Comparative Analysis of Urban Land Changes in the Major Cities of Southeast Asia

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Abstract: Knowledge of the intensity and spatial patterns of urban land changes is important to a wide range of issues, e.g. urban land change modeling, disaster risk management, and landscape and urban planning. In this context, this study examines and compares the intensity and spatial pattern of urban land changes in the major cities of Southeast Asia. Geospatial tools and techniques, including GIS and remote sensing, were used to facilitate the analysis.

Keywords: intensity analysis, land change, land use, spatial pattern

1. Introduction

Urbanization has brought improvements to social welfare and economic development, yet urbanization also has a serious impact on the natural environment, both locally and globally (Grimm et al. 2008; Wu 2010; Seto et al. 2011). Urbanization is arguably the most drastic form of land transformation that results in irreversible landscape changes (Estoque and Murayama *in press*).

It has been projected that rapid urbanization will happen in the developing countries, including those in Southeast Asia, whose urban population has increased from about 15% (27 million) in 1950 to 44% (262 million) in 2010 and has been projected to increase to approximately 66% (500 million) by 2050 (UN 2012). This shows that in the next few decades, urban landscapes will become even more important for the everyday life of the majority of the population in Southeast Asia.

Knowledge of the spatiotemporal pattern of urban land changes (ULCs) – the changes in land from non-built-up to built-up – might help in landscape and urban development planning, and environmental resources management. Therefore, it is important to examine and monitor the intensity and spatial pattern of ULCs.

The main purpose of this study is to examine and compare the intensity and spatial pattern of ULCs in three major cities of Southeast Asia (SEA), namely Bangkok, Jakarta and Manila, between the 1990s (1990-2000) and 2000s (2000-2010). These time periods have been important in the respective growths of these cities. Geospatial tools and techniques, including GIS and remote sensing, were used to facilitate the analysis.

2. Methods

2.1. Land-use/cover (LUC) mapping

In order to examine and compare the intensity and spatial pattern of the ULCs in the three capital cities of SEA, their respective time-series LUC maps were first prepared. For this purpose, we used Landsat imageries captured around the 1990, 2000 and 2010 time points.

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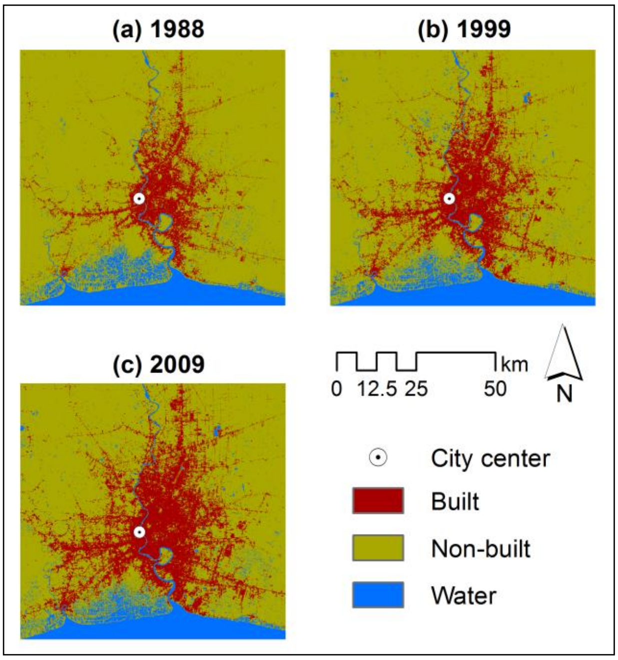

Fig. 1 Land-use/cover maps of Bangkok.

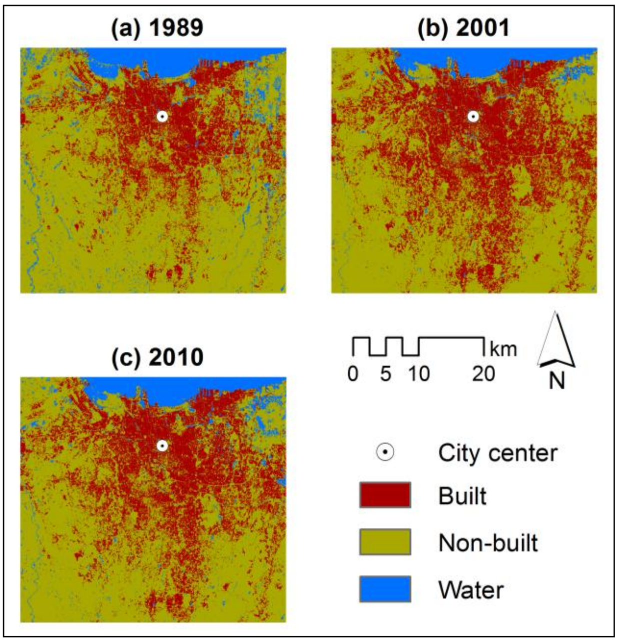

Fig. 2 Land-use/cover maps of Jakarta.

We used a Random Forest image classification approach (Liaw 2002; R Core Team 2012) to classify the satellite images and produce LUC maps that contain three classes, namely built (meaning built-up lands), non-built (meaning non-built-up lands), and water (meaning bodies of water) (Figs. 1-3). We checked the accuracy of the classified 2000 and 2010 LUC maps using at least 360 sample reference pixels or points for each time point per city verified from Google Earth imageries. The 2000 and 2010 LUC maps had at least 90.28% overall accuracy. The 1990 LUC maps were verified through a careful visual comparison with the satellite images.

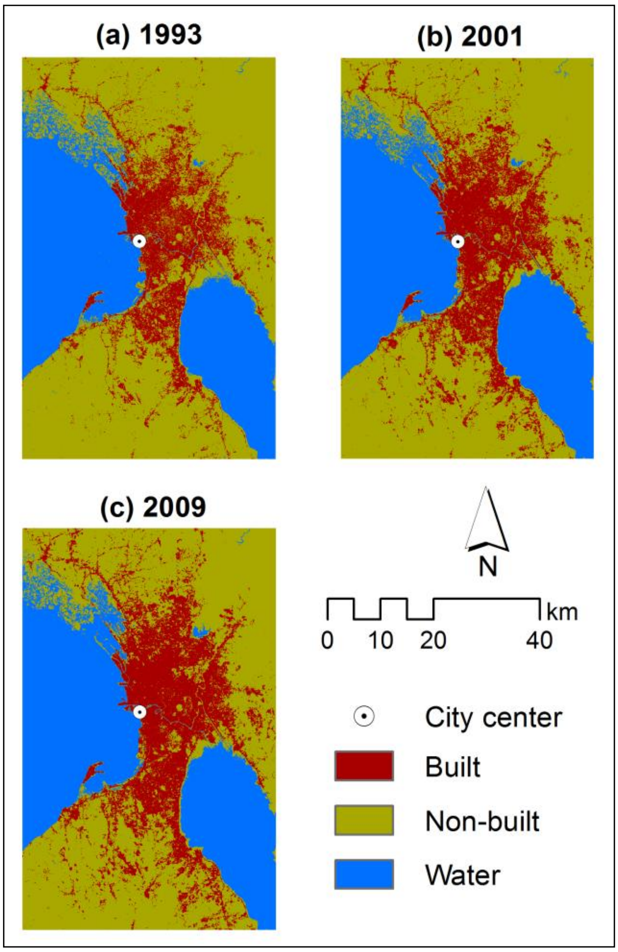

Fig. 3 Land-use/cover maps of Manila.

2.3 Intensity analysis

At the time interval level, intensity analysis aims to examine how the size and rate of land change vary across time intervals (Aldwaik and Pontius 2012). This study focuses on ULC, i.e. change from non-built to built. Thus, in order to measure the intensity of ULCs in the three capital cities, the time interval annual change intensity (TI-ACI) of land change from non-built to built for each of the two time intervals, i.e. t1-t2 and t2-t3, was first determined (Eq. (1)).

$$\text{TI-ACI} = \frac{(\text{LC}/\text{LA})}{\text{TE}} \times 100, \quad (1)$$

where LC is the area of land change from non-built to built in a given time interval (e.g. t1-t2); LA is the area of the entire landscape; and TE is the time extent of the given time interval (i.e. t1-t2).

Subsequently, the derived TI-ACI for each time interval was compared with the uniform rate of ULC in each city, called the uniform intensity (UI) (Aldwaik and Pontius 2012). The UI is the rate of change not for each time interval, but rather for the entire time extent of the land change analysis. In this study, two time intervals (i.e. t1-t2 and t2-t3) out of three time points (i.e. t1, t2, and t3) were considered. Therefore, the UI of ULC in each city was determined based on the total time extent (TE) of the two time intervals (TI) (Eq. (2)).

$$\text{UI} = \frac{[(\text{LC}_{\text{TI}_1}) + (\text{LC}_{\text{TI}_2})]/\text{LA}}{\text{TE}_{\text{TI}_1} + \text{TE}_{\text{TI}_2}} \times 100 \quad (2)$$

Finally, to characterize the intensity of ULC, we propose six category levels (CL), namely very slow, slow, medium slow, medium fast, fast and very fast. These categories can be determined using Eq. (3) and the proposed land change intensity scale (Fig. 4).

$$\text{CL} = \frac{\text{TI-ACI} - \text{UI}}{\text{UI}} \times 100 \quad (3)$$

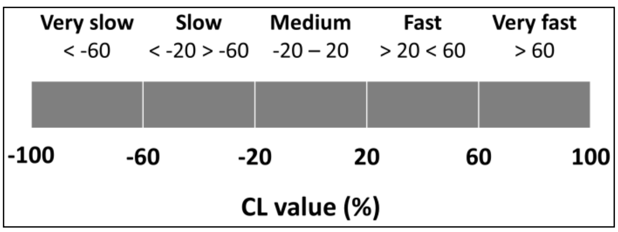

Fig. 4 Land change intensity scale. Medium slow is from ≥ -20 to 0; medium fast is from > 0 to ≤ 20.

2.4 Spatial pattern analysis

In order to capture the spatial pattern of ULCs or the changes from non-built to built, we derived the density of urban development (DoUD) along the gradient of the distance from city center in each city (Eq. (4)).

$$\text{DoUD}_\text{i} = \frac{\text{x}_\text{i}}{\text{a}_\text{i} - \text{b}_\text{i}} \times 100, \quad (4)$$

where DoUD_i is the density of urban development in zone i; x_i is the area of 'built' in zone i; a_i is the area of zone i; and b_i is the area of 'water' in zone i. The distance interval of the 'multiple ring buffer' from each city center, from which each zone was derived, was set to 1.5 km (see Fig. 5).

The respective city centers of the three study areas were identified based on geographical and socio-cultural (symbolism, historical) significance. The city center of Bangkok is the Grand Palace in Bangkok City; for Jakarta, it is the National Monument in Central Jakarta; and for Manila, it is the Kilometer Zero (KM 0) landmark in Rizal (Luneta) Park, Manila.

Another spatial metric, called the path cohesion index, was also used to determine the level of aggregation or physical connectedness of built-up lands in the three cities based on the extent of their respective LUC maps. This index, which has a value that ranges from greater than zero (> 0; less aggregated) to less than or equal to 100 (≤ 100; more aggregated), was derived using the FRAGSTATS program (version 4; McGarigal et al. 2012).

3. Results

Table 1 summarizes the results of the intensity analysis of the ULCs in the three cities. Figure 5 presents the derived DoUD in the three cities along the gradient of their respective distances from city center. The 18 km maixmum distance used (Fig. 5) was based on the extent of the smallest LUC maps, which belong to Jakarta. Figure 6 shows the results of the measurement of aggregation or physical connectedness of the built-up lands of the three cities.

Table 1. Intensity analysis results.

	Bangkok		Jakarta		Manila	
	t1-t2	t2-t3	t1-t2	t2-t3	t1-t2	t2-t3
ICA*	5.24	5.92	7.91	3.70	3.92	3.47
TI-ACI*	0.48	0.59	0.66	0.41	0.49	0.43
UI*	0.53		0.55		0.46	
CL (%)	-10.42	11.46	19.23	-25.64	6.16	-6.16
ICA – Interval Change Area; * Unit: Percent of landscape						

4. Discussion and Conclusions

The results revealed that the intensity of ULC in Bangkok was 'medium slow' during the 1990s and 'medium fast' during the 2000s (Table 1; Fig. 4). For Jakarta, it was 'medium fast' in the 1990s and 'slow' in the 2000s. For Manila, it was also 'medium fast' during the 1990s and 'medium slow' during the 2000s. These results indicate that there seem to be some variations in the temporal pattern of urban development between the 1990s and 2000s among the three cities.

The results also revealed, however, that the three cities had similar pattern in terms of DoUD along the gradient of the distance from city center (Fig. 5). In all the three cities, it can be observed that the pattern of DoUD can be likened to the Newling's model of urban population density, characterized by the presence of a "central density crater with a rim or crest" (Newling 1969). In this study, the presence of a central density crater in all the three cities was due to the presence of urban open spaces, including green spaces, in areas close to the city center. It can also be noted that the relative increase of built-up lands from t1 to t2 and from t2 to t3 has been relatively higher in the areas farther from the city center (Fig. 5). This is an indication that the urban development in the three cities has been expanding outward of the city center.

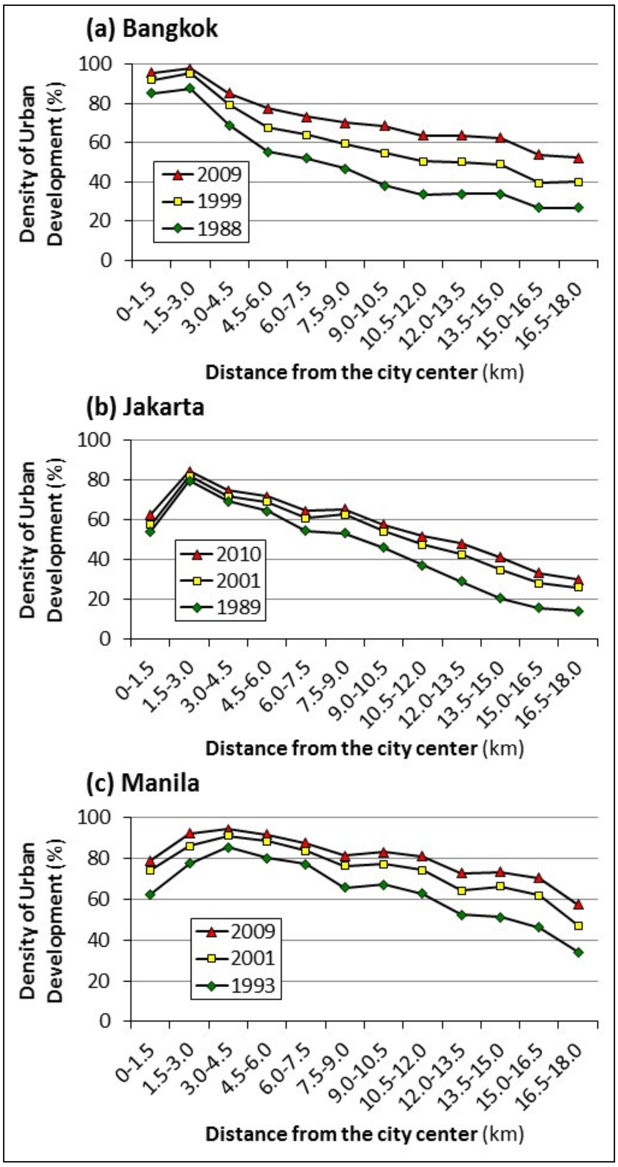

Fig. 5 Density of urban development (DoUD) along the gradient of the distance from city center.

The results also showed some evidence that the built-up lands of Manila were relatively more aggregated or physically connected than those of Bangkok, but more especially those of Jakarta (Fig. 6). Across the two time intervals, the increase in the value of the patch cohesion index was very little in Manila as compared with the increase in the other two cities. Bangkok and Manila, however, had a relatively more stable increase across the two intervals, while Jakarta had a much higher increase during the 1990s than in the 2000s. The variation in the increase of the patch cohesion index between the two time intervals could be partly due to the type of urban development that was dominant in each city during each time interval (e.g. infilling or dispersed). Further, it could also be partly due to the difference in time extent (year) and ICA or TI-ACI between the two time intervals in each city (Table 1). Nevertheless, the increasing trend in the patch cohesion index indicates that the three cities have been experiencing, not only a spatial expansion of urban development outward of the city center (Fig. 5), but also an infilling urban development.

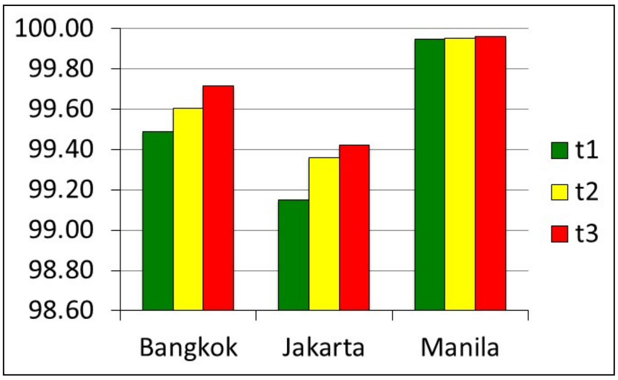

Fig. 6 Patch cohesion index of built-up lands.

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