Quantifying Spatiotemporal Patterns of Urbanization: A Case Study of the Colombo Metropolitan Area, Sri Lanka

Shyamantha SUBASINGHE and Yuji MURAYAMA

Abstract: This study aims to quantify the geospatial dimension of urbanization in the Colombo metropolitan area (CMA), Sri Lanka's only metropolitan area. The urbanization process was analyzed using land change intensity analysis and spatial matrices. The results reveled that urbanization of the CMA was rapid in 1990s compared to 2000s, while the area is experiencing more diffusion than coalescence during last two decades.

Keywords: GIS, remote sensing, land change intensity analysis, spatial metrics

1. Introduction

The land change intensity (Aldwaik and Pontius, 2012), and spatial metrics are used by several studies to quantify the urban expansions as a major components of urbanization process. This study employs the land change intensity analysis and spatial metrics to characterize the urbanization patterns of the CMA.

Upon the conclusion of the 30-year civil war in 2009, the CMA began an era of rapid urban development that has led to higher population concentrations and more intense industrial activity in Colombo and its suburbs (Senanayake et al. 2013). This rapid urbanization poses challenges for urban planning initiatives, as the urban expansion of CMA frequently outpaces the planning process.

The techniques proposed by Aldwaik and Pontius (2012) for analyzing the intensity of land change enable understanding of the size and speed of land change across various time intervals. This technique has been employed by several urban studies to characterize temporal pattern of urban land use changes. There is also an increased interest in the use of spatial metrics for characterizing the landscape structure and spatial pattern of landscape changes.

In such context, both land change intensity and spatial metrics to expand the understanding of urbanization in the CMA.

2. Methods

The CMA, situated in western Sri Lanka, is the country's most important administrative, industrial, and commercial center.

Landsat images were used to map the land-use/cover of the CMA for three time points, i.e. 1992, 2001, and 2014. Landsat-5 TM image acquired on January 13, 1992, Landsat-7 ETM+ image acquired on December 27, 2001, and a Landsat-8 OLI/TIRS image acquired on January 21, 2014 were used.

We used the pixel-based supervised classification technique employing the maximum-likelihood classification algorithm. The training sites/sample preparation, signature development, and classification were employed to classify the Landsat images. Built, non-built, and water were major land use/cover classes. Built includes human-constructed structures such as buildings, roads, and other impervious surfaces. Non-built includes pervious surfaces such as agricultural lands, forests, grasslands, and bare lands. Water includes the sea, rivers, ponds, and other waterbodies. 900 sample points (300 per class) were used to assess the accuracy. We used Google Earth images and topographic maps as a reference in the accuracy assessment. The classified land-use/cover maps had an overall accuracy of 88.66% (1992), 90.33% (2001), and 92.66% (2014).

Land-change intensity analysis was used to examine the extent and rate of urban land change (ULC) in the CMA (ULC; i.e. a change from non-built to built) across the two time intervals (i.e. 1992–2001 and 2001–2014). We first calculated the annual change intensity (ACI) for each time interval (1992–2001 and 2001–2014) (Equation 1). Then, we compared each ACI to the uniform intensity (UI), which is the rate of change relative to the entire time extent of the land-change analysis (Equation 2). If the ACI in a particular time interval (e.g. t1–t2) is less than the UI, then the ACI intensity of that particular time interval is considered slow; but if it is greater than the UI, it is considered fast.

$$\mathrm{ACI}\ (\%) = \frac{(\mathrm{LC}/\mathrm{LA})}{\mathrm{TE}} \times 100 \qquad (1)$$

where ACI is the annual change intensity for a given time interval (e.g. t1–t2), LC is the area of land change from non-built to built for a given time interval, LA is the area of the entire landscape; and TE is the duration of a given time interval.

$$\mathrm{UI}\ (\%) = \frac{[(\mathrm{LC}_{\mathrm{TI1}} + \mathrm{LC}_{\mathrm{TI2}})]/\mathrm{LA}}{\mathrm{TE}_{\mathrm{TI1}} + \mathrm{TE}_{\mathrm{TI2}}} \times 100$$

where LC_{TI1} and LC_{TI2} are, respectively, the land change from non-built to built during time interval 1 and time interval 2. TE_{TI1} and TE_{TI2} are, respectively, the time extent of time interval 1 and time interval 2.

For the landscape fragmentation and connectivity analysis, we used three landscape-level metrics and five class-level metrics. The landscape-level metrics included the contagion index (CONTAG), the landscape shape index (LSI), and Shannon's diversity index (SHDI). The class-level metrics included the percentage of landscape (PLAND), path density (PD), mean patch size (Area_MN), area-weighted mean patch fractal dimension (Frac_AM), and mean Euclidean nearest neighbor distance (ENN_MN). All these metrics were calculated using the FRAGSTATS 4.1 software, employing the 8-cell neighbor rule.

3. Results

The results revealed that the CMA's built-up land had an area of 11,165 ha in 1992, which increased to 19,393 ha in 2001, and to 35,876 ha in 2014 (Figure 1).

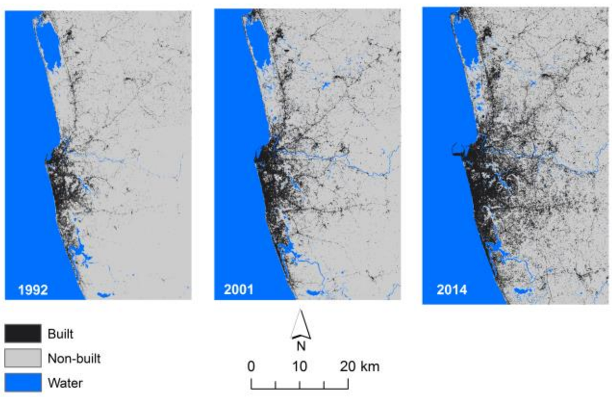

Figure 1. ULC in the CMA

The ULC intensity analysis revealed that the ACI during the first time interval (1992–2001) was 0.39%, while the second interval (2001–2014) had an ACI of 0.54% (Figure 2).

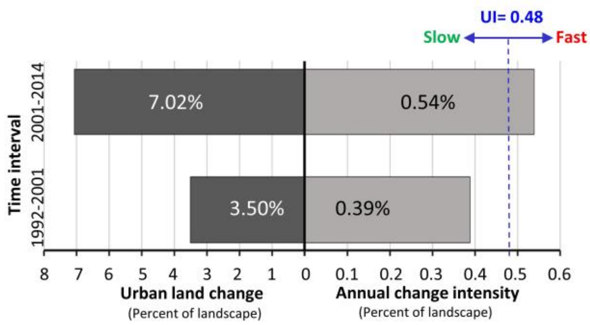

Figure 2. Land change intensity analysis

With a UI of 0.48%, the ACI during the 2000s is considered fast, while the ACI during the 1990s is considered slow

The spatial metrics results show that from 1992 to 2014, the value of the CONTAG has decreased, while the values of the LSI and SHDI have increased (Figure 3). This indicates that the landscape of the CMA has become more fragmented and dispersed; its patch richness has also increased. The values of PLAND, PD, AREA_MN, and Frac_AM have increased from 1992 to 2014, whereas the value of ENN_MN has decreased

(Figure 3). The increase in the values of PLAND and PD indicates that the CMA's built-up lands have become more fragmented. The size and shape of the CMA's patches of built-up lands have also become larger and more complex, as indicated by the increase in the values of AREA_MN and Frac_MN, respectively. The decrease in the value of ENN_MN was due to the increase in the size of built-up patches (i.e. AREA_MN) and the development of new built-up patches near or in between existing built-patches (i.e. PD).

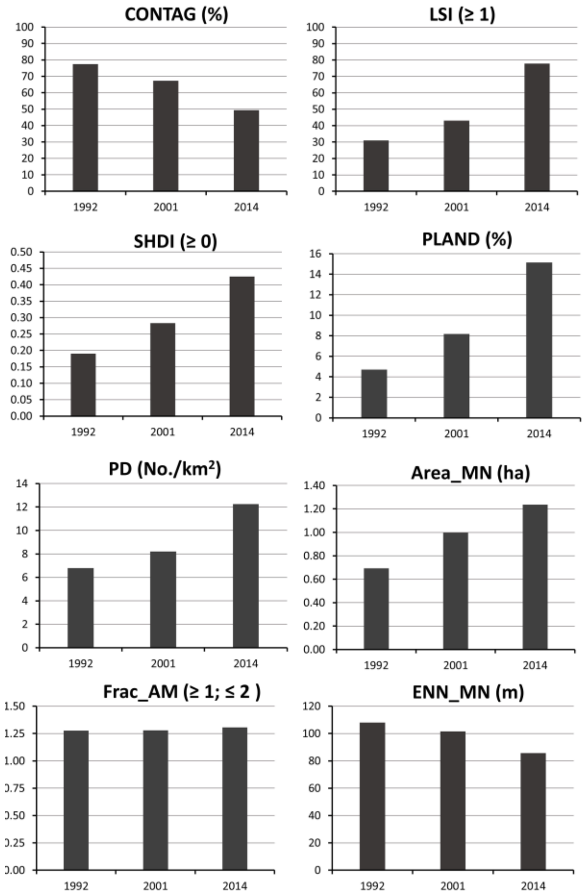

Figure 3. Landscape metrics

4. Discussion

Sri Lanka faced several political movement in 1990s (i.e., Janatha Vimukthi Peramuna's—JVP and civil war). The influence of political movements slowed economic development in general and urbanization in particular. However, after the end of these political movement in 2000s, Sri Lanka starts rapid economic growth and economic growth. These factors mainly characterize the rapid urbanization in 2000s.

The spatial metrics analysis revealed that the CMA's built-up lands have become more fragmented. Moreover, the spatial metrics provides evidences for the more diffusion that the coalescence. Based on the results, we can say that the CMA is still in the early stages of this oscillating process, i.e. it is experiencing more diffusion and less coalescence. As a metropolitan area, the CMA is still young, with its urban development recovery having just started after the civil war ended in 2009.

5. Conclusions

This study has examined the spatiotemporal patters of urban growth CMA, Sri Lanka's only metropolitan area and the country's main socioeconomic "powerhouse", from 1992 to 2014 using remote sensing data and GIS techniques. The analysis revealed that ULC was more intense or faster during the 2000s than in the 1990s in relation to the recent rapid economic growth of the country. Based on the spatial metrics results, we can say that the CMA is a young urban area.

References

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Corresponding authors name: Shyamantha Subasinghe

Affiliation: University of Tsukuba

Address: 1-1-1 Tennodai, Tsukuba, 305-8572 JAPAN

E-mail address: subasinghepgia@gmail.com