Ecological Indicators 81 (2017) 274–284

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Impact of rapid urban expansion on green space structure

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ARTICLE INFO

Keywords:
Land Change Modeller
Markov Chain
Landscape metrics
Spatial structure and pattern
Simulated model
Master planning and policies

ABSTRACT

Rapid urban expansion has had a significant impact on green space structure. A wide variety of modelling approaches have been tested to simulate urban expansion; however, the effectiveness of simulations of the spatial structure of urban expansion remains unexplored. This study aims to model and predict urban expansion in three cities (Kuala Lumpur, Metro Manila and Jakarta), all experiencing rapid urban expansion, and to identify which are the main drivers, including spatial planning, in the resulting spatial patterns. Land Change Modeller (LCM)-Markov Chain models were used, parameterised on changes observed between 1988/1989 and 1999 and verified with the urban form observed for 2014. These models were then used to simulate urban expansion for the year 2030. The spatial structure of the simulated 2030 land use was then compared with the 2030 master plan for each city using spatial metrics. LCM-Markov Chain models proved to be a suitable method for simulating the development of future land use. There were also important differences in the projected spatial structure for 2030 when compared to the planned development in each city; substantive differences in the size, density, distance, shape and spatial pattern. Evidence suggests that these spatial patterns are influenced by the forms of rapid urban expansion experienced in these cities and respective master planning policies of the municipalities of the cities. The use of integrated simulation modelling and landscape ecology analytics supplies significant insights into the evolution of the spatial structure of urban expansion and identifies constraints and informs intervention for spatial planning and policies in cities.

1. Introduction

Globally, urban expansion has increased over recent decades (Cohen, 2006). This is expected to continue as urban areas are expected to absorb most of the global population growth in the upcoming decades (United Nations Department of Economic and Social Affairs UNDESA, 2012). Cities have grown rapidly in size and density (Turrini and Knop, 2015) and in some developing countries, cities have tripled in size (Seto et al., 2012), often denominated rapid urban expansion. In Southeast Asia, the urban expansion rate is 2.8% higher when compared to many urbanised regions of the world (Cohen, 2006; United Nations Department of Economic and Social Affairs UNDESA, 2012). As a consequence, urban green space has come under increasing pressure during the urbanization process and this negatively affects ecosystem services, cultural associations, psychological well-being and the health of urban dwellers (Tian et al., 2011). The conversion of green spaces into the built-up areas has become one of the major reasons for habitat destruction worldwide (Turrini and Knop, 2015) and therefore, if some of this green space can be retained, protected or reclaimed, then it becomes important to monitor and understand the changes in spatial complexity of an urban ecosystem as rapid urban expansion occurs.

Urban dynamics, planned or unplanned, can cause changes to the structure, shape and functions of built and non-built areas (Madureira et al., 2011). In Southeast Asia, the relatively weak structure of urban policy poses challenges for the adoption of appropriate urban management strategies. Uncoordinated master planning strategies often lack information on the past, present and future changes to the urban and green space structure. In this study, we define the master plan as a land use map that determines future urban growth. However, master plans prepared to guide urban development have rarely been successful (Sharifi et al., 2014; Todes, 2012). This is because these plans are often created by international planning consultants who are not aware of the local conditions (Seto et al., 2012; Sharifi et al., 2014). Subsequently, the present understanding of the spatial effects of urban planning arising from rapid urban expansion remains unclear and poorly understood.

The planners often employ simulation modelling to forecast future urban expansion with a view to improve land management policies and

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http://dx.doi.org/10.1016/j.ecolind.2017.05.031
Received 21 September 2016; Accepted 11 May 2017
Available online 12 June 2017

practices (Bhatti et al., 2015). The integration of remote sensing, geographic information systems (GIS) and urban simulation modelling has been successfully applied to create better understanding of urban development dynamics and to anticipate urban planning activities (Zhang et al., 2011). Numerous simulation modelling techniques have been developed to simulate urban changes, for example; Artificial Neural Networks (ANN), Markov Chain models, Land Change Models (LCM) and cellular automata models (Losiri et al., 2016; Roy, 2016; Triantakonstantis et al., 2015). While these models have potential to inform urban planning, this is difficult to reach in practice as there is a lack of empirical evidence on the relative effectiveness of urban planning in cities under rapid urban expansion (Zhou and Wang, 2011).

Here we seek to understand the effectiveness of these spatial models to identify the effects of master planning strategies in cities experiencing rapid urban expansion. We use a combination of Land Change Modeller (LCM) and Markov Chain modelling, incorporating GIS data and remote sensing satellite imagery. The LCM is less complex, faster and a more understandable process when compared to most modelling techniques (Eastman, 2006; Triantakonstantis et al., 2015). The quantity of change is modelled through a Markov Chain temporal analysis for the LULC types, and the process relies on the historical transitions and past changes (Sinha and Kumar, 2013), as there is evidence that urban land use depends on the historical development process of each city (Niemelä, 2014).

We then combine this with spatial metrics (indicators) associated to the shape, form and spatial distribution of the urban green space. As the landscape becomes urbanised, the resulting fragmentation affects landscape structure and decreases the landscape connectivity (Vergnes et al., 2012). Consequently, green spaces become isolated by a matrix composed of buildings and streets, limiting the distribution and the connectivity of green space patches. Spatial metrics quantify and interpret the changing spatial urban characteristics and patterns based on the characterisation of spatial pattern (size, density, shape, distance of patches) due to the fragmentation of the green space. They are effectively indicators (Uuemaa et al., 2013), describing the changes in shape complexity and variety due processes of urban compaction, aggregation, dispersion and isolation (Aguilera et al., 2011). The quantification of landscape structures using spatial metrics in a simulated model (Kong et al., 2012) is important in assessing and monitoring the effectiveness of master planning when rapid urban expansion occurs.

This paper aims to: (1) test the applicability of integrated LCM-Markov Chain models for three cities undergoing rapid expansion (Kuala Lumpur, Malaysia; Jakarta, Indonesia and Metro Manila, Philippines) to model and simulate the observed spatial patterns of urban expansion and changes to green space structure and (2) use the developed LCM-Markov Chain model to describe, using spatial metrics, the simulated rapid urban expansion potential with proposed master plan 2030. We also identify which are the main drivers, including spatial planning, in the resulting spatial patterns. We hypothesised that the spatial effect of rapid urban expansion and green space are influenced by the historical spatial changes, implementation of the previous master planning efforts and uncontrolled urban expansion.

2. Methods

2.1. Study area

The study focusses on three cities in Southeast Asia: Kuala Lumpur, Malaysia; Jakarta, Indonesia and Metro Manila, Philippines (Fig. 1). Kuala Lumpur, the capital of Malaysia, is located at the confluence of the Klang and Gombak rivers and its total area is approximately 23 934 ha (239 km^2). Jakarta, the capital city of Indonesia, consists of five municipalities within a lowland context on the North Coast of Java Island. The city occupies an area of 64 000 ha (640 km^2). Jakarta has a flat terrain, and the land gradually rises across the city from 5 to 50 m above mean sea level (Murakami et al., 2005). Metro Manila, the capital of the Philippines consists of eight contiguous cities, including Manila, and nine other municipalities, covering an area of approximately 63 800 ha (638 km^2). The capital is located in the lowlands of south-western Luzon Island and is situated on the eastern coast of Manila Bay at the mouth of the Pasig River (Murakami et al., 2005).

2.2. Data acquisition

Landsat satellite imagery was used to obtain LULC (land use land cover) information for each study area. 1988 and 1999 Landsat-5 Thematic Mapper 30 m resolution imagery for Kuala Lumpur was obtained from the Malaysian Remote Sensing Agency (MRSA). The same type of imagery for the years 1989 and 1999 were downloaded from the Global Land Cover Facility (http://glcf.umd.edu/) for Jakarta and Metro Manila. Landsat-8 Enhanced Thematic Mapper 30 m resolution images for 2014 covering the three cities were downloaded from the U.S. Geological Survey (http://www.usgs.gov/). The images were projected to the appropriate Universal Transverse Mercator UTM Zone for each city on the WGS84 datum. The availability of satellite remote sensing data has increased significantly in the last two decades, and it constitutes a useful data source for mapping the composition of urban settings and analysing changes over time (Patino and Duque, 2013). The master plan maps for each city were obtained from the each city authority (Kuala Lumpur City Hall, 2005; Government of Jakarta Special Capital Region, 2011; Metropolitan Manila Development Authority (MMDA, 2012).

2.3. Methodological framework

In this study, LULC categories were modelled using the Land Change Modeller (LCM) software package (Eastman, 2006; available as ArcGIS 10.2 extension, http://www. clarklabs.org) to derive the predicted future LULC maps (Eastman et al., 2005 Pérez-Vega et al., 2012; Shooshtari and Gholamalifard, 2015). The LULC modelling procedures consisted of two stages (Fig. 2). The first stage involved the modelling of potential change using LULC maps of 1988/1989 and 1999 to simulate the year 2014 (15 years interval). The model enabled the comparison of the actual map for 2014 with the results from the simulated model to verify the ability of the model to simulate urban development. We assess the evidence of spatial effects of the urban master plan on the urban expansion pattern by examining the differences between the predicted spatial patterns of urban expansion and the actual expansion observed for 2014. The second stage involved modelling the potential change using actual LULC maps of 1999 and 2014 to generate simulations of the LULC in the year 2030 (15 years interval) and then comparing this with the 2030 master plan map using landscape metrics to detect differences in spatial structure.

2.4. Image processing

Nine satellite images were processed using ERDAS Imagine 2014 (Intergraph Corporation, Madison, AL) and ArcGIS 10.2 (ESRI, Redlands, CA) to produce LULC maps for each city. The geocoded satellite images were subsetted using the boundary of the cities obtained from the Global Administrative Areas database (http://www.gadm.org/) to extract the area of interest from the images. LULC types were classified into three types: built-up area, green space and waterbody, to match the LULC types used on the digitized master plan maps for 2030. The LULC types were classified using maximum likelihood supervised classification (ERDAS Imagine, Hexagon Inc., Jensen, 1996; Fonji and Taff, 2014; Zhou and Wang, 2011) (Table 1). In the classification process, the existing land use maps, topographic maps and visual interpretation of Google Earth imagery were used to provide the training data for the classifier and a separate validation dataset. The accuracy assessment was based on an error matrix that compared the classification results with the validation dataset, expressed as the overall