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Frontiers of urbanization: Identifying and explaining urbanization hot spots in the south of Mexico City using human and remote sensing

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ABSTRACT

This article applies a multi-method approach to develop a better measurement of urbanization dynamics using remote and human sensing based on a GIS platform. The results demonstrate the benefits of bringing human and remote sensing sources together in a framework of hot spot analysis for a megacity such as Mexico City. Furthermore, our analysis suggests that human and remote sensing work well together in detecting the expansion of illegal urban settlements. Looking at the driving factors of illegal settlements, the existence of strong association between the expansion of illegal urban settlements and socioeconomic factors such as unemployment, provides some answers and reveals new questions. Illegal urban growth often leads to the loss of ecological areas in the urban frontiers, especially in areas where the urbanization potential is high. As a consequence, there are conflicts with legal settlers who dislike the illegal expansion. This approach can be extended to and replicated in new urbanizing areas, in particular in Africa and Asia.

1. Introduction

Since many cities have been growing as a result of globalization and will continue to expand in the coming decades, increasing efforts to improve planning in integrated sustainable land use are needed (DESA, 2014). This development is further promoted through advanced communication technologies, falling transportation costs and the centralization of economic activities, combined with rising added values in cities (IPCC, 2014). Studying these processes is especially challenging because this form of expansion is associated with a growing trend of illegal urbanization in the developing world and related social and environmental problems (Benítez, Pérez-Vázquez, Nava-Tablada, Equihua, & LuisÁlvarez-Palacios, 2012).

The key research question of this study focuses on the expansion of horizontal illegal urban settlements along the frontiers of cities: How can this form of expanding urbanization be estimated and how accurate are these estimations? A second aspect is: Which drivers of growth are compelling this illegal urban settlement expansion? More specifically, which indicators of urban expansion are available from remote and human data sources and how are these related?

We have selected the city with one of the biggest accumulations of illegal settlements in the world: Mexico City (Davis, 2006). This urban agglomeration serves as a case study with a focus on the urban/peri-urban spaces in which a horizontal expansion of illegal urban settlement has taken place (Aguilar, 2008; Aguilar & Santos, 2011). Our project goal is to confirm and visualize observed trends from the social sciences, combining satellite imagery for land use change analysis, human sensing based on Volunteered Geographic Information (VGI) and the relevant existing census and statistical data about this urban expansion.

Regarding the question on the visualization and better understanding of estimating the illegal settlements, this study jointly analyses data from different acquisition contexts (remote sensing, VGI, census). The research on urban growth benefits from newly available information in a complaints database and high definition remote sensing imagery obtained from the RapidEye Science Archive (RESA) Program.

For this article, we take a new approach that combines human and remote sensing to assess urbanization hot spots. Remote

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Abbreviations

AGEB	Áreas Geoestadísticas Básicas
DESA	Department of Economic and Social Affairs
DiB	Data in Brief
GIS	Geographic Information System
HS	Human sensing
INEGI	Instituto Nacional de Estadística y Geografía
IPCC	Intergovernmental Panel on Climate Change
PAOT	Procuraduria Ambiental y del Ordenamiento Territorial del Distrito Federal
RESA	RapidEye Science Archive
RS	Remote sensing
VGI	Volunteered Geographic Information

sensing is based on satellite information and is one of the most prominent and developed sources of geographical information for land use research. The data gathering method of human sensing is related to an emerging field of literature, which is using the potentials of the Web 2.0 to create new and reliable databases for geographical research (Haklay, Basiouka, Antoniou, & Ather, 2010). In both fields, the question of better measurements is a key issue. In this study, remote sensing detects urban change with high-resolution satellite imagery (5 m) from the RapidEye sensor, while human sensing detects illegal settlements in the form of complaints in a georeferenced point data set. This article addresses the question to which degree the estimations of human and remote sensing are comparable and complementary, exploring whether and how the benefits of one technique could compensate for the deficits of the other.

In Mexico City, it is not possible for the administration to avoid unplanned urban development and as a consequence, an increasing number of nature reserves and related ecosystem services such as water regeneration and CO_2 storage (Delgado-Ramos, 2015; Delgado-Ramos, Mancheno, & Rodriguez Lopez, 2014) become lost in unplanned settlement processes. Even existing regulations have so far failed to contain the expansion (Aguilar, 2008; Aguilar & Santos, 2011). The lack of planning and defined land use has led to tensions in Mexico City between the city's center and the periphery. In the city center, land prices are so high that the majority of the population settles in the cheaper suburbs. Streams of people travel in the morning into the city center for work and return in the evening to the periphery (Lomelí, 2008). This phenomenon of peri-urbanization has, as a consequence, produced a growing demand for infrastructure, particularly transport and services such as water and energy supply, but also for accommodation, so that people stay overnight in the peri-urban settlements.

One of the most well-known historical cases is the district Nezahualcoyotl in the metropolitan area of Mexico City (Linares Zarco, 2013). In addition to undeveloped areas and nature reserves being irregular and illegal settlements occupied by the poorer population (Platt, 2010), real estate speculations are also transforming the area (Aguilar, 2008; Aguilar & Santos, 2011). The latter are implicitly promoted with the support or permissive attitude of the authorities (Aguilar & Santos, 2011). A particular problem is that the expansive urbanization with illegal settlements is occupying an area of "great ecological value in terms of climate regulation, water recharge, forest communities, agricultural cultivation, and hilly landscape" (Aguilar, 2008, p. 133). As a result these areas are losing worth (Jujnovsky, González-Martínez, Cantoral-Uriza, & Almeida-Leñero, 2012), with the steady loss of food security and supply of local products (Losada et al., 1998). The gentrification process downtown also additionally intensified the requirements of land use in the peri-urban city (Salinas, 2013a;, 2013b). However, this is only one side of the discussion because this city expansion also promoted the construction of public services (hospitals, schools) in the peri-urban regions (Méndez-Lemus, 2012).

This article is organized into six sections. After this introduction, Section 2 outlines the theory. In Section 3, the analysis of the data with the proposed methods is presented. Sections 4 and 5 contain results and discussion and Section 6 summarizes the work and draws conclusions.

2. Theory and approach

This article presents a multi-method approach to a better measure of urbanization dynamics. Our study investigates the implications of rapid urban expansion for land competition and the environment at the frontier of the city. The methods and findings are of direct practical relevance, given that urban populations are projected to double to 6.4 billion by 2050, and the issues related to urbanization will increase in importance (IPCC, 2014), as will related conflicts and environmental problems that need to be resolved in a sustainable manner. Besides its direct relevance for Mexico City, the ultimate goal of our research is to develop a methodological approach that is appropriate for direct transfer and diffusion to other cities and regions, specifically to the newly flourishing cities in Africa and Asia, which have seen similar patterns of growth, but have not reached the urbanization rate of Mexico.

Our goal is to confirm and visualize observed trends from the social sciences using human sensing (VGI) and remote sensing (satellite imagery), combining it with the relevant existing census and statistical data regarding illegal settlements in Mexico City. VGI has become popular with help of new Web 2.0 technologies; however, the question of quality concerning this kind of data remains open (Bimonte, Boucelma, Machabert, & Sellami, 2014). The policies of Internet companies have allowed the use of this information (e.g. API Twitter) and Google Earth has become a respectable tool for mapping with high-resolution images and at different points in time (Clark & Aide, 2011). Furthermore, Copernicus or Landsat programs provide the opportunity to obtain satellite information of different qualities for almost all parts of the world and at various times.

The uses of VGI vary from emergency responses and urbanization decisions to a valuable tool in data science (Elwood, 2010). However, research about VGI is needed to prove how effective it is and under which circumstances it works best (Goodchild & Glennon, 2010).

Various forms of remote sensing data for rural-urban interactions are available for the vast majority of countries. We propose to complement these data with human sensing and use the opportunity here to match various forms of data with remote sensing imagery to generate new insights (Hagenlocher, Lang, & Tiede, 2012). By combining satellite imagery and VGI in a Geographic Information System (GIS) platform, we aim, for example, to differentiate between settled and un-settled land, as well as used resources (water, food and energy), over the peri-urban areas. Furthermore, census and statistical or qualitative data gathering are expensive and burdensome means of collecting information (McCann, Colby, Easter, Kasterine, & Kuperan, 2005). As the cost of collecting satellite imagery continues to fall and VGI forms of data continue to develop, huge potential exists in combining remote sensing with human sensing data to generate increased value for governments, NGOs, and researchers. This will