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ORIGINAL RESEARCH ARTICLE

Detection of urban growth in the state of Hidalgo using Landsat images

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ABSTRACT

The detection of urban expansion through digital processing of satellite images provides valuable information for understanding the dynamics of land use change and its spatial relationship with environmental factors. In order to apply or generate effective land-use planning policies, it is essential to have a historical record of the regional distribution of human settlements, an element that is practically non-existent in our country. For this reason, this text aims to determine the urban growth rate during the period 2000–2014 in the state of Hidalgo, Mexico, and to identify potential expansion zones from Landsat images. Six Landsat scenes were used for the spatial analysis of the state urban coverage and their relationship with the road influence area was evaluated. Two maps were obtained as cartographic products: one of urban coverage distribution and another of the municipalities with the greatest expansion, whose areas are located in the Valle del Mezquital region. However, Mineral de la Reforma, Tetepango, Tizayuca and Pachuca de Soto stand out for their growth rates during the study period: 183.44%, 102%, 94% and 68.5%, respectively. In total, the state urban area in-creased 72.3 km^2 from 2000 to 2014 with an average growth rate of 1.8% per year. Such growth was associated with the areas of influence of important road infrastructure, such as the Libramiento Arco Norte in Hidalgo. Therefore, the Mezquital Valley and the Mexico Basin are considered as potential regions for urban expansion in the state.

Keywords: Urban Expansion; Territorial Planning; Road Infrastructure; Remote Sensing; Hidalgo

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1. Introduction

Land use change is considered by the Global Climate Observing System (GCOS) as one of the 13 essential climate-influencing variables. In addition, land occupation has been studied as one of the main factors that directly impact biodiversity, ecosystem fragmentation and the provision of environmental services[1-4].

Thus, knowledge of the spatial distribution of land use cover is essential for the formulation of effective land-use planning policies and sustainable management of human activities at different levels of organization[5]. Currently, remote sensing techniques have facilitated land characterization studies and allow the manipulation of large volumes of geographic information[6,7].

In recent years, deforestation has been one of the most evaluated land use change activities in our country[5,8] and it has been observed that the entities with the highest road density are those with the lowest

proportion of area with remaining natural vegetation. In this sense, it is worth noting that the road density for the state of Hidalgo is estimated in the range of 0.51–0.60 km/km^2[9], thus occupying fifth place nationally in highway infrastructure, federal and state roads[10]. However, data from INEGI's Statistical Yearbook of Hidalgo[11] show that about half of the surface area of the state of Hidalgo is occupied by agricultural activity.

In this context, Santos *et al.*[12] explain that the most relevant road infrastructure in recent years, the so-called Northern Arc, has given great economic and urban impetus to the Metropolitan Area of the Valley of Mexico and the northern zone (Mexico Basin Region in the state of Hidalgo) because it crosses the Mexico-Queretaro and Mexico-Pachuca highways in the state of Hidalgo.

Given this scenario, the present research work focuses on the state analysis of urbanization as an indicator for the characterization and land use planning, and aims to provide information on the spatial condition of urban areas in the state of Hidalgo in order to determine the relationship of urban growth with the development of road infrastructure, specifically in the area of northern influence of the Metropolitan Zone of the Valley of Mexico. Therefore, the general objective of this study is to determine the rate of urban expansion during the period 2000–2014 in the state of Hidalgo using satellite information from Landsat sensors to identify potential growth zones and/or municipalities.

2. Methodology

2.1 Study area

The state of Hidalgo is located in the central portion of the Mexican Republic (**Figure 1**) and is part of the physiographic provinces of the Transversal Neovolcanic Axis and the Sierra Madre Oriental. It covers an area of 20,813 km^2 and represents 1.1% of the country's surface. Most of the state has a dry and semi-dry climate (39%) and a temperate sub-humid climate (33%). The northern and northeastern regions of the state have warm humid (16%), warm sub-humid (6%) and temperate humid (6%) climates[11].

2.2 Image processing

The inputs used for this research were Landsat images from the years 2000 and 2014 (**Table 1**) available from the United States Geological Survey (USGS) database (http://earthexplorer.usgs.gov/), which includes the L1T (Level 1 for terrain correction) format, so they are geometrically orthogonal.

Table 1. General characteristics of the satellite images used in this study

Path/Row	Landsat sensor	Date
26/46	ETM+ 7	21/03/2000
26/45	TM 5	10/02/2000
27/46	TM 5	01/12/2000
26/46	OLI 8	31/01/2014
26/45	OLI 8	27/08/2014
27/46	OLI 8	19/09/2014

The general methodology of Jensen[13] was adopted for the extraction of thematic information on land use coverage from remote sensing data. Therefore, for the study area, a pair of image mosaics from the years 2000 and 2014 were generated through the ERDAS Imagine® image processor and the boundary of the state of Hidalgo was obtained based on the Marco Geoestadístico Estatal 2010 version 5 of INEGI[14] (**Figure 2**).

The 2,000 images were calibrated according to the procedure of Chander *et al.*[15], using the radiometric coefficients of the header files of each of the images. From this state image, representative polygons of the area of interest (urban areas) were obtained and a raster image was generated with the urban areas through the supervised method of classification by Maximum Likelihood in the ERDAS Imagine® software. With this process, the base vector layer (year 2000) of urban areas of Hidalgo was obtained and validated with the land use and vegetation cartography series III of INEGI scale 1: 250,000, whose information corresponds to the year 2002.

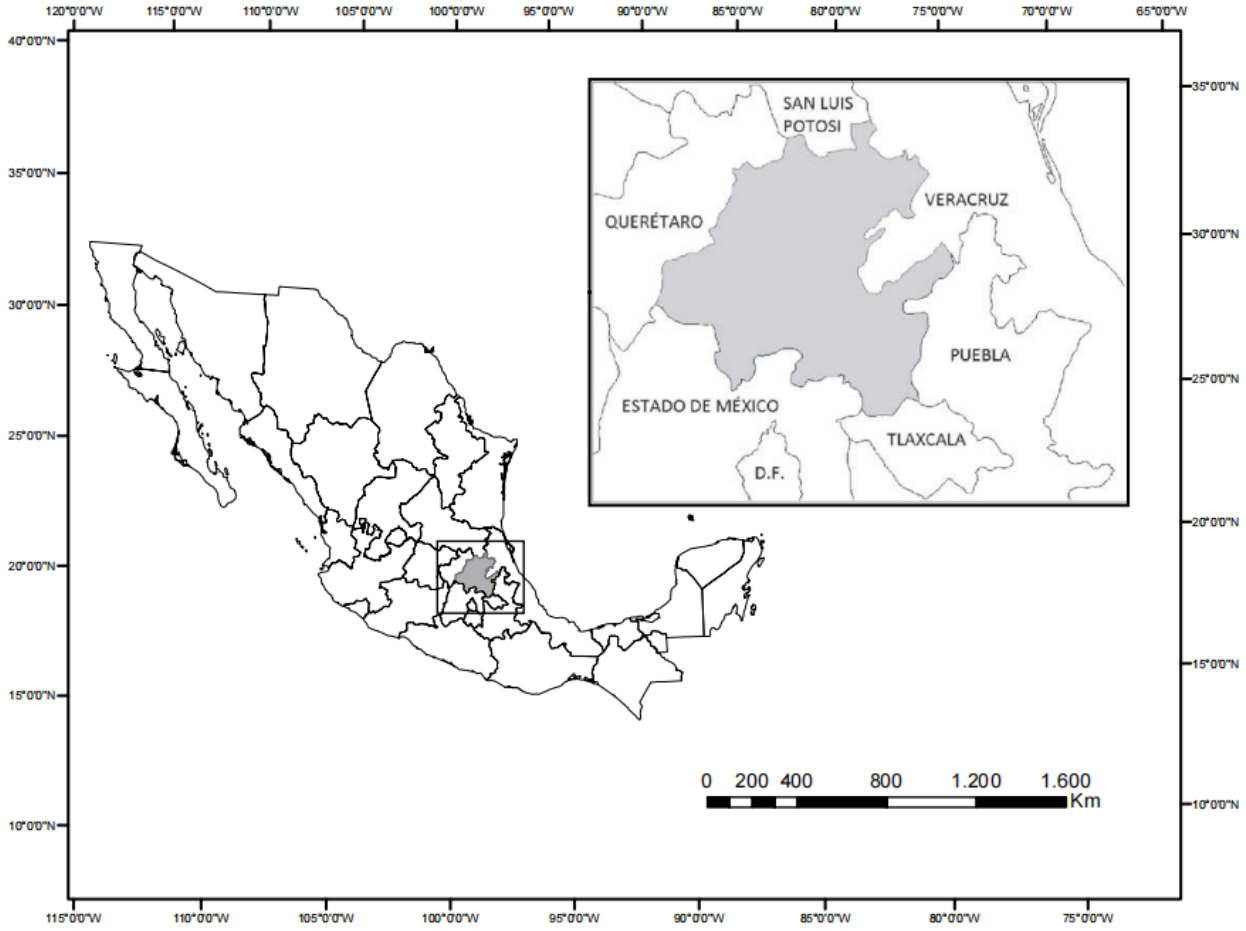

Figure 1. Location of the state of Hidalgo (in gray) in the Mexican Republic.

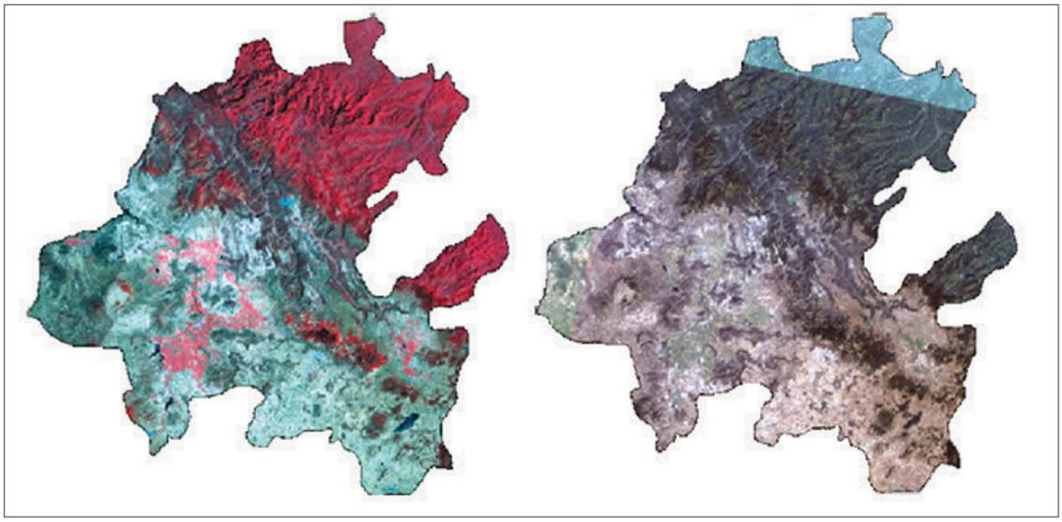

Figure 2. False color composites (RGB: 432) of Landsat image mosaic year 2000 (left) and year 2014 (right) for the state of Hidalgo. Scale 1: 2,500,000.

2.3 Analysis and change detection

The detection of changes in urban growth was performed by the post-classification process through an overlay of previously obtained vector-aster layers. That is, the 2,000 urban use map was updated with the 2014 state image mosaic to obtain the second vector layer by digitizing (**Figure 3**).

Once both maps were generated, the total areas of the urban polygons were calculated for the years 2000 and 2014 as well as the rate of urban expansion by municipality in that period.

Additionally, the 2014 cartographic product

was analyzed by overlaying the road network of the state of Hidalgo taken from INEGI vector files and a road density map was generated in ArcGIS10.0® with the buffer proximity analysis tool (zone of influence). This tool creates a raster output file that shows the distance of each cell of a set of entities by the Euclidean method and served to perform a spatial comparison of the distribution of the areas of influence of road infrastructure and urban areas in the state.

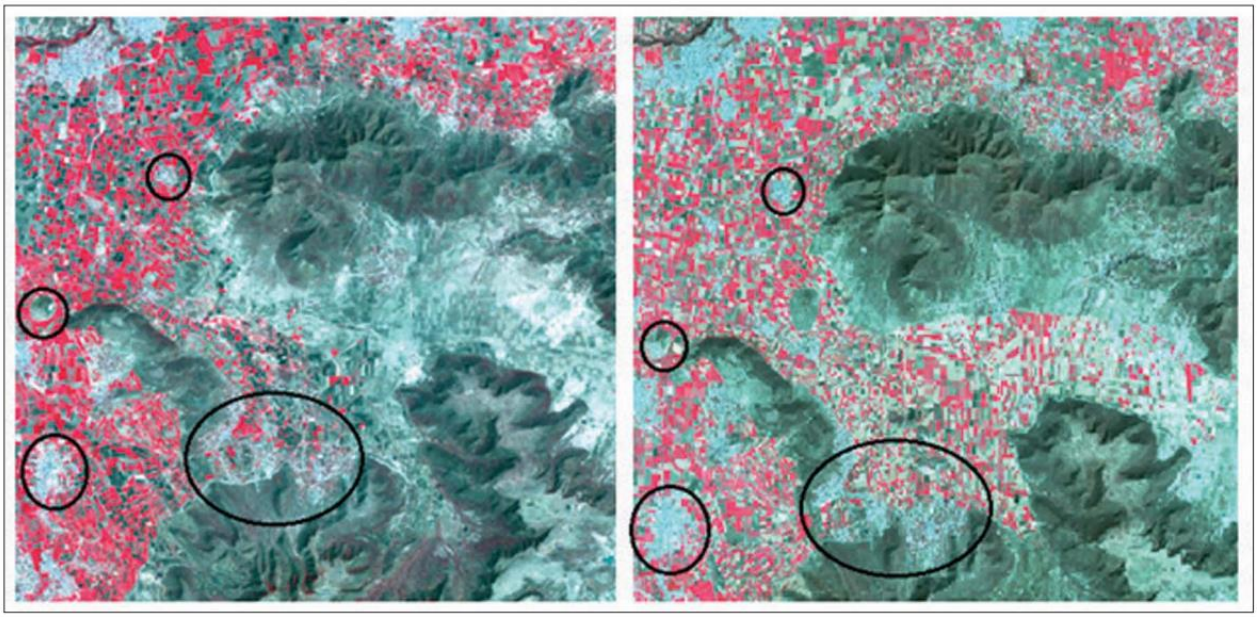

Figure 3. Example of areas with significant urban growth in the Mezquital Valley region, Hidalgo. Left: year 2000 (RGB: 432). Right: year 2014 (RGB: 543). Urban areas in both images are represented by cyan color.

3. Results and discussion

The Landsat images used (spatial resolution of 30 m per pixel) allowed mapping 103 urban polygons in the state territory for the year 2,000 and 123 polygons for the year 2014. Similar to a similar study conducted by Couturier *et al.*[16] in the Toluca-Atlacomulco Valley, differences were found in the number of urban objects reported in the reference database. In this study and in the aforementioned one, a greater number of urban polygons were found and we agree that, in general, certain urban areas are underrepresented in INEGI's cartography.

On the other hand, due to the heterogeneous nature of the urban areas, all the extracted polygons were identified as areas with urban development, from small population centers (24 hm^2 for our case study) to dense consolidated nuclei. The total urban area in the study period is presented in **Table 2**.

At first glance, the percentage growth of urban area in the state seems insignificant (0.35%); however, the results reveal a statewide growth rate for this period of 25.7%. This represents an urban expansion of 7,230.32 hm^2 in 14 years and an average annual rate of 516.45 hm^2. Although there are no previous records of the rate of urban expansion in Hidalgo, these figures suggest an accelerated urban expansion possibly due to population growth. A similar study by López and Plata[15] found that the urban area of the Metropolitan Zone of the Valley of Mexico in the period 1990–2000 increased 202 km^2, 130 km^2 more than the increase in the urban area of Hidalgo in a similar period of time.

Table 2. Total urban area of the state of Hidalgo

Year	hm^2	%
2000	28,115.81	1.35
2014	35,346.13	1.70

According to INEGI's 2010 Population and Housing Census[14], the population growth rate in Hidalgo from 2000 to 2010 was 1.7% and several of the municipalities with the greatest population increase (names in bold in **Table 3**) coincide with the municipalities with the greatest expansion of urban area in the state in recent years. However, urban growth was not homogeneous; the municipalities of Tetepango, Tizayuca and the Pachuca-Mineral de la Reforma conurbation were the regions with the

highest rate of urban expansion (**Figure 4**). With the exception of Pachuca (69%), these municipalities reflected a growth rate close to or above 100% during the last 14 years. Other municipalities with significant urban growth are shown in **Table 3**. Likewise, the map shown in **Figure 4** shows that the regions of the Comarca Minera and Cuenca de México showed the greatest increase and coincide with the areas with the highest road density in the state. However, most of the municipalities that registered growth in their urban polygons belong to the Mezquital Valley region (**Table 3**). Five other municipalities showed less urban growth: Almoloya, Santiago Tulantepec, Huichapan, Zimapán, Huejutla de Reyes and Tlanchinol (urban growth rates of less than 7% in the period studied).

Table 3. Municipalities with the highest urban growth in the period 2000–2014

Municipality	Geographic Region	Urban area (ha)		Place by expansion rate
		Year 2000	Year 2014	
Mineral de la Reforma	Mining Region	890.80	2,524.93	1 °
Tetepango	Mezquital Valley	328.08	662.27	2 °
Tizayuca	Mexico Basin	1,143.00	2,214.00	3 °
Pachuca de Soto	Mining Region	3,128.43	5,273.90	4 °
Cuautepec de Hinojosa	Tulancingo Valley	79.25	130.48	5 °
Villa de Tezontepec	Mexico Basin	154.30	241.00	6 °
Francisco I. Madero	Mezquital Valley	162.82	254.30	7 °
Epazoyucan	Mining Region	137.40	187.00	8 °
Tolcayuca	Mexico Basin	322.88	393.19	9 °
Tulancingo de Bravo	Tulancingo Valley	1,361.20	1,639.36	10 °
Apan	Pulque Highlands	370.58	444.77	11 °
Tlahuelilpan	Mezquital Valley	387.25	443.90	12 °
Tezontepec de Aldama	Mezquital Valley	899.64	977.17	13 °
Mixquiahuala	Mezquital Valley	660.00	711.72	14 °
	Total	10,025.63	16,097.99	

Note: the highlighted municipalities had the highest population growth rate according to INEGI's 2010 Population and Housing Census[14].

According to these results and the road density map obtained, it was found that in addition to the south-central zone of the state of Hidalgo, the Mezquital Valley region has a high road density and despite its predominantly agricultural land use, it represents a potential zone for the expansion of urban centers (**Figure 4**). This suggests the possibility of a more dynamic manifestation of land use in this region in the medium term than in other geographic regions of the state of Hidalgo. Likewise, the type of urban centers with the greatest growth coincides with the observations of López and Plata[17] and Bazant[18], who mention that the rural peripheries are the regions most involved in metropolitan urban growth. It should be noted that as of 2011, the area of influence of the Metropolitan Zone of the Valley of Mexico officially expands northward and within it 21 municipalities of the state of Hidalgo are integrated[4], which include: Ajacuba, Atitalaquia, Atotonilco de Tula, Epazoyucan, Mineral de la Reforma, Mineral del Monte, Mixquiahuala de Juárez, Pachuca de Soto, Progreso de Obregón, San Agustín Tlaxiaca, Tepeji del Río, Tetepango, Tezontepec de Aldama, Tizayuca, Tlahuelilpan, Tlaxcoapan, Tolcayuca, Tula de Allende, Villa de Tezontepec, Zapotlán de Juárez and Zempoala.

According to the Sistema Urbano Nacional (SUN)[19], the southern part of the state of Hidalgo is one of the regions of the country with the highest number of urban centers and population density, as well as neighboring states such as Puebla, the State of Mexico and the Federal District. At the national level, urban growth from 1980 to the present was considered moderate with respect to the accelerated growth that occurred in the period 1940–1980. However, during the 2005–2010 period, the number of urban centers increased and the SUN incorporated six conurbation units in the country. One of them is located in the state of Hidalgo and was called Tetepango-Ajacuba, which coincides in our study with the area of the Mezquital Valley that reflected the highest rates of urban expansion in the state.

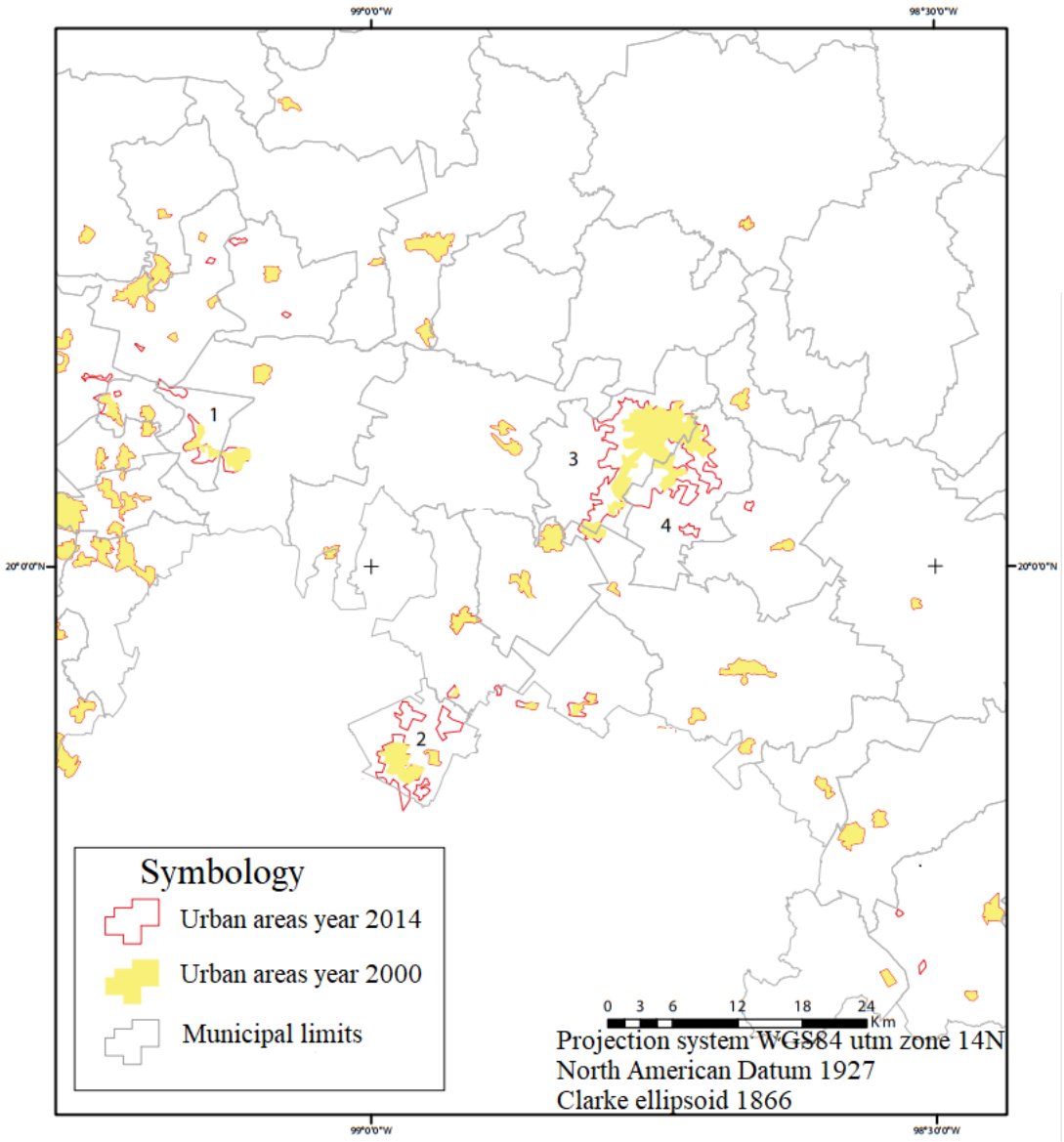

Figure 4. Enlarged view of the four municipalities with the highest urban growth rate in Hidalgo (1: Tetepango; 2: Tizayuca; 3 and 4: Pachuca-Mineral de la Reforma conurbation).

With the above analysis, it was finally established that the urban growth zone is delimited by the area crossed by the Libramiento del Arco Norte in the state of Hidalgo (**Figure 5**). However, a more detailed analysis should be carried out to identify local environmental factors that are influencing or accelerating the rate of urban expansion mainly in the Mezquital Valley region. Likewise, it would be convenient to carry out the extraction of urban coverage by other more novel methods, such as the morpho-spatial analysis for regional scales proposed by Couturier *et al.*[15], who have developed criteria for obtaining urban polygons in different categories through Landsat images to improve the quality of cartographic information in our country.

It is worth noting, following Bazant[17], that when urban growth is characterized by the conurbation of cities (as is the case of this study), and not by the increase of surface area in independent urban centers, urban planning becomes an even greater challenge because each municipality is subject to previously established political-administrative regulations.

In this sense, it is convenient to continue generating quantitative geographic information for the integration of other land management indicators that facilitate the application of political planning instruments at the three levels of territorial organization in Mexico in an efficient manner.

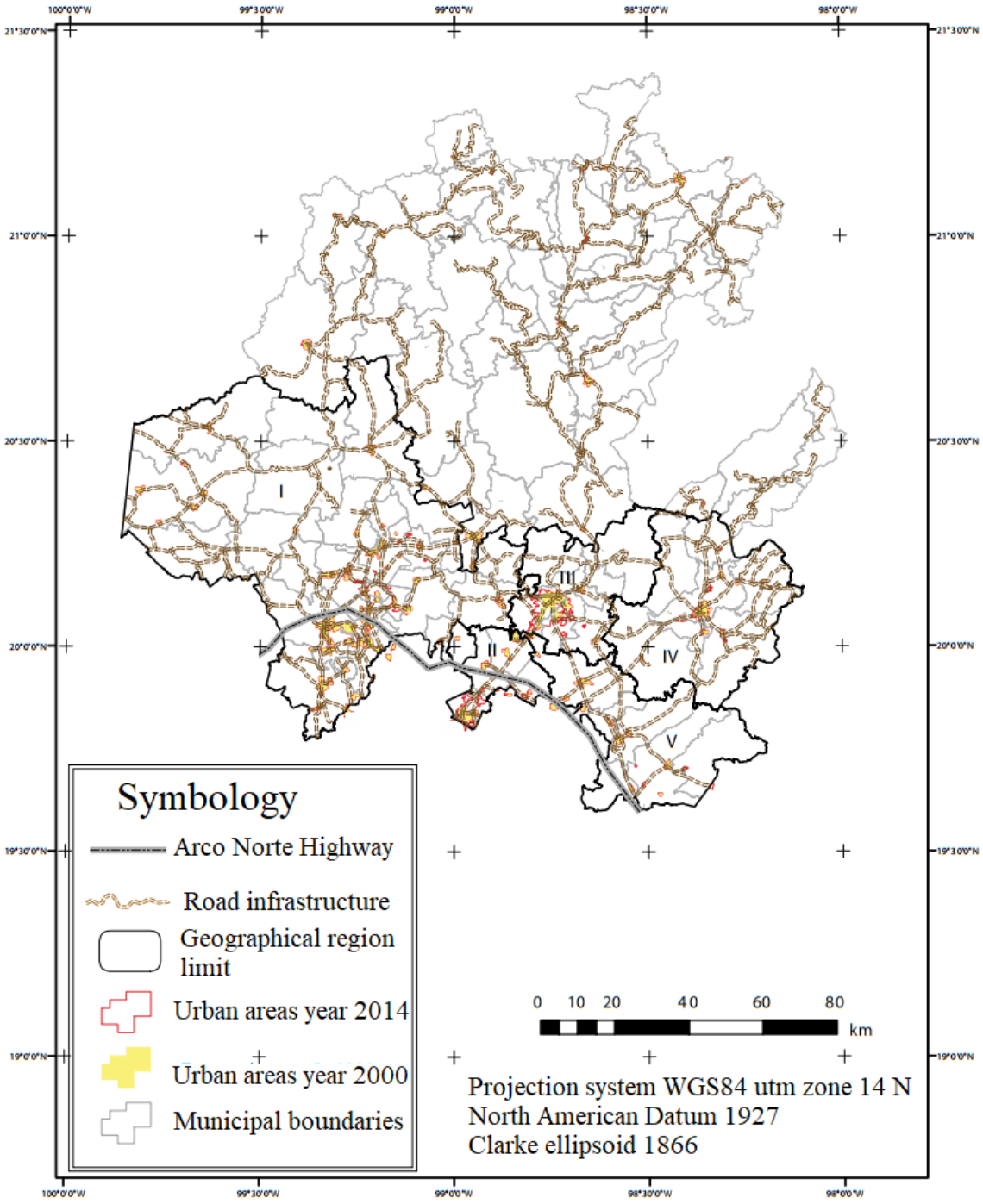

Figure 5. Location of the municipalities with the greatest urban expansion and road influence. 1: Tezontepec de Aldama; 2: Mixquiahuala de Juárez; 3: Tlahuelilpan; 4: Francisco I. Madero; 5: Tetepango; 6: Tizayuca; 7: Tolcayuca; 8: Villa de Tezontepec; 9: Pachuca de Soto; 10: Mineral de la Reforma; 11: Epazoyucan; 12: Tulancingo; 13: Cuautepec de Hinojosa; 14: Apan.

4. Conclusions

Urban land occupation in the state of Hidalgo grew by 7,230.32 hm^2 from 2000 to 2014. This represents an increase of one third of the urban area during ten years in the Metropolitan Zone of the Valley of Mexico. The areas with the highest rate of urban expansion in Hidalgo were located in the central-southern part of the state that converge with the agricultural areas and those with the greatest road infrastructure. At the same time, these zones belong to the municipalities of Hidalgo recently included in the northern region of the Metropolitan Zone of the Valley of Mexico. The four municipalities with the highest urban growth in the study period were Mineral de la Reforma, with an expansion rate of 183.4%; Tetepango, with a rate of 102%; Tizayuca, with a rate of 94%; and Pachuca,

with a rate of 68.5%. The findings of this research suggest the transformation of the Mezquital Valley from a rural territory to a heterogeneous one (rural-urban) and indicate that the establishment of human settlements in the state of Hidalgo is strongly determined by the regional economic development of the center of the country.

This work emphasized the need to direct urban development towards land management that allows a more favorable urban distribution for the adequate use of land resources as part of the new sustainable management policies in Mexico.

Conflict of interest

The authors declare that they have no conflict of interest.

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