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Texture-based identification of urban slums in Hyderabad, India using remote sensing data

Oleksandr Kit*, Matthias Lüdeke [1], Diana Reckien [2]

Potsdam Institute for Climate Impact Research, P.O. Box 60 12 03, 14412 Potsdam, Germany

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ABSTRACT

This paper outlines a methodology to identify informal settlements out of high resolution satellite imagery using the concept of lacunarity. Principal component analysis and line detection algorithms were applied alternatively to obtain a high resolution binary representation of the city of Hyderabad, India and used to calculate lacunarity values over a 60 × 60 m grid. A number of ground truthing areas were used to classify the resulting datasets and to identify lacunarity ranges which are typical for settlement types that combine high density housing and small dwelling size – features characteristic for urban slums in India. It was discovered that the line detection algorithm is advantageous over principal component analysis in providing suitable binary datasets for lacunarity analysis as it is less sensitive to spectral variability within mosaicked imagery. The resulting slum location map constitutes an efficient tool in identifying particularly overcrowded areas of the city and can be used as a reliable source in vulnerability and resilience assessments at a later stage. The proposed methodology allows for rapid analysis and comparison of multi-temporal data and can be applied on many developing urban agglomerations around the world.

Introduction

The rapid advance of urbanisation throughout the world has caused the first ever prevalence of the number of people living in urban settlements than in rural ones (UN, 2009), an increase of 10% or approximately 500 million people from 1990. This phenomenon essentially marks a new stage in the pace of urban development. Such a high rate of urbanisation is often unaccompanied by adequate development of infrastructure, be it housing, transport or utility grids, particularly in the developing world, where most of the urbanisation takes place. Together with the large share of informal low-paid employment, this process extraordinarily contributes to the growth of informal settlements (UN, 2009).

Generally, urbanisation can lead to both, the growth of informal as well as formal urban settlements, of low-, medium- and potentially upper class housing. 'Slum' has become a term to uniformly refer to the large variety of high-density, vastly developing, lower class residential areas with small dwelling unit sizes found in the cities of the developing world, although no common definition across countries exists and some countries lack a definition at all.

The UN Data Glossary (UN, 2011) attempts a common definition but remains rather broad by defining slums as "areas of older housing that are deteriorating in the sense of their being underserviced, overcrowded and dilapidated", whereas the UN HABITAT (UN, 2006) defines slums as households that "lack any one of the following five elements:

1. durability of housing (permanent and adequate structure in non-hazardous location),
2. sufficient living area (not more than two people sharing the same room),
3. access to improved water (access to sufficient amount of water for family use, at an affordable price, available to household members without being subject to extreme effort),
4. access to improved sanitation (access to an excreta disposal system, either in the form of a private toilet or a public toilet shared with a reasonable number of people),
5. security of tenure (evidence of documentation to prove secure tenure status or de facto or perceived protection from evictions).

Abbreviations: HMDA, Hyderabad Municipal Development Authority; MCH, Municipal Corporation of Hyderabad; HUDA, Hyderabad Urban Development Authority; HUA, Hyderabad Urban Agglomeration; INR, Indian Rupee.

* Corresponding author. Tel.: +4933128820718; fax: +49 3128820709.
E-mail addresses: okit@pik-potsdam.de (O. Kit), luedeke@pik-potsdam.de (M. Lüdeke), reckien@pik-potsdam.de (D. Reckien).
[1] Tel.: +49 331 2882578; fax: +49 331 28820709.
[2] Tel.: +49 331 2882628; fax: +49 331 28820709.

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The UN provides general updates on the issue in its "State of the World's Cities Reports", and UN HABITAT dedicated a whole volume to the challenge of slums in 2003 (UN, 2003). More recent estimates give a slum population of about 16% of the world's population (UN, 2009), with India officially scoring below average with 6% slum population (GoI, 2010b) despite the fact that the UN HABITAT definition is stricter than the one applied in India.

In India, slums can be either formally authorised by the city authority or can sprout informally. The designation of a residential area as a slum comes with a certain degree of security and access to facilities, and is necessary to benefit from additional government services and basic infrastructure in return. Slums normally start as informal settlements and are eventually approved after a long time of informal existence. Following definitions of slum areas are used in India:

1. All specified areas in a town or city notified as 'Slum' by state/local government and UT Administration under any Act including the 'Slum Act'.
2. All areas recognized as 'Slum' by state/local government and UT Administration, Housing and Slum Boards, which may have not been formally notified as slum under any act;
3. A compact area of at least 300 population or about 60–70 households of poorly built congested tenements, in unhygienic environment usually with inadequate infrastructure and lacking in proper sanitary and drinking water facilities (Census of India, 2001).

Slums in India are additionally categorized by their building type, which is described as (semi-) pucca or (semi-) kutcha. Pucca refers to houses of more permanent building materials, such as burned bricks, stones, asbestos cement sheets, (corrugated) metal plates and other roof tiles, whereas kutcha describes the use of non-permanent building materials, for example, clay, wood, bamboo, leaves or carton. Pucca houses can have more than one storey and always show a flat roof, while kutcha houses are one storey only and often resemble tents (Baltsavias & Mason, 1997; The Community Studies Team, 2007).

India aims to be slum-free by 2014 (GoI, 2010a) and in so trying, amongst other initiatives, launched an extensive government scheme of 12.7 billion Indian Rupees (INR) (USD 278 million), the Rajiv Awas Yojana. However, recent forecasts to the socio-economic development of Indian cities uniformly estimate that slums will remain one of India's urban features well into the future (UN, 2009).

For obvious reasons, a slum detection algorithm which is based on satellite imagery alone is not capable of considering such properties of a slum as land tenure or service provision. Nevertheless, since it is generally accepted that housing size and density are distinctive properties of a slum (Niebergall, Loew, & Mauser, 2008), it is appropriate to rely on the internal building structure of a slum in the methodology development process.

Reliable identification of slums and tracking of their growth has always been a difficult task for urban administrators in the developing world. As the alternatively used term 'informal settlement' suggests, such developments are, particularly in the early stages, not necessarily reported to the authorities and therefore lack proper referencing in land property registers or urban development plans. The need to know past and future locations of slums arises from the responsibility of a government to provide for its citizens, which can be narrowed down to the identification of the groups in need, development of housing, employment and service provision policies as well as risk reduction measures. While such information might be available on the lowest levels of India's city structure (colonies and wards), the imperfect vertical communication often leads to situations when municipalities and municipal corporations cannot appropriately describe fine spatial and socio-economical structure of the areas they manage, which is vitally important for adequate steering of the city growth. The reliance on the 1994 slum location data in the 2010 Master Plan for Hyderabad is an eminent indicator of the necessity of our research, which aims to provide local and regional planning authorities with a tool, capable of identifying slums through the use of recent high-resolution satellite imagery. Therefore, new methodologies and tools as well as techniques and policies are required to monitor urban growth and alteration across the megacity and to forecast areas of risk – all within shorter time frames and at a larger scale than previously accepted (Herold, Goldstein, & Clarke, 2003). This will support a more proactive and sustainable urban planning and land management (UN, 2002).

The ascent of increasingly high resolution sensors aboard earth-orbiting civil satellites has created spatiotemporally continuous and politically less biased sources of data about the surface of our planet. While first uses of remote sensing data for land use classification were confined to large-scale cartographic and agricultural studies (Lillesand, 1990), the 1970s also saw the initial use of satellite imagery in urban research (Ellefsen, Swain, & Wray, 1973; Lo & Welch, 1977). Some 40 years later, urban planning and administration in megacities is becoming unthinkable without the use of information derived from remote sensing platforms (Maktav, Erbek, & Jürgens, 2005). For example, the mere land use classification of built-up and non-built-up areas performed during the urban expansion of Greater Dhaka, Bangladesh, has produced important insights into the spatial patterns of the city's expansion (Dewan & Yamaguchi, 2009).

Accurate detection and classification of informal settlements using remote sensing data pose real challenges to researchers and decision-makers alike. Unlike agricultural land or other natural vegetation types, urban structures lack unique and easily distinguishable spectral signatures. Even to a first approximation cities are not spatially uniform bodies but constitute a collection of discrete objects, be it streets, houses or green spaces. This is particularly evident in slums where the variety of materials used for roof construction is so great (Baltsavias & Mason, 1997) that it effectively prohibits any attempt of urban fabric classification based on spectral properties alone. On the other hand, internal spatial characteristics of slums such as housing density, size and structure of individual dwelling units emerge as promising and efficient methods of slum detection.

Baud, Kuffer, Pfeffer, Sliuzas, and Karuppannan (2010) successfully merged local knowledge with an indicator-based visual interpretation technique to extract different classes of residential areas matching administrative settlement categories (formal/informal) using high resolution satellite imagery of Delhi/India. The approach, however, extensively relies on manual image processing and is thus of limited use in operational monitoring circumstances where limited human resources and time frames are available for processing of multitemporal datasets. Nevertheless, visual interpretation is still frequently used for visual checking and evaluation of classification carried out by other means (Hurskainen & Pellikka, 21 October, 2004).

The growing availability of computing power as well as the need to continuously track land use change within large and often nebulous spatial boundaries have created a need for rapid slum identification which does not allow for extensive but time-consuming fieldwork. This is the area where fully automated methods start to play an increasingly important role. While summarising challenges and achievements of object detection using multi-scale satellite imagery, Blaschke (2010) stresses the importance of automated object detection in object-based image analysis as the approach becomes increasingly used in planning and