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Research Paper

Measuring intra-urban poverty using land cover and texture metrics derived from remote sensing data

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HIGHLIGHTS

- We quantify intra-urban poverty index from remote sensing metrics in Medellin, Colombia.
- This low-cost approach benefits cities where survey data is scarce or nonexistent.
- We analyze land cover, structure and texture descriptors computed from a VHR image.
- Remote sensing variables explain 59% of the variation of Slum Index.

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ABSTRACT

This paper 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. We use a very high spatial resolution (VHR) image from one of the most socioeconomically divergent cities in the world, Medellin (Colombia), to 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. We evaluate the potential of these descriptors to explain a measure of poverty known as the Slum Index. We found that these variables explain up to 59% of the variability in the Slum Index. 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.

1. Introduction

The majority of the global population today is urban. The percentage of urban dwellers increased from 43% in 1990 to 52% in 2011, and it is expected to grow to 67% by 2050 (United Nations, 2007, 2008, 2012). All population growth from 2011 to 2050 is expected to be absorbed by urban areas, and most of this growth will occur in cities of less developed regions (United Nations, 2012). In developing countries, rapid urban growth normally exceeds the capacity for local governments to deliver services and infrastructure, which increases urban poverty and intra-urban inequalities (Duque, Royuela, & Noreña, 2013).

The monitoring of poverty is a key issue for policy makers because it can help prevent poverty traps and crime nests and allocate public investments where they are needed most (Duque et al., 2013). Urban poverty is a multidimensional phenomenon; as such, there are many ways to measure it. These measures usually include information from at least one of the following dimensions: income/consumption, health/education, and housing (Carr-Hill & Chalmers-Dixon, 2005; Moser, 1998). They are computed from survey or census data, which are quite expensive, time consuming, less frequently produced, and often statistically significant for spatial units that are too large to capture the intra-urban variability of phenomena. This last feature creates inference problems such as the ecological fallacy (Baud, Kuffer, Pfeffer, Sliuzas, & Karuppannan, 2010; Robinson, 1950) or aggregation bias (Fotheringham & Wong, 1991; Paelinck & Klaassen, 1979).

This study works toward overcoming these problems by exploring the possibility of using remote sensing imagery to measure

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urban poverty. This proposal is based on the premise that the physical appearance of a human settlement is a reflection of the society in which it was created and on the assumption that people living in urban areas with similar physical housing conditions have similar social and demographic characteristics (Jain, 2008; Taubenböck et al., 2009). The main advantage of using remote sensing imagery for urban poverty quantification is that this type of data can be obtained faster, at higher frequencies, and for a fraction of the cost required for field surveys and censuses. Poverty mapping usually follows two types of approaches: the expenditure-based econometric approach linked to a poverty line used by World Bank, and the value-focused approach used by United Nations Development Programme (UNDP) based on the Human Development Index (Baud, Pfeffer, Sridharan, & Nainan, 2009). The Index of Multiple Deprivations (Baud, Sridharan, & Pfeffer, 2008), the Slum Index (Weeks, Hill, Stow, Getis, & Fugate, 2007), and the Slum Severity Index (Patel, Koizumi, & Crooks, 2014) all follow the value-focused approach that integrates several dimensions of deprivation in one single measure.

We chose the Slum Index to corroborate this possibility because this measure is based on the physical aspects of dwelling units. A slum household is defined as a group of individuals living under the same roof in an urban area that lacks one or more of the following: durable housing of a permanent nature, sufficient living space (not more than three people sharing the same room), easy access to safe water at sufficient amounts and at an affordable price, access to adequate sanitation in the form of a private or public toilet shared by a reasonable number of people, and security of tenure (UN-Habitat, 2006). Weeks et al. (2007) presented the calculation of the Slum Index from census and survey data as the sum of the fractions of households that lack one or more of the five conditions mentioned above. The value can range from 0, meaning that no slum-like households are present in an area, to 5, where all households in an area lack all five of the features defined by UN-Habitat. The proportion of slum dwellers in cities is strongly correlated with the Human Development Index, which integrates three development indicators: per capita GDP, longevity and educational attainment (UN-Habitat, 2003). Thus, the presence of slums in a city is an indicator of poverty, and the Slum Index is a good proxy variable for urban poverty at the intra-urban level. This paper implements spatial econometric models using data from Medellin (one of the most unequal cities in the world) to assess whether the Slum Index can be estimated using image-derived measures.

Weeks et al. (2007) and Stoler et al. (2012) used land cover descriptors and texture measures from medium to very high spatial resolution satellite imagery to develop spatial econometric models for predicting the Slum Index as a function of remote sensing-derived variables. This work builds on these previous studies by analyzing a wider set of remote sensing variables on land cover composition, image texture and urban layout spatial pattern descriptors to provide empirical evidence that either supports or refutes the hypothesis that remote sensing could be used to estimate the Slum Index at the intra-urban scale. As our intention was to lower the costs of this approach as much as possible, we use data drawn from an RGB composition of a Quickbird scene with a spatial resolution of 0.60 m captured in May of 2008. The imagery is similar in color and spatial resolution to Google Earth and Microsoft Bing images (Quickbird is a commercial Earth-observation satellite that collects very high spatial resolution -VHR- imagery). Although the conclusions of this exercise may not be valid worldwide, we seek to present new, innovative and low-cost means of measuring urban poverty.

The structure of this paper is as follows: Section 2 describes the spatial unit of analysis, the socioeconomic data for Slum Index calculation, the remote sensing data and variables derived from it and the statistical analysis for model specification. The results are presented in Section 3, and the subsequent discussion is presented in Section 4. Section 5 presents the main conclusions and public policy implications of this line of research for local governments and authorities.

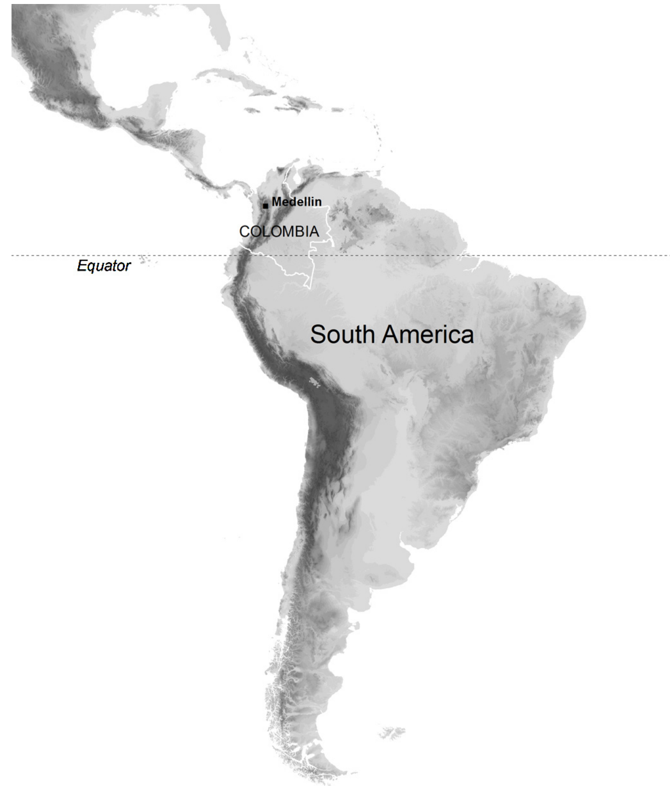

Fig. 1. Location of Medellin in Colombia and South America.

2. Methods

2.1. Spatial unit of analysis

Located in the northwestern Colombia (Fig. 1), Medellin is the second largest city in Colombia with a population of 2.4 million (DANE, 2012). The urban area of Medellin has two levels of administrative spatial units: communes (16) and neighborhoods (243). The Slum Index is typically reported at the commune level from socioeconomic data available in the Quality of Life Survey (whose sampling process is designed to be representative at this spatial scale). There are two main disadvantages to using communes as the spatial unit of analysis. First, these units are too large for studying the spatial patterns of intra-urban poverty levels. Second, the statistical inference based on large administrative units may be affected by aggregation problems such as the ecological fallacy (Robinson, 1950) and aggregation bias (Amrhein & Flowerdew, 1992; Fotheringham & Wong, 1991; Paelinck, 2000). In 2007, the average number of surveyed households at the neighborhood level was 84 ± 57, with values ranging from 3 to 296, and 15.64% of the neighborhoods contained less than 30 surveyed households. Working with such administrative neighborhoods can result in the following three problems: a lack of statistical validity, a small numbers problem for rates calculation (Diehr, 1984), and the potential appearance of spurious spatial autocorrelation (Weeks et al., 2007).

An alternative means of addressing the problems described above involves the use of analytical regions, which are spatial units fulfilling specific criteria (e.g., size, shape, attribute homogeneity, among others) that are relevant to the phenomena of study (Duque,