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The development of a morphological unplanned settlement index using very-high-resolution (VHR) imagery

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ABSTRACT

Spatial metrics combined with spectral information extracted from very-high-resolution (VHR) imagery allow quantification of the general spatial characteristics of urban areas, as well as specific morphological features (i.e., density, size, and pattern) of unplanned settlements. Such morphological features are visible in VHR imagery, but they are challenging to quantify. Still, quantification of the morphological differences between planned and unplanned areas is an important step towards automatic extraction of unplanned areas from VHR imagery. In this work, we discuss how image segmentation assists in the extraction of homogenous urban patches (HUPs), and use spatial metrics to quantify the morphological differences between planned and unplanned HUPs. A set of spatial metrics meaningful to describe morphological features of unplanned areas is selected and combined into an unplanned settlement index (USI) using a multi-criteria evaluation approach. Two case study areas are used to test the USI, i.e., Dar es Salaam, Tanzania, and New Delhi, India. The ability of the developed USI to extract unplanned areas is confirmed via visual comparison with existing land use data, and a quantitative accuracy assessment shows that areas of high USI coincide well with unplanned areas in the reference data. The quantitative accuracy assessment presents an accuracy of greater than 70% for five selected test areas in both cities.

1. Introduction

The morphology of planned and unplanned built-up areas of cities in developing countries often shows distinct differences. An unplanned area is commonly developed without planning provisions and is often associated with informality, overcrowding, insufficient infrastructure provision, poor housing quality, and haphazard layout (UN-Habitat, 2010). Information on the extent and nature of such areas is commonly unavailable and frequently displays poor temporal accuracy and consistency (Herold, Goldstein, & Clarke, 2003). The development of methods for mapping such areas, which can be diverse in nature and present rapid growth, is addressed as a challenge in many previous studies (e.g., Kit, Lüdeke, & Reckien, 2012; Taubenböck & Kraff, 2014). The amount of unplanned areas differs across cities and (developing) countries but, this is an issue in the majority of large cities in developing countries, and the extent of unplanned areas commonly ranges between 30% and 60% of the total urban areas (Busgeeth, Brits, & Whisken, 2008). In fact, in certain Sub-Saharan African cities, the amount of unplanned urban land can drastically surpass the quantity of planned land (Kombe, 2005). Unplanned settlements continue to be a prominent feature in many urban regions, with notably high growth rates observed in the urban periphery (UN-Habitat, 2009).

Mapping and monitoring of unplanned settlements require the development of methods and tools that are both effective and low in cost. As such, good and reliable data and derived information that is easily accessible and timely are important for better management of unplanned urban development (Turkstra & Raithelhuber, 2004). Furthermore, a good understanding of the spatial characteristics of unplanned areas is essential for detecting and/or analysing these areas (Kuffer & Barros, 2011). In very-high-resolution (VHR) imagery (e.g., as shown in Fig. 1), unplanned settlements can be visually identified by an organic layout and densely clustered buildings, whereas transitional areas or areas that have undergone regularisation or newly unplanned settlements on the outskirts will display more complex and ambiguous spatial characteristics.

In this research, we use the term 'unplanned' because it refers to the spatial development process of the settlements, in which building occurs without zoning, site planning, and service

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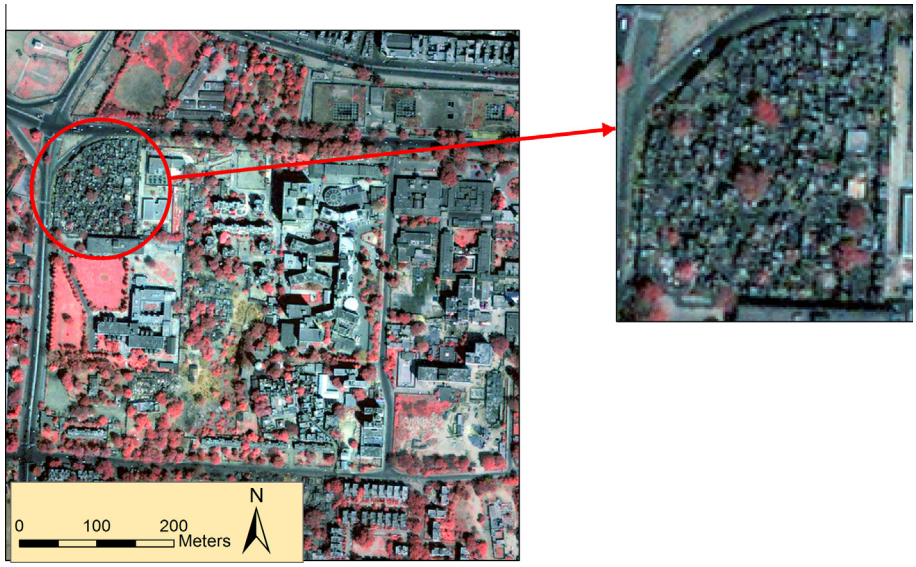

Fig. 1. Example of a false-colour VHR image (Delhi); unplanned settlement (right), (Ikonos 2001).

provision and commonly results in irregular layout patterns that do not conform to planning standards. Other related terms (i.e., informal, spontaneous, illegal, squatter settlements, and slums) have different connotations, and certain of them relate to the tenure or legal status of the settlement, which are characteristics that cannot be captured directly from remotely sensed imagery.

The morphology of unplanned areas displays an organic pattern; these areas are typically more irregular, complex, and diverse and are often more densely built than planned areas (Kit et al., 2012; Kostof, 1991; Weeks, Hill, Stow, Getis, & Fugate, 2007). In addition, such settlements tend to have irregular shaped streets (or pathways) layouts and contain significantly smaller dwellings than planned areas (Kohli, Sliuzas, Kerle, & Stein, 2012). In contrast, planned areas normally contain regular street layouts, larger buildings, and planned open spaces (Kostof, 1991). In the current study, three of these inherent morphological characteristics are used for identification of unplanned settlements in VHR imagery:

(a) Lack of planned road infrastructure causes a more organic **pattern**. The lack of space for urban infrastructure as an outcome of the development of individual dwellings results in an unclear or non-existent road infrastructure (Lemma, Sliuzas, & Kuffer, 2006), which clearly differentiates these areas from planned areas (e.g., Fig. 2-right).

(b) Noncompliance with planning standards causes high building **densities**. In other words, non-compliance with setback rules leads to insufficient spacing between individual buildings (e.g., Fig. 2-left). In their study of Mumbai, Taubenböck and Kraff (2014) found significantly higher densities in slums than in formal settlements. They also found differences in buildings size and height, distance between buildings, and proposed a heterogeneity index that allowed for identifying slum from non-slum areas. Similarly, Rakodi and Lloyd-Jones (2002) found a relationship between high-density settlements and a lack of physical capital (basic infrastructure, e.g., shelter, water, electricity) in households in such areas (for information on household capital assets, see Moser, 1998). However, there is evidence that high densities are also found in low-moderate income (formal) areas as demonstrated by Amato (1970). In his study of four Latin American cities (i.e., Lima, Quito, Santiago, and Bogota) he concluded that middle income groups live in areas of high

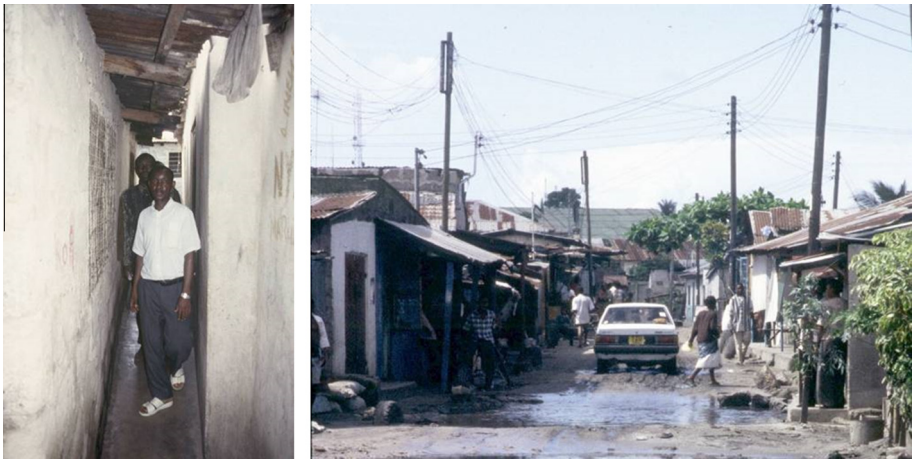

Fig. 2. Unplanned areas in Dar es Salaam; setback between adjacent buildings (left) and street view of the area (right).