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## DEFINING THE BULL'S EYE: SATELLITE IMAGERY-ASSISTED SLUM POPULATION ASSESSMENT IN HYDERABAD, INDIA

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*Abstract:* This paper presents an approach to qualitative and spatial assessment of slum population numbers in Hyderabad, India using circle-based population data from the Census of India and results of the analysis of high resolution QuickBird satellite image data (2003) derived from automatic line detection and lacunarity algorithm. This approach provides plausible and spatially explicit aggregate statistics of slum population numbers within the city. This work suggests that both over- and underreporting of slum population numbers does occur in Hyderabad, and provides an improved view on the slum distribution patterns within this urban agglomeration. [Key words: slum identification, urban remote sensing, Hyderabad.]

Slums remain a pervasive feature of many city-regions in the Global South, presenting serious challenges in the search for "opportunities for constructing better futures for urban dwellers" (Robinson, 2011, p. 1104). It is generally accepted that highly crowded, under-serviced and dilapidated settlements (UN, 2011) are currently home to approximately 828 million people (UN, 2012). Nevertheless, there is a wide range of slum definitions across countries and international organizations—precluding the kinds of systematic information that is essential as "the theoretical epicenter of urban scholars and policymakers adjusts to accommodate" the broad demographic transition that "has shifted the locas of urbanizing populations from the global North to the global South" (Parnell and Robinson, 2012, p. 593).

Slums remain an integral part of the urban landscape in India. The official figures suggest 22% of the total urban population of India and, more specifically, 35% of the population of the city of Hyderabad lives in slums (Census of India, 2001). In its 2010 report, the India Committee on Slums Statistics suggested a definition of a slum which differs from the one adopted by the 2001 Census of India, describing it as "a compact settlement of at least 20 households with a collection of poorly built tenements, mostly of temporary nature, crowded together usually with inadequate sanitary and drinking water facilities in unhygienic conditions" (Government of India, 2010b). This report also stresses the acute need for a reliable slum database and expects the total slum population of India to exceed 100 million mark by 2015.

According to Satterthwaite (2010), many national sample surveys potentially under-represent populations living in informal settlements. This is partially caused by the fact that the process of cataloguing and administrative recognition of slums is led by respective municipalities, corporations, local bodies or development authorities, which either assign

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the slum status to certain parts of the city (naming them "notified slum"), or not, using a frequently untransparent, subjective or misleading set of criteria (Risbud, 2010). This process established the term "non-notified slum"—an area, which is a slum *de facto* but not *de jure*. This claim is supported by Agarwal (2011), who notes that the official statistics on the slum population in urban areas of India tend to be inaccurate, because a large proportion of low income urban clusters are informal and are not classified as "slums" or "notified slums." Furthermore, substantial differences between slum population numbers reported by the Census of India and by local municipal corporations (including the Municipal Corporation of Hyderabad—MCH) were identified by Risbud (2010).

The 65th National Sample Survey (2008–2009) concludes that approximately a quarter of all slums in Andhra Pradesh are non-notified ones (Government of India, 2010a). The survey carried out by the Centre for Good Governance in 2008 stumbled upon a problem that 146 slums from the slum list provided by the Municipal Corporation of Hyderabad did not exist at the time of survey. Furthermore, 21 slums were replaced by multi-level apartments, shopping centers etc (Centre for Good Governance, 2008).

The nonplanned and frequently informal and non-notified nature of slums in Hyderabad seems to fit into the modern, agile urban planning framework adopted by India's metropolitan cities as a consequence of the transition from rigid, impracticable and non-implementable Master Plans to flexible vision documents such as City Development Plans (Kundu, 2011). This, however, does not relieve city administrators of their duties to provide basic public services for all population strata. Lacking or incorrect slum distribution information potentially adds to the strain on public services budget and potentially undermines fair and efficient resource allocation. Therefore, reasonably accurate and timely estimation of numbers and spatial distribution pattern of slum populations in the city will remain an important task well into the future.

Counting individual dwelling units is undoubtedly the most reliable method of slum population estimation. Although very accurate, this method is extremely time- and effort-intensive. On the other hand, remote sensing and advanced image processing methods have the potential to offer a worthy alternative to field data collection in certain situations. By virtue of its uniformity, satellite imagery is a useful tool to address the paucity of data on urban populations.

Almeida et al. (2011) proposed a method to estimate the population of the informal settlements of Rio de Janeiro, Brazil, using Ikonos high resolution satellite imagery and object-based image analysis. However, this method is limited to settlements consisting of multi-storey residential buildings and is therefore not applicable to single- or two-storey slums of Hyderabad. Baud et al. (2010) successfully used an indicator-based visual interpretation technique to identify substandard residential areas of Delhi, India, from Ikonos scenes, but neither covered a substantial number of wards in the city nor attempted to calculate the slum population within those wards. Nolte (2010) relied on the normalized difference vegetation index (NDVI) computed from QuickBird and Landsat imagery to identify built-up area of Ahmedabad, India, and to model the population distribution in the city, but she did not distinguish between the slum/nonslum land use classifications behind the data provided by the Census of India 2001. QuickBird imagery and object-based classification approach are a superior source of information for satellite imagery-assisted urban demography and particularly urban slum study (Stoler et al., 2012).


**Fig. 1.** Location of Hyderabad in India.

The main focus of this paper is to quantitatively assess the numbers and spatial distribution pattern of slum population in Hyderabad, India. This work advances the concept of satellite imagery-assisted slum identification presented in previous work in this field (Kit et al., 2012) by making a step towards assessment of the numbers of slum dwellers within each of Hyderabad's circle- and ward-level administrative units. This paper compares slum population figures obtained through the lacunarity-based slum identification method to official figures and attempts to explain the difference both in numbers and in spatial distribution of slum population. Additionally, we aim to produce seamless aggregate slum population numbers for the area administered by the Municipal Corporation of Hyderabad (MCH) at much finer spatial scale than normally reported by the authorities, namely wards instead of circles.

## STUDY AREA

Hyderabad (Fig. 1) is the capital of Andhra Pradesh state in central South India. It grew from about one million inhabitants in 1951 to about seven million in 2001. It is characterized by population growth rates of more than 50% during 1981–1991 and of 27% during 1991–2001 (GHMC, 2010). The urban agglomeration is expected to host 10-million inhabitants by around 2020, whereas the scenarios for the wider Hyderabad Urban Development Authority area reach the 10 million mark by 2015 (MCH, 2005).

## METHODOLOGY

We consider cities to be complex systems composed of nonlinear and multiple scale iterations of heterogeneous spatial and physical components (Amorim et al., 2009). The starting point of our analysis is the relation between the lacunarity value of a 60 m × 60 m image of an urban subarea and the probability that this subarea is morphologically similar to a slum. Lacunarity is a measure of spatial heterogeneity that identifies the granularity of the visible urban structure. It is sensitive to quasi-regularly repeated small objects and an elaboration of structural measures like the fractal dimension (Amorim et al., 2009). Lacunarity is calculated from a QuickBird satellite panchromatic image (spatial resolution 0.6 m × 0.6 m) comprising of 100 × 100 image pixels for each subarea analysed. Two important parameters to be determined in advance are the size of the subarea and the size of a sliding window which runs over the whole subarea thereby counting the “gaps” (lacunae) for each window position. The size of the window has to reflect the typical scales of houses, paths and non-built up areas in slums while the first parameter depends on what a reasonable scale of spatial analysis in slum identification is. In a former study, which also provides further technical description of the algorithm and discusses ground truthing results (Kit et al., 2012), we showed that the slum morphology encountered in Hyderabad is best analysed in 60 m × 60 m units (the city features many small slum plots) scanned with a 6 m × 6 m overlapping sliding window (typical slum building size). These parameters were optimized in the cited study to generate a sharp threshold in lacunarity values reflecting the distinction between slum and nonslum morphologies for subareas where the spatial distribution of slum areas was identified during field data collection phase. The ground truthing process, described by Kit et al. (2012), consisted of visiting different parts of the city along predefined tracks, taking geotagged photographs and placing the photographs over the slum location map produced by the lacunarity-based algorithm.

Figure 2 shows this basic relation as calibrated for Hyderabad. Subareas with lacunarity values lower than 1.10 and larger than 1.90 exclude the existence of slum structures while the highest probability to find slum morphology (0.83) lies within the lacunarity interval of 1.10 to 1.15. For the subsequent intervals probability drops sharply and stays below 3% for all lacunarity values higher than 1.3.

Considering the probabilistic character of this remote sensing based approach, we find it reasonable to evaluate slum population in the city as expectation values for larger spatial units. The 146 wards of the Greater Hyderabad Municipal Corporation provide an appropriate level of spatial disaggregation, given that the official intraurban slum population data is only available at the next coarser level of circles.

If $i$ is the number of a subarea within a given ward, $L_i$ is the lacunarity value for subarea $i$, $P_i$ is the probability that subarea $i$ shows a slum morphology and $P^s$ is the population of a 1200 m$^2$ slum subarea in Hyderabad we obtain for the expectation value of the slum population within a ward, $P^S_W$,

$$E(P^S_W) = \sum_i p^S_i(L_i) \times P^S,$$

where the function $p^S_i(L_i)$ is depicted in Figure 2. This expectation value can be interpreted as “best guess” for a ward’s slum population as derived from remote sensing.

An inspection of the spatial distribution of the slum probabilities motivated a further step of analysis. We discovered that at the fringes of homogeneous slum areas these

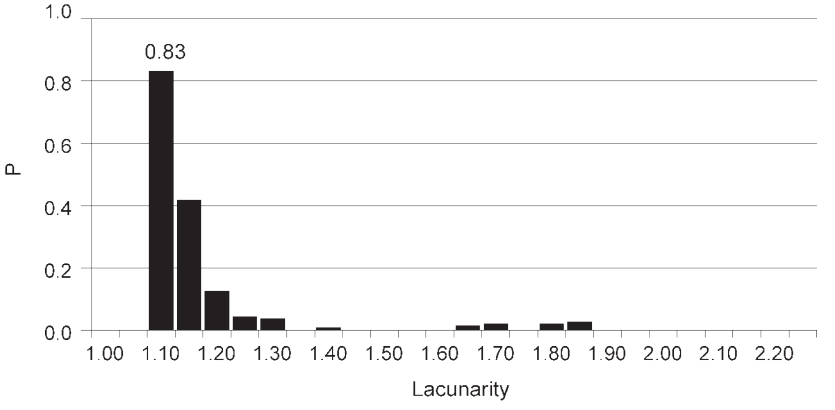


**Fig. 2.** Algorithm validation. X-axis: lacunarity value of a 60 m × 60 m urban subarea of Hyderabad. Y-axis: probability that a subarea with a lacunarity value within the respective 0.05 interval represents slum morphology (after Kit et al., 2012).

probabilities typically become smaller, either due to reduced densities or due to mixed (slum and nonslum) subareas. These areas mostly show lacunarity values greater than 1.15. Accordingly, we define a further expectation value, denoting a core slum population within a ward by evaluating the sum in the equation above only for summands with lacunarity values less than 1.15. This core, high density slum population is expected to correlate better to socioeconomic indicators (e.g., population below poverty line) than the total slum population.

The described algorithm was applied to a 20 km × 20 km QuickBird scene from 2003 (covering the Municipal Corporation of Hyderabad and surrounding circles) which was converted into a binary picture by using a line detection algorithm (details provided by Kit et al., 2012).

In the next step we calculated the fraction of slum dwellers in each ward using census based ward-wise total population data. The election wards in Hyderabad are spatial units, designed to cover approximately equal numbers of people. The median total population of an election ward is 35,000 inhabitants, with ward populations ranging between 20,000 and 40,000 (GHMC, 2009).

The authors are aware of the fact that the population density within a slum is a complex function of environmental and socioeconomic factors that cannot be fully assessed using satellite image analysis only. Nevertheless, because we aim to estimate the number of people inhabiting slums of Hyderabad, we rely upon slum population density ranges calculated by compiling available sources of population and area data of individual slums as per Table 1.

The paucity of available population data and limitations of a satellite imagery-based approach urged us to accept a broad range of slum population densities as equally probable, yielding a median value of 55,000 inhabitants per square kilometer, with lower and upper boundaries of 37,000 and 125,000 respectively. These numbers also cover Hyderabad's average slum density of 40,000 calculated by Adusumilli (2001) and is consistent with the

**Table 1.** Calculation of Slum Population Densities

| Spatial unit name | Slum area, km$^2$ | Slum population, persons | Computed population density, persons/km$^2$ | Sources |
|---|---|---|---|---|
| Municipal Corporation of Hyderabad | 22.33 | 1,195,204 | 53,525 | MCH (2005); Centre of Good Governance (2008) |
| Municipal Corporation of Hyderabad | 22.33 | 1,411,000 | 63,189 | MCH (2005); Census of India (2001) |
| Arsh Mahal slum | 0.07 | 2,618 | 37,400 | Centre of Good Governance (2008) |
| Gulshan Nagar slum | 0.05 | 2,173 | 43,460 | Centre of Good Governance (2008) |
| Indiranagar b  Colony | 0.02 | 1,605 | 80,250 | Centre of Good Governance (2008) |
| Rasolpoora slum | 1.20 | 150,000 | 125,000 | Chapligin (2006), visual slum boundary interpretation by authors |

numbers for similar urban agglomerations in India (Myllylä, 2001; Baud, 2009) reported in the literature.

In the last step, the remote sensing based results for all wards of Hyderabad were compared to existing statistics from the city administration on different aggregation levels. It is important to note that the fuzzy nature of official slum population figures in Hyderabad is indirectly confirmed by qualitative assessment of the results of several fieldwork periods in Hyderabad in 2009 and 2010, when the authors visited a number of slums in the city. Particularly, it has been observed that:

- Not all neighborhoods classified as slums by the local government give the impression of a high-density impoverished neighborhood, and

- Not all neighborhoods that appear extremely impoverished and informal are officially known to the local government, nor are they recognized as slums.

## RESULTS

The application of the method described above yields the following results. Figure 3 compares the remote sensing-based slum population share within election wards in Hyderabad (A) to the best available slum population statistics which are limited to the data collected by the Municipal Corporation of Hyderabad at the urban circle level (B). Both datasets indicate a higher proportion of slum population in the northeastern part of the city. At the same time, the methodology presented by this paper allows for a finer spatial resolution of the urban slum distribution.

The calculated expectation value of the slum population share for the whole of Municipal Corporation of Hyderabad is 29%, which is less than the 35% provided by Census

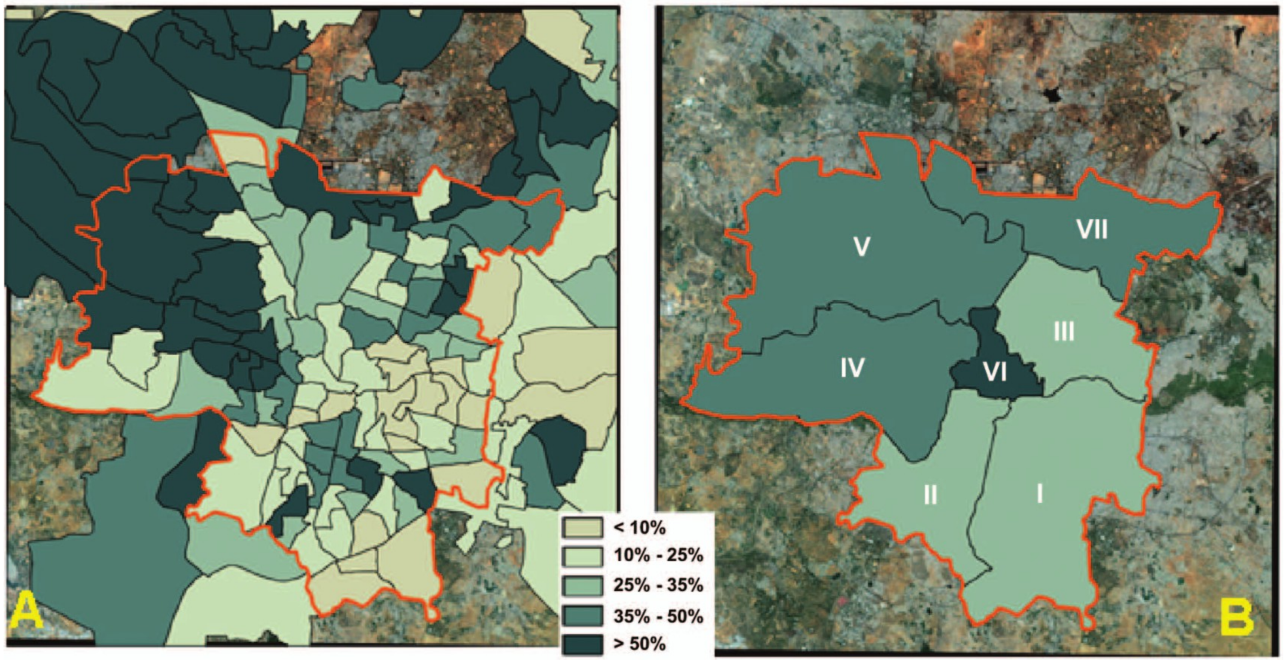


**Fig. 3.** Algorithm verification. A. Estimated percentage of slum population relative to total ward population. B. Percentage of slum population relative to total administrative circle population.

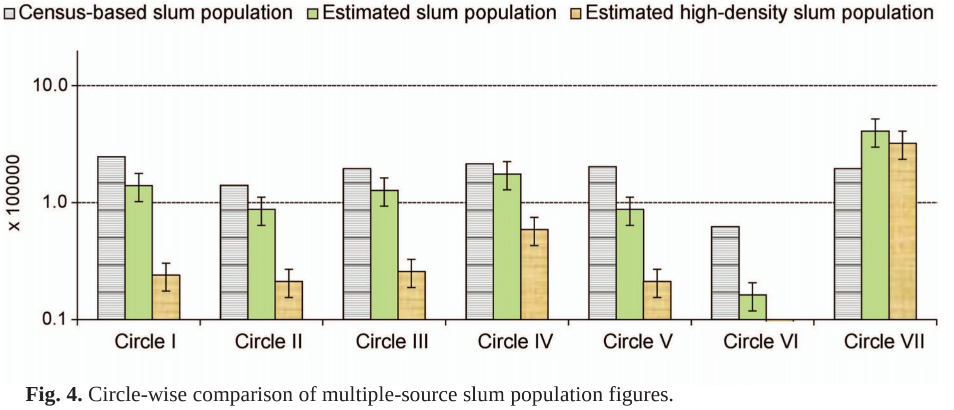


**Fig. 4.** Circle-wise comparison of multiple-source slum population figures.

2001. The calculation also suggests that only 13% of Hyderabad is a core slum, with the remaining 16% assigned to intermediate slum class.

Figure 4 combines circle-wise slum population figures provided by the Census of India, 2001 with those statistically estimated using slum detection algorithm, with error bars indicating probability ranges derived from upper and lower boundaries of slum population density. The median remote sensing-based population figures of all circles apart from circle VII are estimated to host lower slum populations than provided by census. Only circle VII is estimated to be populated by more slum dwellers than the official figures suggest, with conservative core slum population estimates exceeding census data by 10%. Circle VII is indicated to host the highest number of slum population, and circle VI—the lowest. Core slums account for the majority of slum population in circles IV and VII, but are virtually nonexistent in the circle VI.

## DISCUSSION

Satellite imagery is a snapshot in time that covers the complete area of the city. It is not dependent on historical slum notification and recognition processes meaning that a slum identification technique which is based on remote sensing data is well positioned to address the issues of changes in urban morphology caused by slum upgrading processes as well as rapid establishment of new slums. Many of the areas considered to be slums by local authorities and subsequently reported as such by the census might have lost their slum nature (but not the slum status) over the years between their establishment and census data collection—an assumption which is supported by the results of a slum-based child labor survey in Hyderabad in 2007 (Centre for Good Governance, 2008).

The ward level slum population map (Fig. 3A) is generally consistent with the coarse resolution official statistics and unofficial reports, reporting high percentage of slum population in the north and northwest of the city. The majority of the population of 21 out of 144 wards within the MCH boundaries is estimated to consist of slum dwellers. The higher concentration of slums in the northwest of Hyderabad is best explained when viewed in conjunction with industrial development pattern within the city. Many of the industries in the northern rim of the city use low-skilled, low-paid labor provided by slum dwellers, and establishing a slum in the vicinity of work (a large construction site, a quarry, etc.) reduces the need to travel and creates financial and time benefits for workers.

The comparison of slum population percentage maps (Fig. 3) and circle-wise slum population numbers (Fig. 4) indicate that while the method provided by this paper succeeds in capturing spatial pattern of slum locations in Hyderabad and does so at a much finer scale than previously available data. The remote sensing-based slum population figures tend to deviate from the official ones for the most of the city. Particularly, the slum detection algorithm estimated considerably lower presence of slums in the inner city of Hyderabad (circle VI) than reported by official statistics.

While several site visits to Hyderabad by authors did reveal a traditionally dense housing pattern and a considerable degree of poverty in circle VI, the results of the fieldwork allow us to consider the official slum population figure for this circle of 52% to be an unlikely high value.[2] The census-based statistics indicates that approximately 14% of the population in Hyderabad lived below the national poverty line in 2001 (MCH, 2005). Because the aggregate remote-sensing based slum population ratio in the city is 36%, it is highly likely that this city belongs to the places reported by Satterthwaite (2004), where systemic underestimation of the percentage of households falling below the poverty line takes place. This is also supported by a study by Agarwal (2011), who found that 76% of Hyderabad's poorest population does not live in census slums.

This paper by no means seeks to establish the direct link between poverty levels (particularly calculated in such a complex way as in India, where the type of house is only one of 13 parameters used to assign poverty rating to a household) and slums; the possibility of a genuine correlation in the urban context of India is, however, worth exploring. After all, the slums including unlisted poverty clusters have the highest concentration of poor people and often the worst living conditions (Agarwal, 2011).

The authors are aware that the absolute slum population results presented in this paper are sensitive to slum population density figures, which obviously vary among different cities and slums within the same city and depend on a wide range of factors immeasurable by remote sensing methods. The same holds true for the reliability of the method as such—most of the properties of a slum (land tenure situation, availability of services such as drinking water and sanitation, etc.) cannot be established from a satellite, and housing density is certainly not a completely reliable proxy for slum identification. Nevertheless, the satellite imagery-based slum population assessment can provide meaningful insights into slum distribution patterns at spatial resolutions and time scales unavailable to local administrations in the urban context of India.

[2]The circle VI covers the historic center of Hyderabad, which has been assigned ("notified") slum status by the authorities of the city at the early stage of slum notification process. Several expert interviews stressed very limited willingness of slum inhabitants to de-notify the slum they live in even if it does not qualify for slum status, because of preferential tax treatment or access to subsidized goods and services. We did not collect enough hard evidence to support this claim because this was not the main purpose of this paper, but we are working on another publication which looks into the spatiotemporal details of official slum reporting in Hyderabad and discrepancies between the numbers reported and situation on the ground.

## SUMMARY AND CONCLUSIONS

This study confirms suitability of lacunarity-based slum identification for slum studies in Hyderabad. The method not only provides the tools to identify individual slums and their clusters, but also provides meaningful aggregate statistics which are comparable to data collected during censuses.

Apart from providing slum population estimated for the whole Hyderabad, this approach allows for identification of wards with the highest slum population. This data is particularly important for local decision-makers because no official and reliable ward-wise slum population data is collected in Hyderabad. The present study supports the recommendation of Agarwal (2011) to India's city authorities to frequently update official slum lists; the approach outlined in this paper can facilitate this process.

However advanced, remote sensing alone cannot be used to assess such complex issue as slums and slum population. Used in conjunction with other methods, however, it may prove to be an important component of an urban stakeholder's toolbox, e.g. in the process of designing criteria for slum resettlement. The advantage of the remote sensing based method lies in the comprehensive spatial and temporal coverage in high resolution. The disadvantage is the restriction to physical urban morphology. Depending on the scientific objectives, the results may only hint at locations of specific physical change which then have to be investigated more closely by other means or may already give a large part of the answer (e.g., for the investigation of sensitivity towards climate change).

Another way to use the remote sensing methods in slum population assessment is to reconstruct spatial and temporal slum development during the last two decades, as restricted by availability of appropriate high resolution satellite images. This would allow testing various slum development hypotheses and can constitute a promising contribution to the analysis of possible future dynamics of urban agglomerations of the South.

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