Applied Geography 79 (2017) 223–234

Contents lists available at ScienceDirect

Applied Geography

journal homepage: www.elsevier.com/locate/apgeog

A comparison of urban growth and their influencing factors of two border cities: Laredo in the US and Nuevo Laredo in Mexico

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ARTICLE INFO

Article history:
Received 17 May 2016
Received in revised form
17 December 2016
Accepted 27 December 2016
Available online 19 January 2017

Keywords:
Influencing factors
Urban growth
Regression analysis
US
Mexico

ABSTRACT

The adjacent cities of Laredo in the US and Nuevo Laredo in Mexico have been growing at an unprecedented pace over the past decades. The trans-boundary flows of commodities and capital between these two cities, as well as significant population growth have created an interdependent system in this area. This characteristic provides an opportunity to thoroughly examine drivers behind landscape changes in the two cities. The aim of this study is to examine urban growth and the influencing factors of Laredo-Nuevo Laredo. Results of initial remote sensing-GIS analysis indicated that there was considerable urban expansion in both cities from 1985 to 2014. Spatially, Laredo demonstrated a more dispersed and rapid growth pattern compared to Nuevo Laredo. Additional results from a logistic regression using data at the pixel level on both sides of the border revealed a number of factors that influenced urban growth for both cites. These factors included: (1) elevation, (2) distance to nearest urban clusters, (3) distance to local roads, and (4) density of urban pixels. In addition, this study found that some dominant variables (population density and density of highways) affected urban growth differently for the two cities. Furthermore, globalization factors related to industrial activities/maquiladoras also played a significant role in affecting urban growth although the trajectories were not completely clear.

1. Introduction

Over recent decades, rapid urban growth has become a concern for local, national and global environmental management. Although global urban land cover is estimated to occupy approximately 2% or 3% of Earth's total area (Lambin et al., 2001), almost half of the world's population resides in cities. Estimates suggest that the urban population will increase to 61% of the total population by 2030 (United Nations, 2004). Meanwhile, unplanned and mismanaged urban growth has significantly influenced land use patterns as well as placed local demands on natural resources including land, energy, water, etc. (Norman, Feller, & Guertin, 2009; Foley et al., 2005). Population concentration and rapid urbanization, especially in developing countries, calls for efficient land use and land cover (LULC) change monitoring for cities. In land change science, land cover refers to physical and natural component of the earth surface, while land use refers to human activities on the land. For example, built-up land involves various of land use activities, including residential, commercial, and industrial land use as well as transportation networks.

The conventional *in situ* map survey method is expensive and time consuming for land monitoring for an entire city (Jat, Garg and Khare 2008) and historical land patterns cannot be readily accessed. Airborne or satellite remote sensing techniques have been playing an increasingly important role in land change monitoring. Their uniform spatial resolution and revisit frequencies of satellite contributes to efficient historical urban growth monitoring. Urban growth monitoring and prediction constitute the basic information needed for long-term urban planning. In particular, Landsat data have become the foremost source for LULC change studies since 2008 when the archives became freely available.

Cities along the US-Mexico border have grown at an unprecedented pace that reflects the border's unique regional and historical characteristics. The emergence of Mexico's manufacturing plants (i.e., maquiladoras) program is a symbol of economic globalization. With permission from the government, these kind of manufacturing plants can temporarily import goods from abroad tariff-free and the final goods are exported after the manufacture or

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http://dx.doi.org/10.1016/j.apgeog.2016.12.017
0143-6228/

assembly process is completed (Currit & Easterling, 2009). Approximately 3000 maquiladoras employ nearly 1.3 million Mexicans (47.1% of the country's national manufacturing employment) and contribute 52.9% of the national aggregate exports for Mexico (Heid, Larch, & Riano, 2013). Additionally, the North American Free Trade Agreement implemented in 1994 resulted in considerable land use-land cover change in areas along the US-Mexico border, especially in paired border cities (Myint, Jain, & Guhathakurta, 2010). Approximately 15 million people live in counties adjacent to the 3145 km long US-Mexico border, and that number is expected to exceed 23 million by 2030 (Ganster, Pijawka, Rasmussen, & Van Schoik, 2000). Urban areas in these border cities have been and will continue to expand in most cases. This type of urban growth has generated binational environmental and urban management issues (Villarreal, Norman, Boykin, & Wallace, 2013; Norman, Feller, & Villarreal, 2012; Norman et al., 2009).

This study aims to characterize urban growth of two border cities by thoroughly examining the historical urban growth and assessing the underlying physical and development factors that influence landscape change for Laredo and Nuevo Laredo. The trans-boundary flows of commodities and capital between these two cities, as well as significant population growth have created an interdependent system. In land change science studies, researchers study cross-boundary effects between adjacent administrative units because they are of particular importance to explore the effects of policies and regulations, subsidies, and systems (Bürgi, Hersperger, & Schneeberger, 2004). The process of land use change is not stationary (McDonald & Urban, 2006), meaning similar urban growth patterns or rates in different cities may be due to different underlying factors.

Despite the extent and rate of worldwide urban growth, our understanding about urbanization patterns and the underlying processes of urbanization remains a challenge. Many urban growth studies have been conducted for large cities worldwide (Arsanjani, Helbich, Kainz, & Boloorani, 2013; Kuang, Chi, Lu, & Dou, 2014; Luo & Wei, 2009; Pravitasari, Saizen, Tsutsumida, Rustiadi, & Pribadi, 2015; Seto & Kaufmann, 2003; Xie, Mei, Guangjin, & Xuerong, 2005). However, few studies provide comparative analysis of cross-national urban growth patterns and drivers. Exceptions are two studies on the binational watershed in Arizona, USA and Sonora, Mexico (Villarreal et al., 2013; Norman et al., 2012), in which the authors studied the effects of plausible future scenarios of land cover change at the regional scale with simulation models. However, their focus was future scenarios rather than historical urban growth analysis and the drivers of urban growth. To contribute to this gap in understanding urban growth, we provide a comparative study of the Laredo-Nuevo Laredo border cities to better understand factors influencing urban growth in this region. Specifically, this study attempts to address the following two questions: 1) What are the rates of urban growth and the resulting growth patterns, and 2) What factors affect the urban growth of our study area and how do these factors differ between the two cities.

2. Data and methods

2.1. Study area

The Laredo-Nuevo Laredo study area is one of six bi-national urban areas along the US-Mexico border (Fig. 1). Laredo is located in the State of Texas (USA), while Nuevo Laredo is situated in Tamaulipas, Mexico. The two cities are connected by three international vehicle bridges and a railroad bridge across the Rio Grande (Rio Bravo) river.

Over the past several decades, the area has experienced dramatic population increases and urban growth. The population of Laredo increased from 126, 228 in 1990 to 252, 309 in 2014, making it the third most populated city on the US-Mexico border, after San Diego and El Paso (U.S. Census Bureau, last updated at Oct 11, 2016). With a population of 384,033 in 2010 and 310,915 in 2000 (Instituto Nacional de Estadística Geografía e Informática, México(web), Nuevo Laredo is larger, but exhibited rapid growth after Laredo. These two cities are considered the largest land-based port between the US and Mexico, where Mexico's Highway 85 and U.S. Interstate 35 meet.

2.2. Urban growth detection and quantification

Reflective bands of the Landsat 5 TM, 7 ETM+, and 8 OLI sensors have spatial resolutions of 30 m and a temporal resolution of 16 days, which meets our goal to identify the spatial distribution of urban land cover and extract historical urban growth areas. Three cloud-free images were obtained from the USGS Earth Explorer website (Fig. 2). Image preprocessing, classification, and post classification accuracy assessments were all implemented using ERDAS Imagine 2013 (Table 1). Preprocessing included stacking individual wavelength layers per year and then the image stack was clipped to the study for future classification. Conversion to at-sensor reflectance was implemented with the Model Maker tool in Imagine. Digital Numbers (DNs) for all bands were converted into at-sensor radiance using gain and bias parameters provided by Chander, Markham, and Helder (2009) and the image metadata files This step is necessary so that data from different Landsat sensors can have a meaningful common radiometric scale. Finally, top-of-atmosphere (TOA) reflectance was calculated assuming the atmospheric condition is uniform. The cosine effect of solar zenith angles and changes in the exoatmospheric solar irradiance due to variation in the earth–sun distance were corrected (Chander et al., 2009). Thus, the data from different dates and different sensors can be compared and analyzed.

We examined the history land patterns and land types of the study area using Google Earth historical imagery to gain fine scale perspective about prior land cover of the study area. The dominant land cover included vegetation and barren land. Also, the Rio Grande (Rio Bravo) river and lakes are important landmarks of the study area. Taking both the aim of this work and the background characteristics of the study area, the land use and land cover types were merged together and four classes were derived: urban (built-up) land, vegetation, barren land, and water. Specifically, urban (built-up) land refers impervious land surfaces including residential, commercial, industrial, as well as transportation networks. Vegetation includes grassland, shrub/scrub, cultivated crops, pasture, and forest. Barren land refers to the land covered by rock/sand/clay. Water includes rivers, lakes, and ponds.

A supervised classification method using the Maximum Likelihood parametric rule were used for classification. With the help of a city plan map for Laredo and Google Earth historical imagery, we extracted 224, 316, and 333 signatures 1985, 2000, and 2014, respectively. A suite of tools including alarms, contingency matrix, feature space to image masking, signature objects, histograms, signature separation, and statistics were used to evaluate the spectral separation between land cover classes and to determine which subset of bands provided the best results. Post classification accuracy assessments were conducted for each image. Two hundred randomly selected points were used to perform accuracy assessment for each image. We used historical imagery available from Google Earth as the reference data. Accuracy assessment reports included error matrices, accuracy totals, and Kappa statistics.