Characterizing Urban Growth Pattern and its Drivers: Evidence from Four Border Cities in Northeastern Thailand

Keeratikasikorn, C.
Department of Computer Science, Khon Kaen University, Khon Kaen, Thailand
Email: chaiyapon@kku.ac.th

Abstract

Understanding the spatial relationships between urban growth patterns and underlying driving forces is important to better comprehend municipal expansion. Urban development was reviewed for four border cities in northeastern Thailand; Nong Khai, Bueng Kan, Nakhon Phanom and Mukdahan between 2002 and 2015. A logistic regression model and landscape metrics were used to identify significant explanatory factors of land use transition by observing each city over two time periods to characterize urban growth patterns and trends. Landscape dynamics revealed that accessibility resulting from local roads was the most significant driving factor for most cities during both time periods, followed by inter-city highway connections. The density of large and small water bodies in the metropolitan areas had minimal influence on urban growth, while some of the major and minor centers played an important role in urban expansion in a particular time period. The analysis showed that new developments had a tendency to occur within sub-districts with increased populations. Trends of urbanization in all four major cities showed a higher annual growth rate during the first than in the second period, with Bueng Kan experiencing the highest annual growth rate at 12.08%. Landscape metrics analysis results suggested that continuous urban expansion resulted in a more fragmented and complicated urban landscape, and improving the current land use plan was vital for the future development of all four border cities.

1. Introduction

Urbanization can be defined as the changes that occur in the territorial and socioeconomic progress of an area, including the general transformation of land cover/use categories from being non-developed to developed (Weber, 2001 and Pham et al., 2011). Urban growth is also an environmental issue; as new metropolitan areas expand, they impact on their surroundings at multiple levels through greater demand for natural resources. Urbanization is an important issue that has to be addressed by city planners, especially in developing countries of Southeast Asia including Thailand. The adoption of the National Economic and Social Development Plan by the Thai Government resulted in many changes to the country's economy and society (Phuttharak, 2014). Greater reliance was placed on industrial manufacturing rather than agricultural production, and the major urban areas in Thailand changed rapidly leading to the 1997 Asian Crisis. Subsequently, the Thai Government adopted the Philosophy of Sufficiency Economy as the guiding principle in the Ninth Plan (2002-2006) and practical applications became evident during the Tenth Plan (2006-2011) (Steinberg and Hakim, 2016).

Northeastern Thailand is at the center of the Greater Mekong Sub region (GMS), a financial trading hub with Laos, China (Yunnan), and Vietnam, and also an air transportation link with Indo-Chinese countries. The ASEAN Economic Community (AEC) was established in 2015 to promote cooperation and development between ten Southeast Asian Nations allowing free movement of trade goods, services, investment, and skilled labor. This greatly benefitted the northeastern region of Thailand, and the four border towns located along the Mekong River: Nong Khai, Bueng Kan, Nakhon Phanom and Mukdahan became focal hubs for the migration of international goods and labor (Figure 1).

Urban growth and land development in Thailand have been studied from various perspectives (Hara et al., 2005 and Murakami et al., 2005) however, most authors presented descriptive reports or research which lacked scientific methodology and pertinent conclusions. Effective planning and management of urban space require both creative skills and the collection of relevant scientific data through advanced techniques, to gain the comprehensive knowledge necessary to make

ISSN 1686-6576 / © Geoinformatics International

informed decisions and guide sustainable development in rapidly changing metropolitan environments. Classic multivariate statistical analysis was employed to model the transition from non-urban to urban land use, especially logistic regression models (Cheng and Masser, 2003, Hu and Lo, 2007, Luo and Wei, 2009, Poelmans and Van Rompaey, 2010, Dubovyk et al., 2011, Long et al., 2012, Vermeiren et al., 2012, Shafizadeh-Moghadam and Helbich, 2015, Deng and Srinivasan, 2016 and Lui et al., 2016). While spatial metrics are measurements derived from the digital analysis of thematic maps to show spatial heterogeneity at a specific scale and resolution (Herold et al., 2003). Such analyses provide quantitative characterizations of the spatial composition and configurations of habitat or land cover types and can be used to track changes in landscape patterns over time. Spatial metrics provide a useful tool for objectively quantifying the structure and pattern of an urban environment directly from thematic maps. Changes of landscape pattern can be detected and described by the landscape metrics, which quantify and categorize complex landscape into identifiable patterns and reveal some ecosystem properties that are not directly observable (Deng et al., 2009).

Recently, interest in applying spatial metrics techniques in urban environments has increased to elucidate spatial components in metropolitan structures for better understanding regarding the dynamics of the change and growth processes (Huang et al., 2007, Aguilera et al., 2011, Pham et al., 2011, Paudel and Yuan, 2012, Nassar et al., 2014 and Hu et al., 2015). The availability of remote sensing data has increased significantly over the past two decades with a corresponding reduction in cost and provides a useful method for mapping the compositions of cities and analyzing changes over time (Patino and Duque, 2013). Unique characteristics of remotely sensed data including repeat cycle and wide area coverage allow policymakers to analyze and respond to problems involving urbanization processes (Rashed et al., 2005 and Patino and Duque, 2013). Increasing spatial resolution of commercial satellite imagery has resulted in the emergence of new studies and applications related to urban settlements, with the individual identification of objects such as buildings and detailed representation of road networks. QuickBird, IKONOS and GeoEye-1 are types of remote sensing data used to produce high-resolution imagery on Google Earth which is a useful tool for visual interpretation and exploration of urban settlements. Access to conduct field surveys and delineate roads, places, rivers, waterbodies and settlements through GIS applications is not always possible; this also requires resources and manual labor which increase cost and project duration.

This paper aimed to appraise and comprehend the mechanisms of urban development in four Thai border cities, focusing on the driving forces before the establishment of the AEC. The development processes of regional rapid-growth cities were investigated to enhance policy formulation and benefit future urban expansion in the region. The combined application of remote sensing and landscape metrics provides spatially consistent and detailed information about urban structure and change, and consequently, facilitates improved the understanding of both the characteristics of urban areas and its surrounding environment. Research on border cities, especially in northeastern Thailand, is limited and the effects of exploratory variables might differ from existing findings. This study of the four border towns increased the understanding of growth patterns and the determinants affecting land expansion in urban Thailand and analyzed the socio-ecological dynamics to improve planning processes for future sustainable development. The aims were to: (1) examine the changes in urbanization of the four border cities during the period 2003-2015, (2) identify the spatial driving factors that encourage urbanization, and (3) draw connections between the observed landscape dynamics by analyzing urban growth characteristics using landscape metrics.

2. Study Area

Four border cities; Nong Khai, Bueng Kan, Nakhon Phanom and Mukdahan located on the Mekong River in northeastern Thailand were selected (Figure 1). The study area is mostly flat plains between latitudes 14°0′ and 18°30′N and longitudes 101°0′ and 105°0′E covering an area of 160,000 km^2 on the Khorat Plateau and delineated by the Mekong River (along the border with Laos) to the north and east, by Cambodia to the southeast, and by the Sankamphaeng Range south of Nakhon Ratchasima Province. To the west, the region is separated from northern and central Thailand by the Phetchabun Mountains. Within this area, four major urban centers within a 30 km x 30 km rectangular boundary cover an area of approximately 900 km^2. The border cities are impacted by migration of international labor and goods because of their locations adjacent to Laos, with accessible links to Vietnam and southern China after the establishment of the AEC. In the past, all the urban areas were surrounded by farming communities; these have now been overrun by infrastructure development as roads and residences.

Pressures of construction have increased urban land value with most sold and transferred from the local residents to traders both within and outside the province. Development has included the construction of the Mittraphap Road, the major highway to the region and a strategic gateway to promote the northeastern economy, resulting in increased growth rate of the urban areas.

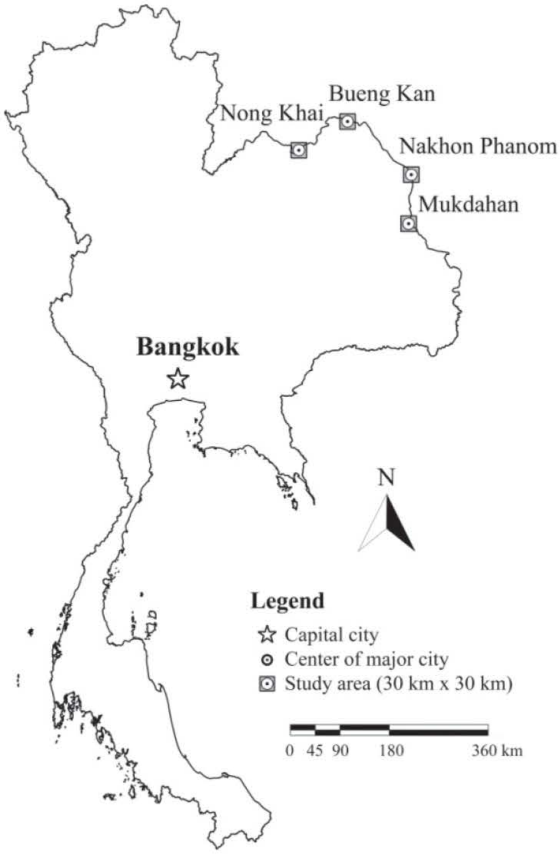

Figure 1: Location of four border cities on Thailand administrative boundary map

3. Materials and Methods

3.1 Dependent Variable

A set of binary maps of the urban areas for each time period were created through visual interpretations of multi-temporal high-resolution imagery available from Google Earth. The rationale behind the approach used for visual interpretation is due to the size of the detectable urban area in the study. Not all cities are major cities that are large enough in terms of urban area to be quantified using satellite-based classification, e.g. supervised classification. Especially for urban areas of growth with much smaller size, it is almost impossible to detect changes in the areas using medium resolution satellite data from sources such as Landsat, for case study in this research. Such that, on screen digitizing of urban patches (impervious surfaces) was performed using Google Earth base map (QuickBird, WorldView II, III) with zoom level height 300-500 m at accuracy equivalent to map scale 1:4,000 in UTM Zone 48N. The study area of the four border cities; Nong Khai, Bueng Kan, Nakhon Phanom and Mukdahan is shown in Figure 2.

Urban changes for the two time intervals were created as a dependent variable. Time intervals differed between cities due to the availability of satellite imagery within Google Earth software as shown in Table 1. A database was created for the study area as a 30 km x 30 km square using a comprehensive plan boundary (dotted line) as the lowest range of the digitizing area. Sample of urban change map of Bueng Kan for the two time intervals was shown in Figure 3.

3.2 Drivers of Urbanization

A general list of factors determining urban development was compiled from a literature review of similar studies (Cheng and Masser, 2003, Hu and Lo, 2007, Luo and Wei, 2009, Vermeiren et al., 2012 and Shafizadeh-Moghadam and Helbich, 2015) coupled with available references from previous literature involving urban growth within the study area. All variables were listed in Table 2 and spatial distribution of independent variables were shown in Figure 4.

Table 1: Data used in the study

City name	D/M/Y	Source	D/M/Y	Source	D/M/Y	Source
Nong Khai	31/12/2003	QuickBird	31/12/2011	QuickBird	31/12/2015	World View II, III
Bueng Kan	3/3/2003	QuickBird	22/12/2011	QuickBird	5/1/2014	World View II, III
Nakhon Phanom	3/12/2004	QuickBird	31/12/2009	QuickBird	2/11/2013	World View II, III
Mukdahan	3/12/2004	QuickBird	4/11/2007	QuickBird	23/2/2012	World View II, III

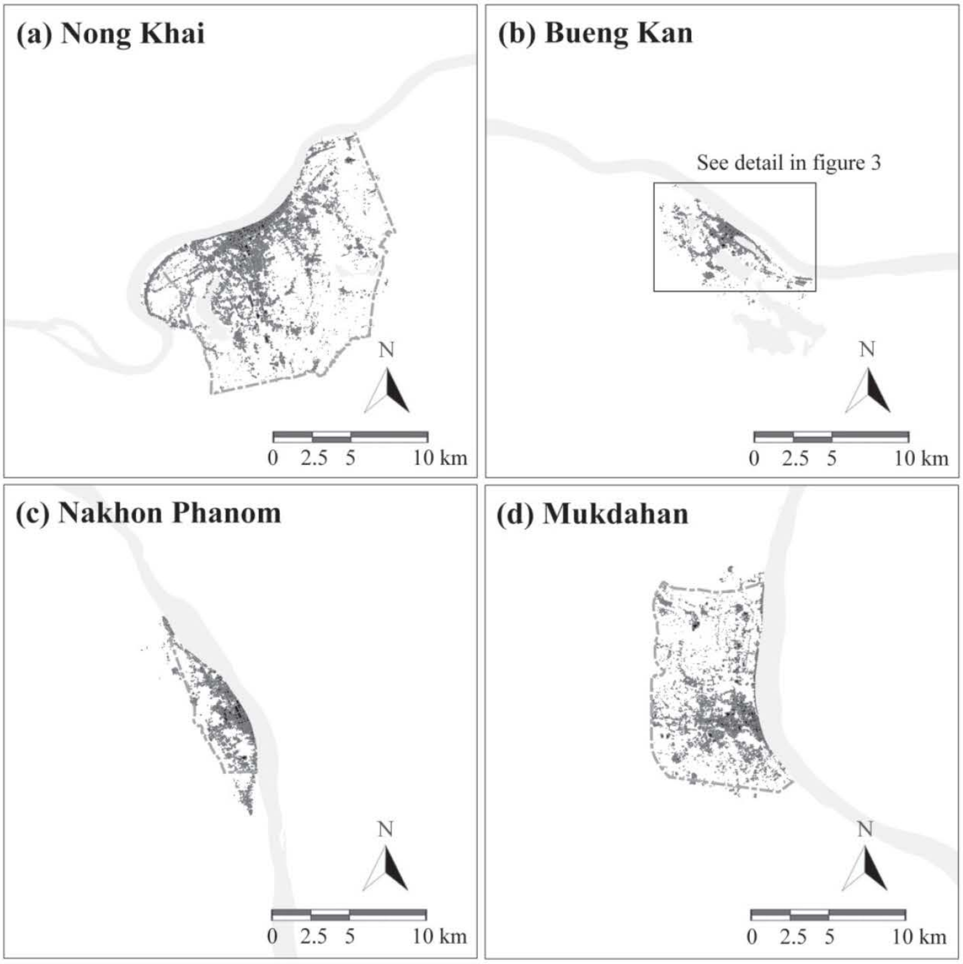

Figure 2: The study area within a 30 km x 30 km rectangular boundary of the four border cities; (a) Nong Khai, (b) Bueng Kan, (c) Nakhon Phanom and (d) Mukdahan. Dotted lines represent city comprehensive plan boundary

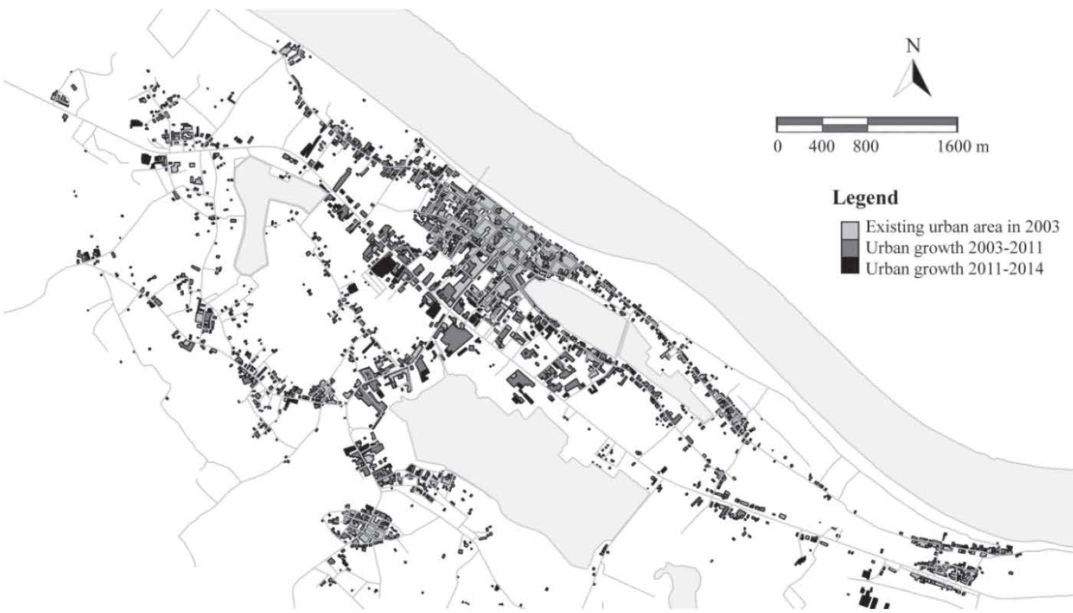

Figure 3: Urban growth in Bueng Kan, 2003-2014

Table 2: Variables and descriptions

No.	Variables	Descriptive
Dependent Variable		
1	Urban Change 1	Binary variable (1: change to urban; 0: no-change) interval time no.1
2	Urban Change 2	Binary variable (1: change to urban; 0: no-change) interval time no.2
Independent Variable		
Proximity Variable		
1	Major Road	Continuous variable, distance from major roads
2	Minor Road	Continuous variable, distance from minor roads
3	Railway	Continuous variable, distance from railway
4	Major Center	Continuous variable, distance from major centers
5	Minor Center	Continuous variable, distance from minor centers
6	Large Waterbody	Continuous variable, distance from large water bodies
Neighborhood Variable		
7	Small Waterbody	Continuous variable, density of small water bodies
8	Existing Urban	Continuous variable, density of existing urban area
Site Specific Variable		
9	Population Density	Continuous variable, population density (person/ha)
10	Population Growth Rate	Continuous variable, percentage change of population between time interval

3.2.1 Proximity variable

Inter-city highways, local roads, and railways formed the cadre of transportation networks in each city, and three variables of accessibility were selected including distance to inter-city highways or major roads, distance to local artery roads or minor roads, and distance to the railway line.

Three more variables to reflect the influence of existing socio-economic factors were chosen including distance to major city centers, distance to minor centers, and distance to large waterbodies. For major city centers, large department stores and major transportation nodes were selected and created as vector point data. Similarly, minor city centers included all modern trade, shopping centers and transportation nodes located outside the urban center. The selection of large waterbodies was based on the area of the waterbody, which also had to serve a community as a recreational zone or a tourist attraction (Phuprasert et al., 2008, Ratchanagool and Preyawanit, 2013, BuengKan Provincial Development Plan (2014-2017), 2013, Satithpongsathaporn, 2015, Puwapornkul, 2015, Office of the Board of Investment, 2015, Information of Nakhon Phanom, 2015, The Treasury Department, 2016 and Office of the National Economic and Social, 2017).

3.2.2 Neighborhood variable

Two neighborhood attributes were selected as the density of built-up land or existing urban area and density of small waterbodies. These variables indicated constraints (density of small waterbodies) or promotion (density of built-up land). The selection of small waterbodies was based on all natural surface water which had no specific social function and was mostly used for agricultural purposes. The neighborhood defined for the two density variables was a circle of 500m radius, with consideration of the distance-decay functions and the practices adopted by other scholars (e.g., Cheng and Masser, 2003 and Luo and Wei, 2009). The study area consisted mainly of plains and small hill landforms; therefore, slope or any terrain information was excluded.

3.2.3 Site specific variable

Traditionally, population is considered an important factor that influences urban expansion. Following Dubovyk et al., (2011), population density and population growth rate were selected as site-specific variables, which were based on administrative units. Aggregation of population statistics for each city within a sub-district at different time intervals was retrieved through the official statistics registration systems website at http://stat.dopa.go.th/. A total of eleven sub-districts in Nong Khai, two in Beung Kan, four in Nakhon Phanom and five in Mukdahan were used in the study. Population density was calculated from the total population divided by each sub-district area, while population growth rate was computed from the difference in population for each sub-district at each time interval.

3.3 Logistic Regression Modeling

Logistic regression was applied to calculate the relationships between factors and the existence of urban development. The probability of a cell being developed was estimated by a logistic regression model which took the following forms:

$$y = a + b_1 x_1 + b_2 x_2 + ... + b_m x_m$$

Equation 1

$$P(U) = \frac{e^y}{1 + e^y}$$

Equation 2

where *P(U)* is the probability of the dependent variable, or urban development being 1, described as a function of the independent factors, or explanatory variables $x_1, x_2, x_3 \cdot\cdot\cdot x_m$, while $b_1, b_2, b_3 \cdot\cdot\cdot b_m$ are estimated model parameters. The variable *y* represents the exposure to the given set of factors of urban development as a binary variable since a value of 1 (y = 1) means an occurrence of a new unit of urban cell, while a value of 0 (y = 0) refers to no change. *P(U)* indicates the probability of the appearance of a new urban development. The input for the function *P(U)* can be any value, while the output is always a value between 0 and 1. The parameters of the logistic models are coefficients of the independent variables and estimated by applying a maximum likelihood algorithm which determines the best fit of the independent variables to explain the known status of a dependent variable (Dendoncker et al., 2007 and Dubovyk et al., 2011). The sign of the coefficient indicates positive or negative correlation to the response of the dependent variable (Huang et al., 2009, Verburg et al., 2004 and Dubovyk et al., 2011).

3.4 Landscape Patch Analysis

Five class-level spatial metrics were selected to characterize the urban composition features of a particular urban class (Table 3). The class area (CA) metric describes the growth of urban areas. CA is the sum of all patch areas in hectares belonging to a given class. It is calculated by computing the area occupied by a particular land cover type (Paudel and Yuan, 2012). The number of urban patches (NP) measures the extent of subdivisions of urban areas as a count of all the patches within a class or across the entire landscape. NP is high when urban expansion remains constant but fragmentation increases (Pham et al., 2011). The mean patch size (MPS) indicates the average size of urban patches. MPS was selected because it represented the primary predictor of diversity within a patch. MPS increases when urban areas become more aggregated and integrated with the urban cores, and decreases if urban areas become more fragmented. The edge density (ED) is a measure of the total edge length of the urban patches. ED was chosen to quantify the dynamics of the abundance and attributes of specific edge types. An increase of the ED which is the length of the urban boundary, indicates the expansion of urban area. The area-weighted mean patch fractal dimension (AWMPFD) is a measure of patch shape complexity. This was selected to assess patch diversity and patch sensitivity to fragmentation. If the patches are more complex and fragmented, this parameter increases to a higher fractal dimension (Pham et al., 2011).

Table 3: Landscape metrics used in the study

Metric	Description	Interpretation
CA	Class area is the sum of all urban patch areas (m^2), divided by 10,000 (conversion to hectares).	The total extent of urban area in the landscape.
NP	Number of urban patches.	The compactness of urban area.
ED	Edge density is the sum of all edge segment length (m) in each patch type, divided by the total area (m^2), multiplied by 10,000 (conversion to hectares).	The relation between the length of edge to the area of each patch. A high ED shows an irregular patch.
AWMPFD	Area weight mean value of the fractal dimension values of all urban patches, is two times the logarithm of patch perimeter (m) divided by the logarithm of patch area (m^2).	The regularity of the patches. It equals 1 for circular shapes or square cells and increases with irregularity.
MPS	Mean value of enclosed urban patches	The average size of total urban patches in the landscape.

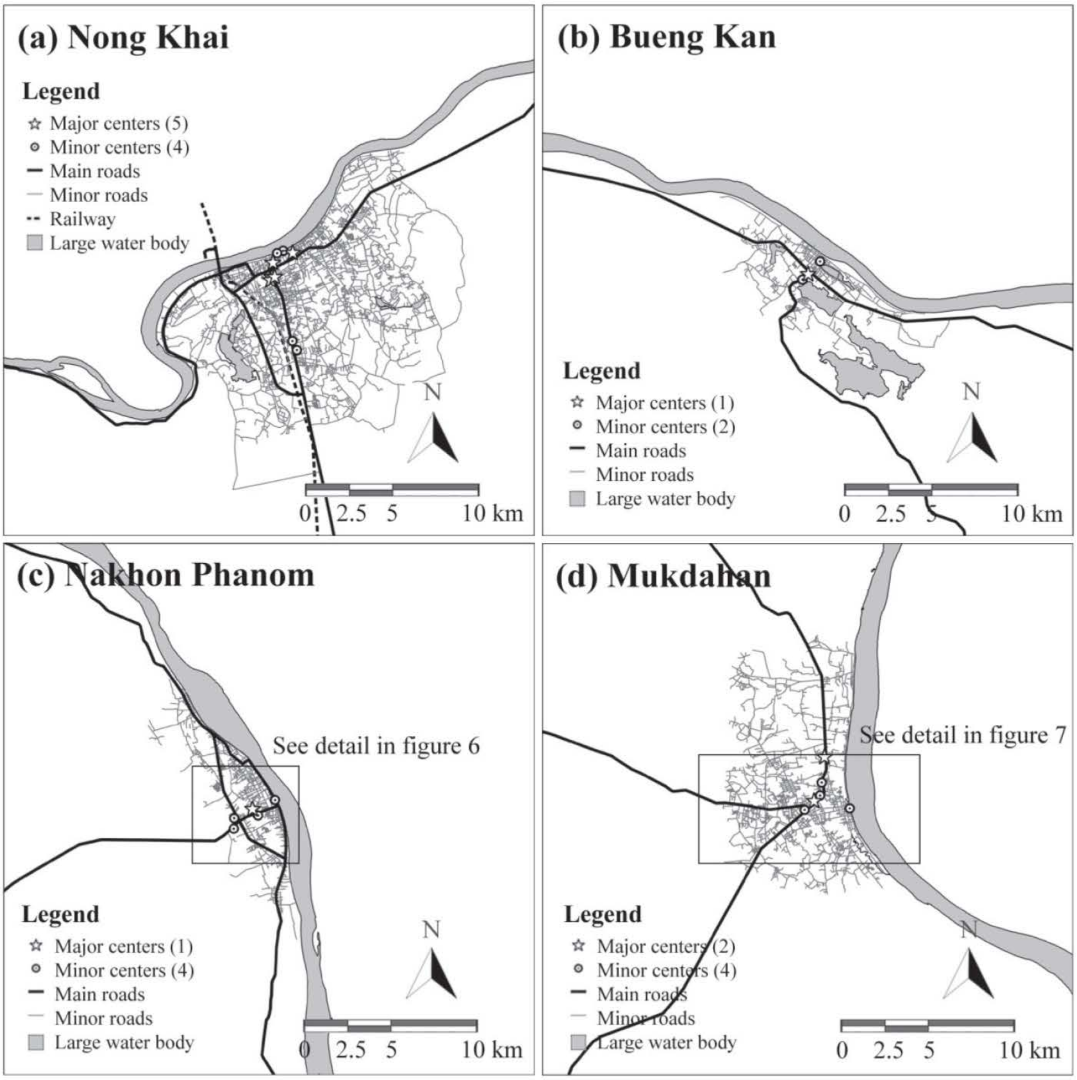

Figure 4: Spatial distribution of independent variables of four cities

3.5 Data Processing

Spatial driving factors of each city were created as point, line and polygon data within the study area (Figure 4). Nong Khai City was represented by all ten variables (Table 2), but as there was no railway line along the Mekong River, the other three cities had only nine variables for analysis. To obtain values of proximity variables for the sample points, lines or planes distance raster surface sets (30m x 30m cell size) were generated using the Euclidean Distance function in the ArcGIS 10.1 software geo-processing tools. Density maps of two variables were generated through neighborhood statistic operations in ArcGIS 10.1 software with density raster surfaces (30m x 30m cell size), and their values were extracted from the generated density raster surfaces for all sample points which all variables were exported into ASCII file format.

Within the MATLAB 2008a environment, raster data in ASCII file format were imported and prepared for logistic regression analysis. ASCII files of all urban change were converted to binary value; with ones (1) representing urban pixels and zeros (0) representing non-urban pixels. Two-dimensional arrays of all data were transformed into columns consisting of Euclidean value or density value, where each row responded to different dependent values of either '1' (urban development) or '0' (non-urban development). In this case, the number of columns represented the number of explanatory variables used in the estimation. The logistic regression model was implemented using MATLAB built-in programming function: *glmfit* (generalized linear model regression) with the selection of binomial distribution and logit transformation.

Patch Analyst is the main software program for landscape metrics calculation and works as an extension within ArcGIS. The software can be freely downloaded at http://en.freedownloadmanager.org/ Windows-PC/Patch-Analyst-FREE.html. Urban areas in shapefile format for each city at each time interval were used as inputs to calculate the spatial metrics. The results provide diverse information for urban growth pattern analysis.

4. Results and Discussion

4.1 Trend in Urban Development

Urban development in all four cities underwent two periods of transition between 2003 and 2015; however, due to available historical data from Google Earth, each city was analyzed over slightly different time intervals.

Nong Khai, the largest of the four cities experienced remarkable urban growth from 2003 to 2011. The class area in the landscape metric table (Table 5) indicates that 1174.2 ha of non-urban area changed to urban area over eight years. By 2011, the city had experienced a significant change of 57.9% (430.6 ha) from the existing urban area in 2003, with an annual growth rate of 7.23%. Bueng Kan experienced the second highest urban growth. Though the smallest city of the four (and also the smallest major city in northeastern Thailand), Bueng Kan showed a 96.6% change in urban area from 2003 to 2011, with an annual growth rate of 12.08%. Similarly to Nong Khai, the city recorded a decrease in annual growth rate during the second period at only 4.8% since only 34 ha of land underwent changes between 2011 and 2015. Annual growth rates in Nakhon Phanom during the two time spans were 6.12% and 3.83% while Mukdahan reported a stable annual growth rate over both time periods at 4.6% and 4.92%, respectively.

4.2 Driving Factors

A logistic regression model was utilized to detect the importance of urban growth drivers in the four cities. Table 4 shows the estimated logistic regression coefficients. As the largest, Nong Khai indicated that spatial development of urban areas was driven by minor roads, major roads and minor centers as the top three influencing proximity factors during the period 2003-2011. The negative relation of these three factors indicated that new urban areas developed along roads and sub-centers had more effective impacts than major centers. During the second period (2011-2015), urban growth in Nong Khai showed greater influence from distance to minor roads than other variables. Also, from model estimation the three variables distance from major centers, density of small waterbodies and existing urban area had very little influence on urban development. The results from modeling showed that urban growth was also influenced by population growth rate during this time period, as confirmed by the compellingly positive coefficient. This indicates that new developments had a tendency to occur within sub-districts with highly increased populations.

Table 4: Logistic regression coefficients of four cities in two time periods

Nong Khai		**Urban Change 1 (2003-2011)**			**Urban Change 2 (2011-2015)**		
No.	**Variables**	**β**		S.E.	**β**		S.E.
Independent Variable							
Proximity Variable							
1	Major Road	-4.108	*	0.2579	-4.109	*	0.4124
2	Minor Road	-60.738	*	2.6935	-52.263	*	5.003
3	Railway	-0.003	***	0.1237	-0.959	*	0.2057
4	Major Center	-0.815	*	0.1268	-1.006	*	0.2246
5	Minor Center	-2.102	*	0.1802	0.155	***	0.3359
6	Large Waterbody	-0.678	*	0.1883	0.241	***	0.3140
Neighbourhood Variable							
7	Small Waterbody	0.014	*	0.0009	0.001	*	0.0011
8	Existing Urban	0.006	*	0.0017	0.003	***	0.0024
Site Specific Variable							
9	Population Density	-0.014	*	0.0029	-0.003	***	0.0041
10	Population Growth Rate	-2.167	*	0.4475	18.688	*	4.9501

β = Coefficient   * significant at 0.01 ($p < 0.01$)   ** significant at 0.05 ($p < 0.05$)   *** not significant

Table 4: (Cont.)

Bueng Kan		**Urban Change 1 (2003-2011)**			**Urban Change 2 (2011-2014)**		
No.	**Variables**	β		S.E.	β		S.E.
Independent Variable							
Proximity Variable							
1	Major Road	-12.877	*	1.7850	-20.328	*	3.5236
2	Minor Road	-58.067	*	6.6444	-59.239	*	11.9740
3	Major Center	-0.694	***	2.0860	-11.370	*	3.8265
4	Minor Center	2.370	***	2.0366	9.610	**	4.1449
5	Large Waterbody	-4.537	**	2.0568	0.755	***	4.0765
Neighbourhood Variable							
6	Small Waterbody	0.010	*	0.0023	-0.022	*	0.0064
7	Existing Urban	0.029	*	0.0095	0.017	***	0.0113
Site Specific Variable							
8	Population Density	-0.205	*	0.0361	-0.052	***	0.0307
9	Population Growth Rate	0.000		0.0000	0.000		0.0000
Nakhon Phanom		Urban Change 1 (2004-2009)			Urban Change 2 (2009-2013)		
No.	**Variables**	β		S.E.	β		S.E.
Independent Variable							
Proximity Variable							
1	Major Road	-8.269	*	1.2246	-22.181	*	1.7284
2	Minor Road	-58.896	*	6.6282	-15.709	*	3.1455
3	Major Center	-6.188	*	1.2161	4.656	*	1.5182
4	Minor Center	3.502	*	1.1520	-4.905	*	1.3980
5	Large Waterbody	-3.015	*	0.6275	0.456	***	0.6278
Neighbourhood Variable							
6	Small Waterbody	0.020	*	0.0016	0.021	*	0.0021
7	Existing Urban	-0.016	*	0.0048	0.002	***	0.0047
Site Specific Variable							
8	Population Density	-0.063	***	0.0948	1.901	**	0.7941
9	Population Growth Rate	4.960	***	6.3520	88.418	*	20.8701
Mukdahan		Urban Change 1 (2004-2007)			Urban Change 2 (2007-2012)		
No.	**Variables**	β		S.E.	β		S.E.
Independent Variable							
Proximity Variable							
1	Major Road	-3.322	*	0.6133	-3.393	*	0.3695
2	Minor Road	-74.821	*	6.5328	-61.368	*	4.1480
3	Major Center	-2.132	**	0.9740	1.968	*	0.6251
4	Minor Center	-0.048	***	0.9372	-0.661	***	0.5815
5	Large Waterbody	-4.742	*	0.4245	-1.569	*	0.2803
Neighbourhood Variable							
6	Small Waterbody	0.006	*	0.0016	0.011	*	0.0009
7	Existing Urban	-0.026	*	0.0042	-0.010	*	0.0028
Site Specific Variable							
8	Population Density	-0.002	***	0.0365	0.030	*	0.0102
9	Population Growth Rate	-3.007	***	4.6876	2.555	*	0.8654

β = Coefficient * significant at 0.01 ($p < 0.01$) ** significant at 0.05 ($p < 0.05$) *** not significant

For Bueng Kan, the smallest city of the four, the top three influencing factors of urban growth were driven by proximity variables. This was confirmed by the strong negative coefficient results from the model during both periods of 2003-2011 and 2011-2014, with significance at the 0.01 level. Among the proximity variables, distance to minor roads had the strongest negative effect on land conversion probability, followed by distance to major roads. In contrast, spatial development of urban areas in Bueng Kan had a tendency to spread around minor centers located close to the city center during the second time period, shown by the positive factor coefficients.

Nakhon Phanom indicated that for proximity variables, the most influencing factors of urban growth were major roads and minor roads. Similarly to Bueng Kan, spatial development of the urban area in Nakhon Phanom between 2004 and 2009 had a tendency to spread around minor centers, indicated by the positive factor coefficient, where both major and minor transportation was accessible. Findings suggested that urban growth in Mukdahan, as well as in the other three cities was largely dependent on road infrastructure development, and local roads were a more important determinant than other variables during both time periods. Interestingly, the results from modeling of Nakhon Phanom showed that population growth rate had a high positive coefficient value during the second time period. Similar to Nong Khai and Mukdahan, this indicates that new developments had a tendency to occur within sub-districts with highly increased populations, though it could also be the result of migration after the implementation of the AEC.

Model estimation parameters indicated that distance to major and minor roads within cities had the highest influence on new urban area development in all four test sites, mirroring the findings of Cheng and Masser (2003), Luo and Wei (2009), Vermeiren et al., (2012) and Shafizadeh-Moghadam and Helbich (2015). New urban areas developed closer to roads in unoccupied suburban regions, suggesting that border city growth in northeastern Thailand was largely dependent on the development of transportation infrastructure, with local roads as the most important driving factor. Model estimation parameters also indicated that distance to major and minor centers influenced new urban growth areas, especially in small and compact cities such as Bueng Kan.

The density of small waterbodies in most cities showed positive signs, contradicting the results of Cheng and Masser (2003), Luo and Wei (2009) and Vermeiren et al., (2012), and indicating that locations far from small waterbodies were preferred for new construction in all four border cities. The result from the study area also indicated that new urban development was concentrated further away from existing urban areas where more land was available. This implied that the four border cities in northeastern Thailand faced uncontrolled urban development, with new urban areas displacing agricultural land surrounding city cores and weakening the role of comprehensive city planning.

4.3 Landscape Pattern

The resulting landscape indices computed for the four cities are listed in Table 5 and shown as graphical trends in Figure 5.

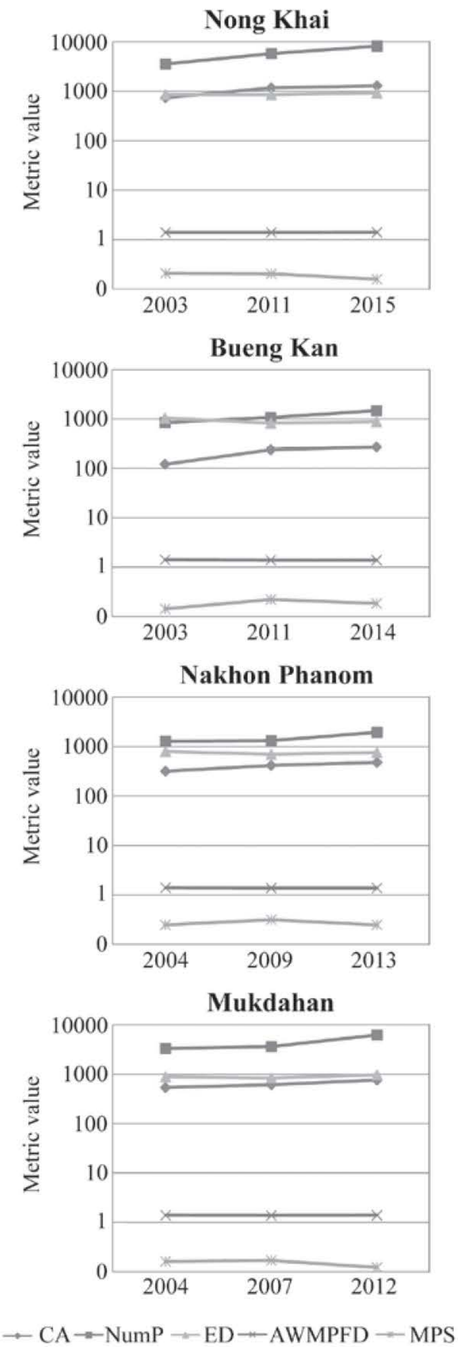

Figure 5: Trend of five spatial metrics using Patch Analysis (refer to Table 5 for metric descriptions)

Table 5: Landscape metrics results of four cities in two time periods

Nong Khai

Year	CA	%	NumP	%	ED	%	AWMPFD	%	MPS	%
2003	743.6		3569		860.2		1.392		0.208	
2011	1174.2	57.9	5773	61.8	854.1	-0.7	1.392	0.0	0.203	-2.4
2015	1290.6	9.9	8174	41.6	926.0	8.4	1.397	0.4	0.158	-22.4

Bueng Kan

Year	CA	%	NumP	%	ED	%	AWMPFD	%	MPS	%
2003	120.6		842		1045.0		1.411		0.143	
2011	237.1	96.6	1074	27.6	824.3	-21.1	1.386	-1.8	0.221	54.1
2014	271.1	14.4	1472	37.1	879.1	6.7	1.389	0.3	0.184	-16.6

Nakhon Phanom

Year	CA	%	NumP	%	ED	%	AWMPFD	%	MPS	%
2004	318.4		1290		794.0		1.395		0.247	
2009	415.7	30.6	1321	2.4	699.2	-11.9	1.380	-1.1	0.315	27.5
2013	479.5	15.3	1946	47.3	759.6	8.6	1.383	0.2	0.246	-21.7

Mukdahan

Year	CA	%	NumP	%	ED	%	AWMPFD	%	MPS	%
2004	537.6		3332		884.2		1.390		0.161	
2007	612.0	13.8	3626	8.8	841.7	-4.8	1.382	-0.6	0.169	4.6
2012	762.3	24.6	6251	72.4	970.9	15.3	1.392	0.8	0.122	-27.8

*** % indicate metric value changed from previous year**

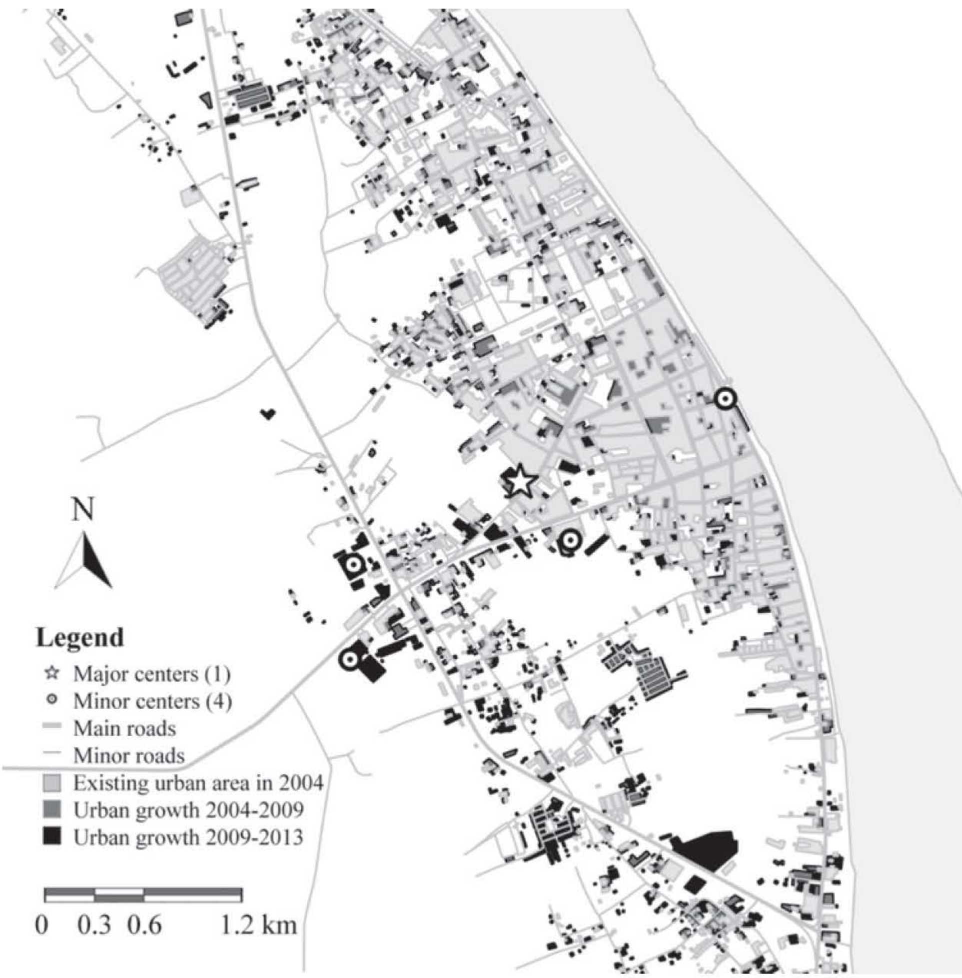

Figure 6: Urban growth in Nakhon Phanom in two time periods, 2004-2009 and 2009-2014

Figure 7: Time series of urban development in Mukdahan during 2004-2007 and 2007-2012

All cities showed a similar trend over both time periods; with the size of the urban areas continuously expanded, indicated by an increase in the class area (CA). However, the landscape became less spatially complex over time, confirmed by the increasing numbers of patches (NP) and mean patch size (MPS), while the complexity of each city also decreased with reduced edge density (ED) and area-weighted mean patch fractal dimension (AWMPFD). Nong Khai, the largest city showed the highest percentage increase in the number of urban patches during the first period of 2003-2011, with minimum change in the shape of the city, illustrated by stable values of ED and AWMPFD. Also, the city trended to expansion in the outlying areas with increase in both CA and ED, while MPS decreased minimally. A rapid expansion in outlying development occurred during the second time period of 2011 to 2015 around Nong Khai, with NP increasing by 41.6% and MPS decreasing by 22.4% from the prior time span. Bueng Kan, the smallest city of the four, recorded a gradual increase in NP and MPS over time during 2003-2011, suggesting that many small rural patches originally located in the urban and suburban areas were converted to urban, resulting in fewer but larger patches in the study site, or infilling rather than leap-frog development. However, the situation changed in the second period when most new developments arose through the conversion of vacant land along the periphery of the city, far away from the city center as illustrated by an increase in both NP and ED, while MPS dropped significantly by more than 21.7% from the previous time span.

Nakhon Phanom experienced a similar situation to the previous two cities. During the first time span of 2004-2009, the urban area was small and fragmented (Figure 6), as corroborated by small MPS values. By 2009, NP and MPS had increased slightly in contrast to a decrease in ED and AWMPFD, indicating that urban areas of Nakhon Phanom experienced infilling development and became more homogeneous. During the second period of 2009-2013, an increase in the development of urbanized patches occurred some distance from the urban core indicated by a rise in ED and a corresponding decrease in MPS. Significant decline in MPS over this time period reflected the extent of fragmentation in the urban area, with increasing AWMPFD and ED values supporting this trend.

Finally, in Mukdahan, development was moderate during the first period of 2004-2007, with most change occurring along the urban fringe (Figure 7). However, in the second period of 2007-2012, a rapid outlying development pattern around the city led to an increase in the size of the urban area, with an increase in both CA and ED. Moreover, the increase in NP at 72.4% and AWMPFD in this time period from the previous time span, with dramatically reduced MPS values reflected an increase in fragmentation of the urban area.

5. Conclusions

This paper had improved the understanding of urban growth expansion in Thailand through a case study of border cities in the northeastern region. Research was based on recent developments in GIS and spatial modeling, logistic regression models and spatial metrics. During the first period (2003-2011) most cities showed a higher rate of urban growth than in the second period. Bueng Kan experienced the highest annual growth rate at 12.08%, followed by Nong Khai at 7.23%. Nakhon Phanom had the highest rate of urban expansion at 6.12% annually. The logistic regression model indicated that most of the major exploratory variables were statistically significant. Among the proximity variables, distance to minor roads or local roads within the city had the strongest negative effect on urban land conversion in all test cities and in every time period, followed by major roads or inter-city highways in all cities except Mukdahan during the first period of 2004-2007. Large waterbodies, density of small waterbodies and density of existing urban areas had minimal influence on urban growth in northeastern border cities. Some of the major and minor centers played an important role in urban expansion, in particular for Bueng Kan during the second period of 2011-2014.

Results confirmed that landscape indices captured significant aspects of landscape patterns. The basic information of urban growth areas contributed an increase in class area (CA). Increasing numbers of patches (NP) and edge density (ED) index along with the area weight mean values of the fractal dimension (AWMPFD) resulted in decreased mean patch size (MPS) for urban areas, suggesting that continuous urban expansion resulted in a more fragmented and complicated urban landscape. Land use master plans of each city are important for guiding their future urban expansion. Results from this study can encourage policymakers to use GIS as tools for planning and assessing environmental impact from urban growth. Spatial metric scan be analyzed to improve current land use development planning which is considered vital for the future development of all four border cities.

Acknowledgments
The author would like to thank the anonymous reviewers and editor who provided valuable comments and suggestions to improve the quality and content of this paper.

References

Aguilera, F., Valenzuela, L. M. and Botequilha-Leitão, A., 2011, Landscape Metrics in the Analysis of Urban Land Use Patterns: A case study in a Spanish Metropolitan Area. *Landscape and Urban Planning*, Vol. 99(3), 226-238.

Bueng Kan Provincial Development Plan (2014-2017), 2013, Retrieved February 22, 2018, from http://www.oic.go.th/FILEWEB/CABINFOCENTER11/DRAWER016/GENERAL/DATA0000/00000026.PDF

Cheng, J. and Masser, I., 2003, Urban Growth Pattern Modeling: A Case Study of Wuhan City, PR China. *Landscape and Urban Planning,* Vol. 62, 199-217

Deng, J. S., Wang, K., Hong, Y. and Qi, J. G., 2009, Spatio-Temporal Dynamics and Evolution of Land use change and Landscape Pattern in Response to Rapid Urbanization. *Landscape and Urban Planning*, Vol. 92, 187–198.

Deng, Y. and Srinivasan, S., 2016, Urban Land Use Change and Regional Access: A Case Study in Beijing, China. *Habitat International*, Vol. 51, 103-113.

Dubovyk, O., Sliuzas, R. and Flacke, J., 2011, Spatio-Temporal Modelling of Informal Settlement Development in Sancaktepe District, Istanbul, Turkey. *ISPRS Journal of Photogrammetry and Remote Sensing*, Vol. 66(2), 235-246.

Hara, Y., Takeuchi, K. and Okubo, S., 2005, Urbanization Linked with Past Agricultural Land Use Patterns in the Urban Fringe of a Deltaic Asian Mega-City: A Case Study in Bangkok. *Landscape and Urban Planning*, Vol. 73(1), 16-28.

Herold, M. Goldstein, N. C. and Clarke, K. C., 2003, The Spatiotemporal form of Urban Growth: Measurement, Analysis and Modeling. *Remote sensing of Environment*, *86*(3), 286-302.

Hu, S., Tong, L., Frazier, A. E. and Liu, Y., 2015, Urban Boundary Extraction and Sprawl Analysis using Landsat Images: A Case Study in Wuhan, China. *Habitat International*, Vol. 47, 183-195.

Hu, Z. and Lo, C. P., 2007, Modeling Urban Growth in Atlanta using Logistic Regression. *Computers, Environment and Urban Systems,* Vol. 31, 667-688.

Huang, J., Lu, X. X. and Sellers, J. M., 2007, A Global Comparative Analysis of Urban Form: Applying Spatial Metrics and Remote Sensing. *Landscape and urban planning*, Vol. 82(4), 184-197.

Information of Nakhon Phanom, 2015, Retrieved February 22, 2018, from http://www.nakhonphanom.go.th/nakhonphanom/nakhonphanom58.pdf

Liu, Y., He, Q., Tan, R., Liu, Y. and Yin, C., 2016, Modeling Different Urban Growth Patterns Based on the Evolution of Urban Form: A Case Study from Huangpi, Central China. *Applied Geography*, Vol. 66, 109-118.

Long, Y., Gu, Y. and Han, H., 2012, Spatiotemporal Heterogeneity of Urban Planning Implementation Effectiveness: Evidence from Five Urban Master Plans of Beijing. *Landscape and Urban Planning,* Vol. 108, 103-111

Luo, J. and Wei, Y. D., 2009, Modeling Spatial Variations of Urban Growth Patterns in Chinese cities: The Case of Nanjing. *Landscape and Urban Planning,* Vol. 91(2), 51–64.

Murakami, A., Zain, A. M., Takeuchi, K., Tsunekawa, A. and Yokota, S., 2005, Trends in Urbanization and Patterns of Land Use in the Asian Mega Cities Jakarta, Bangkok, and Metro Manila. *Landscape and Urban Planning*, Vol. 70(3), 251-259.

Nassar, A. K., Blackburn, G. A. and Whyatt, J. D., 2014, Developing the Desert: The Pace and Process of Urban Growth in Dubai. *Computers, Environment and Urban Systems*, Vol. 45, 50-62.

Office of the Board of Investment, 2015, A Guide to Investment in the Special Economic Development Zones. Retrieved February 26, 2018, from http://www.boi.go.th/upload/content/BOI-book%202015_20150818_95385.pdf

Office of the National Economic and Social, 2017, Retrieved February 24, 2018, from Development http://www.nesdb.go.th/ewt_dl_link.php?nid=6426

Patino, J. E. and Duque, J. C., 2013, A Review of Regional Science Applications of Satellite Remote Sensing in Urban Settings. *Computers, Environment and Urban Systems*, Vol. 37, 1-17.

Paudel, S. and Yuan, F., 2012, Assessing Landscape changes and Dynamics using Patch Analysis and GIS Modeling. *International Journal of Applied Earth Observation and Geoinformation*, Vol. 16, 66-76.

Pham, H. M., Yamaguchi, Y. and Bui, T. Q., 2011, A Case Study on the Relation between City Planning and Urban Growth using Remote Sensing and Spatial Metrics. *Landscape and Urban Planning,* Vol. 100(3), 223-230.

Phuprasert, K.,Weerathaweemad, S. and Hanpachern, R., 2008, The Development of Historic Communities Along the Khong River: NongKhai Province. Retrieved February 22, 2018, from https://arch.kku.ac.th/pr/wp-content/uploads/ 2011/08/ Abstract43.pdf

Phuttharak, T., 2014, Regional Rapid Growth in Cities and Urbanization in Thailand. *Journal of Arts and Humanities*, Vol. 3(1), 57.

Poelmans, L. and Van Rompaey, A., 2010, Complexity and Performance of Urban Expansion Models. *Computers, Environment and Urban Systems*, Vol. 34(1), 17-27.

Puwapornkul, K., 2015, Mukdahan Special Border Economics Zone: MSBEZ. Mukdahan Provincial Industry Office Retrieved February 24, 2018, from http://www.industry.go.th/mukdaharn/index.php/download/22142-sez-muk-pdf/file

Rashed, T., Weeks, J. R., Stow, D. and Fugate, D., 2005, Measuring Temporal Compositions of Urban Morphology through Spectral Mixture Analysis: Toward a Soft Approach to Change Analysis iIn Crowded Cities. *International Journal of Remote Sensing*, Vol. 26(4), 699-718.

Ratchanagool, V. and Preyawanit, N., 2013, A Study of Physical Transformation of a Border City Impacted by the Thai-Laos Friendship Bridge Project, NakornPanom City. *City and Environment.* Vol. 4. 2013-2014. Retrieved February 22, 2018, from: http://www.arch.su-.ac.th/images/book/3archjournal/land/pdf4/03visarut.pdf

Satithpongsathaporn, A., 2015, Retrieved February 22, 2018, from https://www.slideshare.net/FURD_RSU /ss-48181424

Shafizadeh-Moghadam, H. and Helbich, M., 2015, Spatiotemporal Variability of Urban Growth Factors: A Global and Local Perspective on the Megacity of Mumbai. *International Journal of Applied Earth Observation and Geoinformation*, Vol. 35, 187-198.

Steinberg, F. and Hakim, J.(Eds.), 2016, *Urban Development in the Greater Mekong Subregion.* Asian Development Bank.

The Treasury Department, 2016, A Guide to Investment in the Special Economic Development Zones. Retrieved February 22, 2018, from http://www.treasury.go.th/download/article/article_20170802121819.pdf

Vermeiren, K., Van Rompaey, A., Loopmans, M., Serwajja, E. and Mukwaya, P., 2012, Urban Growth of Kampala, Uganda: Pattern Analysis and Scenario Development. *Landscape and Urban Planning*, Vol. 106(2), 199-206.

Weber, C., 2001, Remote Sensing Data used for Urban Agglomeration Delimitation, in *Remote Sensing and Urban Analysis*, M. J. Barnsley, Ed., pp. 155–167, Taylor & Francis, London 155-167.