Monitoring the expansion of built-up areas in Seberang Perai region, Penang State, Malaysia

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Abstract. Rapid urbanization has caused land use transformation and encroachment of built environment into arable agriculture land. Uncontrolled expansion could bring negative impacts to society, space and the environment. Therefore, information on expansion and future spatial pattern of built-up areas would be useful for planners and decision makers in formulating policies towards managing and planning for sustainable urban development. This study demonstrates the usage of Geographic Information System in monitoring the expansion of built-up area in Seberang Perai region, Penang State, Malaysia. Built-up area has increased by approximately 20 % between 1990 and 2001 and further increased by 12% between 2001 and 2007. New development is expected to continue encroach into existing open space and agriculture area since those are the only available land in this study area. The information on statistics of the expansion of built-up area and future spatial pattern of urban expansion were useful in planning and managing urban spatial growth.

1. Introduction

Urbanization is a major planning and policy concern at all spatial scales. This is because more than half of the world's population is now living in an urban area and overwhelming majority is in the developing countries. The adoption of industrialization policy has led to rapid growth of urban population in the Asian countries including Malaysia. The expansion of built-up areas into arable agriculture area would bring potential threat to food security and sustainability of urban areas. The conversion of agriculture land into urban built-up areas reduces the availability of farmland for food and crop production [1]. In the United States, for example, the total area of cropland, pastureland and rangeland has decreased by 76 million acres in the lower 48 states between 1982 and 2003, while the total area of developed land increased by 36 million acres [2]. China also experienced drastic decrease of farmland due to urban expansion, where cultivated land was reduced from 130.03 million hectares to 125.93 million hectares 1996 and 2002 [3]. Similarly, in Peninsular Malaysia, urban built-up areas had increased from 437,090 hectares to 759,900 hectares between 2001 and 2008, while, agriculture areas had decreased from 6,668,730 hectares to 6,267,300 hectares; a reduction of 400,430 hectares between the same period [4,5]. Although this area only covers approximately 5% of total land in Peninsular Malaysia, proper planning and control should be undertaken since it accommodates more than 70 % of the population [6].

The expansion of built-up areas towards the peri-urban has brought economic benefits to many countries with substantial improvement of social services to the population. However, proper planning

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and monitoring need to be undertaken to control and manage the expansion of built-up areas in order to ensure efficient use of limited land resource and reduce its impact on the environment. Thus, this paper aimed to demonstrate monitoring the expansion of built-up areas in the Seberang Perai region, Penang State. The following section discusses the background of the study.

2. Background of the Study

Geographic Information Systems and Remote Sensing have been used in monitoring land use land cover changes for many years. These technologies become important tools for planners and decision makers in managing urban expansion and investigating land use changes [7,8]. The study by [9] for example, used GIS to measure annual urban expansion intensity index Xuzhou City, China. The study found that urban expansion encroached mainly on cropland and woodland. The study identified population growth, industrialization and economic development are the primary driving forces behind urban expansion. Similarly, the study undertaken [10] measured speed of urban expansion in order to identify driving forces of urbanization in Shijiazhuang, China. It was found that population, traffic conditions, industrialization, and policy are the major factors that influenced the urban expansion. In Malaysia, for example, recent study by [8] and [11] investigated the expansion of built-up areas using GIS and remote sensing. Those studies showed that GIS and remote sensing could become planning tools for predicting urban sprawl and monitoring unplanned urban expansion.

The proposed study was conducted to monitor expansion of built-up areas in Seberang Perai region, Penang State, Malaysia. This area has experienced drastic growth since 1990 mainly due to industrialization policies adapted to foster economic growth [6,4,5]. Furthermore, this area is planned to accommodate 60% of Penang state's population of 1.7 million. Seberang Perai which is the mainland part of Penang State, is located in the northwest coast of Peninsular Malaysia, between 5^o 05' N and 5^o 35' N latitude and 100 ^{o} 20'E and 100 ^{o} 40'E longitude, and has an approximate total area of 738.4 km^2. Land use data of 1990 and 2001 at the scale of 1:75,000 were obtained from project previously undertaken at Universiti Sains Malaysia. Land use data of 2007 at the scale of 1:75:000 was obtained from Town and Country Planning Department, Penang State.

3. Proposed Methodology

This aimed to monitor the expansion of built-up areas for the Seberang Perai Region, Penang State, Malaysia. The proposed framework used in this study is illustrated in Figure 1 below. As illustrated by the figure, the study started with monitoring land use changes from 1990 and 2001, then 2001 and 2001. Then, Markov change analysis was conducted to derive transition potential for the CA-Markov model. CA-Markov model was conducted using land use 1990. This model was validated using land use 2007. Finally, the model was used to predict spatial pattern of built-up area expansion in 2015.

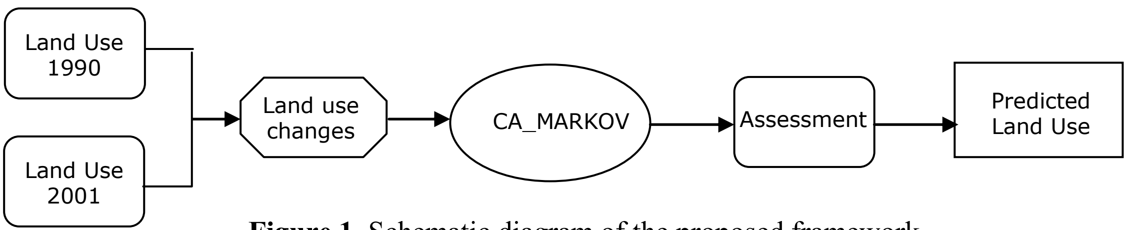

Figure 1. Schematic diagram of the proposed framework.

The study was divided into two parts namely: 1) investigating land use changes from 1990 to 2007 and 2) predicting the spatial pattern of urban growth up to the year 2015. These analyses were undertaken using Equation 1 and Equation 2 below and conducted using ArcGIS 9.3.

$$\Delta LU_{i,j,r}^{t\rightarrow t+1} = LU_{i,j,r}^{t+1} - LU_{i,j,r}^{t} \quad (1)$$

where,

$\Delta LU_{i,j,r}^{t\rightarrow t+1}$ = changes of land use type *r* at location *i* and *j* from *t* to *t + 1*,

$LU_{i,j,r}^{t+1}$ = land use type *r* at location *i* and *j* at time *t + 1*, and

$LU_{i,j,r}^{t}$ = land use type *r* at location *i* and *j* at time *t*.

$$B_{i,t+n} = \left[\left(U_{i,t+n} - U_{i,t} \right) / T_i \times 100 \right] \quad (2)$$

where,

$B_{i,t+n}$ = the annual expansion intensity index of spatial unit *i*,

$U_{i,t+n}$ = urban area in the spatial unit *i* at time *t + n*,

$U_{i,t}$ = urban area in the spatial unit *i* at time *t* , and

T = the land area of spatial unit *i*.

This study then used IDRISI Kilimanjaro to perform CA-Markov. This analysis was performed using Equation 3 and Equation 4 below.

$$^{t+1}LU_{i,j} = f\left(\left(^{t}LU_{i,j}\right) \cdot \left(^{t}P_{x,y,i,j}\right) . \left(^{t}N_{i,j}\right)\right) \quad (3)$$

Where

$^{t+1}LU_{i,j}$ = the potential of cell *i,j* to change at time *t+1*,

$^{t}LU_{i,j}$: = states of cell *i,j* at time *t*,

$^{t}P_{x,y,i,j}$: = probability of cell *i,j* to change from state *x* to state *y* at time *t*, and;

$^{t}N_{i,j}$: = neighborhood index of cell *i,j*.

$$^{t}P_{x,y,i,j} = P\left\{X_t = a_y \mid X_{t-1} = a_x \right\} \quad (4)$$

Where, $^{t}P_{x,y,i,j}$ represents the probability of cell *i,j* to change from activity a_x to activity a_y.

The analysis undertaken above provided the statistics of built-up area expansion, the speed of such expansion and finally predicts the future pattern of built-up area expansion. The result is presented next.

5. Result and Discussion

Seberang Perai experienced significant increased of built-up areas in the last 20 years. In 1990, for example, built-up area was only 15,590.6 hectares and it increased to 18,701.7 hectares (19.95%) and 21,029.9 hectares (12.40%) in 2001 and 2007 respectively (refer to Table 1 below.). The expansion of built-up area, however, has caused significant loss of agricultural land especially surrounding existing built-up area. Agriculture land decreased from 51,880.4 hectares in 1990 to 42,738.5 hectares in 2001 and further reduced to 42,038.2 hectares in 2007. This study then calculated the expansion speed of built-up areas (refer to Figure 2). High speed of urban expansion could be seen in the south Seberang Perai where some of the cells experienced more than 70 % annual urban intensity index between 1990 and 2001. A few cells in the central district experience the same expansion speed of built-up area. Majority of the cells in the north Seberang Perai experienced slow speed.

Between 2001 and 2007, many cells in the north Seberang Perai experienced high speed of expansion speed of built-up area. This was due to leap-frog type of growth or top-down urban development project near Kepala Batas and Betram area. New residential areas and educational institutions such as Universiti Sains Malaysia’s Advance Dental Medical Institute, secondary schools and Industrial Training Institute were being planned and developed which became Kepala Batas-Bertam development corridor. Furthermore, urban growth was also occurred throughout Seberang Perai but at a slower rate.

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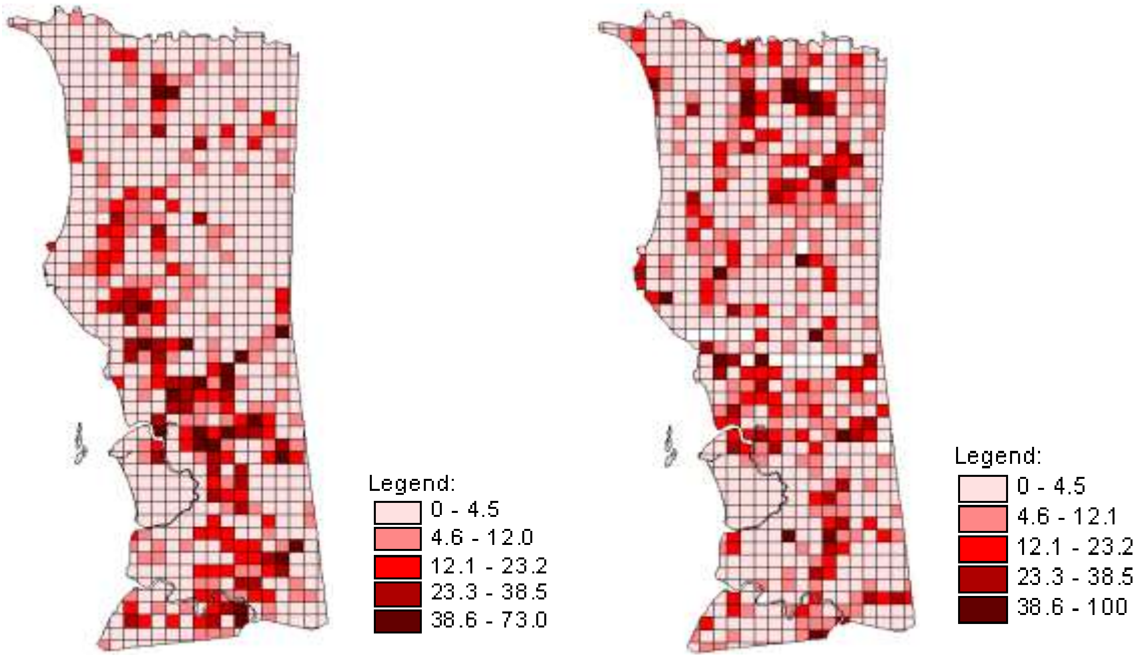
Table 1. Expansion of Built-up areas and reduction of agriculture areas 1990 – 2007.

Year	Built-up Area (Hectares)	Non Built-up Area (Hectares)	% increased of Built-up area	Agriculture Area (Hectares)
1990	15590.464	58126.633	-	51880.427
2001	18701.675	56251.554	19.95	42738.489
2007	21020.959	53804.406	12.40	42038.228



(a) Speed of urban expansion between 1990 and 2001.

(b) Speed of urban expansion between 2001 and 2007.

Figure 2. Speed of urban expansion between 1990 and 2001 and between 2001 and 2007.

This study, then, performed CA-Markov analysis to investigate the spatial pattern of urban growth up to 2015. Five types of land use activities namely residential, commercial and public facilities, industrial, agricultural and others were monitored. The changes between 1990 and 2001 were used to produce the model. The performance of the model was validated using land use 2007. The result obtained is illustrated in Table 2 below.

Table 2. Validation of the CA-Markov Model

Land Use Categories	Kappa Index (x 100) 2007
Residential	70.9
Commercial and public facilities	44.5
Industrial	51.9
Agricultural	82.3
Others	42.8
Overall accuracy	81.04

As illustrated in the table 2 above, overall performance of the model was good where Kappa Index of 81.04 was obtained. However, the performance for commercial and public facilities, industrial, and others were slightly lower. This was probably due to the 2007 land use data used to validate the model was given in cadastral lot format. Thus, it produced error in certain part of the area. Then, this model transition potential was used to simulate the spatial pattern of land use changes in 2015. The result obtained is shown in Figure 3 below. It is expected the expansion of built-up area will continue to occur at the fringe of urban area particularly along major transport network.

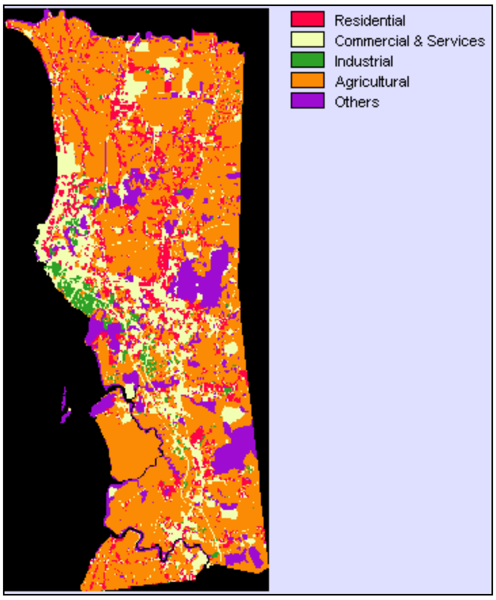


Figure 3. Predicted spatial pattern of land use activities 2015.

6. Conclusion

The study demonstrated the usage of GIS in monitoring the expansion of built-up area in Seberang Perai region, Penang State, Malaysia which is expected to be another urban growth corridor in the northern region of Peninsular Malaysia. The trend of spatial expansion of built-up area is particularly useful in and managing urban spatial growth and formulating appropriate urban planning policies. Furthermore, the expected future spatial pattern of urban expansion could be used in testing formulated policies prior to its implementation.

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