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TESIS DOCTORAL

Cityscape, poverty and crime: A quantitative assessment using VHR imagery

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This work starts by reviewing the potential applications of satellite remote sensing to regional science research in urban settings. Regional science is the study of social problems that have a spatial dimension (Isard, 1975; Isserman, 2004). The availability of satellite remote sensing data has increased significantly in the last two decades, and these data constitute a useful data source for mapping the composition of urban settings and analyzing changes over time (Weng & Quattrochi, 2006). The increasing spatial resolution of commercial satellite imagery has influenced the emergence of new research and applications of regional science in urban settlements because it is now possible to identify individual objects of the urban fabric (Sliuzas *et al.,* 2010).

Although the variables of interest for regional scientists are not directly measured from the air, remote sensing can measure the context of social phenomena and their effects on the land surface (Rindfuss & Stern, 1998). The relationships between urban land cover and other environmental factors and the variables that describe socioeconomic conditions have been explored since the late 1950s with the use of aerial photography (Green, 1956, 1957). Research in the last three decades has explored the use of satellite remote sensing to characterize these relationships at a lower cost. In the urban environment, these relationships are based on the concept that the physical appearance of an urban settlement is a reflection of the society that created it and on the assumption that people living in urban areas with similar physical housing conditions will have similar social and demographic characteristics (Jain, 2008; Taubenböck *et al.,* 2009).

The most common applications found in the literature are the detection of urban deprivation hot spots (Barros, 2008; Hofmann *et al.*, 2008; Kohli *et al.,* 2012), quality of life index assessment (Forster, 1983; Lo, 1997; Jensen *et al.,* 2004), urban growth analysis (Rashed *et al.,* 2005; Doll, 2008; Doxani *et al.,* 2012), house value estimation (Jensen *et al.,* 2004; Yu & Wu, 2006; Taubenböck *et al.,* 2009), urban population estimation (Jensen & Cowen, 1999; Pozzi & Small, 2005; Liu *et al.,* 2006), urban social vulnerability assessment (Rashed *et al.,* 2007; Taubenböck *et al.,* 2008; Ebert *et al.,* 2009), and the variability of intra-urban crime rates (Kuo & Sullivan, 2001; Browning *et al.,* 2010; Donovan & Prestemon, 2012).

The satellite remote sensing imagery used in these applications has medium, high or very high spatial resolution, such as images from Landsat MSS, Landsat TM and ETM+, SPOT, ASTER, IRS, Ikonos and QuickBird. Consistent relationships between socio-economic variables derived from censuses and field surveys and proxy variables of vegetation coverage measured from satellite remote sensing data have been found in several cities in the US (Mennis, 2006; Jenerette *et al.,* 2007; Li & Weng, 2007). Different approaches and techniques have been applied successfully around the world, but local research is always needed to account for the unique elements of each place. Spectral mixture analysis, object-oriented classifications and image texture measures are some of the techniques of image processing that have been implemented with good results (Patino & Duque, 2013). Many regional scientists remain skeptical that satellite remote sensing will produce useful information for their work. More local research is needed to demonstrate the real potential and utility of satellite remote sensing for regional science in urban environments.

The second part of this work focuses on data manipulation and extraction of urban fabric descriptors from a very high spatial resolution (VHR) image, and the integration with socioeconomic data at object level. We extract information on land cover composition using per-pixel classification and on urban texture and structure using an automated tool for texture and structure feature extraction at object level (Ruiz *et al.,* 2011). We use data from Medellin (Colombia), which is the second larger city in the country, and it has been one of the most violent cities in the world in past decades and is still one of the most socioeconomically divergent (Duque *et al.,* 2013a). This city is a useful location for conducting intra-urban variability studies because it has experienced high population growth rates since the 1950s, and the unplanned urban growth in some parts of the city resulted in a high degree of spatial heterogeneity in both the socioeconomic and physical characteristics of its neighborhoods.

The third part of this work contributes empirical evidence about the usefulness of remote sensing imagery to quantify the degree of poverty at the intra-urban scale. This concept is based on two premises: first, that the physical appearance of an urban settlement is a reflection of the society; and second, that the people who reside in urban areas with similar physical housing conditions have similar social and demographic characteristics (Jain, 2008; Taubenböck *et al.,* 2009). We evaluate the potential of the image-derived urban fabric descriptors to explain a measure of poverty known

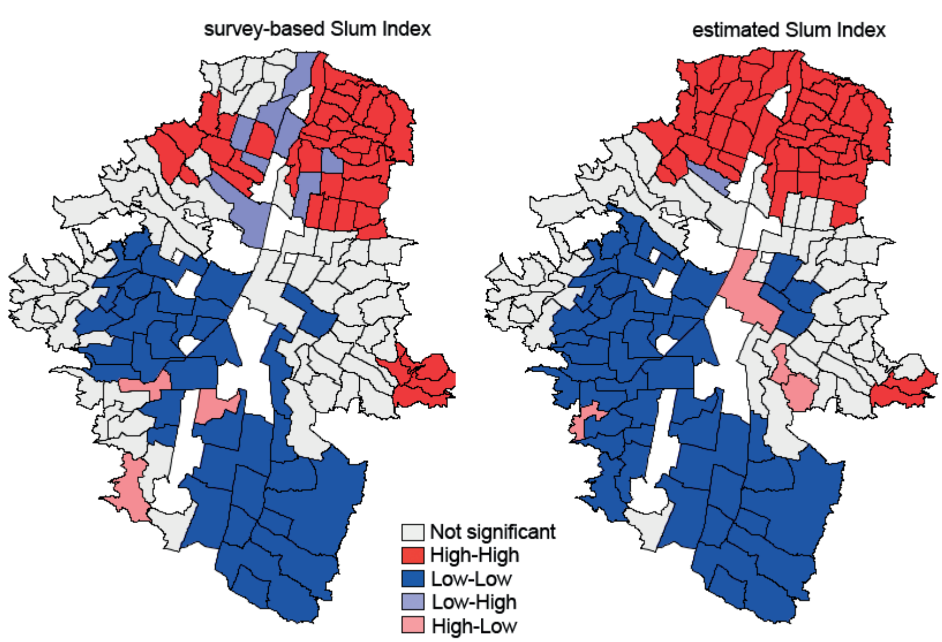

Figure 1. LISA maps of survey based Slum index (left) *vs*. estimated Slum index from image-derived variables.

as the Slum Index (Weeks *et al.,* 2007). We found that these variables can explain up to 59% of the variability in the Slum Index in Medellin, Colombia. Similar approaches could be used to lower the cost of socioeconomic surveys by developing an econometric model from a sample and applying that model to the rest of the city and to perform intercensal or intersurvey estimates of intra-urban Slum Index maps (Duque *et al.,* 2015, 2013b). Figure 1 shows the spatial clusters of high and low values of the Slum index across the city computed from survey data vs. computed from image-derived data. Spatial clusters of high values, showed in red, indicate areas of concentrated poverty, while spatial clusters of low values, showed in blue, indicate areas of concentrated affluence.

Figure 2. Square image tiles (500×500 meters) organized from left to right according to increasing values of the best performing remote sensing variables in homicide model specification. From top to bottom: percentage of impervious surfaces other than clay roofs (P.OTHER.IMP.S), fraction of clay roofs within impervious surfaces (F.CLAYR.IMPS), structure variables SDT and SDF, and texture variable uniformity (UNIFOR).

The last part of this work analyzes the relation between the urban layout and crime. The link between place and crime is at the base of social ecology theories of crime that focus in the relationship of the characteristics of geographical areas and crime rates (Anselin *et al.,* 2000; Cullen & Agnew, 2011). The broken windows theory states that visible cues of physical and social disorder in a neighborhood can lead to an increase in more serious crime (Shaw & McKay, 1942; Wilson & Kelling, 1982). The crime prevention through environmental design (CPTED) planning approach seeks to deter criminal behavior by creating defensible spaces (Cozens, 2008). Based on the premise that a settlement's appearance is a reflection of the society, we ask whether a neighborhood's design has a quantifiable imprint when seen from space using urban fabric descriptors computed from VHR imagery.

We tested which land cover, structure and texture descriptors were significantly related to intra-urban homicide rates in Medellin, Colombia, while controlling for socioeconomic confounders. The percentage of impervious surfaces other than clay roofs, the fraction of clay roofs to impervious surfaces, two structure descriptors related to the homogeneity of the urban layout, and the uniformity texture descriptor were all statistically significant. Figure 2 shows square image tiles of urban areas that have different values of the best performing remote sensing variables in model specification. Areas with higher homicide rates tended to have higher local variation and less general homogeneity; that is, the urban layouts were more crowded and cluttered, with small dwellings with different roofing materials located in close proximity to one another, and these regions often lacked other homogeneous surfaces such as open green spaces, wide roads, or large facilities. These results seem to be in agreement with the broken windows theory and CPTED in the sense that more heterogeneous and disordered urban layouts are associated with higher homicide rates (Patino *et al.,* 2014).

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