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Urban Morphology of Unplanned Settlements: The Use of Spatial Metrics in VHR Remotely Sensed Images

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Abstract

Information about unplanned settlements in developing cities is often unavailable, despite their extent, which at times can dominate residential land-use. This research aims to contribute to the development of tools for monitoring such areas, by using spatial metrics as means for the identification of the morphology of unplanned urban settlements in VHR images. The methodology is tested in two case study areas: Dar es Salaam and New Delhi. The methodology builds on using image segmentation and on the assumption that segments representing homogenous urban patches are different in planned and unplanned areas. The morphological aspects (size, density and layout pattern) of planned and unplanned areas are analyzed using spatial metrics on segmented images. A final set of metrics has been used to build an 'unplanned settlement index'. Comparison between results and land use data showed that the index can assist in the identification of unplanned settlements.

Keywords: Unplanned settlements; image segmentation; spatial metrics; unplanned settlement index

1. Introduction

The urbanization of cities in developing countries is frequently suffering from insufficient planning and management [1]. High development pressure and insufficient supply mechanism of affordable land are causing the growth of unplanned areas coinciding often with deprived areas [2,3]. Thus localizing such areas, as well as understanding their heterogeneity and development dynamics, is not only a major global concern but also a challenge for local authorities [4]. Many cities in developing countries have large areas

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of unplanned development [5], which can exceed the amount of planned [6]. A forecast of the UN estimates that by the year 2035 more than 50% of the global population will live in such areas [7]. When aiming at analyzing or detecting such settlements, it is important to understand what spatial characteristics make these areas differ from planned. However no general theory on such settlement locations exits in literature [8]. According Barros Filho and Sobreira [1] they share globally the same spatial features, in respect of fragmentation and scaling of morphological structure. Common spatial feature are summarized in tab.1, e.g. non compliance with planning standards or the absence of planned public open spaces [9].

Table 1 Common spatial features of unplanned area

Residential Type	Spatial features in VHR images
Unplanned areas	• High densities (roof coverage densities at least 80% and more) • Organic layout structure (no orderly road arrangement non compliance with set-back standards) • Lack of public (green) spaces in the vicinity of residential areas • Small (substandard) building sizes
Planned areas	• Low – moderate density areas • Regular layout pattern (showing planned regular roads and compliance with set-back rules) • Provision of public (green spaces) within or in vicinity of residential areas • Generally larger building sizes

This research focused on employing spatial features to extract unplanned settlements, using spatial metrics. Spatial metrics is a growing research field in urban applications, e.g. Herold et al. [10](p. 371) stresses that spatial metrics in combination with remote sensing "can provide more spatially consistent and detailed information on urban structure and change than either of these approaches". 'Landscape or spatial metrics' have originated from landscape ecology [10, 11]. Despite the fact that spatial metrics is one of the most growing applications of remotely sensed data [12], they have been not much used in the image classification phase, as it was believed that only classified images can be analyzed by spatial metrics, but, the only prerequisite for its use is the presence of homogeneous regions (patches) [13]. Despite its extensive use in urban application [14], no standard set of spatial metrics suitable for urban application has been agreed on [10]. The most basic information that can be extracted from an image is segments of homogenous regions [15]. It is the initial step in image analysis and pattern recognition [16]. An important differentiation exists between complete and partial segmentation, the first extracts real-world objects while the later is used as input into further image analysis [15]. The advantage of segmentation is that various information levels can be extracted from an image (fig. 1); from the most basic level of pixels, to segments using homogenous patches (HUPs at object level). Larger areas of homogenous physical characteristics (HUPs at area level) can be extracted using spatial characteristics like texture.

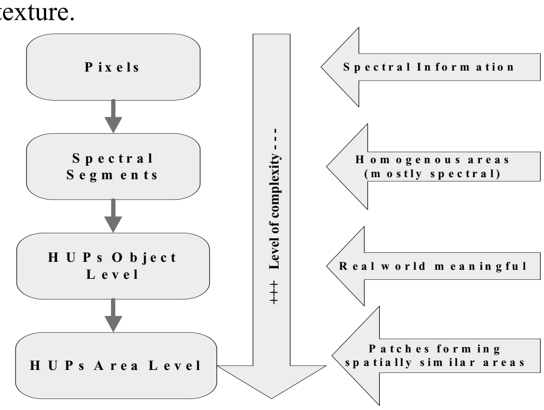


Figure 1: Information levels of image segmentation

2. Methodology

The focus of this research is to analyze spatial characteristics of unplanned settlements, employing spatial metrics and combining them to an ‘unplanned settlement index’ for two case studies showing contrast between an Asian and African example. The selected Asian example is the city of New Delhi (India), a very densely built-up urban environment, with many different types of unplanned settlements, ranging from small squatter pockets to large unplanned settlements. Dar es Salaam (Tanzania) is a good example of an African city with large areas of unplanned development dominating planned areas. Risbud [17] estimated that around 38% of the population of Delhi lives in such areas while for Dar Kombe [6] estimated that 70% of the residential land is unplanned. For Delhi Ikonos scenes of the years 2001/2002 have been pan-sharpened to 1m resolution. For Dar a multispectral QuickBird image mosaic of 2007 was pan-sharpened resulting in 0.6m resolution. Five test areas to extract a set of spatial metrics and two assessment areas have been selected, covering various types of planned/unplanned areas. The research provides three main outcomes. First, homogenous urban patches (HUPs) extracted by image segmentation, second a set of spatial metrics that have the potential of distinguishing unplanned from planned settlement, third an unplanned-settlement-index of the most significant spatial metrics. Segmentation is performed to extract HUPs as much as possible at object level. Subsequently the arrangement patterns of the segment are analyzed using spatial metrics, focusing to assess the potential to differentiate planned versus unplanned areas. Spatial metrics that have the potential to measure one dimension of the spatial features of unplanned areas, namely size/density/pattern have been selected reviewing several research papers [1,10,12,14,18-22]. A final set of metrics was consequently selected. The design of an unplanned-settlement-index (USI) is combining the most significant spatial metrics within a spatial multi-criteria evaluation framework. This final set is a selection of metrics that best represent spatial characteristics while excluding highly correlating within one dimension. The output, a composite index of equal-weighted and standardized indicator maps shows value range of ‘unplannedness’. The USI is aggregated using larger segments (HUPs at area level), in order to extract homogenous areas and to remove small scale variations. The result is evaluated using land use data.

3. Results and Discussion

The initial step was to generate segmented images being the input for the spatial metrics (fig. 2). A complete segmentation was not achieved caused by clustering of small buildings in unplanned areas. For the case of Delhi several metrics are highly correlating. Shannon diversity has been excluded as it highly correlates with Simpson’s evenness index. Splitting index was excluded, as it highly correlates with division and mesh. Area mean was excluded highly correlating with mesh and edge density was excluded highly correlating with patch density.

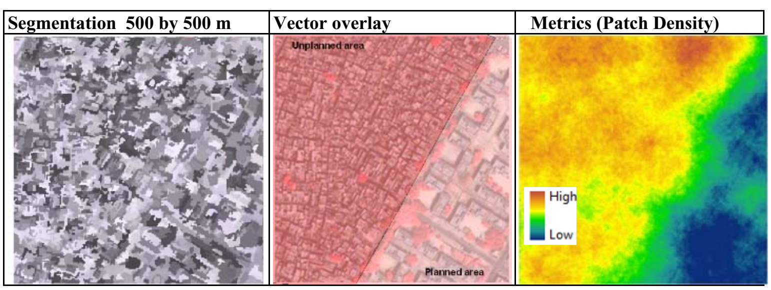
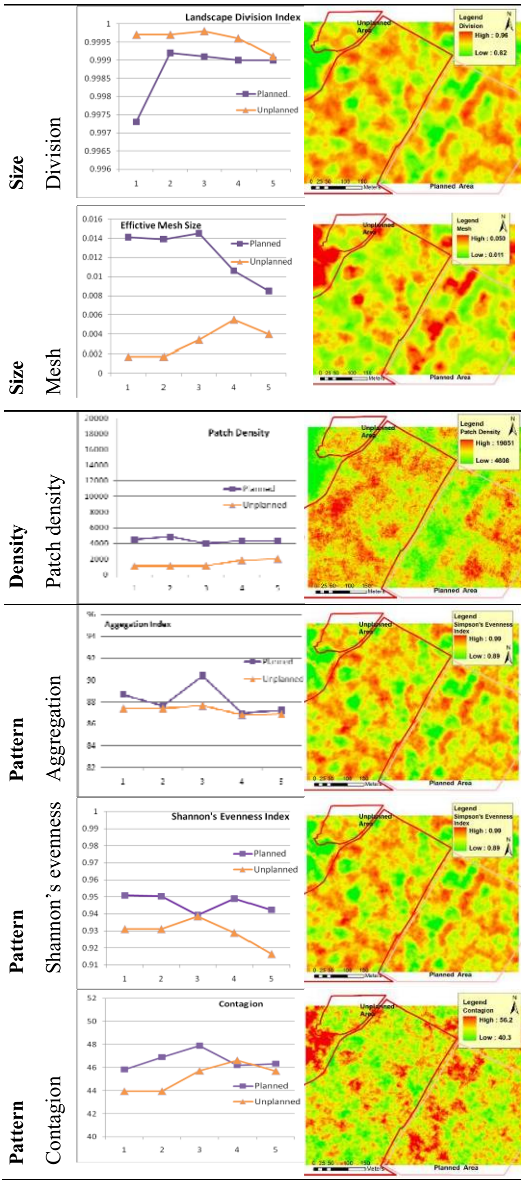


Figure 2: Example of segmentation, reference data and selected spatial metrics



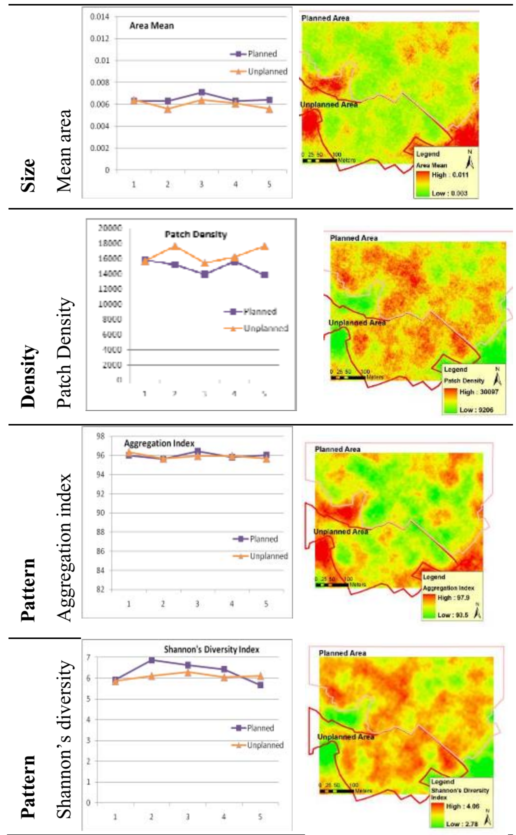


Figure 3 and 4: For one test areas selected spatial metrics for Delhi (left) spatial metric for Dar (right)

For Dar, patch, edge and patch richness density are highly correlating; thus patch richness and edge density was excluded. The final set of metrics for Dar (fig. 3-4) was mean area, patch density, aggregation and Shannon's diversity index and for Delhi division, mesh, patch density, aggregation, Shannon's evenness and contagion index. For extracting the USI, homogenous patches were generated using image segmentation at area level using the scale parameter 80 for Delhi and 160 for Dar. The reason for the much smaller scale parameter in Delhi is that unplanned areas tend to be frequently small pockets, while in Dar unplanned areas are commonly larger settlements. The extracted segments are used to aggregate the composite maps of the USI using the mean value. The result was compared with land use data for assessment areas (fig. 5). The USI was classified in 5 different classes (very high-very low) using equal frequency. After a visual inspection it can be concluded that high to very high values match in general with reference data of unplanned areas. For the assessment area 1 of Dar the main unplanned area falls into the category very high, some small areas along its edges are not well detected by the USI, also the planned area in the West falls into the high category as it is a rather high density planned settlement. The assessment areas 2 of Dar shows a similar picture, the large unplanned area falls mainly into the category high while parts are within the category very high but also moderate. Smaller unplanned areas along the edge of the settlement fall into various categories, as well as small areas within planned settlements have high values mainly due to high densities. But in general the USI gives an overall indication of unplanned areas. For Delhi, assessment area 1 is rather complex, the two unplanned areas in the centre and South (mainly slums) are within the category high. While the un-planned area in North-East falls into various categories, the area is a typical example of being unplanned but not a slum (with larger roofs and lower densities). Another visible problem is that some small segments in planned areas have (very) high USI values. This shows that the smaller scale value for Delhi (which was necessary extracting small slum pockets) tends to cause problems (outliers). The result for area 2 of Delhi shows more clearly the location of the unplanned areas, with the exception of the two smaller areas. Intersecting the USI and the reference data it can be concluded that for Dar 88%, and 67% and in Delhi 40% and 70% of the unplanned areas are indicated by the USI values of high to very high. However it can be stated the USI has the potential to indicate unplanned settlements but smaller cluster and better-off unplanned areas as well as high density planned areas are not well detected.

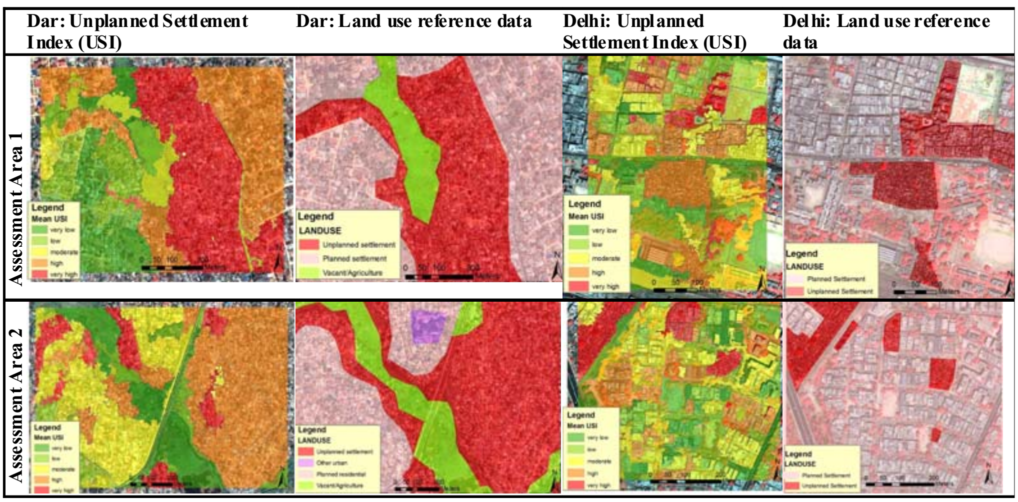


Figure 5: Result of unplanned settlement index (USI) compared with reference (land use) data

4. Conclusions

A set of spatial metrics describing the morphology of unplanned areas have been extracted. However, the set as well as the values differ for the two case studies. After excluding several highly correlating metrics, the selected set of metrics for Dar is mean area (size), patch density (density) and aggregation index as well as Shannon's diversity index (pattern). For Delhi the selected set is effective mesh size, landscape division index (size), patch density (density), contagion, aggregation and Simpson's evenness index (pattern). Thus it was possible to utilize spatial metrics to analyze the morphology of unplanned areas. One problem is that the segmentation result on object level is not well representing the on-ground spatial characteristics (e.g. due to under segmentation the area size of objects in unplanned areas did not match with the on-ground reality). The sets of spatial metrics were combined using spatial multi-criteria evaluation to a composite index. The extracted USI index is indicating areas of high likelihood of ‘unplannedness’ considering the three dimensions (size/density/pattern). In order to outline areas that are possibly unplanned another segmentation procedure was employed using much larger scale parameters which allowed upscaling to HUPs at area level. Comparing the extracted USI with existing land use data it can be concluded that (very) high USI values are indicating unplanned areas. Besides the overall relatively good performance, problematic areas are small zones of unplanned development as well as planned areas that have similar spatial characteristics as unplanned.

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