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Territorial transformations due to changes in land occupation in San Miguel Coatlinchán, Texcoco

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Abstract

San Miguel Coatlinchán is a locality with rural and urban characteristics that contrast today; within its internal structure, primary activities, social and cultural organization, ecclesiastical traditions, customs and traditions, etc., stand out, along with values that have transcended across family nuclei. In recent years, urban growth has mainly transformed the territory, altering natural processes primarily through changes in land occupation. This research aimed to analyze changes in land occupation in a space-time period from 1999 to 2023 using geographic information system tools. The results of this research enabled the integration of spatial information, producing a dynamic map of land-use transition that enables the identification of the degree of urban growth and the estimation of the most affected areas, namely the rainfed agriculture and bare land classes.

Keywords:

geographic information systems, land occupation, territorial transformations.



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Introduction

San Miguel Coatlinchán is a town located south of the municipality of Texcoco in the State of Mexico, adjacent to the old Lake Texcoco, on the extinct Arrieros Road. It has a rich and historical cultural past in its composition and territorial structure. Its main communication routes are the Mexico-Texcoco highway and the State of Mexico Outer Loop.

Since the mid-twentieth century, the population of San Miguel Coatlinchán has increased significantly, making it the second most populous locality in the municipality of Texcoco (INEGI, 2020); this phenomenon has been one of the factors present in the localities of the municipality of Texcoco.

The dynamics of changes in land occupation are mainly linked to the expansion of urban sprawl and high-impact irregular forms, such as real estate developments, shopping centers, and mainly human settlements; this type of pattern has occurred in recent years in all areas adjacent to developing cities (Cruz *et al*., 2002; Toscana, 2018; Humacata, 2020; Salado, 2022).

There are different factors that influence land-occupation changes, such as economic, sociocultural and demographic factors, which together cause environmental deterioration and loss of biological diversity; this occurs not only at the local level but also regionally and globally (Bocco, 2001; Challenger and Dirzo, 2009; Rivera *et al*., 2021).

For the National Geographic Institute (IGN, 2023), land occupation must study the characteristics of the land surface from two different, albeit related, points of view: 1) land cover (LC) or categorization of the land surface into units based on their biophysical properties, such as urban areas, crops, forest trees; and 2) land use (LU) or characterization of the territory according to its functional dimension or current socioeconomic purpose, such as industrial, commercial or recreational use, etc.

The town of San Miguel Coatlinchán has various land uses, such as residential, urban, economic-industrial, service, facilities, agricultural and forestry, mining, transport and infrastructure and open space.

This research aims to analyze land occupation using satellite images from 1999 to 2023 to generate a cartographic model that allows identifying aspects of land-use change and estimating affected areas (losses, gains and stable areas), with a spatial analysis scale of 1:20000, using a two-map cross-tabulation methodology known as a change matrix (Pontius *et al*., 2004; Plata *et al*., 2009).

Conducting temporal and dynamic studies is important because they provide a basis for understanding the transformations a given region undergoes, and the results will enable a diagnosis of spatial dynamics to make decisions in territorial planning (Senisterra *et al*., 2014).

Materials and methods

Cartographic method

The cartographic methodology used to analyze changes in land occupation in the town of San Miguel Coatlinchán from 1999 to 2023 included two satellite images: 1) black-and-white digital orthophotos at a scale of 1:20 000 from 1999, provided by INEGI; and 2) images from 2023 from Google Hearth Pro (Google, 2024) at a scale of 1:20 000, downloaded from the platform of the same server and subjected to georeferencing.

Georeferencing involves rectification by establishing a correspondence between the coordinates of the pixels of the image and the actual ground coordinates of the objects they represent and where it is necessary to define a coordinate system that is used for the projection system (Cascón *et al*., 2018).

A total of 100 control points were assigned in the image to reduce discrepancies between the actual coordinates, using a third-degree polynomial method and a nearest-neighbor model to adjust the mean square error to less than 0.5 (Ortega, 2025). The parameters used to construct and generate the land occupation maps were defined based on the extreme coordinates verified in the field (Table 1).

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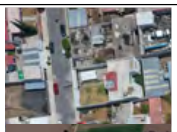
Table 1. Extreme coordinates of San Miguel Coatlinchán, Texcoco.

Geographic coordinates		UTM coordinates	
Latitude	Longitude	X	Y
19° 34' 19.94''	98° 37' 41.85''	496 000	2 143 000
19° 22' 55.87''	99° 02' 17.57''	539 020	2 164 000
Central meridian of Mexico City Projection system		99°= 500 000 WGS 84 Zona UTM 14 N.	

Selection of land occupation classes

The classes were selected based on INEGI (2017) methodology, which consists of representing elements in the images that can be identified by generating digital information. Nine classes were selected and used to identify land occupations (urban, rainfed agriculture, bare land, water bodies, runoff, irrigated agriculture, greenhouses, grassland and mines). These were identified through field visits in the study area (Table 2).

Table 2. Characterization of land occupation classes.

Type of cover	Features	Drone images
Urban	Land designated for human activities (houses, commercial establishments, infrastructure, and other uses). They include the presence of public services	
Rainfed agriculture	Areas where crops are produced and planted only during rainy periods; they lack irrigation systems	
Bare land	Soil that has little or no vegetation, is susceptible to moisture loss, and is always exposed to the effects of solar radiation	
Body of water	They are mainly used to store water during rainy seasons	
Runoff	It is the water that flows toward a river on the surface of the ground	
Rainfed agriculture	It is the area of land that receives water through various irrigation methods. This type of agriculture requires hydro-agricultural infrastructure such as pumping wells	
Greenhouse	Infrastructure that is used to maximize crop production in a controlled environment. They have been used as covers for cattle, providing a protected, controlled environment	

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Type of cover	Features	Drone images
Grassland	It is an ecosystem dominated by grasses and shrubs, sometimes accompanied by herbs from different families	
Mines	Areas intended for the extraction of materials (sand, gravel, and stone)	

Digitalization

To identify the classes, they were digitized using the photo-interpretation technique, employing the same projection system and spatial resolution in each map in QGIS (version 3.22).

The digitization was detailed by the spatial location and the description of the classes, among which the following were considered: 1) interpretation of the orthophoto and the digital image; 2) characterization of land occupation; 3) digitization of segments and lines; 4) a polygon-type vector was used as an entity because it enables the positioning of areas and surfaces; and 5) the rainfed agriculture class was generalized (urban area, ejido area and communal area).

During digitization, each polygon was assigned a specific class, identifier, name, and color, creating a relational database (Del Bosque *et al*., 2013) that allows manipulation, analysis and stratification of each variable. Each layer was corrected using overlay algorithms to avoid errors and achieve more than 95% capture certainty.

Cross-tabulation

The change in occupation was obtained by analyzing the cross-tabulation matrices for the period 1999-2023 using the IDRISI Selva program, following the methodology of Pontius *et al*. (2004), which allows comparing two pairs of maps by cross-tabulation, with the classes of map 1 represented in the rows and the classes of map 2 represented in the columns.

The cross-tabulation results were used to construct a dynamic map and the results were quantitatively calculated in an Excel table, yielding the stable, loss and gain areas (Eastman, 2012; Pineda, 2019).

Results and discussion

The change in land occupation was obtained from orthoimages from 1999 to 2023, which enabled the creation of a cartographic model to identify aspects of cover changes and main classes, resulting in the generation of updated information on land-occupation dynamics. To develop the cartographic model, two maps from different dates were obtained and constructed in two geographic information system formats (raster and vector) (Escalona *et al*., 2017).

The result of the cross-tabulation matrix -processed in IDRISI with the Crosstab function, which determines the cross-tabulation overlay- enabled the generation of a map of land-occupation changes identified in a numerical matrix that determines the changes detected in this process (Table 3).

Table 3. Land occupation 1999-2023 (ha).

Occupation	1999	2023	Losses	Gains	Stable area	Difference 1999-2023
Urban	165.7	369.1	8.6	211.6	156.9	203.4
Rainfed agriculture	1714.8	1594.5	268.6	149.0	1445.4	120.3
Bare land	112.1	143.3	48.6	79.4	63.8	31.2

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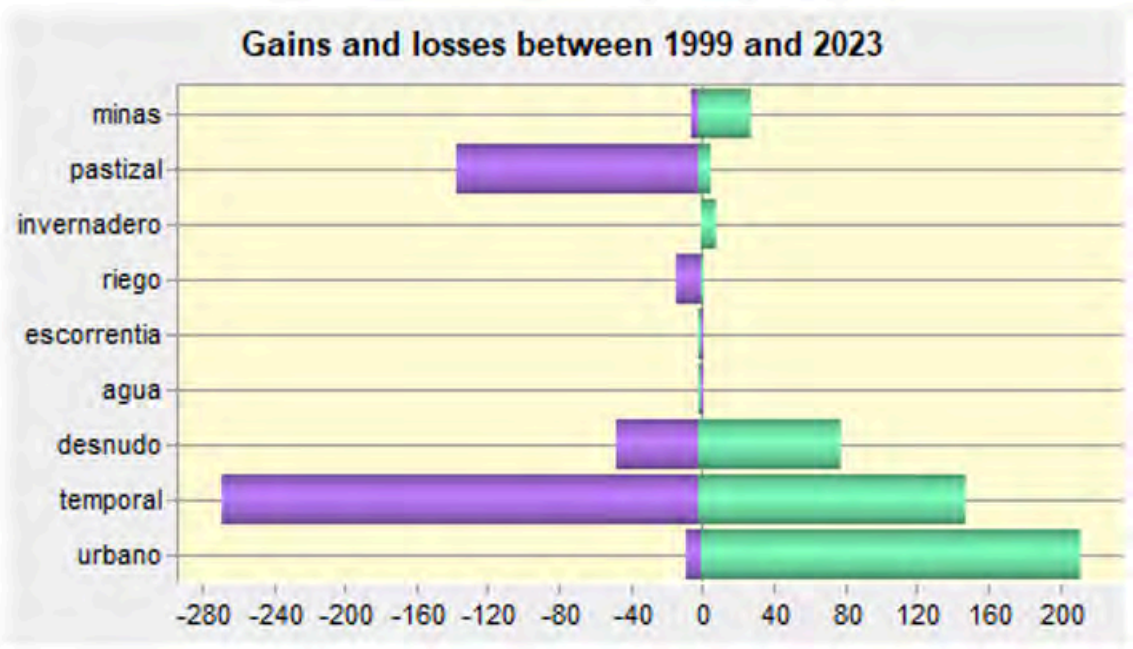
Occupation	1999	2023	Losses	Gains	Stable area	Difference 1999-2023
Bodies of water	1.2	1.5	0	0.3	1.2	0.3
Runoff	32.8	33	0.8	1.3	32	0.2
Irrigated agriculture	50.3	36.6	13.8	0.3	36.5	13.7
Greenhouses	0.1	7.8	0.1	7.8	0	7.7
Grassland	1440.5	1309.8	137.6	6.2	1302.8	130.7
Mines	52	74.3	6.2	28.5	45.8	22.3
Total	3569.6	3569.9	484.3	484.3	3084.4	529.7

The behavior of stable areas shows that the rainfed agriculture class is the most stable, with 1 445.4 ha. For the area of gains, which is obtained from the differences between the two periods, the urban area was the one with the greatest transition, with 203 ha; for the losses, which are obtained from the difference between the sum of time 1 and time 2, rainfed agriculture was the most affected, with 268.6 ha.

The class with the greatest transition is the urban area, with 211.6 ha, representing an annual growth of 8.81 ha over the last 24 years, primarily disturbing areas used for rainfed and irrigated agriculture. Figure 1 shows the losses and gains of all classes.

Figure 1. Gains and losses for all classes.



The urban area increased due to its proximity to rainfed agricultural areas, with 169.4 ha and scattered fractions in the center of the locality, such as the bare land class, which contributed 35.9 ha. Martínez (2010) notes that a main cause of urban expansion may be the lack of municipal regulation.

Texcoco is an example of public policies that allow the urbanization of agricultural land, favoring its devaluation through marked urban area expansion and increased human settlements that promote environmental problems (Soto, 2016).

Rainfed agricultural areas show characteristics rooted in crops such as corn and barley, which are for self-consumption and for feeding backyard livestock. The locality has an irrigated agricultural area of 50.3 ha, where up to two annual agricultural cycles are carried out.

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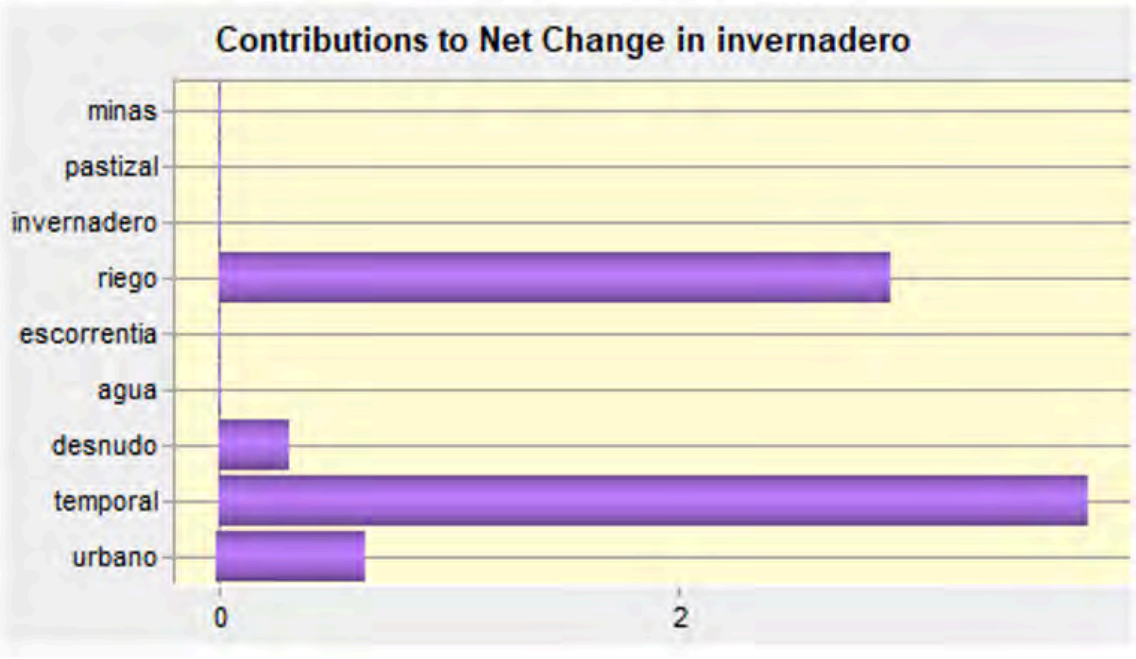
It is worth noting that the rainfed agriculture cover is considered within the area of the ejido zone, communal zone and private property, as defined by the RAN (2020) polygonal delimitation, with a total of 1 714.8 ha in 1999; this figure decreased by 120.3 ha in 2023, and this transition mainly increased the classes of urban use, bare land and mines.

Land occupied by greenhouses increased by 7.8 ha by 2023, mainly taken from rainfed and irrigated agriculture areas (Figure 2). FAO (2012) notes that producing in a greenhouse offers many advantages, enabling control over the internal environment, modifying the climate and creating conditions for crop development at any time of the year.

Figure 2. Greenhouse class gains.



Field verification confirmed that this class is not for agricultural use but for sheltering cattle herds; currently, this infrastructure provides benefits for animal adaptation, supporting development and controlling the environment during hot and rainy seasons.

On the other hand, the mine class increased by 22 ha compared to 1999; these areas are open-pit, and their purpose is to obtain materials such as gravel, stone, and sand, which are mainly used for construction. This class generates environmental problems such as the elimination of agricultural areas, erosion, and loss of biodiversity (Oyarzun *et al*., 2011) and can also affect society by altering its economic and social composition (Garriga, 2012).

Figure 3 and Figure 4 show maps of land-occupation changes for 1999 and 2023. Figure 5 shows a dynamic map of territorial transformation for the period analyzed.

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Figure 3. Map of land-occupation change, 1999.

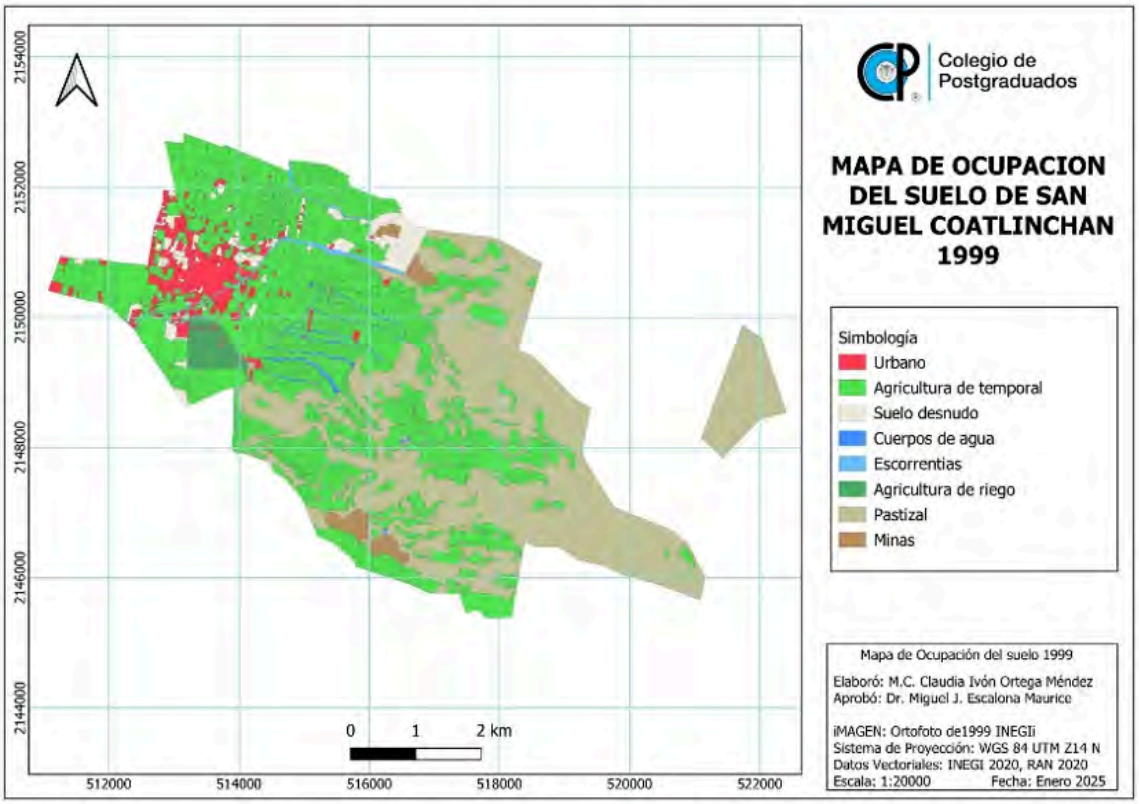

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Figure 4. Map of land-occupation change, 2023.

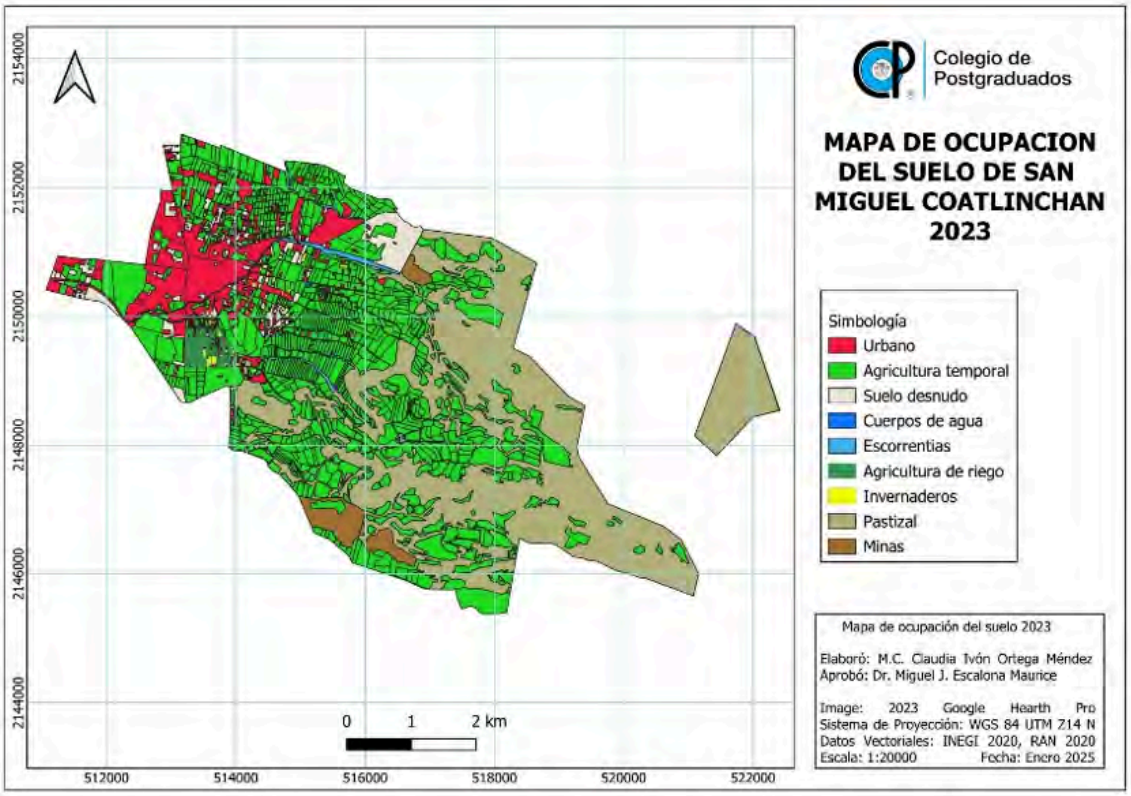

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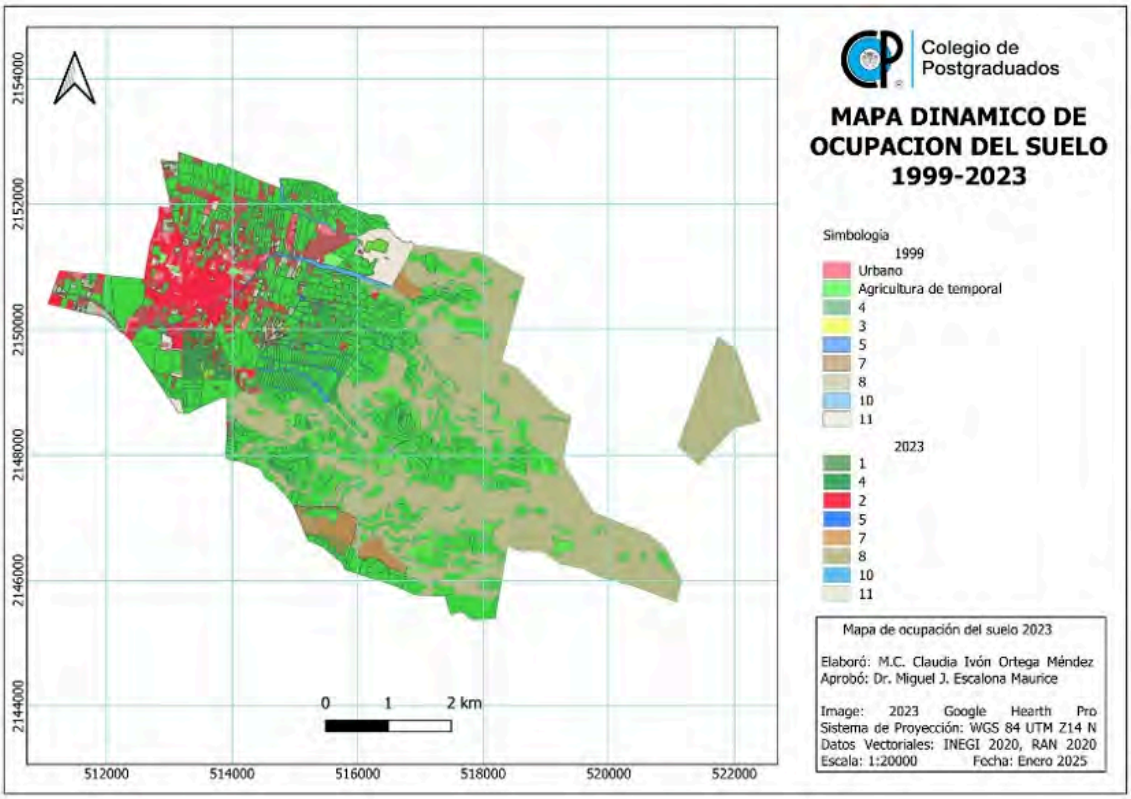
Figure 5. Dynamic map of land-occupation change, 1999-2023.



Conclusions

Analyzing land-occupation change with high-resolution images enables identification, at a local scale, of the various classes related to and affecting a territory. In addition, it is verified that the cross-tabulation method enables us to effectively test techniques for obtaining land-occupation changes, showing the identification of losses, gains and stable areas qualitatively.

This work enabled us to verify that the town of Coatlinchán has undergone a territorial transformation due to changes in land occupation from 1999 to 2023, especially in the rainfed agricultural class, which experienced a total change of 268.7 ha, losing an average of 11 ha year^{-1}, which represented a total loss of 268.6 ha over the 24 years.

Likewise, the pattern of the spatial analysis carried out in the study area allowed us to identify that urban growth is a factor that mainly manifests in the rainfed agriculture, irrigated agriculture and bare land classes due to their high vulnerability.

Finally, using temporal analysis methodologies enabled the generation of a broad overview of transitions observed in the territory due to changes in land occupation, allowing us to approach a tangible reality and they can serve as an analysis tool to strengthen methods for territorial planning.

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