of management systems that allow for the sustainable use of forest ecosystems that recognize local communities as dependent on natural resources is a priority (Ellis *et al*., 2016).

Finally, as a result of the study documented herein, it is evident that the northeastern part of the municipality is degraded; therefore, it is necessary to characterize its soils in order to identify the present problems and propose conservation and restoration actions in the most affected sites.

Conclusions

Results show that human settlements have increased rapidly over the last 12 years. Despite a positive rate of change for tree vegetation (0.7 %) in the 33-year period analyzed, it is evident that arboreal and shrub vegetation have been under strong pressure from the use that inhabitants have made of it in the 2008-2020 period. This suggests the need to develop a forest management program for timber and non-timber species that will allow a sustainable use of forest resources in *San Pablo Cuatro Venados* municipality, *Zaachila, Oaxaca*.

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Conflict of interests

The authors declare no conflicts of interest.

Contribution by author

María Jesús Hernández Pérez: methodology definition, satellite image processing, and drafting of the manuscript; Elizabeth Hernández Acosta: methodology definition, data analysis, and drafting of the manuscript; Rosa Sánchez Jiménez: field verification and drafting of the manuscript; Catalina González Gervacio: review and editing of the manuscript; Susana Madrigal Reyes: review and editing of the manuscript.

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