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Remote Sensing of Sustainable Rural-Urban Land Use in Mexico City: A Qualitative Analysis for Reliability and Validity

Abstract | Mexico City is one of the largest cities on the globe and a site where important transformations of nature reserves into urban areas have been taking place. This paper compared the southern part of Mexico City based on free images available (Landsat – 30m) and high-resolution imagery (RapidEye – 5m) from an explorative qualitative perspective in the logic of reliability and validity. We argue that the resolution of the free imagery available for the assessment of urban development on the structural level of land use is not sufficient to identify the development of specific parts of the city. Despite the fact that the general pattern of changes in land use is observable, changes within the urban structure are difficult to see with a resolution of 30 meters per pixel in the Landsat images. For validity, this analysis is merely graphic, and it shows a promising matching of urban development with environmental and land complaints, nevertheless, a numerical analysis is needed in the future.

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Keywords | remote sensing – qualitative analysis – PAOT complaints – land use – Mexico City

Introduction

Since cities are growing as a result of globalization, plans for integrated sustainable land use are needed. The southern part of Mexico City,¹ one of the world's

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1 Legally, Mexico City refers to the 16 boroughs that comprise the Federal District (Distrito Federal). Thus, it excludes the major conurbation, which adds 60 adjacent municipalities of the states of Mexico and Hidalgo (www.conapo.gob.mx/es/CONAPO/Zonas_metropolitanas_2010). We focus our research only on Mexico City.

megacities, has been an example of transformation from nature reserves into urban land use (Aguilar 2008; Aguilar and Santos 2011). Remote sensing provides an opportunity and tool for observing land use and urban development (Hacker *et al.* 2013; Kit and Lüdeke 2013; Kit *et al.* 2012; Kohli *et al.* 2012; Odindi *et al.* 2012; Taubenböck and Kraff 2014; Ward and Peters 2007), which can also improve the understanding of land use change from nature reserves to urban spaces. More specifically, we investigate the following research question: how can the principles of reliability and validity be qualitatively tested using remote sensing for the case of the southern part of Mexico City? This paper aims to develop two exploratory tests, one for reliability and the other for validity of the remote sensing analysis. To test for reliability, high and medium spatial resolution imageries are compared from two sources: Landsat and RapidEye satellites. For validation, the second approach is to graphically collate high resolution imagery with a map of complaints placed at the “*Procuraduría Ambiental y del Ordenamiento Territorial del Distrito Federal*” (PAOT), a governmental entity responsible for reviewing and processing environmental and land use offences.

While some authors have employed remote sensing for the case of Mexico (Aguilar 2008; Aguilar and Santos 2011), questions of reliability and validity have not yet been addressed. Therefore, our research connects the results of a methodology of high resolution remote sensing (Object-Based Image Analysis) with the case of land use in the southern part of Mexico City to show the potentials and shortfalls of this methodology under the principles of reliability and validity in a qualitative approach.

The next section provides an introduction to how Mexico City and its periphery face the challenge of uniting the normative principles of sustainable development with the methodological principles of reliability and validity. Next, the methods and results sections display the resulting image classification of land use at different times in the southern part of Mexico City, analyzing for reliability and validity in a qualitative approach. The discussion of results includes a broad review of the literature about urban development in Mexico City and environmental conflict. Finally, conclusions are drawn in relation to the benefits and costs of high resolution remote sensing in the case of Mexico City.

Literature review and theory

Mexico City is located inland in the middle of the southern part of the country (Figure 1), and is one of the largest cities on the globe. It also comprises one of the world’s largest accumulations of informal settlements as a product of rural-urban and urban-urban migration (Marx *et al.* 2013; Platt 2010). In addition, the level of political and social conflict has been historically high in this area



Figures 1 and 2. Location map and research area.

(Davis 1994; 2006; Marshall and Cole 2014). This growing urban space has put a high demand on resources, especially water, which flows from north and south through the rural and peri-urban areas (Delgado Ramos 2015). In the case of the south, water flows through the nature reserves or “preservation zone (suelo de conservación)” into the urban areas (Jujnovsky *et al.* 2012), where the illegal settlements have been growing (Aguilar 2008; Aguilar and Santos 2011). Interactions also take place between the urban and rural areas in relation to food and social services: the growing urban area affects the farmers, who also suffer from scarcity of resources (water, soil, and air) produced by urbanization. Nevertheless, urban farmers also profit from urban services, such as access to education and better health care (Méndez-Lemus 2012).

A detailed description of the region between urban and peri-urban contexts should include a settlement expansion with strong population growth in Mexico City (Pérez-Campuzano and Santos-Cerquera 2013). The built-up areas of the city grow and spread towards the periphery in all directions, at the expense of nature reserves, especially in the south (Aguilar 2008; Aguilar and Santos 2011). For this reason, we are looking at the south part of the city as a research area (Figure 2). The preservation zone covers about 87.294 hectares, mainly in the south part of Mexico City. It covers about 59% of the total territory of Mexico

City offering key ecological services such as: preservation of biodiversity, regulation of local weather, water capture that recharges the City's aquifer at an average rhythm of about 151.4 million m³ annually (41% of the water consumed comes from such aquifers), the reduction of air pollutants and carbon storage (total carbon storage has been estimated at 8.5 million tons of CO₂), among others (GO-DF 2014). The population of this area is estimated at around 2.2 million, of which 700,000 (8% of the total population of Mexico City) are related to the preservation zone (Aguilar 2013). Almost 80% of the preservation zone is social property² corresponding to urban centers, agricultural zones and forest areas of the 36 rural villages settled there; 15% is privately owned (housing, commercial establishments and services) and 5% federally owned (urban canyons, water bodies and federal infrastructure such as the electric grid) (PAOT 2010). Three administrative districts comprise the main part of the preservation zone: Milpa Alta (32.2%), Tlalpan (29.4%) and Xochimilco (11.9%) (GO-DF 2014; Rodriguez *et al.* 2013). The broad, intricate and thus confusing legal framework involving the three levels of government (municipal, provincial and national levels) for the preservation zone has created a window of opportunity for ordinary citizens, property speculators and even local authorities for taking advantage or being permissive concerning law interpretation and enforcement. Therefore, the definition of the preservation zone has periodically changed, and the dividing line between preservation land and urban soil has had to be legally updated as it is overtaken by social processes (Aguilar 2013). The over-regulation, particularly, which divides the urban and preservation zones and thus the legal obligations among different regulators, has allowed the dilution or duplication of responsibilities. Consequently it is hardly surprising that between 1970 and 2010, boroughs with nature reserves increased their population by 25.54%, a rate higher than in the rest of the city's boroughs (Santos 2013). Such population increase has produced land use changes and the erosion of ecological services such as those mentioned above (GO-DF 2014). With this background, we address the research question by developing tests for the reliability and validity of remote sensing analysis in the southern part of Mexico City.

2 Three types of land property exist in Mexico: private, public and social. The latter is a consequence of the Mexican Revolution that led to the restitution of land grabbed from rural communities by landlords (which conformed the "communal land" as designated within the Constitution of 1917) and the endowment of land as a common property to Mexican peasants (which conformed the "ejidal land"). In the country 53% of land property is of the social type. In Mexico City, after urban expansion and erosion processes of land that led to land expropriations, 33,938 hectares under social property remain, mostly within the preservation zone; 25,916 *ejidatarios* and *comuneros* live there (Vargas and Martínez 1999). It is worth noting that some of the most conserved areas correspond to social property.

Assessing the problem of sustainable land use in Mexico City requires progress towards better methodological measurements which respect certain principles, in particular the principles of reliability and validity (see, for example, on the use of these principles: deMarrais and Lapan 2004; King *et al.* 1994; Singh 2007; Vaus 2002; Walliman 2006). Reliability is easy to check because there are a good number of standardized methods to prove it, such as test-retest and alternate form (Jupp 2006, 262–263). Reliability concerns the fact that using either the same measurement methods (test-retest) or the two forms of the same testing methodology to the same observed individuals (alternate form), the data provides the same results (King *et al.* 1994).³ A second principle is to maximize the validity of our measurements where validity is defined as “measuring what we think we are measuring” (King *et al.* 1994, 25). A good method of evaluation of validity is triangulation, i.e. measuring the same phenomena with various methods (deMarrais and Lapan 2004, 260).

Mexico City as case study was chosen for being historically one of the least sustainable cities in the world (Davis 1994; 2006). However, Mexico City has been presented in recent years as a pioneer in the formulation of formal and informal governmental and civil society responses to the challenges of sustainability (Aguilar 2008; Aguilar and Santos 2011). This research approach extends a growing interdisciplinary platform to promote research on a sustainable urban design (Heldens *et al.* 2011) contributing with an exploratory qualitative analysis using remote sensing for this problem.

There is abundant literature showing the potentials and shortcomings of using high-resolution data vs. Landsat imagery (Heldens *et al.* 2011); however this paper aims to test the potentials as well as the disadvantages for the case of Mexico City in specific. High-resolution images (RapidEye) have been of value for the research project because they have a higher spatial resolution (5 meters) and could provide fast, current and homogeneous data for large areas in Mexico City. Two RapidEye images (summer 2009 and end of summer 2014) with a resolution of 5 meters gave us the opportunity to show the advantages of high-resolution images compared to the Landsat images (30 meters resolution) for the observation of land use in the southern part of Mexico City. For example, although Landsat images show urban development at the expense of nature reserves, changes within the urban structure are difficult to see with the Landsat

³ In this context, it is not a minor issue that the current legal cartographic standard for decision making has been set differently for preservation of land and urbanized land; the first at a scale of 1: 20,000 and the latter at a scale of 1: 50,000 (PAOT 2010). Cartographic overlaps and range errors are thus present, aspects that certainly do not contribute to integrated land use planning.

resolution of 30 meters. Similar results were supported also by other scientists in other parts of the world (see Heldens *et al.* 2011 for a review of the literature).

Methods

An object-based image analysis method (Dupuy *et al.* 2012) was used for the observation of land conversion between 2009 and 2014. Results were then contrasted with PAOT's database on environmental and land use complaints. The total information in the PAOT's database included almost 18,000 georeferenced complaints between 2002 and 2013. This dataset could be partly downloaded from the website of the PAOT, but we asked the PAOT directly—via CEIICH, UNAM—for the complete database and they provided the file for all the available years (2002 to 2013). The PAOT collects the complaints on five basic topics: illegal land use, deterioration of green areas, waste, noise / vibrations, and animals. Anyone can start the procedure to file a PAOT complaint by phone, electronically, or in person. First, the PAOT should decide about the legal character of the complaint admitting it within 13 working days. After this admission, the PAOT generates a preliminary report in 30 working days. The complaint ends with the resolution, conciliation act, or action recommendation for other actors, such as the police or the health office. The key point for our work is that the urban expansion should produce an increase in the number of complaints about the illegal settlement within the research area.

The main land-cover types in the research area were identified by direct observation and with the help of expert's knowledge and images from Google Earth. The final set of land cover classes was selected based on two criteria: analytical feasibility and relevance according to the goal of this study. Given the small number of images available, a detailed time series analysis was not possible; therefore, the ability of identifying complex, dynamic land cover classes was limited. With these limitations in mind, and considering that the main goal of this study is to analyze the impact of urbanization on protected areas, emphasis was placed on the mapping of urban and forested areas, because these latter are often associated with protected areas. Although the forest-land cover is important to estimate the impact of urbanization on protected areas, ultimately, the effect of urban growth needs to be assessed based on the legal extent of protected areas provided by ancillary vector information. Therefore, the land cover classes included in this analysis were: urban, forest, non-forest vegetation (grassland and crops), bare soil and water.

Two tiles (IDs 1447913 and 1447914) of Rapideye 3A level products were acquired to cover the area of interest, for two dates: November 2009 and August 2014. One Landsat 5 and one Landsat 8 (path: 026, row: 047) images were also

acquired, for February 2009 and August 2014, respectively. The two RapidEye tiles were mosaicked to obtain one full coverage for each date. Landsat scenes were clipped to the size of the Rapideye mosaics. Both Landsat and Rapideye images were pre-processed with haze removal and geometric co-registration procedures as needed, to improve both their spectral and spatial accuracy.

All four images were classified with an object-based approach using E-cognition. In the case of Landsat 5, all the available seven bands were used, and for Landsat 8, bands 1-7 were selected. For the analysis of RapidEye data, all available five bands were used.

Using the multiresolution segmentation algorithm, and after trying different segmentation parameters, the optimal segment size for each of the sensors was chosen and applied as follows:

- Landsat 5: scale parameter = 10, compactness = 0.9, shape = 0.1
- Landsat 8: scale parameter = 50, compactness = 0.9, shape = 0.1
- RapidEye: scale parameter = 50, compactness = 0.5, shape = 0.1

For a definition of these parameters, see Laliberte *et al.* (2004). The classification system was trained using about 10-20 well-distributed samples for each land cover class. The following variables (object features) were used for the classification: NDVI, mean brightness, mean reflectance of each band, GLCM Homogeneity and GLCM Entropy texture algorithms in all directions.

After classification, a visual inspection was performed to assess accuracy, with the help of additional information; in some cases, a re-sampling and subsequent classification had to be performed, and in others some final manual class re-assignment was done. Most of the major differences between dates of the same sensor were observed in the vegetation classes of the Landsat images, because February (Landsat 5, 2009) is a particularly dry month in the Mexico City region, which contrasts with the wetter month of August. A semi-quantitative accuracy analysis indicated an overall accuracy of over 80%. To be able to visualize the urban growth dynamics, a post-classification change detection analysis was carried out for the RapidEye data.

The combination of remote sensing and complaints is very interesting because it represents a new form of remote sensing with statistical information. We believe the combination of remote sensing and statistical analysis has the potential to change the way that social scientists analyze social phenomena. We use this project as a concrete exploratory example of how social scientists can practically utilize remote sensing with information collected by ministries and other state offices. Census and statistical data gathering are expensive and burdensome means of collecting information. As the cost of collecting satellite imagery

continues to fall, we see a large potential to combine remote sensing with census and statistical data to generate more value about this available information.

Results

To test the reliability of Landsat and RapidEye imagery in an explorative approach, this section uses the same measurement methods of remote sensing to appreciate the differences in the results in both sources of information at the same and different points in time with different resolutions. This procedure is known as alternate-form reliability (Jupp 2006, 275) and differs from test-retest, in which the reliability is based on the different forms (RapidEye and Landsat) of the same test (remote sensing) to the same observed area in the comparison. For the case of validity, a graphic triangulation is presented (deMarras and Lapan 2004) between the measurements of land use and a database of PAOT's complaints. The objective of triangulation is to ensure that what is being measured corresponds to what is claimed to be measured.

It is clear that the higher the pixel resolution the better the image resolution will be for the reliability of alternate methods. How much better could it be? Addressing the research questions about qualitatively testing the principles of reliability and validity, Figures 3a and 3b present a comparison of a land cover classification with Landsat and RapidEye over the entire area researched in Mexico City respectively. These figures were produced by the detailed images obtained on the same day, 27.08.2014 (Landsat and RapidEye). It gives a graphical idea of the degree of improvement provided by an image with 5 meter resolution (RapidEye) in comparison with the 30 meter resolution image (Landsat). It is easy to see how the pattern of the whole picture is similar since all the big urban structures are represented in both images and, especially, the difference between urban and non-urban is clearly identifiable.

Checking for reliability in a qualitative approach, Figures 4a to 4d compare a subsample of the entire area researched, and it observes the "Parque Ecológico de Xochimilco" (Xochimilco Ecological Park) and surrounding areas. This area was chosen because it is easily identifiable and potentially useful for future field research since a good number of phenomena such as agriculture, occupation of land, and water bodies are present in this small part of the analysis. If we look at the Landsat imagery, when the analysis is scaled down in Figures 4a and 4c, some specific structures of the urbanization within the park or in the southern part of the park, are lost, for example streets and water facilities. Summing up, the limits between urban and non-urban areas, are easily recognizable in the whole research area as for example the triangular form of the "Parque Ecológico de Xochimilco" (clearly identifiable in Figures 3a and 3b). However, it

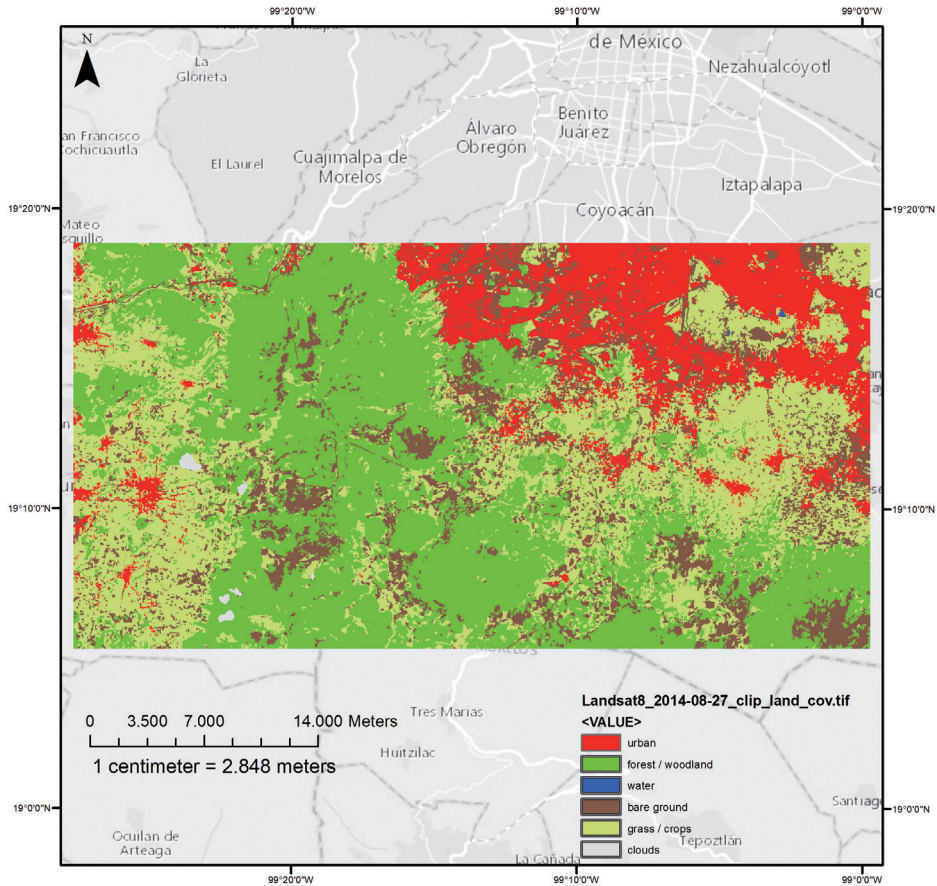


Figure 3a. Comparing the land cover classification of land use with Landsat and RapidEye on 27.08.2014 / Landsat (30 m).

is not possible to speak about the same pattern of the urban space when we are looking into a smaller territorial scale within “Parque Ecológico de Xochimilco” (see and compare 4a and 4b for 2009 and 4c and 4d for 2014). Most of the internal variation and substructures within “Parque Ecológico” (e.g. urbanization in the south of the park) disappear, and the different urban activities on the boundaries of this reserve tend to be difficult to distinguish on the Landsat imagery (see Figures 4a and 4c). Moreover, the lower resolution results in misclassification. It’s not only what you don’t see, but also what you wrongly identify. This error is due to the abundance of mixed pixels in Landsat.

In order to obtain a first validation of the results, this paper presents a

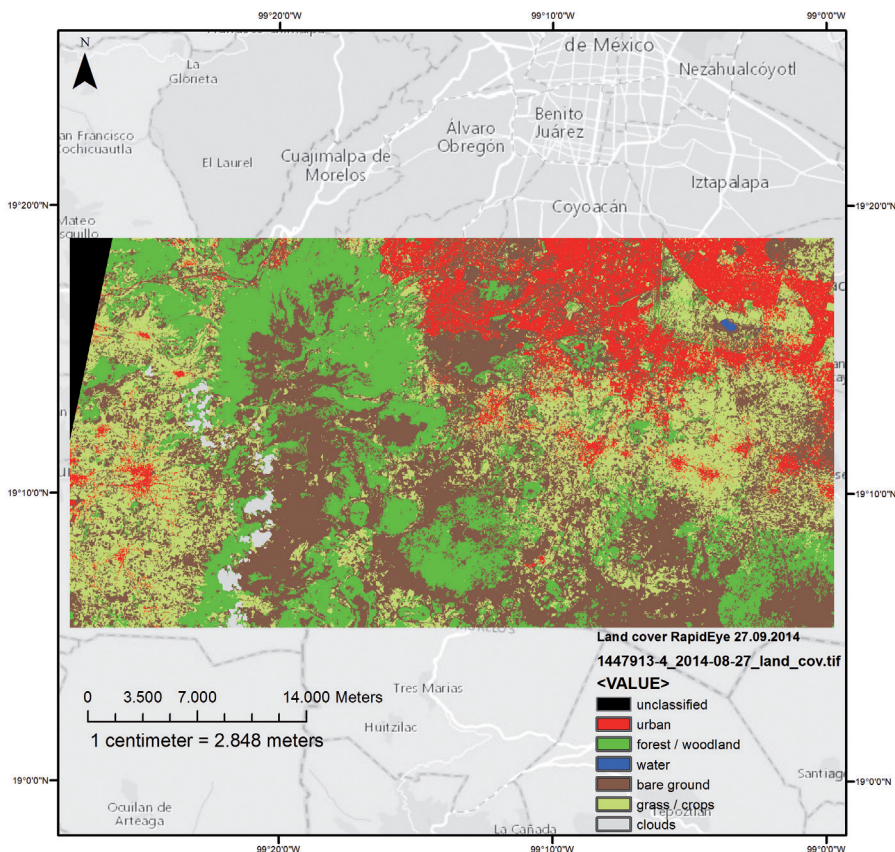


Figure 3b. Comparing the land cover classification of land use with Landsat and RapidEye on 27.08.2014 / RapidEye (5 m).

graphic triangulation of data for the changes in land use classifications between 2009 and 2014 (Figure 5a, RapidEye) and PAOT’s complaints regarding improper land use (Figure 5b) in the southern part of Mexico City. The changes between both classifications of the remote sensing area were produced by an object-based image analysis. The database of ecological complaints, as said, was obtained from PAOT. For this case, the land use change between 2009 and 2014 is used to show the ensuing pattern of urban expansion (in red, Figure 5a) in comparison with the complaints only for improper land use of protected soil (Figure 5b, dots in red). It is remarkable how the georeferenced complaints are allocated close to the new anthropogenic zones identified between 2009 and 2014 (in red, Figure 5a). Assuming that we are speaking here about the frontiers between the

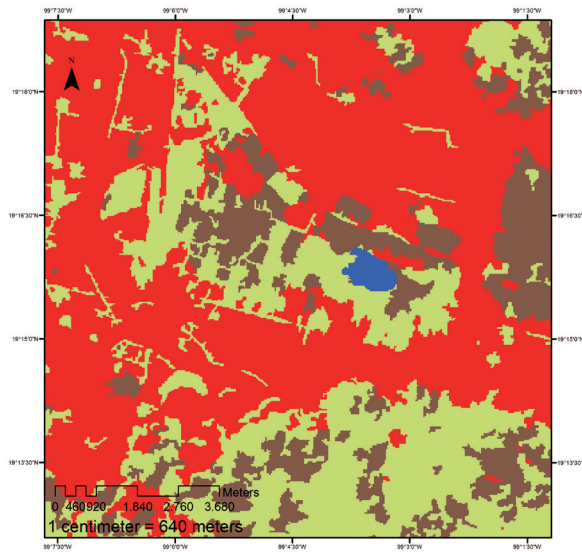


Figure 4a. Comparing the cost-effectiveness for classifications of RapidEye and Landsat Imagery.

Example: Parque Ecológico de Xochimilco / Landsat 30 m (2009).

Red: urban / Green: grass and crops / Brown: bare ground / Blue: water.

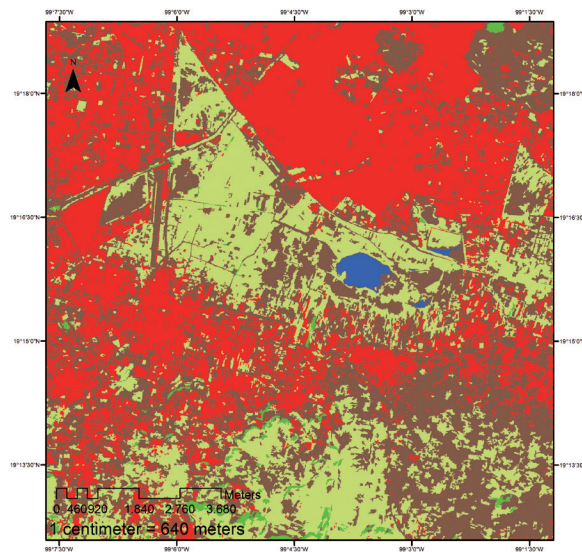


Figure 4b. Comparing the cost-effectiveness for classifications of RapidEye and Landsat Imagery.

Example: Parque Ecológico de Xochimilco / RapidEye 5 m (2009).

Red: urban / Green: grass and crops / Strong green: forest and woodland / Brown: bare ground / Blue: water.

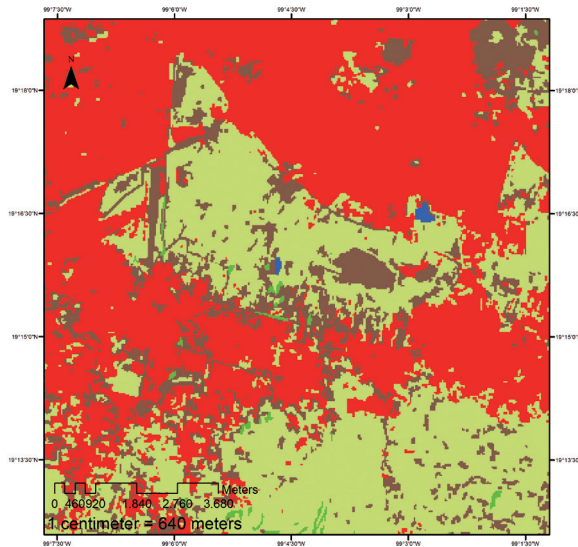


Figure 4c. Comparing the cost-effectiveness for classifications of RapidEye and Landsat Imagery. Example: Parque Ecológico de Xochimilco / Landsat 30 m (2014).
Red: urban / Green: grass and crops / Brown: bare ground / Blue: water.

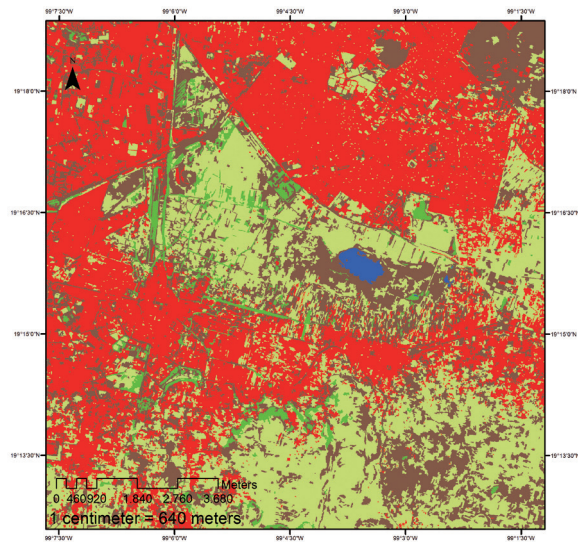


Figure 4d. Comparing the cost-effectiveness for classifications of RapidEye and Landsat Imagery. Example: Parque Ecológico de Xochimilco / RapidEye 5 m (2014).
Red: urban / Green: grass and crops / Strong green: forest and woodland / Brown: bare ground / Blue: water.

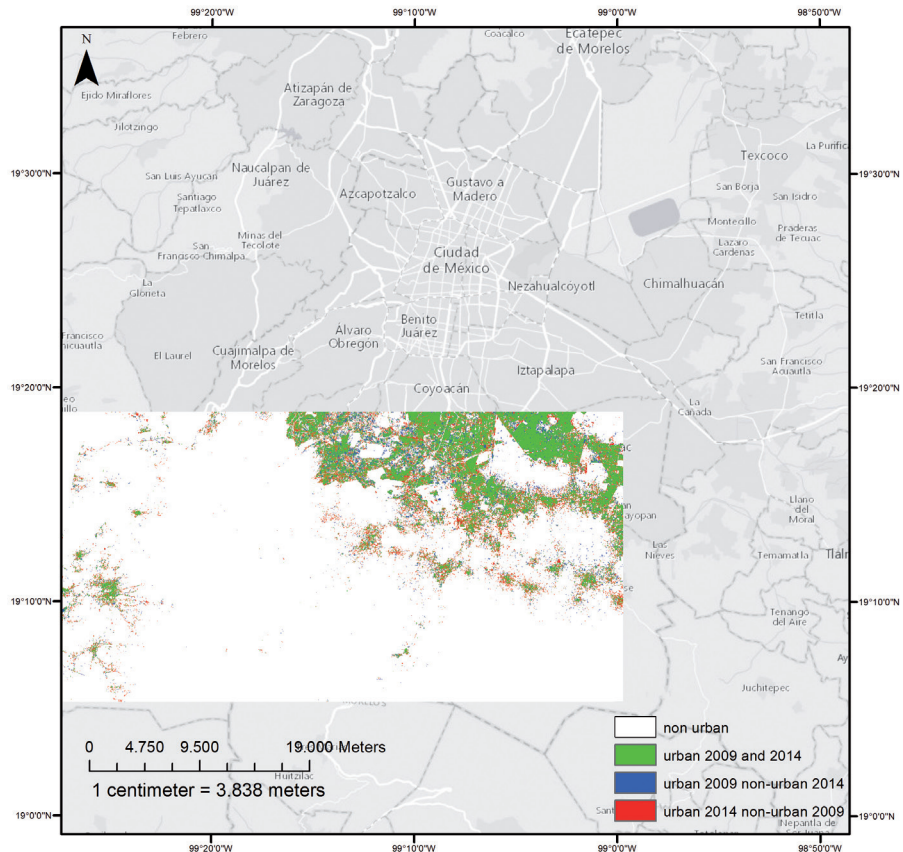


Figure 5a. Validating the results with field information / Land use change. Land use change between 2009 and 2014.

urban and the natural reserves, it is possible to observe the advance of the former over the latter. Comparing both Figures 5a and 5b, this triangulation shows the possibilities of crossing various data sources to explain the same phenomena and to offer some assurance that the observed phenomena are the same as what is claimed to be under observation. Because of space and time constraints, this analysis is merely graphic, but it would be possible to extend this to a numeric analysis.

It should be noted that the change from urban to non-urban (in blue, Figure 5a), although may be reflecting some real changes (road modifications or disappearance of buildings), it may also be partially due to an artifact of the classification, and not to an actual reversion from urban land use. Looking at an extract

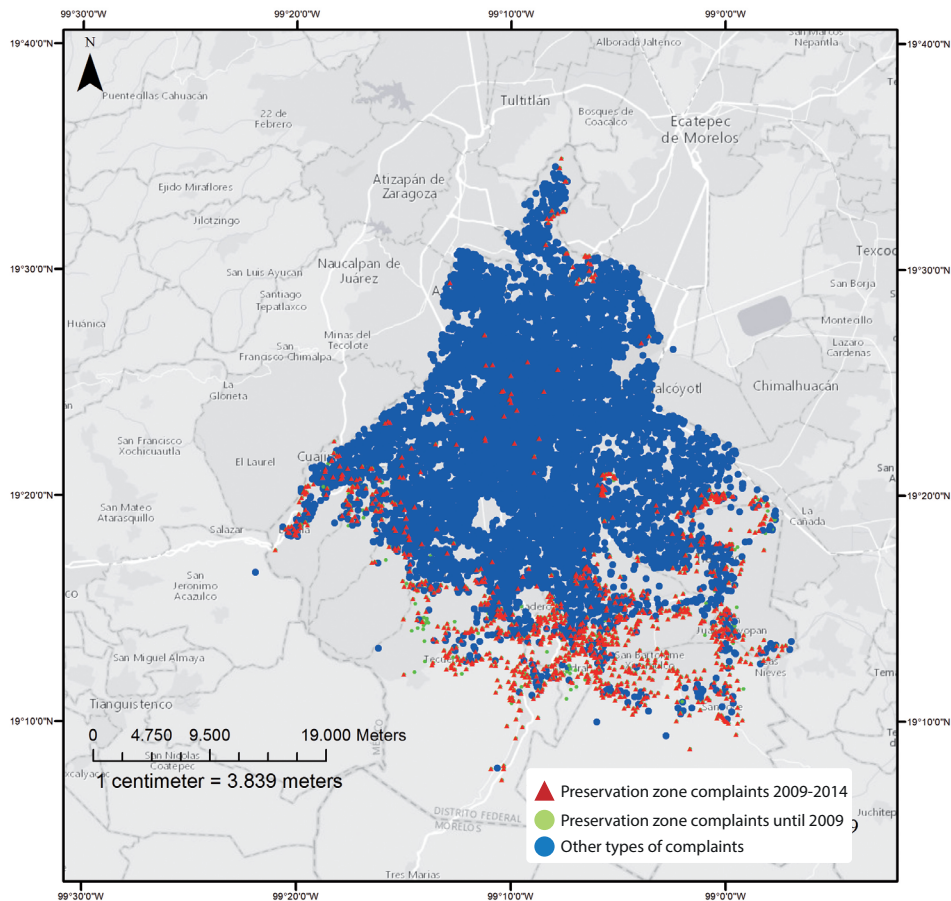


Figure 5b. Validating the results with field information / Graphic with environmental complaints (2009-2014).

of the urban expansion (see Figure 6), the fact that the newly urbanized areas (red) predominate over the urban class losses (blue) at the periphery of the stable urban cover (green), indicates that there is a clear pattern of urban expansion as expected. Additionally, urban loss areas tend to lack the typical structure of house conglomerates and streets, reinforcing the idea that these areas may be mostly due to confusion between urban land cover and other classes with high reflectance properties, such as bare soil.

The trend described above can be validated with previous data on urban expansion, for example, within the three more relevant boroughs in terms of the

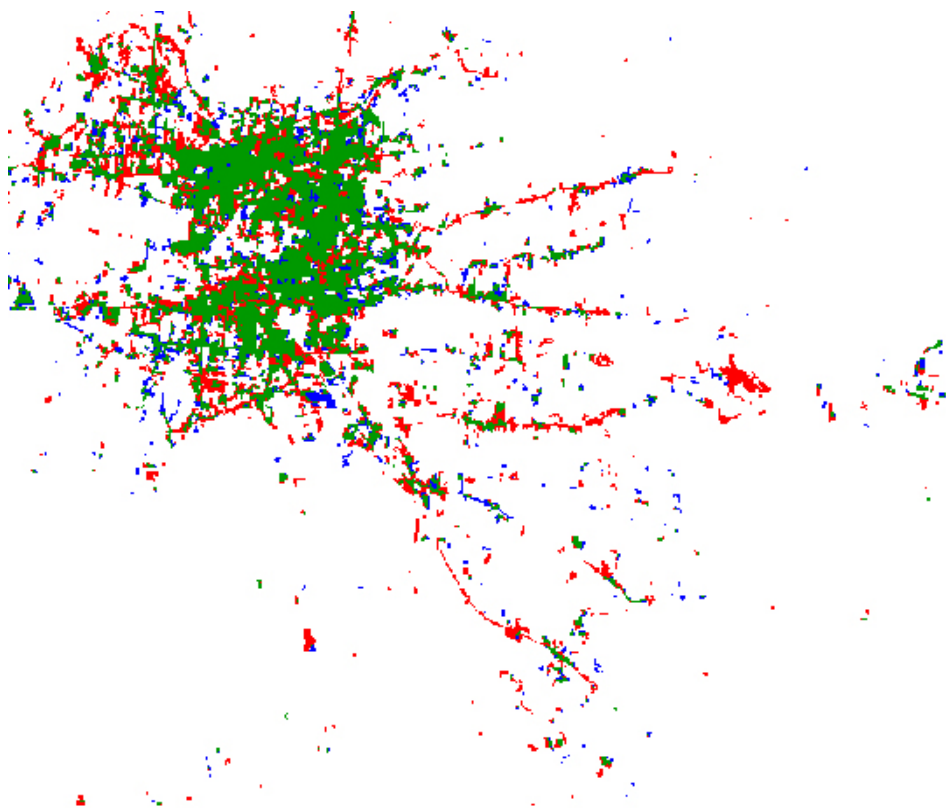


Figure 6. Pattern of urban expansion 2009 – 2014 (Extract: RapidEye).

Red: Newly urbanized areas / Blue: urban class losses / Green: stable urban cover.

nature reserves surface: from 1970 to 2007 the built environment expanded at an estimated rate of 567% in Xochimilco borough (from 346 ha to 1,963 ha), 373% in Milpa Alta borough (from 350 ha to 1,305 ha) and 1,133% in Tlalpan borough (from 194 ha to 2,195 ha) (Rodríguez *et al.* 2013). In the same time period, land dedicated to seasonal agriculture diminished 32.2% while grassland surface did the same by 9.4% (Ibid).

Discussion of results

The interdisciplinary discussion of sustainable land use increases the need for reliability and validity of the remote sensing observation in the south of Mexico City and its integration to other analyses of socioeconomic and policy nature. It

is key to find the appropriate scale between the resolution of the pixel and image size of remote sensing, as the more precise the resolution of the pixel in meters is, the more images are required for the same mapping (Griffiths *et al.* 2010; Heldens *et al.* 2011). This is relevant when the information is expensive to obtain. Therefore, the pixel should be neither too large nor too small to capture the phenomena with a minimal number of images. Landsat imagery is a possibility since it has been used on many occasions and it is relatively easy to obtain with open access. There is also a variety of possibilities with higher resolution but with costly access. RapidEye is an example of this, with a better resolution of 5 meters and being more suitable to study our question of urban development. Other possible services are Ikonos, Quickbird, and GeoEye. For the analyzed case, the resolution of 5 meters allows an adequate tradeoff between the number of images and resolution, and this is illustrated by the fact that the images covered 80% (estimated) of the nature reserve base with the RapidEye Title IDs 1447914 and 1447913. On the other hand, the cost constraints are a reality and these could be estimated between \$2 and \$30 per km² (GOFC-GOLD 2014, 28). In the specific case of the research here presented, the imagery of RapidEye would have a cost of around €1000 for every observation. Nevertheless, prices of remote sensing imagery have been falling continuously in the past, and it has been possible to obtain this information for free by writing a scientific proposal, as in the case of RESA program (RapidEye Science Archive) or Copernicus (European Programme for Earth Observation).⁴ It is important to clarify that the high-resolution images have been obtained, without charge, through the agreement of DLR (German Space Association) and Blackbridge (producer and distributor of RapidEye data), which became possible with an affiliation to a German research institution within the RESA program.

The importance of the results of this paper relates to the growth of the urban space over nature (Figure 5a) and this opens several discussions. First, growing urban space has put a high demand on resources as revealed by the literature (Aguilar 2008; Aguilar and Santos 2011; GO-DF 2014). Since Mexico City depends on the water flowing from outside the urban space (e.g., the Magdalena River south of Mexico City), active water management is needed to maintain the water supply and the ecosystem (Burns 2009; Jiménez *et al.* 2011; Delgado Ramos 2015), as said, especially in the southern area where most of the preservation zone or nature reserves are located. Second, the management of food production is also essential in urban expansion as producers change from rural to urban farmers (Méndez-Lemus 2012) but also as agricultural land is urbanized.

4 For more information on the RESA program see: <http://resaweb.dlr.de> And for Copernicus, see: www.copernicus.eu

Although the results of the transformations in a growing megacity can negatively affect the farmers on the borderland, who can suffer from a scarcity of resources (water, soil, and air) produced by urbanization, they can also profit from urban services, such as access to education and better health care (Méndez-Lemus 2012). Such interactions affect both the rural and peri-urban areas. We observe a spatial heterogeneity in the effects of keeping traditional agriculture or changing to a more intensive form of industrial agriculture with its associated environmental impact (Torres-Lima and Rodríguez-Sánchez 2008). The analysis of the presented imagery is precise about the differences between the urban and non-urban areas, but we should work with more field information to better calibrate the identification between forests / woodland and the other two biological land cover classes (bare ground and grass / crops) to better measure the ecological services in future research. While bare ground and grass / crops could not be unambiguously defined, the main areas of dense forest were accurately mapped.

As a third point, the other significant topic is socio-environmental conflicts (from PAOT's complaints analysis), particularly in between the urban and non-urban areas, all in an increasing national violent context (Davis 1994; Marshall and Cole 2014; Delgado 2015). The democratization of the system during this century—via conventional representative democracy—has not helped to reverse this situation (Davis 2006). Therefore, the nexus between urban environmental conflicts, land use and democracy is another area into which the research about this specific case might be extended by developing interdisciplinary research based on an urban political ecology approach (Loftus 2012; Rossi and Vanolo 2012; Swyngedouw *et al.* 2005); an effort that would be even more desirable if it is expanded at a metropolitan and regional scale, since the rapid megalopolization process experienced in the whole center of the country—which includes the Metropolitan Area of Mexico City and surrounding cities such as Toluca, Pachuca, Puebla and Cuernavaca—is amply recognized.

Last but not least, a discussion about the ethical dimensions of big data and the protection of civil rights is both relevant and needed. If remote sensing is to be adopted in the social sciences, a more intensive discussion about its use and its ethical and moral implications should be addressed.

Conclusions

This paper compared the case of the Mexico City region based on freely available images (Landsat) and high-resolution imagery (RapidEye) from a qualitative reliability and validity perspective. It came to the conclusion that the resolution of the free imagery available for the assessment of urban development on the

structural level of land use is not sufficient to identify the development of specific parts of the city. For example, in our case study (Figures 4a to 4d), the Landsat images (Figures 4a and 4c) show urban development at the expense of the nature reserves of the “Parque Ecológico de Xochimilco.” Despite the fact that the general pattern of changes in land use is observable, changes within the urban structure are difficult to see with a resolution of 30 meters in the Landsat images. Urban growth assessment problems, or change detection at the district or neighborhood level as problems related to the urban space can only be addressed with high-resolution imagery. However, high-resolution imagery is costly. Although it is becoming cheaper and more accessible, it is not free.

This paper raises some limitations. Remote sensing permits the identification of anthropogenic land use, but the differences within non-anthropogenic land use, e.g. between grass or crops and bare ground, are more complex to identify and more field information is needed.

In the end, the four analyzed tiles that conform the two images (for the years 2009 and 2014) with a resolution of 5 meters, gave us the opportunity to show the advantages of these high-resolution images compared to the Landsat images for our future research about sustainable urban development in the south of Mexico City. Other topics, such as urban and peri-urban resource relationships, environmental conflicts or the urban political ecology in play, and the ethical implications of remote sensing, will be addressed in the future.

The above said seems to be increasingly relevant to better inform local authorities, and thus for a democratic—even participatory—decision making process; certainly, aspects of increasing importance like socioecological and climate impacts appear to worsen, and urgent and renovated actions are needed to confront a rapidly changing reality.

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