Assessment of Urban Expansion Impacts on Agricultural Area in Chiang Mai-Lamphun Basin, Northern Thailand

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Abstract

The building of new towns and city expansion are often associated with consequences against existing environment conditions. Land use changing is a dynamic process that links to natural and human systems effecting on the environment at local, national and global scales. Urban regimes in Thailand including Chiang Mai-Lamphun intermontane basin have been intensely bounded with social and economic structures which are difficult to formulate national land use planning policies in sustainable manners. Additionally, Chiang Mai and Lamphun area are undergone the economic pushing factors leading to an upsurge land value, declining agricultural yields, unrest changing of land ownerships and unending deforestation. As a result, irrigation and drainage management in this globally changing land use are currently foremost challenge toward sustainable food security. The measurement of land use transitions effects is needed. Therefore, the assessment of urban expansion impacts on agriculture area in Chiang Mai-Lamphun intermontane basin of northern Thailand was developed to offer expectation of land use transitions caused by known factors to support a better strategic development toward land use controlling and managing in a sustainable way. This study utilized Geographic Information System (GIS) spatial dynamics simulation of cellular automata model (CA) called the SLEUTH model which have been effectively used to predict physical urbanization trends. The urban expansions prediction interval is 5 years for Chiang Mai and Lamphun municipals separately. The percentage results of Chiang Mai's urban area are expanded from 18.27%, 31.51%, 38.70%, 45.61% and 51.27% while the percentage results of Chiang Mai's agricultural area are declined from 43.52%, 36.41%, 32.47%, 28.00% and 23.98% from the year 2010, 2015, 2020, 2025 and 2030 respectively. Likewise, the percentage results of Lamphun's urban area are expanded from 21.31%, 32.40%, 36.22%, 40.52% and 45.15% while the percentage results of Lamphun's agricultural area are declined from 65.19%, 57.45%, 54.86%, 51.63% and 48.02% during the mentioned years. The three urban expansions major causes stated by the SLEUTH model for Chiang Mai are 43.06% road-influenced, 34.27% new spreading center, and 19.28% edge spreading while Lamphun's major causes are 31.32% new spreading center, 28.74% road-influenced, and 27.96% slope resistance. The results from this study are expected to benefit national land use planning policies formulation toward sustainable agriculture area preservation in Chiang Mai-Lamphun area which would result in sustainable food security. Moreover, the accomplished application from this study has unrestricted possibly to be implemented in other area of interested as well.

Keywords: Land use transitions, Urban expansion, Chiang Mai-Lamphun area, Cellular automata model, The SLEUTH model prediction

Background

Chiang Mai city is growing at a rapid rate, creating extensive urban sprawls in different patterns. A rapid urbanization has led to land conversions from farmlands, wetlands and others into human settlements. Land use changes are complex, dynamic process that links between the human and natural systems. Changes in land use affect water, soil and atmosphere and have related to many global environmental issues including crop protection which is therefore a key element in farmers' sustainable strategy to meet increasing global food demand (Meyer and Turner, 1994). Chiang Mai and Lumphun cities are linked spatially and economically at local, national and international levels in the form of clustering to promote long term growth and to preserve the Lanna culture. Urban expansion from Chiang Mai city to Lumphun city is much accelerated by the expansion of transportation networks. In the near future, there is a tendency for Lumphun to become another city center in this Valley. Presently, commercial and business areas have been built and expanded to urban-rural fringe of Chiang Mai, leading to the loss of prime agricultural areas (Sangawongse et al., 2010). The expansion of impervious surfaces, such as settlements on flood prone areas, has resulted in changing water drainage regimes.

Politically, land use changes are much pronounced at urban-rural fringes of Chiang Mai city, which are mainly used for rural settlements and agricultural areas. Land use zoning inside Chiang Mai and Lumphun cities was conducted by Department of Public Works and City Planning (DPWCP), Ministry of Interior, which designated Chiang Mai Comprehensive Plan (CMCP) and Lumphun Comprehensive Plan (LPCP) (Department of Town and Country Planning, 1983). It is argued that the comprehensive plan area was conducted without participation n from local governments. Also, this plan does not take important geographic variables into account. As a result, land use zoning and its enforcement has gained a little success. In this research, the SLEUTH model could be used as a tool in the planning and management process of CMCP, LPCP and their surroundings in northern Thailand.

This paper pursues 2 main objectives: (1) To apply SLEUTH cellular automaton (CA) model for mapping spatial and temporal dimensions of urban growth and land use changes in Chiang Mai and Lumphun cities, focusing on the agricultural areas; (2) To assess the cause of urbanization and land use changes on from 2010 to 2030.

Studied Area

The studied area lies in the Monsoon Asian region of the Chiang Mai–Lumphun Valley, northern Thailand including Chiang Mai and Lamphun cities. The Chiang Mai–Lumphun cities is one of the most developed regions in Thailand. It has been undergoing a rapid urbanization within the past 20 years which are most likely become twin cities in the near future. Urbanization process plays a significant impact on the environment, particularly on the agricultural area decreasing in this region. Topography, climate, history and policy play important roles in how urban regions develop and the industrial-urban corridor that links Chiang Mai and Lumphun together are mostly related to transportation roads development.

From Figure 1, the left hand side map represents boundaries of Chiang Mai and Lumphun provinces. The right hand side map represents the boundaries of CMCP and LPCP areas. CMCP and LPCP boundaries were designated by Department of Public Works and City Planning (DPWCP) for land use zoning. The comprehensive plan is a guide for the city's future growth that includes the future land use plan, transportation plan, and recommended goals with objectives to carry out the plans. The CMCP area encompasses 7 administrative districts including Muang, Mae Rim, Sansai, Saraphi, Hangdong, Sankumphaeng and Doi Saket with total area of 408 square kilometers. The LPCP area covers only one administrative district and it has total area about 61 square kilometers. The topography of the study area is characterized by valley floor. Elevations in CMCP and its surroundings range from 300 m MSL to about 1,650 m MSL, whereas LPCP elevations range from 285 m ASL to 320 m MSL.

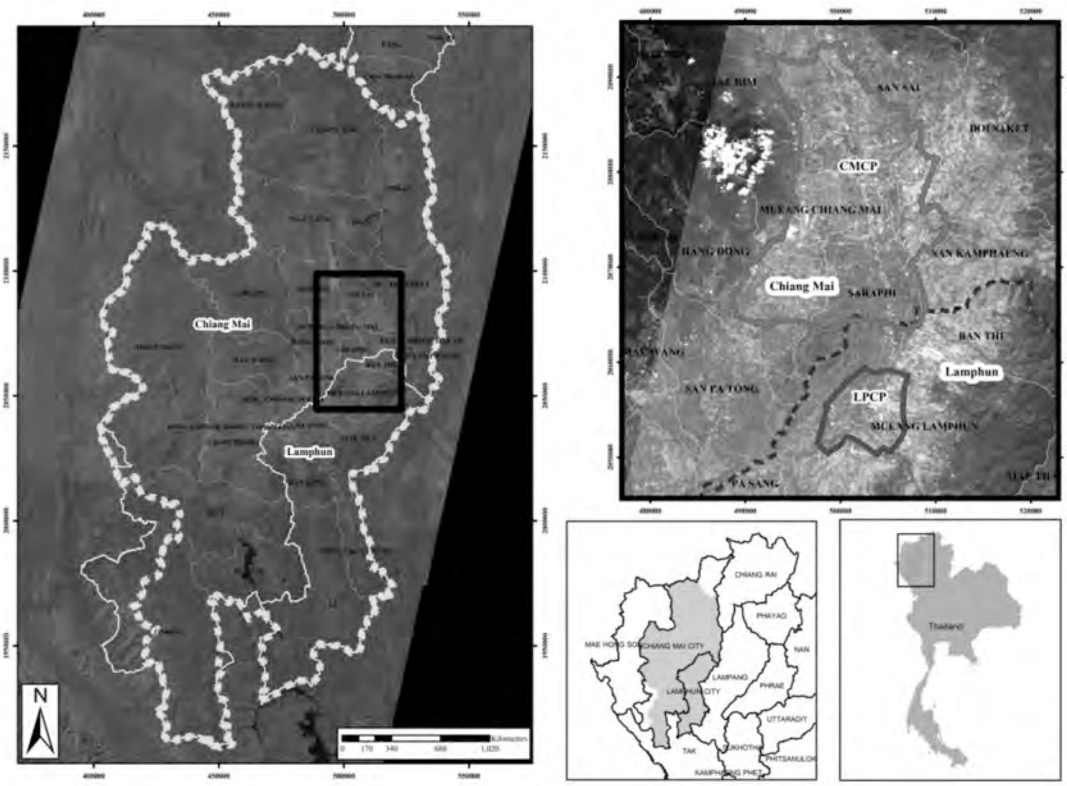

Figure 1 Study area in Chiang Mai–Lumphun Valley (the yellow boundary)
Chiang Mai Comprehensive Plan area (the red boundary)
and Lumphun Comprehensive Plan area (the purple boundary)

Data Sources

Spatial and temporal data, including topographic 1:50,000 scale maps, muti-temporal satellite data, digital elevation model (DEM) and GIS database were compiled, managed, and analyzed using remote sensing and GIS techniques. The input data required by SLEUTH model include at least four urban extent layers, two transportation layers, two land use layers and each slope, exclusion and topographic hillshade layers, respectively. Chiang Mai and Lumphun datasets consisted of urban extent layers in 1973, 1989, 2000 and 2009, land use layers in 1989 and 2009, road layers in 1969, 1992 and 2007. It is noted that the land use data in 1989 and 2009 were obtained by a supervised classification of LANDSAT-5 TM data (Sangawongse, 2009). Input data were prepared at three resolutions (30m, 60m and 120m) for the SLEUTH model calibration. Data input for SLEUTH model are listed in Table 1 and two sets of input data are represented by grayscale gif images (8 bit), as shown by Figures 2 and 3 respectively.

Table 1 Data Input for SLEUTH Model

Data Input	Year	Data Types
1. **S**lope		Digital Elevation Model (DEM)
2. **L**and Use	1989, 2009	ALOS (AVNIR-2), LANDSAT MSS ,LANDSAT -5 TM, LANDSAT-7 ETM $^{+}$
3. **E**xcluded Area	2009	Classified ANDSAT TM 2009
4. **U**rban Extents	1973,1989,2000,2009	Classified LANDSAT data of corresponding dates
5. **T**emporal road layers	1969,1992,2007	Topographic Map at 1:50,000 and GIS data base
6. **H**illshade		Digital Elevation Model

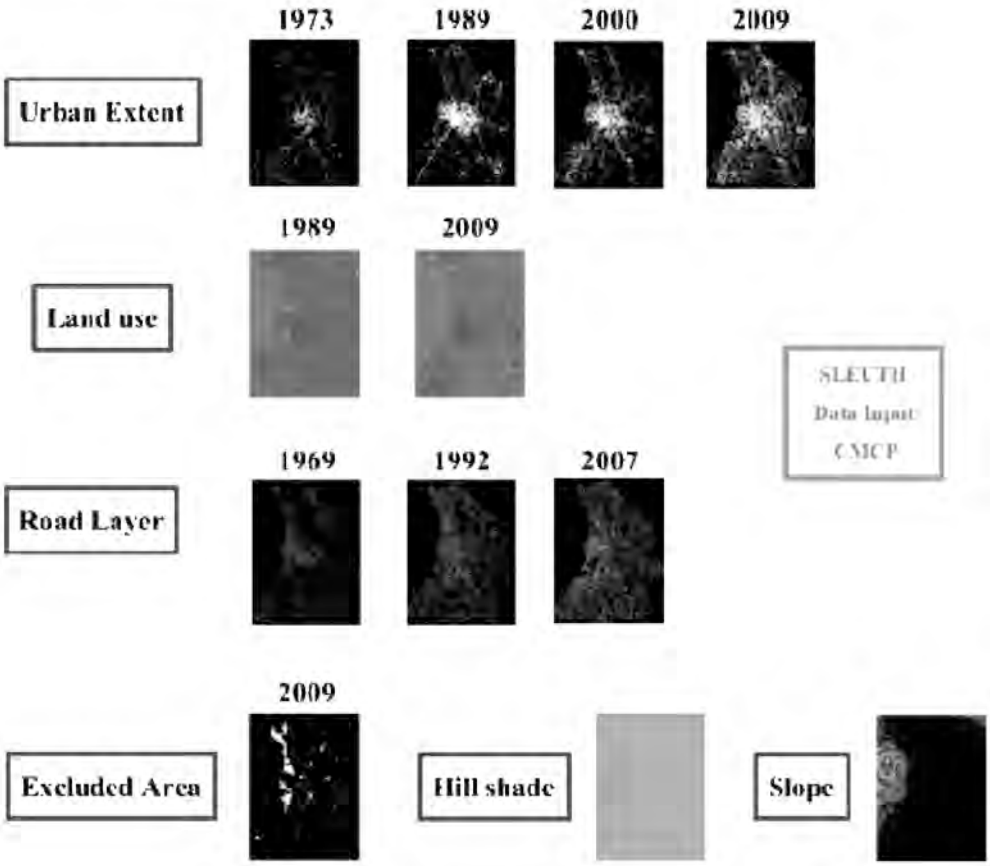

Figure 2 Grayscale gif images input for CMCP

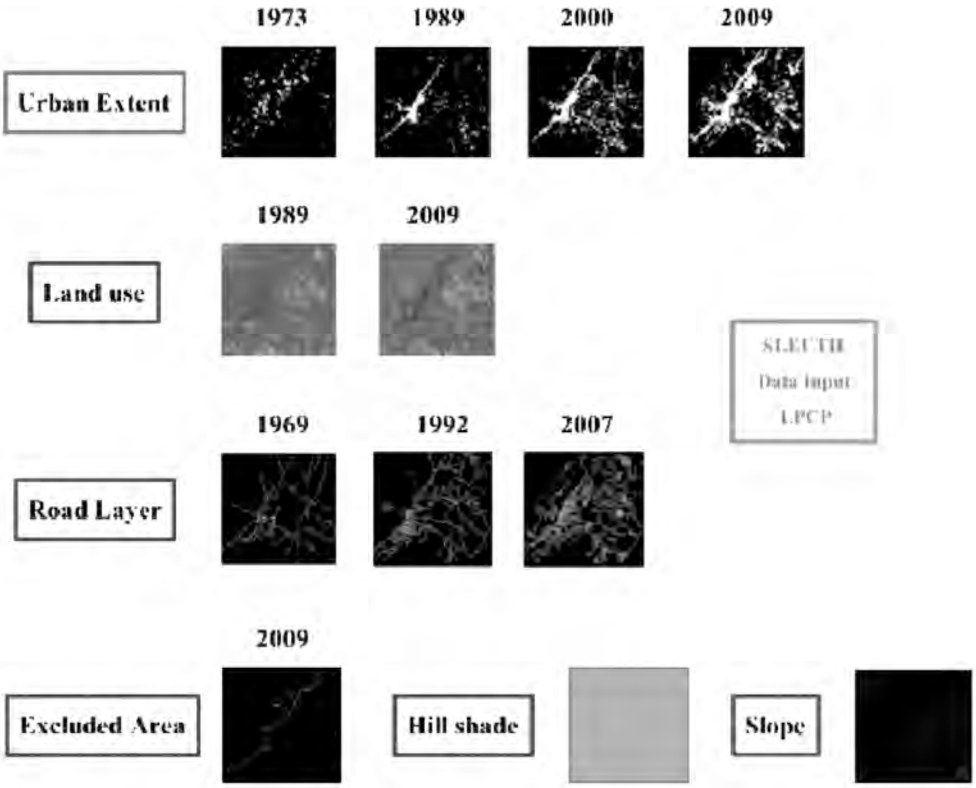

Figure 3 Grayscale gif images input for LPCP

Methodology

In recent years, spatially open simulation models of urban growth patterns have occurred. The SLEUTH model is the one that can simulates four types of urban land-use change: spontaneous growth, new-spreading center growth, edge growth, and road-influenced growth. Moreover, SLEUTH also has a functionality termed `self-modification' which allows the growth coefficients to change throughout the course of a model run and which is intended to simulate more realistically the different rates of growth that occur in an urban system over time. Inclusive methodology for this research project consists of 2 parts: (1) SLEUTH model and (2) Land use Classification (see Figure 4).

SLEUTH Model: SLEUTH is an adaptive cellular automaton (CA) model, which consists of urban growth sub-model (UGM) and land use changes sub-model (Deltatron). The UGM is mainly used for simulating urban growth, but the Deltatron is incorporating land use data into the model to further divide urban land into different land use categories. SLEUTH is a raster-based model, which is considered as one of powerful simulation models (US, EPA, 2000). The model has been used successfully to simulate spatial complexity in many cities

(Silva and Clarke, 2002; Xiaolu et al., 2009). The SLEUTH version 3 was downloaded from the National Center for Geographic Information Analysis, University of California Santa Barbara website (http://ncgia.ucsb.edu/projects/gig/project_gig.htm). It was written in C programming language and can be operated by either Linux or Cywin systems. SLEUTH model simulates four types of urban and land use changes including spontaneous growth, new spreading center growth, edge growth, and road-influenced growth. The growth patterns are controlled by the interactions of five growth-coefficients comprising diffusion, breed, spread, road gravity and slope, as summarized in Table 2.

Table 2 Growth types and their controlling parameters

Growth types	Controlling parameters	Summary description
Spontaneous	Diffusion	Randomly selected new growth cells
New spreading center	Breed	Growing of urban center from spontaneous growth
Organic (edge)	Spread	Old or new urban center spawns additional growth
Road-influenced	Road-Gravity	Newly urbanized cells spawn growth along transportation network
Slope resistance	Slope	Effects of slope on reducing probability of urbanization

Source: Silva and Clarke (2002).

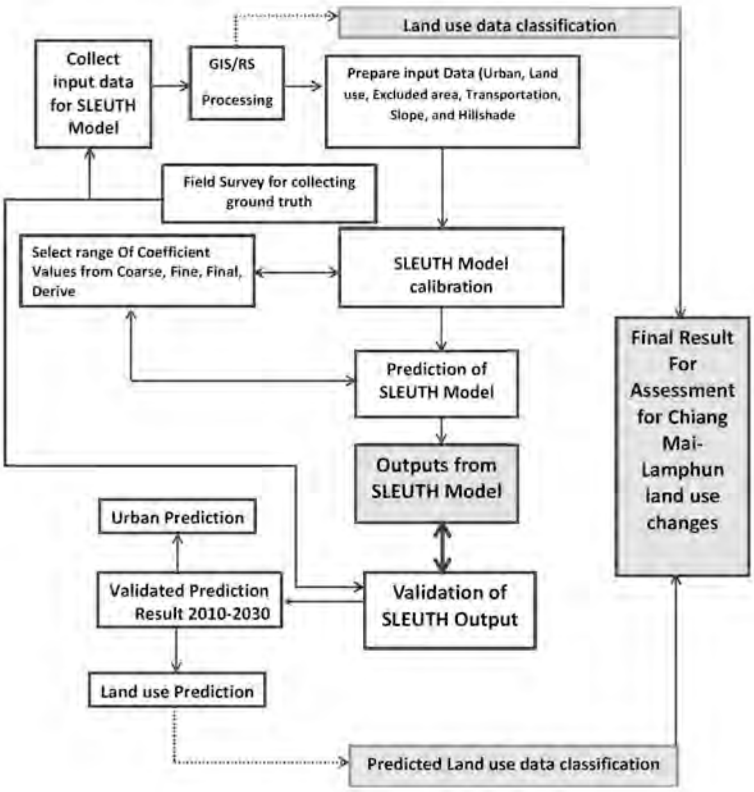

Figure 4 Methodology flowchart

The main procedures for modeling are calibration, prediction and validation. Calibration is the crucial part of modeling process, because it requires heavy computing time to simulate growth until the goodness of fit are obtained. The model calibration was divided into 3 phases: coarse calibration, fine calibration and final calibration. Each phase was conducted based on CMCP and LPCP input data at coarse, fine and finest resolutions using different Monte Carlo iterations, ranges of growth coefficients and step values that the operator put in the scenario files before executing the model (Tables 3 and 4). At the end of each calibration phase, the regression metrics are sorted and parameters of the highest scores are used as the start of parameters for the next phase (Dietzel, and Clarke,2007). For this calibration, Lee-Sallee scores were selected to form the parameter range used in the fine and final calibration phases. Lee-Sallee or shape index, is a measurement of spatial fit between the model's growth and the known urban extent for the control years. For a perfect match, the Lee Sallee measure gives a value of 1.0 similar to an r-squared value. The statistical outputs were used for determining the urban growth and land use changes dimension.

Table 3 Calibration Process at three phases for CMCP

	Coarse calibration		**Fine calibration**		**Final calibration**	
	Monte Carlo iterations = 4		Monte Carlo iterations = 7		Monte Carlo iterations = 9	
	Total number of simulations = 3,125		Total number of simulations = 7,776		Total number of simulations = 6,480	
	Lee -Sallee = 0.239		Lee- Sallee = 0.216		Lee –Sallee = 0.213	
Growth Parameters	**Range**	**Step**	**Range**	**Step**	**Range**	**Step**
Diff	0-100	25	0-25	5	1-5	1
Breed	0-100	25	0-25	5	30-50	4
Spread	0-100	25	0-25	5	20-25	1
Slope	0-100	25	0-50	10	5-20	3
Roads	0-100	25	0-75	15	45-75	6

Table 4 Calibration Process at three phases for LPCP

	Coarse calibration		Fine calibration		Final calibration	
	Monte Carlo iterations = 4		Monte Carlo iterations = 7		Monte Carlo iterations = 9	
	Total number of simulations = 3,125		Total number of simulations = 7,776		Total number of simulations = 6,480	
	Lee -Sallee = 0.239		Lee- Sallee = 0.216		Lee –Sallee = 0.213	
Growth Parameters	**Range**	**Step**	**Range**	**Step**	**Range**	**Step**
Diff	0-100	25	0-25	5	1-5	1
Breed	0-100	25	0-25	5	30-50	4
Spread	0-100	25	0-25	5	20-25	1
Slope	0-100	25	0-50	10	5-20	3
Roads	0-100	25	0-75	15	45-75	6

It is important to note that the success of model prediction depends greatly on the calibration result (Silva and Clarke, 2002). For this reason, the calibration output should be checked carefully before running the prediction. The breed and road growth parameters were the most significant variables throughout the calibration process, and thus have higher ranges and coarser steps. The final coefficients values that produced the highest scores for Lee-Sallee in CMCP were: Diffusion =3.87, Breed =51.64, Spread =29, Slope =1, Road Growth = 64.5. The final coefficients values that produced the highest scores for Lee obtained from the final coefficients values for LPCP were: Diffusion =1.42, Breed = 44, Spread = 43.34, Slope = 54.75, Road Growth = 56.27. These values determined the growth trends that were used to initiate the "Derive" coefficients for forecasting future urban growth and land use changes patterns in the study area from 2009 to 2030.

Results and Discussion

SLEUTH Model

Calibration

The selected metrics and five growth parameters obtaining from the overall calibration result was compared and used for determining urban growth patterns of CMCP and LPCP areas over the period 1973 to 2009. Table 5 shows three selected metrics (r^2 Pop, r^2 Edges and Lee-Sallee) by resolutions from overall calibration process. Figure 5 and 6 represent the urban growth patterns of CMCP and LPCP.

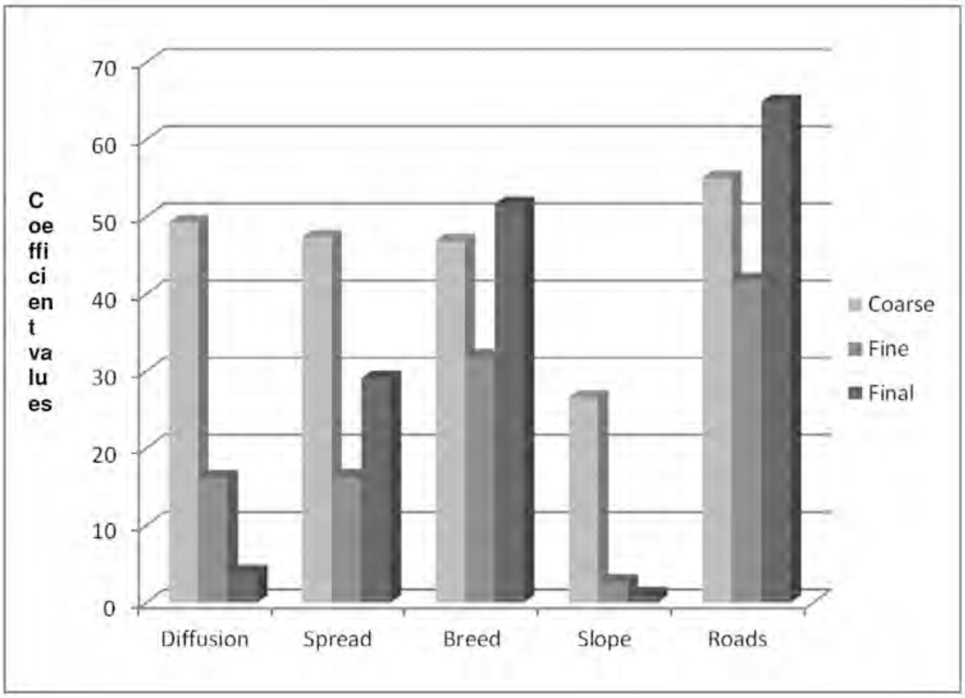

Figure 5 Urban Growth Patterns for CMCP

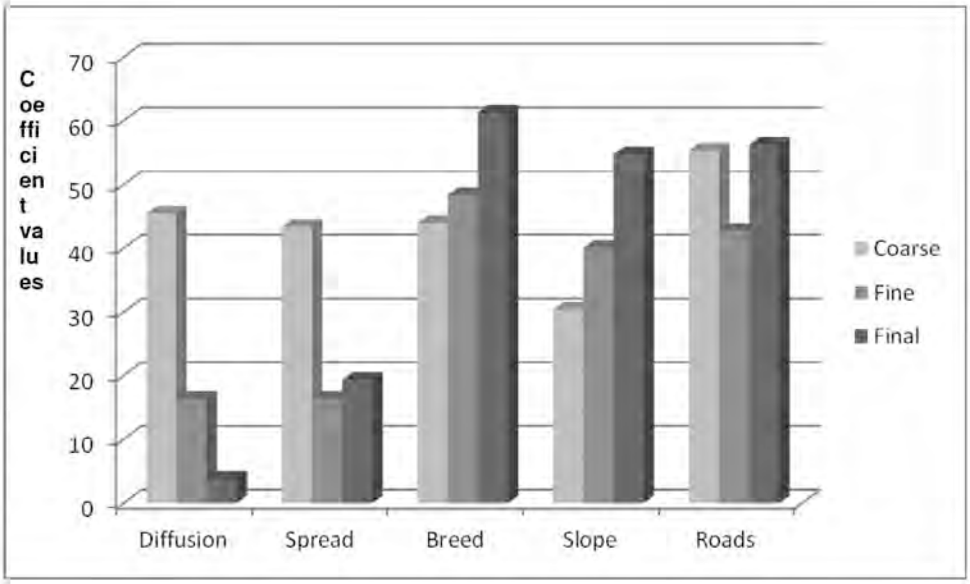

Figure 6 Urban Growth Patterns for LPCP

Score/resolution	CMCP Coarse 89 * 120	CMCP Fine 179 * 241	CMCP Final 358 *482	LPCP Coarse 78 *76	LPCP Fine 157 *152	LPCP Final 314 *304
r^2Pop	0.908	0.863	0.831	1	0.863	0.831
r^2 Edges	0.999	0.889	0.767	1	0.889	0.767
Lee-Sallee	0.239	0.216	0.213	0.213	0.216	0.213
Diffusion	49.24	16.17	3.87	45.44	16.35	3.87
Breed	46.79	31.93	51.64	44	48.37	61.32
Spread	47.29	16.31	29.05	43.44	16.35	19.36
Slope	26.56	2.7	1.03	30.4	40.08	54.75
Roads	55.03	41.76	64.89	55.37	42.7	56.27

Table 5 Complete calibrations by resolutions for CMCP and LPCP

r^2Pop: modeled urbanization compared with actual urbanization for the control years.

r^2 Edges: model urban edge counts compared with actual urban edge counts of the control years

Lee-Sallee: shape index, calculated by taking a ratio of the intersection and the union of the simulated and actual urban areas (Clarke and Gaydos, 1988).

From Table 5, Figure 5 and 6, it can be explained that "Diffusion" in CMCP decreased from coarse to fine calibration, but Spread values decreased from coarse to fine, and slightly increased from fine to final calibration. It is noted that "Breed" growth is much increased from fine to final (31.93-51.64) showing a good adjustment of model to the actual growth. This result corresponds to Xialoa et al., 2009 who suggested that before 1980, the development of urban center in Chiang Mai city was low. After 1980s, there was a tremendous diffusive area sprawling outward. As for the Slope factor, it decreased over the calibration phase, showing less significant for the growth in CMCP. Road growth decreased from 50 to 40, but much increased during the final calibration showing that roads are very significant factor for urban growth in CMCP. This result coincided with the recent construction of new roads in Chiang Mai. Diffusion and Spread values for LPCP are similar to CMCP, except the Spread values increased slightly from fine to final calibration. The "Breed" growth for LPCP is significant because the values increased throughout the calibration phases. It is interesting to note that "SLOPE" for LPCP increased over the calibration phases, indicating that growth in LPCP is influenced by slope. Road growth for LPCP is similar to CMCP, except the final calibration value (56.27) is less than CMCP, showing that urban growth in LPCP is much influenced by roads.

The calibration output should be assessed for obtaining good accuracy before prediction. The assessment of SLEUTH output can be conducted by different methods. For example, Jantz et al. (2003) used reference pixels and modeled pixels from the output to generate an error matrix, Xialou et al. (2009) used landscape metrics that reflects the landscape in 3 levels (patch, class and landscape) to evaluate the internal urbanized structure. Xian and Crane (2005) used remote sensing data for assessing the accuracy of the model output.

Prediction

The prediction results generated statistical files and simulated images, which can be used for analyzing future trends in urbanization and land use change. The simulated images of urban growth in CMCP and LPCP in 5 years interval are represented in Figures 7. From the analysis of statistical files, the number of growth pixels generated throughout the prediction period for CMCP and LPCP is 55,931 and 15,002 respectively. Figures 8 represents simulated images of land use change in CMCP and LPCP in 5 years interval. The different color schemes in Figure 7 represent the probability of pixels for urbanization as described in Table 6. The yellow pixels are referred to the original urbanized areas in 1973, having 100 % probability: light green are pixels that have the probability to convert to urban areas at 40-60 %, dark greens 60-70 %, dark orange 70-80 %, violet red 80-90 %, and dark red 90-100 %, respectively.

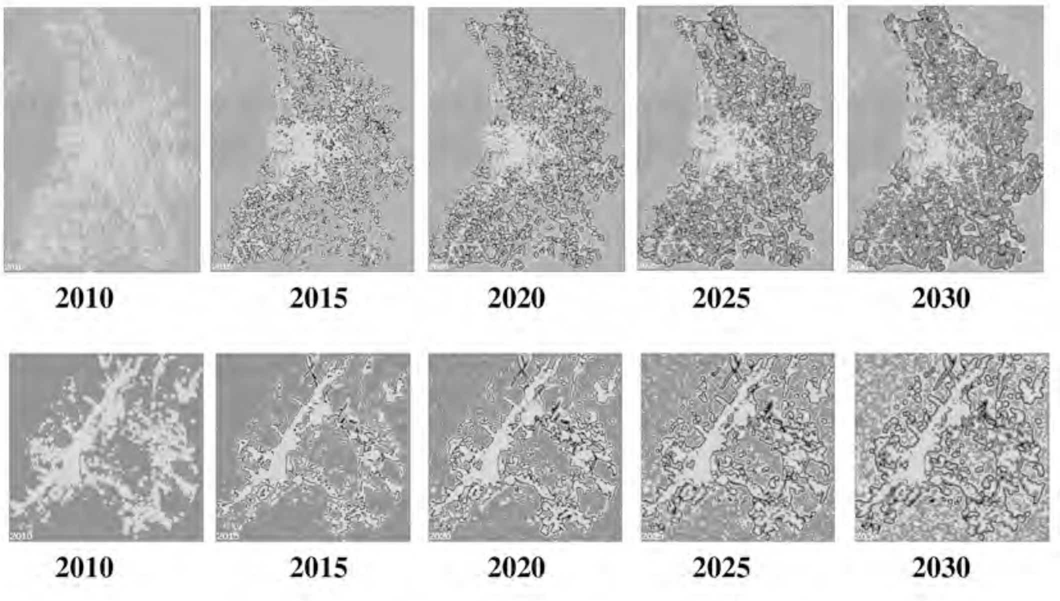

Figure 7 Prediction of Urban Growth for CMCP (above) and LPCP (below) in 5 years interval (2010-2030)

Table 6 Urbanization probabilities and associated color pixels

Pixel color	Probability for urbanization
yellow	100% (existing in seed year)
light green	40%-60%
dark green	60%-70%
dark orange	70%-80%
violet red	80%-90%
dark red	90%-100%

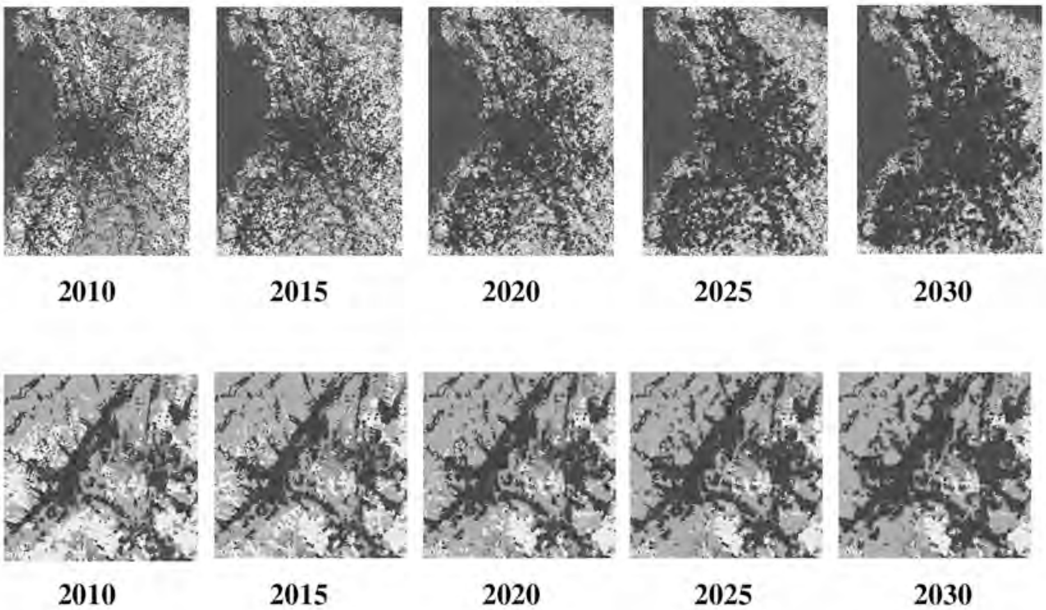

Figure 8 Simulated images of land use changes in CMCP (above) and LPCP (below) in 5 years interval (2010-2030)

Table 7 Land use change probability and associated color pixels

Pixel color	Probability for land use change
Urban	Dark red
Agricultural and Orchards	Yellow+Orange
Forest	Green
Water	Blue
Other	Pink
Bare land	White

The urban areas in CMCP increased from 29.18 square kilometers in 1973 to 112.62 square kilometers in 2009, with an increase to 340.72 square kilometers in 2030. The urban areas in LPCP increased from 3.41 square kilometers in 1973 to 16.55 square kilometers in 2009, with an increase to 37.33 square kilometers in 2030. Figures 9 and 10 represent urban growth in CMCP and LPCP during 1973-2009 and 2000-2009, respectively.

The prediction of Land Use Change in CMCP and LPCP from 1989-2030 shows that urban areas increased, but agricultural areas decreased over time. From Table 8, urban areas in CMCP increased from 10.6 % in 1989 to 51.27 % in 2030 and agricultural areas decreased from 59 % in 1989 to 24 % in 2030. Land use changes in LPCP follows the same trend as CMCP in which urban areas increased from 6 % in 1989 to 45 % in 2030 and agricultural areas decreased from 83 % in 1989 to 48 % in 2030 (Table 8 and 9).

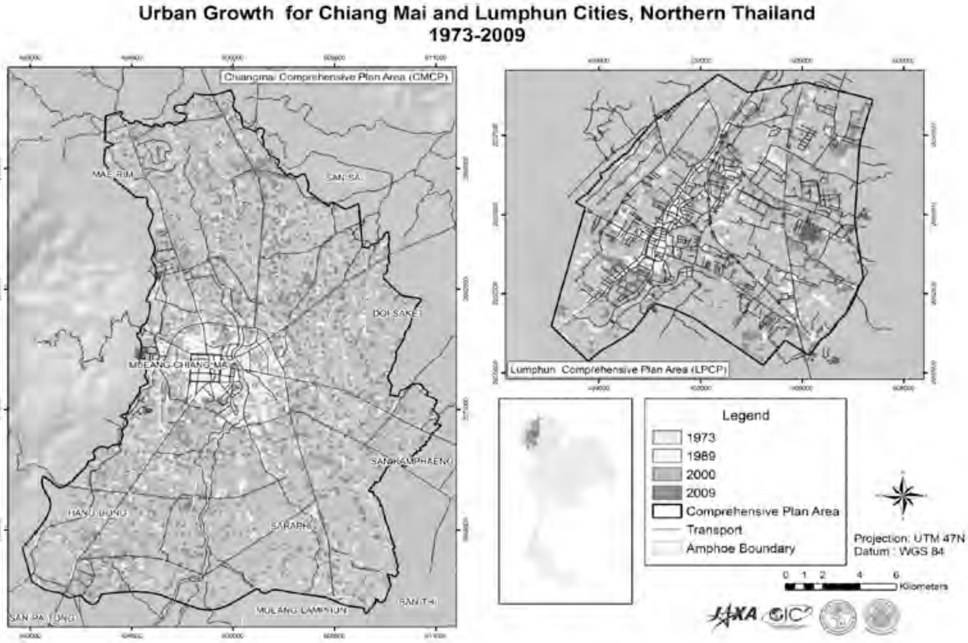

Figure 9 urban growth dimension in CMCP and LPCP between 1973-2009.

Table 8 Prediction of Land Use Types by proportion in CMCP from 1989-2030

CMCP Land Use Type	1989	2000	2010	2015	2020	2025	2030
Urban	10.60	12.09	18.27	31.51	38.70	45.61	51.27
Agricultural	58.81	54.12	43.52	36.41	32.47	28.00	23.98
Forest	18.07	22.54	24.86	22.83	21.65	20.74	20.08
Water	0.60	0.39	4.08	3.16	2.76	2.40	2.12
Other	10.61	10.76	9.09	6.00	4.38	3.22	2.53
Bareland	1.32	0.10	0.18	0.09	0.05	0.03	0.02

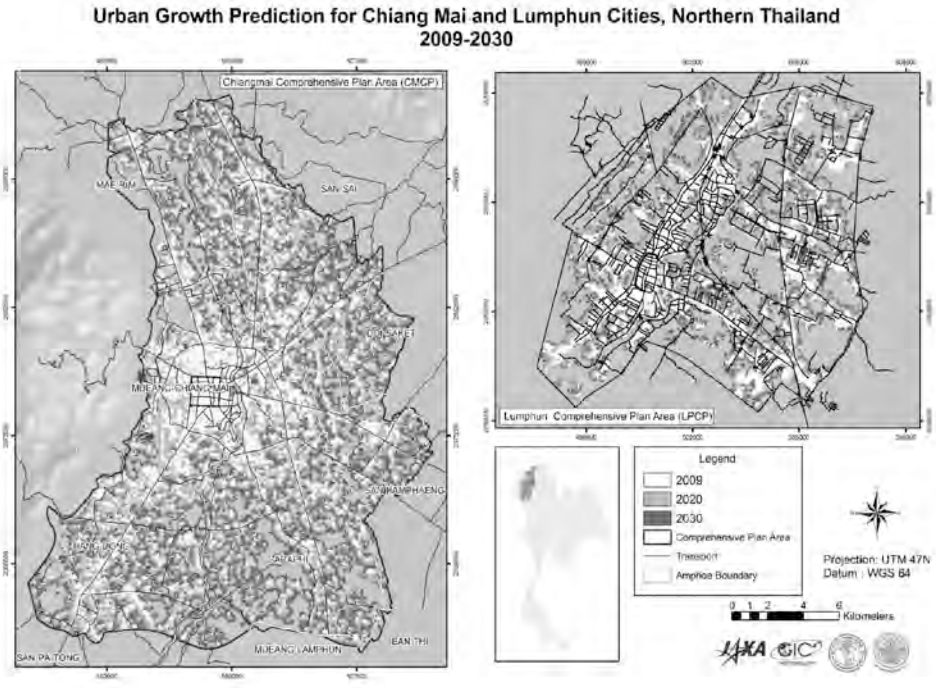

Figure 10 Urban growth dimension in CMCP and LPCP from 2009-2030

Table 9 Prediction of Land Use Types in LPCP by proportion from 1989-2030

LPCP-Land Use Type	1989	2000	2009	2015	2020	2025	2030
Urban	6.08	18.71	21.31	32.40	36.22	40.52	45.15
Agricultural	83.66	72.15	65.19	57.45	54.86	51.63	48.02
Forest	0.64	0.58	1.04	0.80	0.68	0.57	0.49
Water	0.57	0.09	0.31	0.30	0.28	0.27	0.25
Other	5.57	7.26	10.53	7.90	7.02	6.23	5.50
Bareland	3.46	1.23	1.61	1.14	0.94	0.77	0.59

Conclusions

Results from the SLEUTH model suggest that urban growth in CMCP and LPCP has a tendency to increase overtime. Urban growth patterns are best captured by road influenced growth and new spreading center growth (breed). The slope factor plays fewer roles in shaping the urban landscape for Chiang Mai, but significantly for Lumphun, as shown by an increase of slope values in every calibration phase.

Although some area planning for CMCP and LPCP area are already carried out, both Chiang Mai and Lamphun need the technology and expertise to run simulations of future development. The results from this regional scale assessment have provided provocative insights into the future of the region. In terms of pinpointing areas at risk for future development, the performance of the model in terms of spatial accuracy must be carefully considered. The visualization of potential land-use change has proven to be a powerful tool for raising public awareness and facilitating discussion. SLEUTH may be a tool that can meet these needs has been recognized by Thailand's administration and regional agencies. There is a need for both government and the local residents in Chiang Mai and Lumphun cities to closely monitor the impact of urbanization on land use changes on a regular basis. The impacts from urbanization and land conversion have deteriorated the environmental quality at a considerable rate. SLEUTH model provided satisfactorily result for mapping urbanized areas and land use changes from historic time (1973-2009) in figure 11 to the future time (2010-2030) in figure 12 for this study. The ALOS (AVNIR-2) image at 10m resolution acquired in January 2009 provided land use at a finer level of information. The classified ALOS AVNIR-2 data was used for assessing the accuracy of the model prediction output. The land use proportions obtaining from classified LANDSAT data in 1989, ALOS AVNIR-2 data in 2009, and the predicted image in 2030 (by the model) were used as the inputs toward assessment of urban expansion impacts on agricultural area in Chiang Mai-Lamphun valley of northern Thailand.

The calibration result needs more evidences from the past situations for proving the results. Prediction is much relied on the calibration results and should be done in accordance with different scenarios. The overall conclusions on applying SLEUTH model for this study can be summarized as follows:

(1) SLEUTH model is able to capture urban growth and land use changes in the study area successfully;

(2) High performance computing and a parallel processing are strongly recommended for modeling SLEUTH, especially for mapping changes in larger areas.

(3) SLEUTH model is mainly developed for modeling spatial and temporal dimensions of any system. It is not designated to cope with socioeconomic variables such as population and policies but would rather work as decision guidance for the cities' administrative.

Finally, it can be concluded that integration between SLEUTH is the primarily framework for forming sound policies in guiding environmentally sustainable growth. The result of this project can be best applied to government and non-government agencies, including other agencies that are concerned with urban and land resources management and planning. The results from this study are expected to benefit national land use planning policies formulation toward sustainable agriculture area preservation in Chiang Mai-Lamphun area which would result in sustainable food security. In future, the accuracy improvements of SLEUTH output are expected with would generalize to other meaningful spatial units, such as HUC11 watersheds model. Given these findings, SLEUTH could be an appropriate model for regional assessments of urban land-use changes, the results of which could be used to guide more localized modeling efforts. Moreover, the accomplished application from this study has unrestricted possibly to be implemented in other area of interested as well.

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