Modeling Sprawl of Un-authorized Development Using Geospatial Technology: a Case Study in Kuantan District, Malaysia

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Modeling Sprawl of Unauthorized Development Using Geospatial Technology: Case Study in Kuantan District, Malaysia

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Abstract

The paper explores a framework combining remote sensing and GIS-cellular automata concepts aimed at improving the modeling of unauthorized land use sprawl. Remote sensing data have been used in urban modeling and analysis, the use of high resolution remote sensing data in assessing unauthorized development is quite unexplored. This work has demonstrated systematic combination utilization of geospatial analyses tools to acquire new level of information to enable urban modeling and sprawl analysis in assisting urban sustainable management. In this study, Kuantan city, Malaysia was selected in simulation of the unauthorized land use with cellular automata concept for a period of 15 years (2000-2015), with main input time-series land use observation from 1995 to 2005. The 2000 and 2005 land use input was also used as calibrated and test assessment of the simulation. The results show excellent agreement between in-situ changes of the un-authorized land use classes and the corresponding simulated classes within the same periods. In conclusion, cellular automata model can lead to new levels of understanding of how urban areas grow and change as in view of digital earth aspiration.

KEYWORD: cellular automata model, un-authorized land use sprawl, Remote Sensing and GIS

1. Introduction

Urban Dynamics research in landscape characterization, urban growth models, and geographic understanding provide the data necessary for analyzing the impacts of population growth and land use

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change. This information can be used to analyze the causes of urban congestion, pollution, and loss of natural resources. Each of these impacts is linked to changes in the extent of urban, agricultural, and forested lands, and (or) transportation systems. Planners use Urban Dynamics data to evaluate environmental impacts, to delineate urban growth boundaries or service areas, develop land use zoning plans, and to gauge future infrastructure requirements. Traffic congestion, a common malady of urbanization, is the result of urban growth increases in population density, and out-dated transportation infrastructure. By evaluating trends associated with land use change over time, solutions to traffic congestion may be obtainable (Burchell et al., 1998; Downs et al., 1999; Galster et al., 2001; Hasse and Lathrop, 2003).

Urban growth and the concentration of people in urban areas are creating societal problems world-wide. A century ago, approximately 15 percent of the world's population was living in urban areas, but today, the percentage has risen to nearly 50 percent. In the last 200 years, world population has increased six times, stressing ecological and social systems. Over that same time period, the urban population has increased hundred times, concentrating more people on less land even as the total land devoted to urbanization expands (Hasse and Lathrop, 2003). Yet, the temporal and spatial dimensions of the land use changes that shape urbanization in Malaysia are little known.

Malaysia is experiencing rapid urbanization which is a result of natural population growth and rural urban migration due to push and pull factors of physical, social and economic conditions (Ghani, 2000). In addition, sprawl is also the result of the moving of urban populations from major city centers to urban fringe areas due to the changing lifestyle which emphasized on spacious comfortable and environmentally friendly living environment (Burchfieldet al., 2006). With this trend continuing to happen, towns and cities in Malaysia will continue expand in accommodating to the growth due to the complex demand of the people. Worsening conditions of crowding, unauthorized development and insufficient or obsolete infrastructure, as well as increasing urban environment and ecological problems underline a greater than ever need for effective management and planning of urban regions (Burchell et al., 1998; Downs et al., 1999; Galster et al., 2001; Hasse and Lathrop, 2003). Experiences also shown that rapid and uncontrolled expansion of towns and city has led to amongst other deterioration in the quality of urban environment and sprawling of urban development onto prime agricultural and forest areas as well as cities starting to lose their identity (Sierra Club, 2008). In order to avoid such phenomena continuing to happen, particularly in conurbation area, towns and cities in Malaysia need to be properly planned, and managed so that their growth or expansion can be controlled and managed in a sustainable manner.

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Urban sprawl monitoring and prediction are the fundamental information that are required for long term planning. For balanced development, municipal authorities need tools to monitor how the land is currently used, assess future demand and take steps to assure adequacy of future supply (Jantz et al., 2003; Jat et al., 2008). For a better planning of future urban development and infrastructure planning, municipal authorities need to know sprawl phenomenon and in what way it is likely to move in the years to come. Recently, innovative approaches to urban land use planning and management such as sustainable development and smart growth has been proposed and widely discussed (American Planning Association, 2002).

In recent years, the use of computer based models of land use change and urban growth has greatly increased with the potential to become important tools in support of urban planning and management (Li and Yeh, 2000; Torrens and Sullivan, 2001; Couclelis, 2002 and Silva & Clarke, 2002). This development was mainly driven by increased data resources, improved usability of multiple spatial datasets and tools for their processing, as well as an increased acceptance of models in local collaborative decision making environments (Batty et al, 1997; Clarke and Gaydos, 1998; Samat, 2002; Cheng, 2004; Almeida et al 2005; Sudhira et al 2007; Mohd Noor and Hashim, 2009[a], 2009[b]). However, the application and performance of urban models strongly depend on the quality and scope of the data available for parameterization, calibration and validation, as well as the level of understanding built into the representation of the processes being modeled (Batty 1997; Longley et al, 2001). In order to justify the control of unplanned growth, it is important to develop a conceptual framework of modeling of un-authorized sprawl in Malaysia context to analyze the physical trajectory of sprawl to more planned growth.

2 Materials and Method

2.1 Study Area

The study area is located between 03°45N to 03°52N latitudes and 103°17E to 103°23E longitudes (Figure 1). Kuantan is situated 160 km from Kuala Lumpur, the capital city of Malaysia. Kuantan enjoys the status of being one of the major centers of conurbation in east Malaysis, apart from having historic importance. The administrative area of Kuantan spreads over an area of 13,501 hectares. Majority of the land use pattern consist built-up areas (residential, industrial, commercial, institutional, recreation area, road, infrastructure and utilities) and un-built (agriculture, forest, bare land and water bodies). The population of Kuantan was 106,704 in the year 2000, and it is projected to be 241,197 in 2015, as per the

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present growth rate (Kuantan Local Plan, 2004). To provide a better planning of future urban development and infrastructure planning, municipal authorities need to know sprawl phenomenon of this study area such as its distribution, factors and in what way it likely to move in the years to come.

>> insert Figure 1 about here

2. Materials and Method

2.1 Satellite Data And Ancillary Information

Two sources of data have been used in this study: (i) primary data and (ii) ancillary data (Table 1). The primary data used are topographic maps, land use map, un-authorized development data and IKONOS pan-sharpened satellite data for the year of 2005. The ancillary information collected from secondary sources include road network, drainage pattern, cadastral map of alienated land parcels, urban map and records of unauthorized development.

>>> insert Table 1 here

2.2 Methods

In order to understand the dynamic phenomenon of urban sprawl, the basic requirement is the availability of information on land use change, urban pattern identification and computation of landscape metrics (Cihlar and Jensen, 2003). In this study all these required information has been compiled and converted to digital forms and are readily used in both Digital Image Processing System and Geographic Information Systems. The ERDAS Imagine and Ecognition are two main Digital Image Processing systems used in the study, while ArcGIS software system is the Geographic Information System used to generate various thematic layers consisting of Kuantan administrative boundaries, roads, contours and administrative boundary map using compiled corresponding topographic maps of the area. Complete methodology of the study is summarised in Figure.2.

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The image pre-processing and data preparation techniques are firstly carried out; these involved image rectification and mosaicking techniques. The image-to-map registration approach was adopted in the rectification of the IKONOS satellite image. Using set of 20 control points appeared in both map and image set, the rectification is performed in two step procedures: (i) the transformation of the image to map geometry using second degree polynomial transformation; and (ii) the resampling process of the pixel intensity values from the raw IKONOS data to the transformed geometry. We ensure the accuracy (RMSE) of the transformation is within less than $\pm$0.5pixel, so that we ensure the classes of fine details within the urban land use is not loss. In the resampling process, the nearest neighbour resampling scheme is adopted as the amount of translational shifts (in *xy* plane) and the rotations observed is very marginal upon cursory examination of both transformed and raw data set.

The rectified data sets are then mosaicked producing the entire study area from six sets of the raw IKONOS data. Image classification is then applied to the pre-processed image, where the land use classes map of the entire study area is produced. The supervised classifications techniques have been chosen for this study, performed using object-based classifier using eCognition software system, which have enabled all fine details of land cover to be classified, later merged accordingly to form the classes in accordance to urban land use classes used in urban planning practice (Mohd Noor and Hashim 2007).

In this study the object-based classifier is employed to build optimal training areas and build-up knowledge for each classes of interest prior to classification of the entire image. Initially, the algorithm trains the spectral classes by supervised training process, after collection of parametric and non-parametric signatures (training samples). After completion of the training process, the entire knowledge on the class's occurrence within the IKONOS image is generated. The knowledge is then used to identify all the pixels of the image into the trained classes with multi-resolution segmentation approach. The classes identified were then re-categorized into two main classes of un-built and build-up, apart from identifying it further into detailed 10 land uses for 3 land use that have shown potential to expand or risk as un-authorized land use sprawl, namely: the residential, commercial and industrial areas.

The spatial factors for all the 3 main land uses are then derived based on the proximity of the classes of interest to highway strips, segregation land use and leapfrog development (Hasse and Lathrop, 2003; Hasse and Kornbluh, 2004). All the spatial factors obtained are then feed into the cellular automata (CA) sprawl model for the sprawl analysis.

>> insert Figure 2 here

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According to Shamsuddin and Yaakup (2005),a cellular automaton (pl. cellular automata, abbrev. CA) is a discrete model studied in computational theory, mathematical physics, complexity sciences and theoretical biology. and microstructure modeling. It consists of a regular grid of *cells*, each in one of a finite number of states, such as "On" and "Off" (in contrast to a coupled map lattice c). The grid can be in any finite number of dimensions. For each cell, a set of cells called its neighborhood (usually including the cell itself) is defined relatively to the specified cell. For example, the neighborhood of a cell might be defined as a set of cells a distance of 2 or less from the cell. An initial state (time t=0) is selected by assigning a state for each cell. A new *generation* is created (advancing t by 1), according to some fixed rule (generally, a mathematical function) that determines the new state of each cell in terms of the current state of the cell and the state of the cells in its neighborhood. For example, the rule might be that the cell is "On" in the next generation if exactly two of the cells in the neighborhood are "On" in the current generation; otherwise the cell is "Off" in the next generation. Typically, the rule for updating the state of cells is the same for each cell and does not change over time, and is applied to the whole grid simultaneously, though exceptions are known.

The CA model is employed in the sprawl analysis where it is used to simulate the spatial pattern of urban sprawl in the residential, commercial and industrial areas of Kuantan which have been reported as to expand as un-authorized development. Using a three element of spatial factor the expansion of these land uses are defined based on 2005 data. Four basic elements of CA have been determined according cells, states, neighborhoods and transition rules. The cell is intrinsically linked with the observed space to represent land parcel. Although the original pan-sharpened IKONOS had ground resolution of 1x1m, all the cells are resampled to 10 x10m for faster simulation and also to support an average parcel size in imagery of this study.

The state of each cell represented land use activities Lt_{ij} which are divided into seven categories of built-up areas (residential, commercial, industrial, institution, infrastructure, utility, open space and recreation and transport) and un-built area comprises agriculture, forest and vacant land. The simulation consist of many iterations or loops for computation so that cities will grow gradually at each iteration (Table 2). At the end of an iteration, CA will decide whether the state cell will be converted or not for urban and non-urban development. The model of CA employed in this study is given in equation (1) adopted from Shamsuddin and Yaakup (2005); such that:

$$Gt_{ij+1} = \int (Lt_{ij}.Nt_{ij}.T_r)^t \qquad (1)$$

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where,

Gt_{ij+1} is potential of cell for un-authorized land use L at time t

Lt_{ij} is zoning status of the cell for un-authorized land use L at time t

Nt_{ij} is neighborhood space effect on the cell for un-authorized land use L at time t, and

Tr is the transition rules contains factors which determined of Lt_{ij} for land use L.

Neighborhood Nt_{ij} in a CA-based model consists of a window of predefined size and shape that is used to define the sphere of influence for urban development, which we used using 3x3 window neighborhood, to represent 30x30m area. The transition rules is formulated to govern cell evolution, where cells state at any time step is determined by the state of cells at previous time step and suitability index calculated on the basis of factor influencing urban sprawl. The un-authorized land sprawl model is represented by equation 1 above.

>> insert Table 2 here

The highway strip measure is calculated in this analysis by determining whether a new development unit occurred within a 100 m buffer of a main road. The development areas within the highway buffer were assigned as common development, whereas housing units outside the buffer in the contact of this study assigned as un-authorized sprawl. The segregated land use index, as developed in this analysis, measure the degree to which the land use is mixed at a pedestrian scale. It is a measure of a number of different types of land uses that are within reasonable walking distance to a housing unit. Nelessen (1994) suggests that 500m (the distance that an average pedestrian will walk in 10 minutes) constitutes reasonable walking distance. The index is calculated by counting the number of different land use types within 500m of unit as buffered in maps. The leapfrog index is calculated in this analysis by a straight-line distance measurement using 500m walking distance from each housing unit to the perimeter of the nearest land use area. If there are more than three land uses, this is consider well development and is otherwise if that areas have less than three types of land uses (Table 3).

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3 Results and Discussion

3.1 Image Analysis

The 6 sets of IKONOS imagery have been successfully merged altogether and geometrically corrected with transformation to local mapping coordinate with RMSE ±0.5 pixel to ensure accuracy of the sprawl analyzed. In fact this RMSE has been widely used as accurate geometric output. The image classification carried out in two steps process to produce first level classes of built and un-built areas, and further detailed land use classes within the built-up areas. Final classified image for the land use classes are tabulated as in Table 4.

>> insert Table 4 here

The corresponding vector layer of land parcels are used as contextual information in labeling level of the classified spectral class in GIS system. The rule is only one class (label) output is allowed for each polygon at spectral classes within land parcels (alienated lots). The assessment of the classification is carried out based on the classified image with the in situ information. Table 5 below summarizes the accuracy of IKONOS image classification for the urban land use. An overall classification accuracy of over 86% has been achieved with Kappa 0.86. This is indeed very good classification confirmed with significant test.

>> insert Table 5 here

3.2 The Sprawl Simulation

The unauthorized land use sprawl model was run using ArcMap model builder within Arc/Info. The development of the CA model within a GIS package can facilitate the retrieval of spatial information and the use of its powerful spatial processing functions. The model is tested in Kuantan, Malaysia, a very fast growing region in eastern region of Peninsular Malaysia. A GIS database was built to contain the information of land use, transportation and administrative boundaries. The four elements of cellular automata model (cells, state, neighbourhood and transition rules) have been integrated using tools in

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ArcGIS to generate a future 2015 urban scenario. The Arctools of *greater than equal* = transition rules and *focal statistic* = neighborhood were integrated to produce the land use projection based on land use in 2004 and projection in year 2015.

The model was calibrated by running a simulation for the period 1990 to 2005 (Figure 3). The simulation was initiated using historical datasets for the year 1990 in order to test the simulation results using the reference datasets for the year 2005. Subsequently, a simulation for ten years was undertaken for the period of 2005 to 2015. The testing of simulation results has often considered a weakness in urban CA. The practical way of testing the calibration of the model is to run a simulation using historical datasets. Through this approach, the calibrated simulation of fifteen years was tested by comparing it with the reference land use datasets for 2005. Once the result was satisfactory, the future simulation of land use can be carried out using the parameters of the already calibrated model, assuming, however, that the calibrated factors will remain relatively stable during the period to simulated.

>> inset Figure 3 here

The increase of decrease in the number of cells each land use in the fifteen years period calibration test was calculated from the historical and reference datasets; thus the calibrated simulation accounts for an exact evolution in the land-use surfaces. During the fifteen years period 1990-2015, the measured un-authorized area in study area grew tremendously. It is noticeable that the land-use classes which showed most increase in this period was commercial, industrial and other built-up categories. In the period 1990-2005, the industrial and commercial showed the largest expansion among urban land use classes in study area (Figure 4).

>> inset Figure 4 here

The simulation of future land use with the year 2000 as original time of the model unauthorized land use sprawl are simulated and predicted at study area at model time t = 15. In this case the demands for land use were calculated on the basis of trends in spatial factors from previous decades. In the period 2000-2015, the commercial discontinuous urban fabric has shown the largest expansion among other land use classes in study area with percentage of changes is 181.7% and residential areas increase of 95.7% respectively and the industrial area was shrunk with -0.3% (Table 6). From the absolute point of view, the area occupied by residential was the largest land use-class by area in study area although it has shown a less accelerated growth in recent years than the commercial land use class while in the industrial land use

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was shrunk by 12% due to the decrease in sprawl for 2015. Figure 5 shows the simulated sprawl for 2015 for the residential, commercial and industrial area based on changes from 1990 to 2005.

>> insert Figure 5 here

>> insert Table 6 here

Projection for the year 2015 shown in Table 6 has been defined taking into consideration the previous hypotheses and the land use evolution for the last fifteen years. As can be seen in Table 4, the more important land use of residential are predicted to grow much as they did between 1990 to 2005, whereas commercial also predicted to increase more than they did in the previous 10 years period. Although the growth rate trend is relatively high for these three land use classes, from the point of view of their total area they will affect greatly on the structure of the city particularly with development of infrastructure respectively. Industrial area is foreseen as shrunk approximately with the city trend, as their dynamics are depends on government policy which relocated all industrial area from urban to suburban area particularly in Semambu and Gebeng area.

4.3 Predicting Scenarios of un-authorized sprawl

Un-authorized land use sprawl in Kuantan has been projected using integration of remote sensing data and GIS-Cellular automata concept. Likely increase in the impervious area (un-authorized) is predicted using equation (1) as spatial factors are available from the historical data. To project the un-authorized area from year 2005 to 2015 (decade growth) within the notified municipal area corresponding spatial factors has been undertaken as transition factor of simulation model. It is estimated that the percentage residential and commercial categories have been increased respectively. This implies that by year 2015, the residential and commercial area in the municipal limit would rise to 3528.28 ha and 726.61 ha, which nearly 100 and 200% more than area on year 2005 (1802.77 ha) and 257.95 ha while the industrial area shrunk into -0.3% to 234.53 ha on 2015 due on factor which was stated in the above discussion. Thus, the pressure on land would further grow and the vegetal areas, vacant land and region around highways strips are likely to become prime targets for urban sprawl.

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Fine spatial resolution remote sensing data such as IKONOS data used in this study can be considered an important data source of several model parameters, especially in the context of urban planning practice. The case study presented in this paper shows the importance of remote sensing data in historical time series as an important data source for the parameterization and calibration of urban sprawl models, as an essential condition for the prediction of future development and scenario modeling. The indispensable for dealing with dynamic phenomenon It also indicates the capability of high resolution space-borne remote sensing imagery as an appropriate source of data. This approach can be used to acquire data that meet the spatial, temporal and thematic requirement of most urban land use change models with regard to using an inner-urban discrimination of several urban land use and socioeconomic categories (Herold et al 2002; Herold et al 2003 and Herold et al, 2005).

5. Conclusion

This paper provides a framework for the simulation of un-authorized land use sprawl in the city in Malaysia's perspectives. The land use sprawl is seen as one of the potential challenge to sustainable development where urban planning with effective resource utilization, allocation of natural resources and infrastructure initiatives are key concerns. The study attempted to analyze potential un-authorized land uses to expand as a sprawl based on prediction of land uses for 2015 using CA. Remote sensing and GIS techniques have been used to demonstrate their application for the monitoring and modeling of dynamic phenomena. Urban CA modeling appears to be useful tool to planners. It can be used to study different planning strategies, to measure the spatial consequences of policy decision, and in particular, future land-use dynamics. However, bearing in mind the difficulty of testing future models, the no foreseeable events that can occur in the urban system, and the uncertainty of this kind of modeling per se, future simulations should be treated as hypotheses of event that are likely to occur. These hypotheses can only be verified with time. Despite this constraint, the capacity of certain CA models to reproduce the actual urban shape through large-scale patterns is remarkable. On the other hand, this aspect of urban CA is being also being developed by the spatial and attribute data of the region which have been aided in statistical analysis and defining few of the spatial factors. These spatial factors and relationship between urban sprawl and some causative factors are useful for the local development authorities and municipalities to determine spatial distribution authorities. The integrative approach of remote sensing, GIS with sprawl model will provide planners with more powerful tools for the generation of urban and regional scenarios.

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Norzailawati Md Noor received her MSc degree (2006) in Remote Sensing, BSc degree (2004) in Urban & Rural Planning from *Universiti Teknologi Malaysia*. She recently (April 2010) completed her PhD degree, and her research interest lies in the applications of remote sensing and GIS for urban and rural planning.

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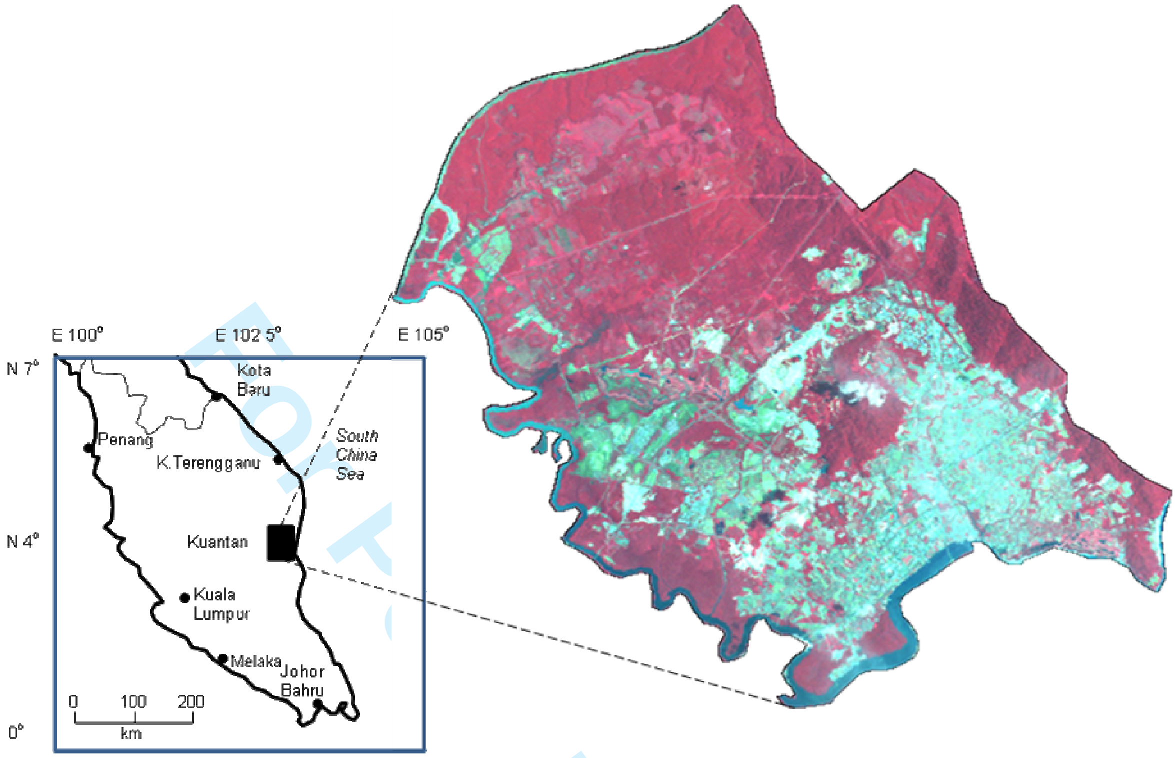

Figure 1: Study area, Kuantan district, Malaysia

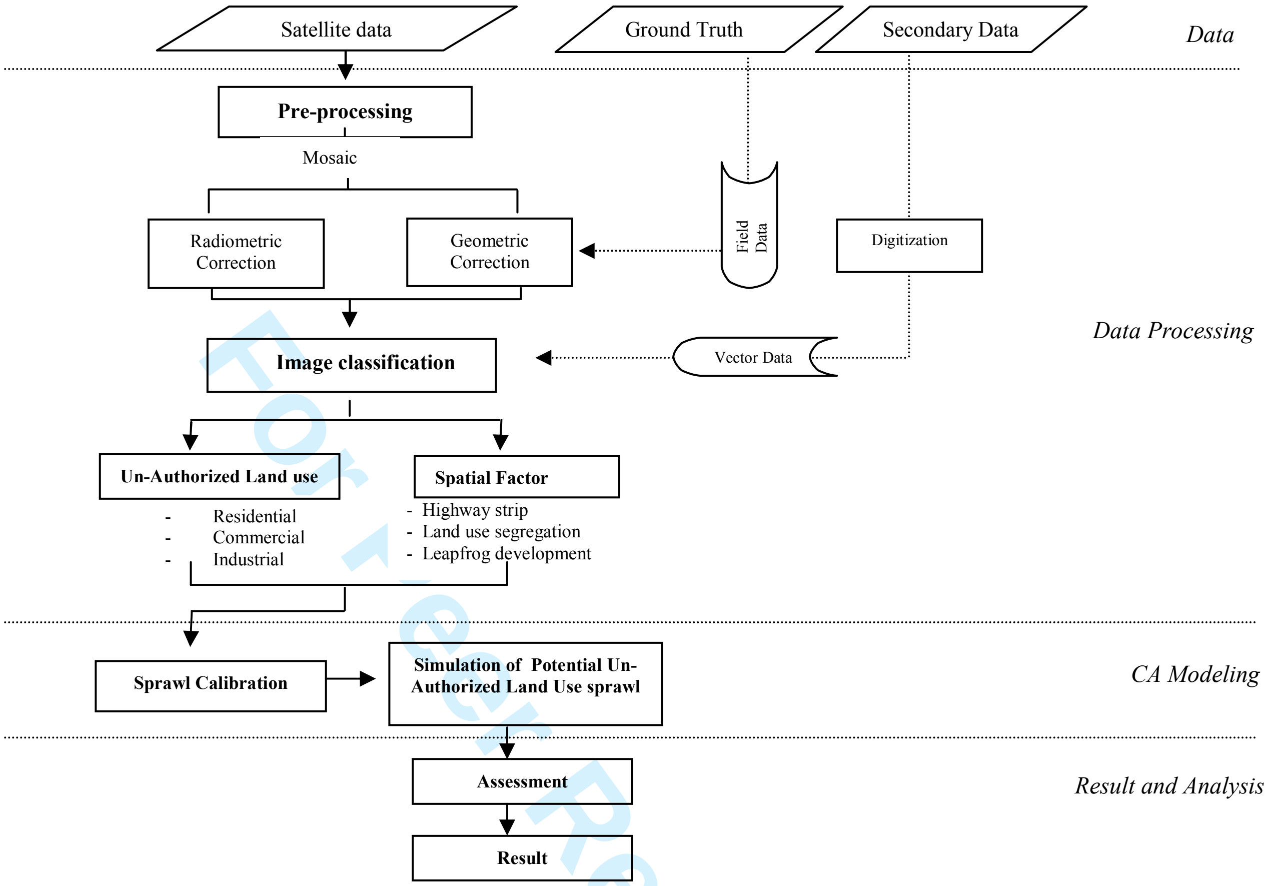

Figure 2: Flowchart of data processing adopted in the study.

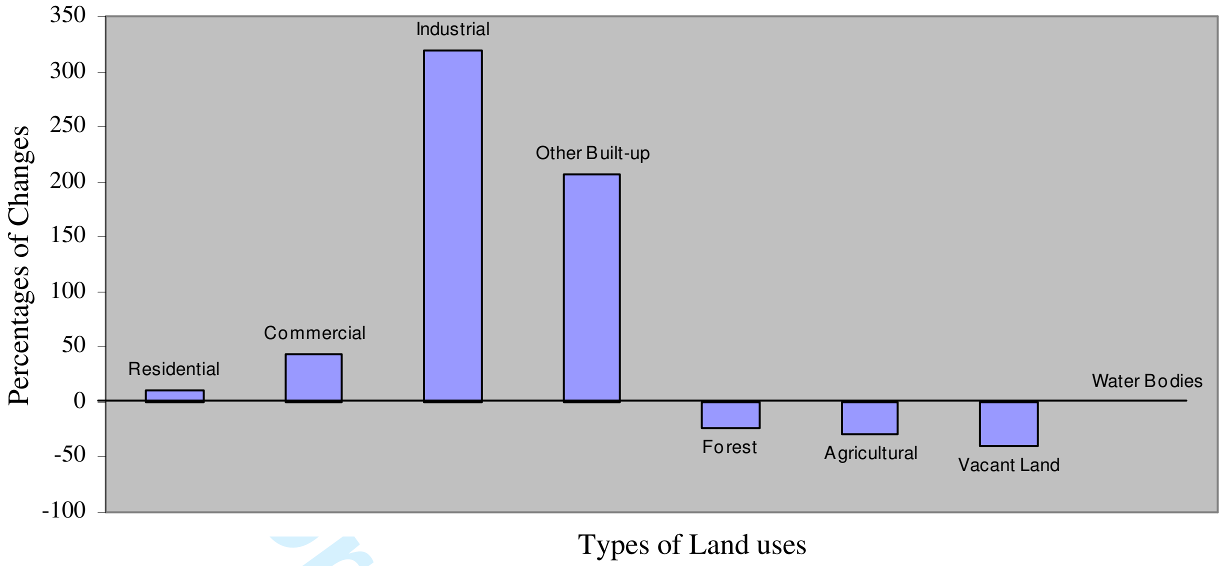

Figure 4: Evolution of calibration land use changes in the study area from year 1990 to 2005 in percentage.

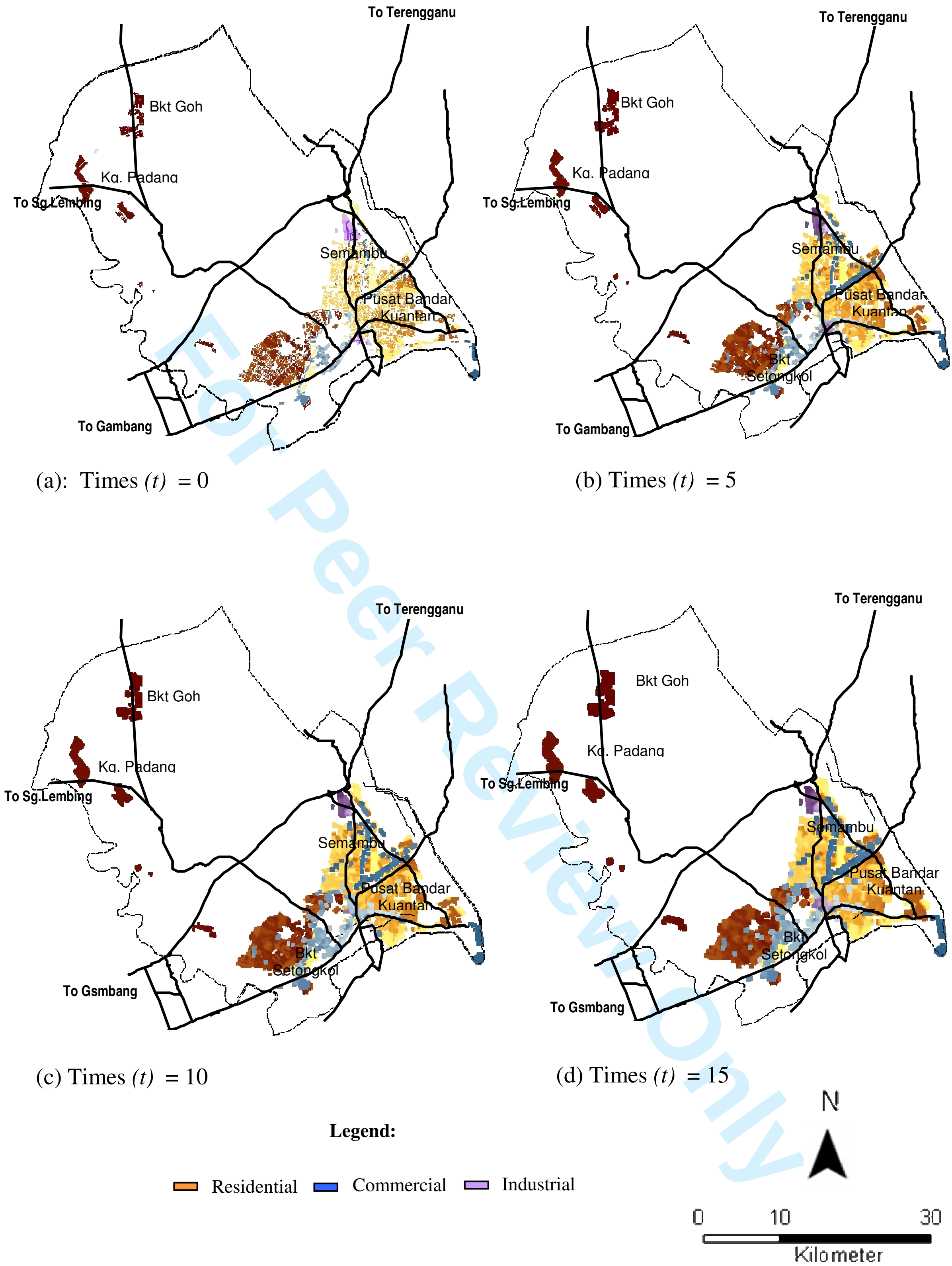

Fig 3: Simulation of un-authorized land use sprawl in study area (a) un-authorized area in 1990; (b) simulated un-authorized area 1995; (c) simulated un-authorized area 2000; (d) simulated un-authorized area 2005.

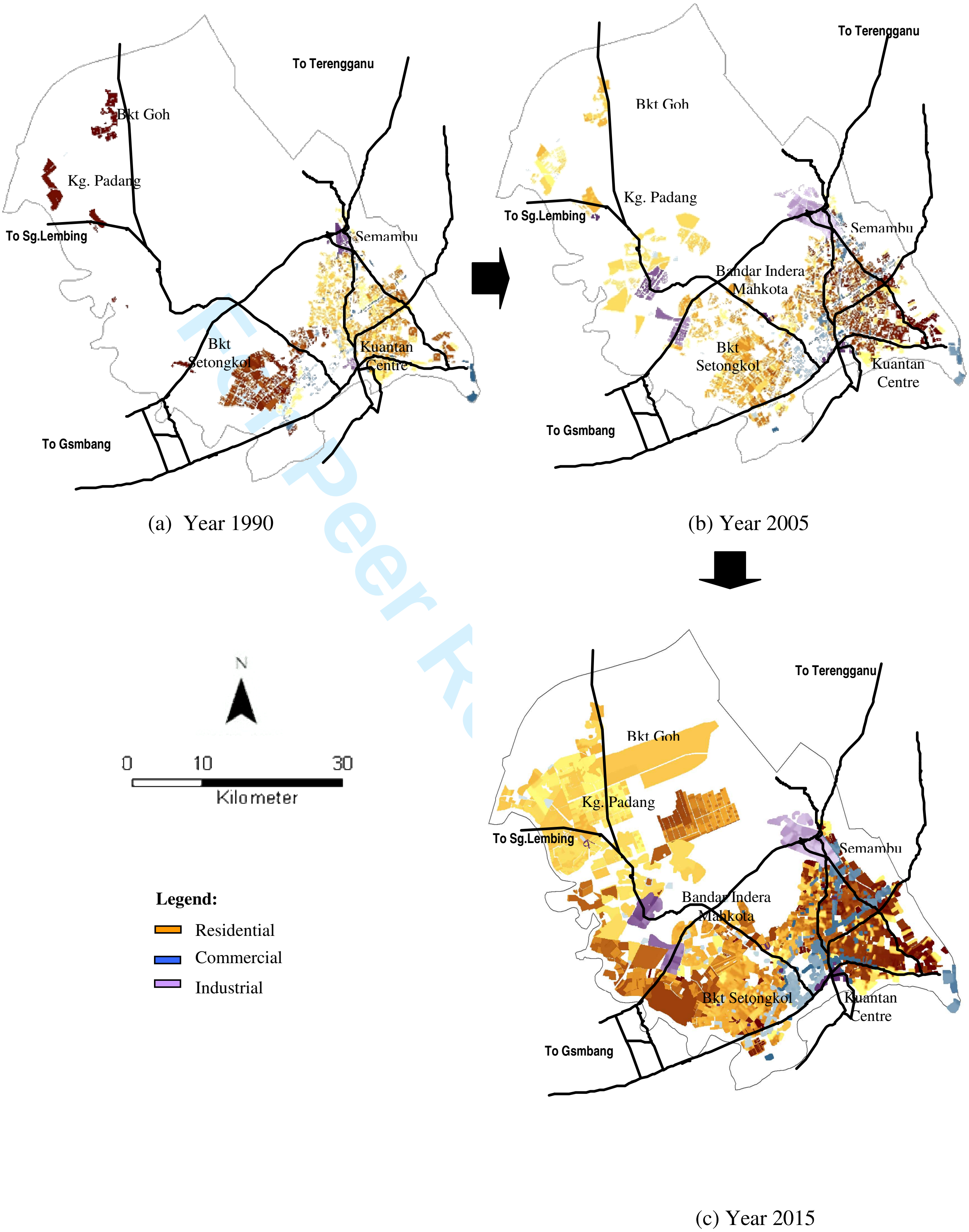

Figure 5 : Evolution of un-authorized land use sprawl in study area: (a) un-authorized area in year 1990; (b) simulated un-authorized area year 2005; (c) simulated un-authorized area in year 2015.

Table 1. Different type of data used

No	Type of data used	Year of acquisition /Publication	Sources
1	IKONOS satellite data (6 sets)	2005	Malaysian Remote Sensing Center
2	Topographic map	1975	Mapping Department
3	Land use Map	1990 and 2005	Kuantan Municipal Council
4	Road Map	2003	Transport Department
5	Drainage Map	2003	Drainage Department
6	Cadastral Map (Land Lot)	2003	Mapping Department
7.	Contour Line	1975	Kuantan Municipal Council
8	Urban Map	2005	Kuantan Municipal Council
9	Un-Authorized Development Data	2008	Kuantan Municipal Council

Table 2: Summary of parameters used in Cellular Automata for modeling sprawl of unauthorized development.

Cellular Automata Based	Parameter on study
Cells (Gt_{ij+1})	It was aggregated to 10m x 10m grid resolution to represent a land parcel in this study area.
State (Lt_{ij})	The states of each cell represented land use activities which represented by zoning status of un-authorized land use consist of residential, commercial, industrial, institution and infrastructure & utility, open space and recreation and transport and un-built area comprises of agriculture, forest and vacant land.
Neighborhood (Nt_{ij})	Consists of a window of predefined size and shape used to define the sphere of influence for urban development using a 3 x 3 windows neighborhood.
Transition rules (T_r)	cell state at any time step was determined by the state of the cell at the previous time step and the suitability index calculated on the basis of a factor influencing urban sprawl combined with Boolean IF, THEN and ELSE statements such that eg: IF tested pixel under consideration is water bodies, THEN no sprawl (0) at this pixel, otherwise IF tested pixel under consideration is vacant land, THEN sprawl (1) at this pixel with described: Tr = 1 *(If) sprawl* *0 otherwise*

Table 3. Parameter for spatial factors

Spatial Factors	Parameters	Weightage
Land use segregation (Total number of different Land use within parameter)	> 500 m < 500 m	Un-Authorized Sprawl Common Development
Highway Strip (walking Distance)	> 100 m < 100 m	Un-Authorized Sprawl Common Development
Leapfrog (Total number of land use within distance)	> 5 types < 5 types	Un-Authorized Sprawl Common Development

Source: modified from Hasse, 2004

Table 4 : Land use classified for year 2005

Land Use Classes	Area (ha)	Area (%)
Residential	1802.77	13.33
Commercial	257.95	1.9
Industrial	235.25	1.7
Other Build-up	3572.31	26.4
Forest	3080.6	22.8
Agriculture	3629.09	26.8
Vacant Land	447.19	3.3
Water bodies	489.84	3.8
TOTAL	**13515**	**100**

Table 5. Result of paired Samples T-test (Correlation)

	Paired Differences					Correlation
	No.Of Class	Std.	Std. Error Mean	95% Confidence Interval of the Difference		
				Lower	Upper	
Pair 1 Existing - Image	11	125.35	37.80	-84.2108	84.2108	.995

Table 6: Actual and projected un-authorized land use in hectares with percentage changes.

Landuse types	2005	2015	% of Changes
Residential	1802.77	3528.82	95.7%
Commercial	257.95	726.61	181.7%
Industrial	235.25	234.53	- 0.3%