การวิเคราะห์ผลกระทบพหุสิ่งแวดล้อมเชิงพื้นที่และการวางแผนการใช้ที่ดินอันเนื่องจากการเติบโตของเมือง

นายมนตรี พิมพ์ใจ

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต

สาขาวิชาภูมิสารสนเทศ

มหาวิทยาลัยเทคโนโลยีสุรนารี

ปีการศึกษา 2555

SPATIAL ANALYSIS OF MULTI-ENVIRONMENTAL IMPACT AND LAND USE PLANNING DUE TO URBAN GROWTH

Montree Pimjai

A Thesis Submitted in Partial Fulfillment of the Requirements for the

Degree of Doctor of Philosophy in Geoinformatics

Suranaree University of Technology

Academic Year 2012

SPATIAL ANALYSIS OF MULTI-ENVIRONMENTAL IMPACT AND LAND USE PLANNING DUE TO URBAN GROWTH

Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy.

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มนตรี พิมพ์ใจ : การวิเคราะห์ผลกระทบพหุสิ่งแวดล้อมเชิงพื้นที่และการวางแผนการใช้ที่ดินอันเนื่องจากการเติบโตของเมือง (SPATIAL ANALYSIS OF MULTI-ENVIRONMENTAL IMPACT AND LAND USE PLANNING DUE TO URBAN GROWTH) อาจารย์ที่ปรึกษา : รองศาสตราจารย์ ดร.สุวิทย์ อ๋องสมหวัง, 246 หน้า.

การเปลี่ยนแปลงการใช้ที่ดินและสิ่งปกคลุมดินอันเนื่องจากการเติบโตของเมืองที่เกิดขึ้นอย่างรวดเร็วในพื้นที่โดยรอบของมหาวิทยาลัยมหาสารคาม ก่อให้เกิดปัญหาด้านสิ่งแวดล้อมหลายประการ วัตถุประสงค์หลักของการศึกษาคือ เพื่อประเมินการเปลี่ยนแปลงการใช้ที่ดินและสิ่งปกคลุมดินและการกำหนดคุณลักษณะการเติบโตของเมือง การประเมินผลกระทบทางด้านสิ่งแวดล้อมเนื่องจากการเติบโตของเมือง และการวางแผนการใช้ที่ดินในอนาคต องค์ประกอบหลักของวิธีการศึกษาประกอบด้วย (1) การประเมินการใช้ที่ดินและสิ่งปกคลุมดินและการเปลี่ยนแปลงที่เกิดขึ้น (2) การเจริญเติบโตของเมือง (3) ผลกระทบทางด้านสิ่งแวดล้อม และ (4) การวางแผนการใช้ที่ดิน

ผลการประเมินการใช้ประโยชน์ที่ดินและสิ่งปกคลุมดินและการเปลี่ยนแปลงในระหว่าง พ.ศ. 2544-2564 จากการแปลตีความด้วยสายตาและแบบจำลอง CA-Markov พบว่า พื้นที่เมืองและสิ่งก่อสร้างเพิ่มขึ้นอย่างต่อเนื่อง ในขณะที่ พื้นที่เกษตรกรรมและป่าไม้ลดลงอย่างต่อเนื่อง สำหรับการกำหนดคุณลักษณะการเติบโตของเมือง พบว่า รูปแบบการเติบโตของเมืองในระหว่าง พ.ศ. 2544-2549 เป็นการพัฒนาตามแนวถนน แต่ในระหว่าง พ.ศ. 2549-2554 รูปแบบการเติบโตของเมืองเปลี่ยนเป็นการพัฒนาแบบกระจาย สำหรับในอนาคต รูปแบบการเติบโตของเมืองในระหว่าง พ.ศ. 2554-2564 ยังคงเป็นการพัฒนาแบบกระจาย ตำบลส่วนใหญ่มีอัตราการขยายตัวค่อนข้างต่ำ ระดับความเป็นเมืองอยู่ระหว่างปานกลางถึงสูง และการพัฒนาอยู่ในระดับปานกลาง

สำหรับผลกระทบทางด้านสิ่งแวดล้อมอันเนื่องจากการเติบโตของเมือง พบว่า ค่าเฉลี่ยปริมาณน้ำท่าในแต่ละตำบลในระหว่าง พ.ศ. 2544-2564 มีค่าแตกต่างกัน โดยค่าเฉลี่ยปริมาณน้ำท่าเพิ่มขึ้นอย่างต่อเนื่อง และจำนวนของตำบลจากการวิเคราะห์การแบ่งเขตผันแปรโดยตรงกับการเติบโตของเมือง ความสัมพันธ์เชิงเส้นตรงระหว่างการเปลี่ยนแปลงพื้นที่เมืองกับการเปลี่ยนแปลงปริมาณน้ำท่าให้ค่าสัมประสิทธิ์การตัดสินใจ (R^2) เท่ากับร้อยละ 87.82 และการเปลี่ยนแปลงพื้นที่เมืองเชิงพื้นที่และความเป็นเมืองมีความสัมพันธ์กับการเปลี่ยนแปลงปริมาณน้ำท่าสูง ในขณะเดียวกัน ในการวิเคราะห์ศักยภาพการเกิดน้ำท่วม พบว่า พื้นที่ที่มีศักยภาพการเกิดน้ำท่วมระดับปานกลางและสูงอยู่ในบริเวณที่ราบน้ำท่วมถึงและตะพักลำน้ำตามแม่น้ำชี พื้นที่ที่ไม่มีศักยภาพการเกิดน้ำท่วมตั้งอยู่ในพื้นที่ที่มีความสูงมากกว่า 170 เมตร เหนือระดับน้ำทะเลปานกลาง นอกจากนี้ พื้นที่ที่ถูกน้ำท่วมจริงส่วนใหญ่ในระหว่าง พ.ศ. 2548-2554 จากรายงานของสำนักงานพัฒนา

เทคโนโลยีอวกาศและภูมิสารสนเทศ พบว่า ตั้งอยู่ในพื้นที่ที่มีศักยภาพการเกิดน้ำท่วมระดับปานกลางและสูง

ในการประเมินผังเมืองและการวางแผนการใช้ที่ดิน พบว่า เมืองและสิ่งก่อสร้างใน พ.ศ. 2564 มีพื้นที่น้อยกว่าเขตที่กำหนดในผังเมืองรวมประมาณร้อยละ 41 จากผลลัพธ์ที่ได้รับเหล่านี้สามารถบ่งชี้ได้ว่า ผังเมืองรวมในปัจจุบันสามารถรองรับผลคาดการณ์การใช้ที่ดินและสิ่งปกคลุมดินใน พ.ศ. 2564 ได้ ในขณะเดียวกัน การจัดสรรการใช้ที่ดินที่เหมาะสมมากที่สุดและน้อยที่สุดในแผนการใช้ที่ดินใน พ.ศ. 2564 ได้แก่ พื้นที่เกษตรกรรมและการอนุรักษ์ (ร้อยละ 83.00) และพื้นที่พาณิชยกรรม (ร้อยละ 0.48) นอกจากนี้ พบว่า การเปลี่ยนแปลงปริมาณน้ำท่าเฉลี่ยที่คำนวณจากข้อมูลแผนการใช้ที่ดินลดลงในทุกตำบลเมื่อเปรียบเทียบกับข้อมูลการใช้ที่ดินและสิ่งปกคลุมดินที่คาดการณ์ใน พ.ศ. 2564 จากผลที่ได้รับแสดงให้เห็นว่า แผนการใช้ที่ดินที่ดีสามารถช่วยบรรเทาการเกิดน้ำท่วมได้

จากผลการศึกษาที่ได้รับสามารถสรุปได้ว่า เทคโนโลยีภูมิสารสนเทศสามารถนำมาใช้เป็นเครื่องมือสำหรับการประเมินการเปลี่ยนการใช้ที่ดินและสิ่งปกคลุมดินและผลกระทบด้านสิ่งแวดล้อม อันเนื่องมาจากการเติบโตของเมืองได้

สาขาวิชาการรับรู้จากระยะไกล	ลายมือชื่อนักศึกษา____________
ปีการศึกษา 2555	ลายมือชื่ออาจารย์ที่ปรึกษา____________
	ลายมือชื่ออาจารย์ที่ปรึกษาร่วม____________

MONTREE PIMJAI : SPATIAL ANALYSIS OF MULTI-ENVIRONMENTAL IMPACT AND LAND USE PLANNING DUE TO URBAN GROWTH. THESIS ADVISOR : ASST. PROF. SUWIT ONGSOMWANG, Dr. rer. Nat. 246 PP.

GEOINFORMATICS/SPATIAL ANALYSIS/URBAN GROWTH MODELING/ ENVIRONMENTAL IMPACT//LAND USE PLANINNG

Due to rapid growth of the Mahasarakham University, LULC change takes place in the campus and its vicinity, various types of environmental impacts occur in the area. Main objectives of the study are to assess LULC change and urban growth characteristics, environmental impact assessment due to urban growth and land use planning in the future. Main components of methodology are consisted of (1) LULC assessment and its change, (2) urban growth, (3) environmental impact, and (4) land use planning.

Results of the LULC assessment and change during 2002 to 2021 from visual interpretation and prediction by CA-Markov model showed that urban and built-up areas had continuously increased while agricultural and forest land had continuously decreased. For urban growth characteristics, urban growth pattern during 2001 to 2006 was linear strip development but its pattern was changed to be a scattered development during 2006 to 2011. For the future time, urban growth pattern during 2011 to 2021 were still scattered development. Most of sub-districts had expanded at slow-speed level and had urban land percentage at moderate and high urbanization level and had developed at moderate level.

For environmental impact assessment due to urban growth, mean value of surface runoff during 2001 to 2021 was different from each other and its value had continuously increased and number of sub-districts by zonal analysis directly varied due to urban growth. The linear relationship between urban area change and surface runoff change was positive with the R^2 of 87.82% and spatial urban area change and urbanization strongly related with surface runoff change. Meanwhile for potential flood analysis, moderate and high potential flood areas were situated in floodplain and terrace along Chi River. No potential flood area was located at elevation more than 170 m above MSL. In addition, most of actual flooded areas during 2005-2011 from GISTDA's report were located in moderate and high potential flood areas.

For evaluation of the existing comprehensive city plan and land use planning, it revealed that urban and built-up area in 2021 was less than city plan assignment about 41%. This result indicates that the existing comprehensive city plan can support the predicted LULC in 2021. Meanwhile, the most and least of suitable land use allocation in land use plan in 2021 was agricultural and conservation area (83.00%) and commercial area (0.48%). In addition, mean surface runoff change deriving from land use plan data had decreased in all sub-districts by comparison with the predicted LULC in 2021. These findings show that a well land use plan can mitigate flooding.

In conclusion, it appears that geoinformatics technology can be used as a tool for LULC change and environment impact assessment due to urban growth.

School of Remote Sensing	Student's Signature ________________________
Academic Year 2012	Advisor's Signature ________________________
	Co-advisor's Signature______________________

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Montree Pimjai

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LIST OF ABBREVIATIONS

AGR	=	Annual Growth Rate
ARC	=	Antecedent Runoff Condition
CA-Markov	=	Cellular Automata and Markov Model
CN	=	Curve Number
CU	=	Chulalongkorn University
DEM	=	Digital Elevation Model
DEQP	=	Department of Environmental Quality Promotion
DOPA	=	Department of Provincial Administration
DPT	=	Department of Public Works and Town & Country Planning
GDP	=	Gross Domestic Product
GIS	=	Geographic Information System
GISTDA	=	Geo-Informatics and Space Technology Development Agency (Public Organization)
HSGs	=	Hydrologic Soil Groups
LCM	=	Land Change Modeler
LDD	=	Land Development Department
LULC	=	Land Use and Land Cover
MOT	=	Ministry of Transport
MSL	=	Mean Sea Level

LIST OF ABBREVIATIONS (Continued)

MSU	=	Mahasarakham University
PSO	=	Permanent Secretary Office
PU	=	Urban Land Percentage
SAW	=	Simple Additive Weighting
SCS-CN	=	Soil Conservation Service Curve Number
SI	=	Urban Land Expansion Index
SPOT	=	Satellites Pour l’Observation de la Terre
TD	=	Treasury Department
THEOS	=	Thailand Earth Observation Satellite
TMD	=	Thai Meteorological Department
USDA	=	United States Department of Agriculture

CHAPTER I

INTRODUCTION

1.1 Background and significance of the study

Understanding of land use change, urbanization and urban growth are critical to city planners and resource managers in the rapidly changing environments because changes in land use will cause changes in environmental conditions (Meyer and Turner, 1994). When land use change occurs due to urbanization (the building up and paving over of undeveloped areas) and along a city boundary, it increases the size of the city as it grows (Fang, Gertner, Sun, and Anderson, 2004).

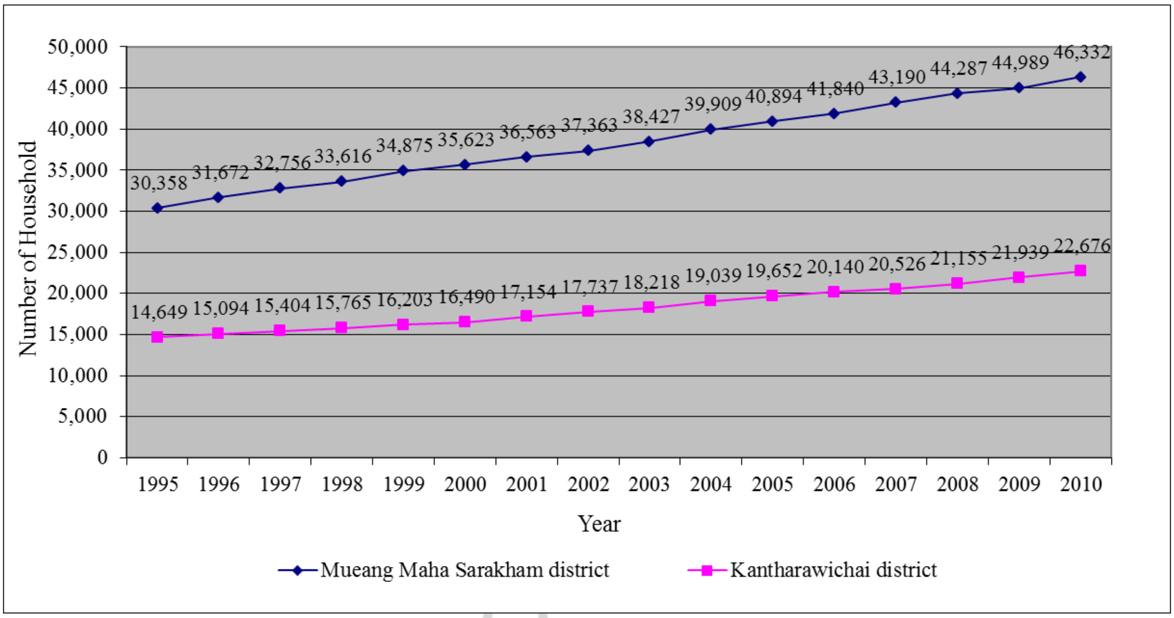
Moreover, urban growth is a special kind of land use change, urban areas make up a small proportion of the land surface area can cause very large changes in environmental conditions, more than other land use changes which must be monitored and predicted to preserve natural resources in urbanize areas (Lin, Lin, Wang, and Hong, 2008).

When land use change and urbanization resulting, its process has a considerable environmental impact such as hydrological impact in terms of influencing the nature of runoff and other hydrological characteristics, stream flow response, delivering pollutants to rivers, and controlling rates of erosion. Surface runoff from storm events is part of the natural hydrologic process. It can arise from overland surface flow, flow within drainage pipes and sewers, or flow from the top, saturated layers of soil near the stream.

In recent years, geoinformatics technology was popular among land use and urban planners and geographers as a geospatial simulation tool which has been emphasized in the previous LULC change studies such as Landis (1995); Clarke and Gaydos (1998); Batty, Xie, and Sun (1999); Li and Yeh (2000); Wang and Zhang (2001) and Wu, (2002).

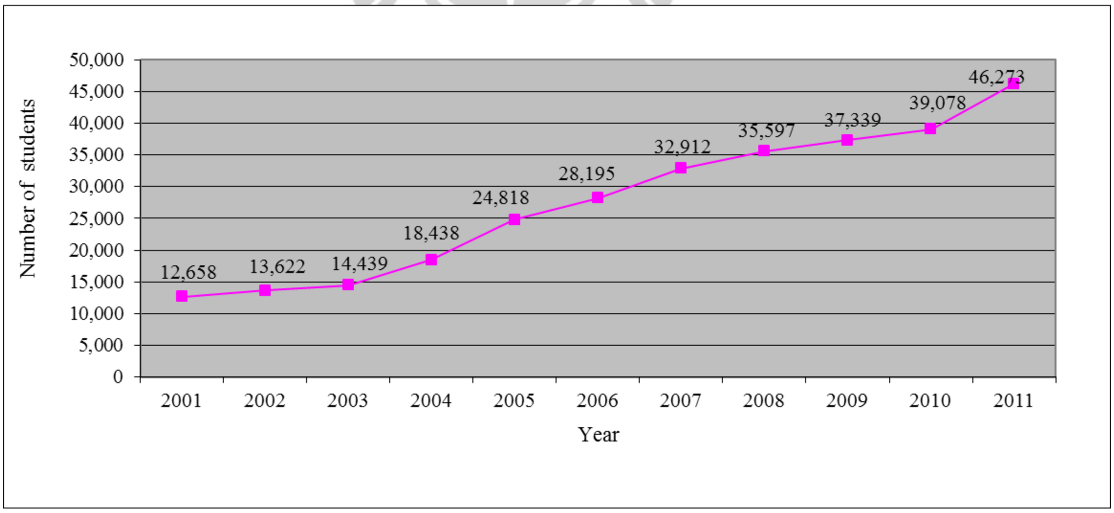
Due to rapid growth of Mahasarakham University (MSU), LULC change takes place in the campus and its neighbor. As a result, the number of households has continuously increased (Figure 1.1). Moreover, in the past decade the number of MSU students is continuously rising from 12,658 persons in 2001 to 46,273 persons in 2011 (Mahasarakham University, 2011) as shown in Figure 1.2.

Therefore, various types of environmental problems occur in this area such as urban flood due to heavy rainfall, dusty problems and road accidents, rubbish and wastes. Therefore, this study aims to apply spatial analysis to study land use/land cover change, urban growth, environmental impact and land use planning in the future. Results will be useful for city planning and mitigation and prevention environment impact in the future.



Source: Department of Provincial Administration (2010).

Figure 1.1 Development of households in Mueang Maha Sarakham and Kantharawichai districts between 1995 and 2010.



Source: Mahasarakham University (2011).

Figure 1.2 Statistics of the registered students of MSU between 2001 and 2011.

1.2 Research objectives

The aims of this research are to study land use/land cover change, urban growth, environmental impact and land use planning in the future. The specific objectives are as follows:

(1) to quantify the characteristics of LULC and urban growth for LULC prediction with an optimum predictive LULC change model;

(2) to identify urban growth impact on surface runoff and potential flood; and

(3) to evaluate the existing comprehensive city plan for land use planning.

1.3 Scope of the study

Scope of this study can be summarized in the following lists.

(1) LULC data in 2001, 2006, and 2011 are extracted from color orthophoto, SPOT and THEOS data using visual interpretation on the screen at the scale of 1: 10,000. Then, post classification comparison change detection algorithm is applied for LULC change using spatial analysis.

(2) Driving force for urban growth are identified by spatial simple and multiple linear regression based on relevant factors including physical conditions, public service accessibility, economic opportunities, demography, and plan and policies.

(3) LULC prediction is conducted using an optimum predictive model from CA-Markov Model or Land Change Modeler based on overall accuracy, and Kappa coefficient of agreement.

(4) Urban expansion is explained about size, pattern, direction and annual growth rate (AGR), urban land percentage (PU), and urban land expansion index (SI) using spatial analysis.

(5) SCS-CN method is applied for distributed relative surface runoff estimation in 2001, 2006, 2011, 2016, and 2021 based on interpreted and predicted LULC, soil and maximum rainfall in 30 years (1981-2010) of the climatological data of Thailand.

(6) Impacts of urban growth on surface runoff are evaluated using spatial analysis in term surface runoff change in the past (2001-2006, 2006-2011) and in the future (2011-2021).

(7) Potential flood in 2011 is analyzed using index model with SAW method based on relevant factors including surface runoff, elevation, slope, soil drainage, distance to river network, river drainage density, and road network density.

(8) Evaluation of the existing comprehensive city plan is conducted using overlay analysis.

(9) Land use planning in 2021 is analyzed using geospatial model based on potential suitable area for future development using index model with SAW method, and sieve analysis.

1.4 Limitation of the study

Due to limitation of historical LULC record in 2001 and 2006, only accuracy assessment of LULC in 2011 is performed.

1.5 Study area

Mueang Maha Sarakham and Kantharawichai districts where Mahasarakham University situated are selected as the study area (Figure 1.3). These two districts represent fast LULC change and urbanization in this study. The total study area is about 977 sq. km.

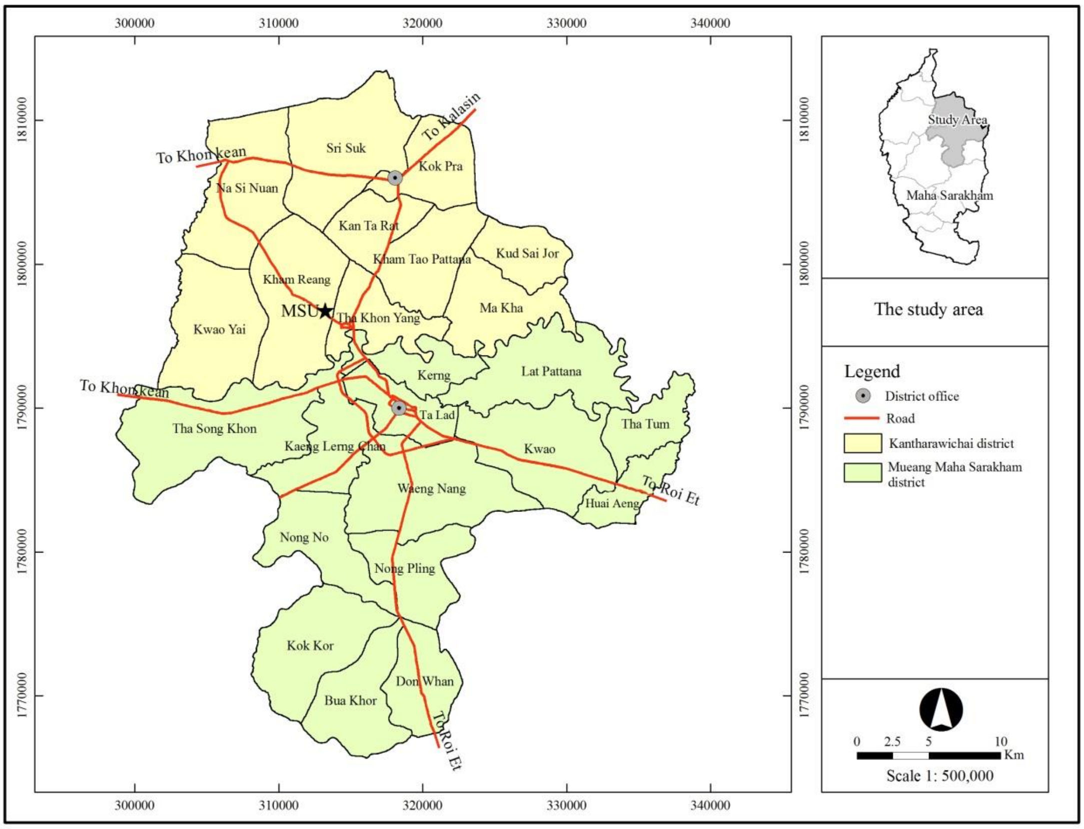


Figure 1.3 Map of the study area.

Topographically, the study area is located in the northeast of Maha Sarakham province, where most area is flat with slope between 0 - 5%. The elevation ranges approximately from 140 to 215 meters above mean sea level (Figure 1.4). The hydrological condition in this study has Chi River which flows through the middle from west to east and divides administration’s boundary between Mueang Maha Sarakham district and Kantharawichai district.

Figure 1.4 Topography of the study area.

1.6 Benefits of the study

(1) The characteristics of LULC and its change and urban growth and its driving force are identified and explained in terms of qualitative and quantitative information. In addition, effect of urban growth on surface runoff and potential of flood are identified and they are applied for land use planning.

(2) Methodology from this study might be useful to other researchers, managers, city planners, government officers and public for further uses and application and investigation in the future.

(3) Results and findings in the study are useful for urban planning and management, especially environmental impact mitigation in various dimensions for the urban smart growth.

CHAPTER II

RELATED CONCEPTS AND LITERATURE REVIEWS

The concepts and literature reviews related to this study are here summarized including driving force for LULC change, impact of LULC change and urban growth on environment, and surface runoff estimation using SCS Curve Number method.

2.1 Driving force for LULC change

LULC change is controlled by many factors and it may be difficult to determine what factor has the highest influence. Driving forces and potential for LULC change is dependent on the political, social and economic conditions in each city. Bürgi, Hersperger, and Schneeberger (2004) identified LULC change driving force into five groups included: political, economic, cultural, technological, and natural factor.

Furthermore, Zondag and Borsboom (2009) identified seven clusters of urban growth driving force.

(1) Demographic factor. The first and foremost cause of urban growth was increase in urban population; natural increase in population and migration to urban areas. This factor which consists of different components, affects size and composition of population and households. Demographic developments are especially influential because the behavior of actors is often related to demographic characteristics.

(2) Economic factors. A varied set of economic developments and determinants are LULC change factor. Examples of important economic developments affecting land use are growth in income and trust funds, rise in double-income households, changes in economic structure, agglomeration forces, global and local market developments (e.g. agricultural products), and organization of production processes. Expansion of economic base creates demand for new housing or more housing space and encourages for rapid construction of new houses.

(3) Technology factors. They are an important driving force behind developments in many sectors and the organization of society as a whole, which often results in land-use changes. Examples are technological developments which increase productivity in agriculture, technological options affecting underground storage or desalination of water, or internet enabling online shopping.

(4) Social values and trends factor. They have a significant influence on almost any type of land use. For example, changes in people's lifestyles can directly affect housing types and locational preferences, as well as consumption patterns. More indirectly, societal values regarding nature, landscape or agricultural production, for example, may affect governmental budgets, such as for nature development, and restrictions and regulations could affect the size and type of agricultural production.

(5) Climate change factor. Climate change influences land use in multiple ways; for example, via rising sea levels, periods of intensified rainfall or drought, changing temperatures and moisture affecting conditions for biotopes or agricultural production.

(6) Policy factors. Realize government drives, the various government levels have accessed to a large and diverse set of policies affecting land-use. These policies

can be categorized by dimension; scale such as international, national or local or sector level such as spatial planning or sector specific.

(7) Existing land use patterns. They have a very dominant influence on future land use. The time dynamics of the changes in land use are very slow and therefore the existing land use is a very important given for future land use. Further, the likelihood that a land use cha nge occurs at a location depends on the existing land use.

Thapa and Murayama (2010) studied about drivers of urban growth in the Kathmandu valley, Nepal, by grouping the driving force factors into seven categories, whose details are summarized in Table 2.1.

Table 2.1 Driving factors of LULC change representation and synthesis.

Cluster	**Synthesis**	**Representation characteristics**
1	Physical conditions	Topography, slopes, soils and rivers in the valley are playing a role to land use changes, for example, soil with lower slope area for brick factories, river dynamic (erosion, deposition, and changing route pattern), and hillocks for attractive residences or resorts and so on.
2	Public service accessibility	Services available in the valley are: transportation, electricity, education, drinking water, health services, commercial services, waste disposal, open spaces, and recreation facilities. The concentration of these services may differ by location.
3	Economic opportunities	Kathmandu, as a major economic hub in the country, provides several high-paying jobs and business opportunities in tourism, finance, industry, education, health, wholesale, and retails.

Table 2.1 (Continued).

Cluster	Synthesis	Representation characteristics
4	Land market	Local people, land broker and real estate developers in Kathmandu are very active in acquiring the undeveloped lands with scattered ownerships, and later develop the land and put on sale.
5	Population growth	High population influx (5.2% per year) in the valley puts high pressure on limited resources by demanding more urban services ultimately increasing the land use changes.
6	Political situation	Kathmandu, as the capital of the country, is the safest place during the conflict period of time. People having interest or business in politics and seeking safety have migrated in different places that enhanced the demand of services.
7	Plans and policies	The effectiveness of zoning, land reforms, land pooling, guided land development, economic and investment plans of the government were consider

Source: Thapa and Murayama (2010).

As results from the reviews, major driving force clusters and their variables for urban growth based on Zondag and Borsboom (2009) and Thapa and Murayama (2010) were selected with some modification and used in the study.

2.2 Impact of LULC change and urban growth on environment

Urbanization is detrimental to the environment. As urban areas rise, the environmental problems grow exponentially. There are many of the environmental impacts caused by urbanization (Frumkin, 2002). These included:

(1) Temperature. Temperature increases drastically due to factors such as paving over formerly vegetated land, increasing number of residences and high-rise apartments and industries. Many cities and suburbs experience a heat island effect, where the temperature increases in the urban area.

(2) Decrease in air quality. Factories and automobiles are symbols of urbanization. Due to harmful emissions of gases and smoke from factories and vehicles, air pollution occurs. In urban area is high amount of suspended particulate matter in air, particularly in cities, which contributes to allergies and respiratory problems there by becoming a huge health hazard.

(3) Water issues. When urbanization takes place, water cycle changes as cities have more precipitation than surrounding areas. Due to dumping of sewage from factories in water bodies, water pollution occur which can lead to outbreaks of epidemics.

(4) Destruction of habitats. To make an area urbanized, a lot of forested areas are destroyed. Usually these areas would have been habitats to many birds and animals.

(5) Impacts on surface runoff. When urbanization takes place, much of the vegetation and top soil is replaced by impervious surfaces such as building, roads, parking lots, and pavement (Water Science for Schools, 2012). Natural land is changed, rainfall that used to be absorbed into the ground change to be collected by storm sewers that send the water runoff into local streams. So many impacts when runoff occurs such as; flooding, increasing sediment loads into stream. Moreover, water running off can pick up oil, chemicals from the pavement and grass. These chemicals would usually be filtered out of the water through the ground, however, due

to the increase in concrete, now run off into streams. Fertilizers from yards run off into streams causing algae blooms. The algae blooms decrease the oxygen in the water, killing the fish. The water supply for the towns becomes contaminated.

(6) Loss of wetlands. Wetlands surrounding streams help prevent flooding. In addition, wetlands slow down runoff entering a stream. Wetlands absorb chemicals in runoff. Without wetlands to act as buffer, the water supply becomes contaminated and more areas flood.

(7) Loss of green space. Urbanization takes away green space used for recreation, farmland, and improvement of air quality.

As the result from the review, surface runoff estimation and change is selected to represent the impact of LULC change and urban growth on environment.

2.3 Surface runoff estimation using SCS Curve Number

Surface runoff is the portion of the precipitation that runs off at the surface directly during and just after a rainstorm (Calson, 2004), known as the rainfall is the main contributor to the generation of it. When rain falls over a watershed or catchments it will fall on all of an impervious or a pervious area. Some rainfall can be infiltrated the subsurface and some of the remainder is surface runoff (Zoppou, 2001). This is different in the case of an impervious area, that nearly all of the rainfall becomes runoff, especially in urban area, where much of the impervious surfaces which include rooftops, sidewalks, roads, paved areas, and parking lots. Therefore the result in urban area is by extensive impervious areas, is an increase in runoff volume and flow that can result in flooding and habitat destruction. Therefore, the drainage system of urban areas is relatively different from natural system.

In the past year, scientists and engineers have sought to develop models to represent and predict the behavior of hydrology systems. Right now there are several approaches for watershed runoff estimation. Examples are the Soil and Water Assessment Tool (SWAT), Long Term Hydrologic Impact Assessment (LTHIA), The EPA Storm Water Management Model (SWMM), SCS Curve Number model, and Geomorphological Instantaneous Unit Hydrograph (GIUH), TOPMODEL, HEC Model. Among these the SCS Curve Number is widely used as an efficient method for estimating direct runoff from a rainfall event in a particular area (Weng, 2001, Mishra, Takara, and Tachikawa, 2008, Shaw and Walter, 2009) because of its flexibility and simplicity (Ebrahimian, See, Ismail, and Malek, 2009).

The Soil Conservation Service Curve Number (SCS-CN) method (now called Natural Resources Conservation service Curve Number (NRCS-CN) method) was developed by United States Department of Agriculture (USDA) to represent the potential for storm water runoff within a drainage area. By developing runoff curve number from field experiments of runoff in small catchments, with an interpretation for urban areas presented in TR-55, (USDA, 1986) a technical release on urban hydrology for small watersheds, for the combinations of different hydrological soil group, land cover and soil moisture.

The runoff equation is:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}, \tag{2.1}$$

where

Q = direct runoff (in),

P = rainfall (in),

S = potential maximum retention after runoff begins (in), and

I_a = initial abstraction (in).

The initial abstraction (I_a) is all losses before runoff begins. It includes water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration. I_a is highly variable but generally is correlated with soil and cover parameters. Through studies of many small agricultural watersheds, I_a was found to be approximated by the following empirical equation:

$$I_a = 0.2S. \tag{2.2}$$

By removing the I_a as an independent parameter, this approximation allows use of a combination of S and P to produce a unique runoff amount. Substituting equation 2.2 into equation 2.1 gives:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}, \tag{2.3}$$

where S is related to the soil and cover conditions of the watershed through the Curve Number (CN). The CN has a range of 0 to 100, and S is related to CN by:

$$S = \frac{1000}{CN} - 10, \tag{2.4}$$

where

S = potential maximum retention after runoff begins (in), and

CN = Curve Number.

Figure 2.1 and Table 2.2 are used to solve equations 2.3 and 2.4 in order to get a range of CN's and rainfall.

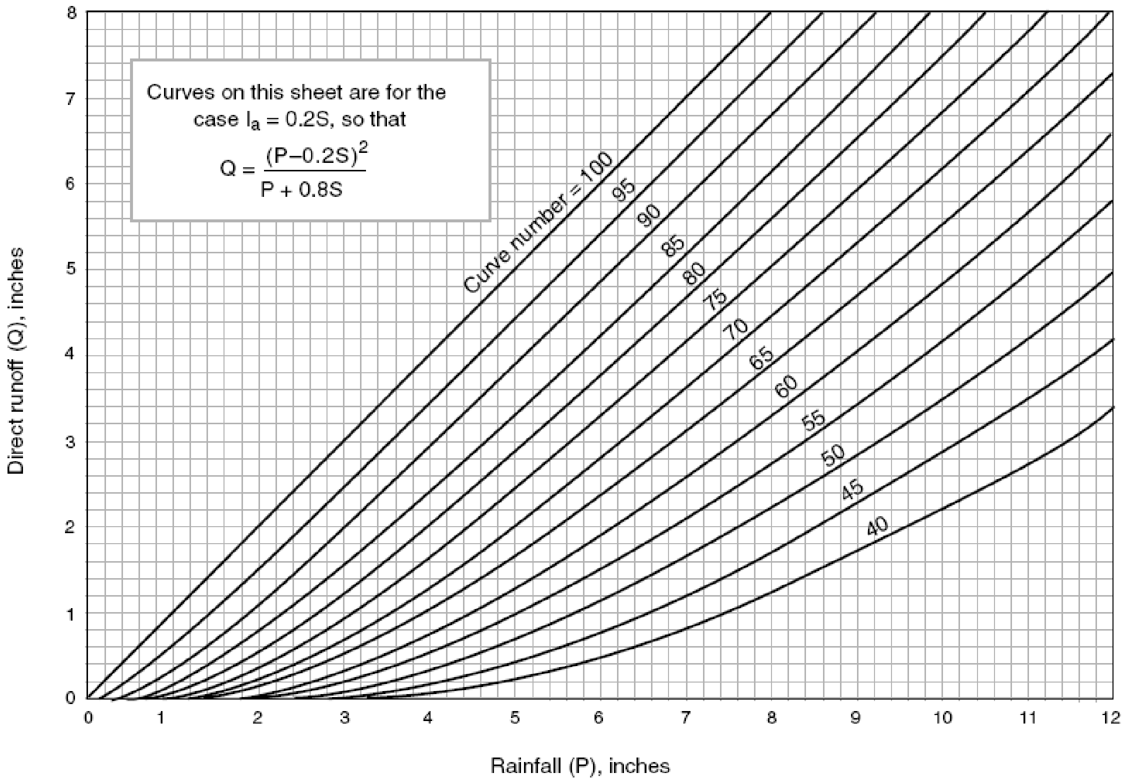


Figure 2.1 Solution of runoff equation (USDA, 1986).

The SCS curve number method uses a soil cover curve number (CN) for computing excess precipitation. The curve number (CN) is related to hydrologic soil group, cover type and treatment, hydrologic condition, antecedent runoff condition, and impervious areas connected/unconnected to closed drainage system.

2.3.1 Hydrologic soil groups (HSGs)

Hydrologic soil groups (HSGs) are the infiltration rates of soils. By classifying soils into four groups (A, B, C, and D) depending on their minimum infiltration rate, which is obtained for bare soil after prolonged wetting and the infiltration rate is the rate at which water enters the soil at the soil surface. This factor is controlled by the soil profile. The four groups of HSG are defined by USDA in the following soil group (USDA, 1986).

(1) Group A. Soils having a high infiltration rate (low runoff potential) when thoroughly wet. They consist mainly of deep, well to excessively drained sands or gravelly. This soil group has a high rate of water transmission.

(2) Group B. Soils having a moderate infiltration rate (moderately low runoff potential) when thoroughly wet. These consist mainly of moderately deep to deep, moderately well to well drained soils that have moderately fine to moderately coarse texture. This soil group has a moderate rate of water transmission.

(3) Group C. Soils having a slow infiltration rate (moderately high runoff potential) when thoroughly wet. These consist mainly of soils having a layer that impedes downward movement of water and soils of moderately fine to fine texture. This soil group has a low rate of water transmission.

(4) Group D. Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist mainly of clay soils that have a high swelling potential soils that have a permanent high water table, soils that have a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious material. This soil group has a very low rate of water transmission.

The soil profile may be considerably altered and the listed group classification may no longer apply. TR-55 was suggested to determine HSG according to the texture of the new surface soil, provided that significant compaction has not occurred (Table 2.3).

Table 2.2 Runoff depth for selected CN's and rainfall amounts [1].

Rainfall	Runoff depth for curve number of												
	40	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**98**
1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08	0.17	0.32	0.56	0.79
1.2	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.07	0.15	0.27	0.46	0.74	0.99
1.4	0.00	0.00	0.00	0.00	0.00	0.02	0.06	0.13	0.24	0.39	0.61	0.92	1.18
1.6	0.00	0.00	0.00	0.00	0.01	0.05	0.11	0.20	0.34	0.52	0.76	1.11	1.38
1.8	0.00	0.00	0.00	0.00	0.03	0.09	0.17	0.29	0.44	0.65	0.93	1.29	1.58
2.0	0.00	0.00	0.00	0.02	0.06	0.14	0.24	0.38	0.56	0.80	1.09	1.48	1.77
2.5	0.00	0.00	0.02	0.08	0.17	0.30	0.46	0.65	0.89	1.18	1.53	1.96	2.27
3.0	0.00	0.02	0.09	0.19	0.33	0.51	0.71	0.96	1.25	1.59	1.98	2.45	2.77
3.5	0.02	0.08	0.20	0.35	0.53	0.75	1.01	1.30	1.64	2.02	2.45	2.94	3.27
4.0	0.06	0.18	0.33	0.53	0.76	1.03	1.33	1.67	2.04	2.46	2.92	3.43	3.77
4.5	0.14	0.30	0.50	0.74	1.02	1.33	1.67	2.05	2.46	2.91	3.40	3.92	4.26
5.0	0.24	0.44	0.69	0.98	1.30	1.65	2.04	2.45	2.89	3.37	3.88	4.42	4.76
6.0	0.50	0.80	1.14	1.52	1.92	2.35	2.81	3.28	3.78	4.30	4.85	5.41	5.76
7.0	0.84	1.24	1.68	2.12	2.60	3.10	3.62	4.15	4.69	5.25	5.82	6.41	6.76
8.0	1.25	1.74	2.25	2.78	3.33	3.89	4.46	5.04	5.63	6.21	6.81	7.40	7.76
9.0	1.71	2.29	2.88	3.49	4.10	4.72	5.33	5.95	6.57	7.18	7.79	8.40	8.76
10.0	2.23	2.89	3.56	4.23	4.90	5.56	6.22	6.88	7.52	8.16	8.78	9.40	9.76
11.0	2.78	3.52	4.26	5.00	5.72	6.43	7.13	7.81	8.48	9.13	9.77	10.39	10.76
12.0	3.38	4.19	5.00	5.79	6.56	7.32	8.05	8.76	9.45	10.11	10.76	11.39	11.76
13.0	4.00	4.89	5.76	6.61	7.42	8.21	8.98	9.71	10.42	11.10	11.76	12.39	12.76
14.0	4.65	5.62	6.55	7.44	8.30	9.12	9.91	10.67	11.39	12.08	12.75	13.39	13.76
15.0	5.33	6.36	7.35	8.29	9.19	10.04	10.85	11.63	12.37	13.07	13.74	14.39	14.76

[1] Interpolated values shown to obtain runoff depths for CN's rainfall amounts not shown.

Table 2.3 HSGs determination by according to soil texture (USDA, 1986).

HSGs	**Soil textures**
A	Sand, loamy sand, or sandy loam
B	Silt loam or loam
C	Sandy clay loam
D	Clay loam, silty clay loam, sandy clay, silty clay, clay, silt

2.3.2 Cover type and treatment

Cover type and treatment factors are used in the preparation of hydrological soil-cover complex, which in turn are used in estimating direct runoff. Types of land use are classified on runoff producing such as fallow bare soil, row crops, small grains, legumes or rotation meadow, pasture, brush, vegetation, woods, farmsteads or impervious surfaces. For the first four cropping cover types, combinations of treatments describe the land use. Treatment aspect of the cover complex considers the percentage area covered with crop residue and the type of tillage system or combination (USDA, 1986).

2.3.3 Hydrologic condition

The hydrologic condition (good, fair or poor) indicates the effects of cover type and treatment on infiltration and runoff. Some factors to consider in estimating the effect of cover on infiltration and runoff are (a) canopy or density of lawns, crops, or other vegetative areas; (b) amount of year-round cover; (c) amount of grass or close-seeded legumes in rotations; (d) percentage of residue cover; and (e) degree of surface roughness (USDA, 1986). By good hydrologic condition indicates that the soil usually has a low runoff potential for that specific hydrologic soil group, cover type, and treatment.

2.3.4 Antecedent runoff condition (ARC)

Antecedent runoff condition (ARC) is the index of runoff potential before a storm event, which is an attempt to account for the variation in CN at a site from storm to storm. CN for the average ARC at a site is the median value as taken from sample rainfall and runoff data.

2.3.5 Impervious areas connected/unconnected to closed drainage system

TR-55 also suggests that consideration is given to whether impervious areas are connected (outlet directly to the drainage system) or disconnected (flow is spread out over a pervious area before entering the drainage system) in curve number selection and includes graphical figures based on the percent directly connected impervious areas to select the appropriate curve number (USDA, 1986).

As results from the reviews, the SCS Curve Number method is here applied for estimating and predicting relative surface runoff from a maximum rainfall event during 1980-2010 in the study area using grid based operation.

2.4 Literature reviews

Major research works related to this study are reviewed included driving force on urban growth, LULC prediction, estimation of surface runoff using SCS-CN method and potential flooding assessment.

2.4.1 Driving force of urban growth

Ma and Xu (2010) applied remote sensing and driving force analysis for urban expansion in Guangzhou City, China. This study area is very fast with high speed development of the economy. In the 23 years period (1979 to 2002), the built-up area of Guangzhou City attains a net increase of 325.5 sq.km, and reaches 397.4 sq.km in 2002, which is nearly 4.5 times of that in 1979 and means an annual average expansion of 14.2 sq.km and an annual growth rate of 19.7%. The built-up area of Guangzhou City is highly correlated with the gross domestic product (GDP), total population, urban resident income and urban traffic of the city, which are the dominating driving factors for expansion of the built-up urban area of Guangzhou City.

Thapa and Murayama (2010) explored the driving factors of urban growth in Kathmandu Valley using analytic hierarchy process. The dynamic pattern of urban growth in the valley has been greatly influenced by seven driving factors: physical conditions, public service accessibility, economic opportunities, land market, population growth, political situation, and plans and policies. These factors have played important yet different roles in the city core, fringe, and rural areas. Among these factors, economic opportunities in the core, population growth in the fringe, and the political situation in the rural areas are identified as the highest impact factors of urban growth. Due to the lesser land availability in the city core, the land market factor had a smaller role in the core compared to the fringe and rural areas. The plans and policies factor is evaluated as minimally effective in all thematic areas. The physical condition factor had a low impact in the city core and fringe areas, but played a larger role than the economic opportunities, public service accessibility, and plans and policies in the rural areas. Due to spatial disparities in the public service establishments in the valley, the public services accessibility factor had a low impact in the rural area. A representative model of driving factors is presented to explain the overall relationship between the factors in the urban growth process of the metropolitan region.

Aguayo, Wiegand, Azocar, Wiegand, and Vega (2007) quantified the relationship between urban growth and its driving forces and to predict the spatial growth pattern based on historical land-use changes for the city of Los Angeles in central Chile: (1) distance variables, indicating distances to certain elements such as roadway infrastructure or the city perimeter; (2) neighborhood variables, indicating the scale-dependent densities of certain elements such as roadway infrastructure within a circular area of specific radius from a focal point); or (3) environmental variables, indicating the presence, absence, or value of environmental factors that may limit or strengthen urban growth. The result showed that the best models correctly predict ~90% of the observed land-use changes for 1992–1998. The distance to access roads, densities of the urban road system and urbanized area at various scales, and soil type were the strongest predictors of the growth pattern.

Tian et al. (2005) analyzed spatiotemporal characteristics of urban expansion in China using satellite images and regionalization methods. Landsat TM images at three time periods, 1990/1991, 1995/1996, and 1999/2000, are interpreted to get vector land use datasets of scale 1:100,000. The study calculates the urban land percentage and urban land expansion index of every 1 km^2 cell throughout China. The study divides China into 27 urban regions to conceive dynamic patterns of urban land changes. Urban development was achieving momentum in the western region, expanding more noticeably than in the previous five years, and seeing an increased growth percentage. Land use dynamic changes reflect the strong impacts of economic growth environments and macro urban development policies.

As results from the reviews, driving force on urban growth and measurement index of urbanization were selected with modification and applied in urban growth analysis.

2.4.2 LULC prediction

Pérez-Vega, Jean-Francois, and Ligmann-Zielinska (2012) applied DINAMICA EGO and Land Change Modeler to assess LULC in tropical deciduous forest in western Mexico. The first model, DINAMICA EGO, uses the weights of evidence method which generates a map of change potential based on a set of explanatory variables and past trends involving some degree of expert knowledge. The second model, Land Change Modeler, is based upon neural networks. Both models were assessed through Relative Operating Characteristic and Difference in Potential. At the per transition level, they obtained better results using DINAMICA. However, when the per transition susceptibilities are combined to compose an overall change potential map, the map generated using LCM is more accurate because neural networks outputs are able to express the simultaneous change potential to various land cover types more adequately than individual probabilities obtained through the weights of evidence method. An analysis of the change potential obtained from both models, compared with observed deforestation and selected biodiversity indices showed that the prospective LUCC maps tended to identify locations with higher biodiversity levels as the most threatened areas as opposed to areas that had actually undergone deforestation. Overall however, the approximate assessment of biodiversity given by both models was more accurate than a random model.

Tewolde and Cabral (2011) applied geospatial tools to analyze the spatiotemporal urban land use changes of the Greater Asmara Area (GAA). LUCC analysis and urban sprawl analysis using Shannon Entropy were carried out. The Land Change Modeler (LCM) was used to develop a model of urban growth. The Multi-layer Perceptron Neural Network was employed to model the transition potential maps with an accuracy of 85.9% and these were used as an input for the 'actual' urban modeling with Markov chains. Model validation was assessed and a scenario of urban land use change of the GAA up to year 2020 was presented. The result of the study indicated that the built-up area has tripled in size (increased by 4,441 ha) between 1989 and 2009. Specially, after year 2000 urban sprawl in GAA caused large scale encroachment on high potential agricultural lands and plantation cover. The scenario for year 2020 shows an increase of the built-up areas by 1,484 ha

Henriques, and Tenedorio (2010) applied GIS and Land Change Modeler to analyze for the quantification and localization of land use change in Maputo City, Mozambique. Two types, which are also categories of change, can be identified: the central land use changes which have little significance but are important from a functional point of view; and the suburban land use changes, which involve vast areas of dominant residential land use. The result corresponds to the analysis of these changes in the context of the Municipal Urban Master Plan, recently approved. This study focus on the importance of the land use maps produced, in the absence of other maps, to supply the Municipal Urban Master Plan and its permanent update based on satellite images that provide territory monitoring.

Fan, Wang, and Wang (2008) applied integration of GIS and Remote Sensing methods for detecting LULC's change which includes image processing, change detection, GIS-based spatial analysis, Markov chain and a Cellular Automata (CA) models. The core corridor of Pearl River Delta was selected as study area. The temporal and spatial LULC's changes from 1998 to 2003 were detected by remote sensing data. At the same time, urban expansion levels in the next 5 and 10 years were predicted temporally and spatially by using Markov chain and a simple Cellular Automata model respectively. The result showed: (1) the rate of urban expansion was up to 8.91% during 1998–2003 from 169,078.32 to 184,146.48 ha; (2) the rate of farmland loss was 5.94% from 312,069.06 to 293,539.95 ha; (3) a lot of farmland converted to urban or development area, and more forest and grass field converted to farmland accordingly; and (4) the spatial predicting result of urban expansion showed that urban area was enlarged ulteriorly compared with the previous results, and the directions of expansion is along the existing urban area and transportation lines.

Ye and Bai (2008) applied CA-Markov model to simulate LULC change of Nenjiang County based on LULC change during 1985 - 2000. In this study, remote sensing and GIS methods were used to find the changes temporally and spatially. The result indicates that the forests were fallen in a large area, from 49.46% to 39.03% of total land area. Simultaneously, the croplands were increased rapidly from 26.02% to 37.42%. The conversion of forests and croplands were the main activities of land use. Oppositely, urbanization resulted in the decrease of the croplands in Southeast China during this period. CA-Markov model was used to predict the land use in 2015 and 2030 in this region. The predicting result indicated that from 2000 to 2015, 2000 to 2030, the croplands would increase 2.53% and 2.85% respectively.

Wu et al. (2006) applied Markov chains and regression analysis to monitor and predict land use change in Beijing using remote sensing and GIS. In this study, land use change dynamics were investigated by the combined use of satellite remote sensing, geographic information systems (GIS). The results indicated that there had been a notable and uneven urban growth and a major loss of cropland loss between 1986 and 2001. Most of the urban growth and loss of agriculture land occurred in inner and outer suburbs. Land use change was projected for the next 20 years using Markov chains and regression analysis. The further integration of remote sensing and GIS technologies with Markov model and regression model was found to be useful for describing, analyzing and predicting the process of land use change.

Weng (2002) studied on land use change analysis in the Zhujiang Delta of China using satellite remote sensing, GIS and stochastic modeling. In this study, land use change dynamics were investigated by the combined use of satellite remote sensing, geographic information systems (GIS), and stochastic modeling technologies. The results indicated that there has been a notable and uneven urban growth and a tremendous loss in cropland between 1989 and 1997. The land use change process has shown no sign of becoming stable. The study demonstrated that the integration of satellite remote sensing and GIS was an effective approach for analyzing the direction, rate, and spatial pattern of land use change. The further integration of these two technologies with Markov modeling was found to be beneficial in describing and analyzing land use change process.

Lopez, Bocco, Mendoza, and Duhau (2001) used Markov chains and regression analysis for predicting LULC change in the urban fringe. In the study, LULC change was quantified for the last 35 years within and in the vicinity of a fast growing city in Mexico, using rectified aerial photographs and GIS. Herein, Markov chains and regression analysis was used to project LULC change for the next 20 years. The study also explored the relationships between urban growth and landscape change, and between urban growth and population growth. The analysis of Markov matrices suggests that the highest LULC attractor is the city of Morelia, followed by plantations and croplands. Grasslands and shrub lands are the least stable categories. They are found that the most powerful use of the Markov transition matrices seems to be at the descriptive rather than the predictive level. Linear regression between urban and population growth offered a more robust prediction of urban growth in Morelia. In addition, they suggest that linear regression should be used when projecting growth tendencies of cities in regions with similar characteristics.

As results from LULC change prediction model reviews, CA-Markov and Land Change Modeler are here selected for an optimum model identification based on its derived overall accuracy and kappa coefficient of agreement comparison with actual interpreted LULC data.

2.4.3 Estimation of surface runoff using SCS-CN method

Ebrahimian et al. (2009) used GIS and NRCS-CN for estimating the runoff depth in the semi-arid Kardeh watershed. The curve number values from NRCS standard tables were assigned to the intersected hydrologic soil groups and land use maps to generate CN values map. The curve number method was followed to estimate runoff depth for selected storm events in the watershed. Effect of slope on CN values and runoff depth was determined. The results showed that there was no significant difference between observed and estimated runoff depths ($P > 0.05$). In this study, statistically positive correlations were detected between observed and estimated runoff depth ($r = 0.56$; $P < 0.01$). About 9% and 6% of the estimated and slope adjusted runoff values were within ±10% of the recorded values, respectively. Moreover, about 43% and 37% of the estimated and slope-adjusted values were in error by more than ±50%, respectively.

Elhakeem and Papanicolaou (2009) used SCS-CN for estimating in-situ runoff curve number for selected agricultural fields in the State of Iowa via rainfall simulators. In this study, representative fields in six counties were selected to identify the effects of the following variables on runoff CN: rainfall intensity, soil type, soil moisture condition, tillage practice, and residue cover. The result found that rainfall simulators are useful instruments for estimating in-situ runoff CN because rainfall intensity was adjustable during an experimental run. In addition, they found the simulators eliminate the need of natural storm events. The range of the estimated CN values in summer agreed well (deviation less than 6%) with the reported CN values. However, the range of the estimated CN values in fall was generally less the reported CN values (deviation of about 40%) due to the high residue levels found in the fields after harvest. The effects of tillage practice and crop type were insignificant compared to residue cover and soil moisture.

Liu and Li (2008) applied Soil Conservation Service (SCS) method for simulating the surface runoff for single rainstorm in Wangdonggou watershed, a typical small watershed in the Loess Plateau, located in Changwu County of Shaanxi Province of China. This study, based on the remote sensing geo-information data of land use and soil classification all obtained from Landsat images in 1996 and 1997 and conventional data of hydrology and meteorology. The result of calculated runoff process using the SCS method and the hydrograph of observed runoff process coincided very well in height as well as shape, and the model was of high precision above 75%. It is indicated that the SCS method is legitimate and can be successfully used to simulate the runoff generation and the runoff process of typical small watershed based on the remote sensing geo-information.

Carlson (2004) analyzed and predicted the urban growth and its effect on surface runoff on the Spring Creek Watershed. In this studied presents the concept of urban sprawl is addressed within the context of predicted increases in urbanization by relating the implied increase in surface runoff within the watershed. By using the SLEUTH model to predict the urban growth in 2025 and after that using three simple methods (SCS Method, Arthur's Method and The Penn State (PSU-IV) runoff model) to calculate the direct runoff. The results showed that increases in surface runoff and peak flow in the watershed will be rather small (a few percent or less) up to the year 2025, despite the large increase in urbanization predicted by the urban growth model. The reason for the weak response of the hydrology in the face of increased development is that wooded area is also predicted to increase, in accordance with a long term trend in this state. It was found, however, that in the absence of the predicted increase in woodland, the increase in surface runoff and peak discharge will be somewhat larger.

Tripathi, Panda, Pradhan, and Sudhakar (2002) applied an integrated GIS remote sensing and SCS-CN for runoff modelling in the Nagwan watershed of the Damodar Valley Corporation, Hazaribagh, Bihar, India. GIS was used to extract the hydrological parameters of the watershed from the remote sensing and field data. The Digital Elevation Model (DEM) was prepared using contour map (Survey of India, 1:50000 scale) of the watershed. The EASI/PACE GIS software was used to extract the topographic features and to delineate watershed and overland flow-paths from the

DEM. Land use classification were generated from data of Indian Remote Sensing Satellite (IRS -1B - LISS - II) to compute runoff curve number. Data extracted from contour map, soil map and satellite imagery, viz. drainage basin area, basin shape, average slope of the watershed, main stream channel slope, land use, hydrological soil groups and CN were used for developing an empirical model for surface runoff prediction. The result found that the model can predict runoff reasonably well and is well suited for the Nagwan watershed. Design of conservation structures can be done and their effects on direct runoff can be evaluated using the model. In broader sense it could be concluded that model can be applied for estimating runoff and evaluating its effect on structures of the Nagwan watershed.

Wang and Jin (2001) used GIS and SCS-CN method to simulated runoff depths and flood stage elevations for 1980 and 1992 in the Mill Creek watershed, an urban stream in Cincinnati, Ohio, USA. The results showed strong spatial connection between urban growth and increased runoff and flood stage elevation, which indicates that rapid urban growth, a process of expansion of urban area and conversion of farm land to paved areas, has contributed to higher risk of flooding.

Weng (2001) studied urban growth effects on surface runoff by integration of remote sensing and GIS. In his study, SCS-CN method was applied for surface runoff estimation without gauged measurement to the Zhujiang Delta of southern China. The results revealed a notably uneven spatial pattern of urban growth and an increase of 8.10 mm in annual runoff depth during the 1989–1997. An area that experienced more urban growth had a greater potential for increasing annual surface runoff. Highly urbanized areas were more prone to flooding. Urbanization lowered potential maximum storage, and thus increased runoff coefficient values

As results from the reviews, SCS-CN method is chosen to estimate and predict surface runoff in study periods of the study where it has no runoff gauge station.

2.4.4 Potential flood assessment

Camarasa-Belmonte and Soriano-García (2012) suggested a methodology for mapping flood risk in ephemeral streams, based on assessing flood hazards and global exposure. The method has been applied to the peri-urban area of Valencia, extended over the floodplains of the Barranco del Carraixet and Rambla de Poyo catchments. Hazard was assessed using hydrogeomorphological methods. Synthesis mapping was elaborated to spatially rank flood risks, in terms of their hazard and exposure components. The method is simple, effective and easily comparable. The results reveal diverse risk configurations for each floodplain, even though both are in the vicinity of Valencia city (metropolitan area). This flood risk mapping method is very useful for land use planning because it enables swift diagnosis of the nature of risks and can supports decision making by risk managers and urban planners.

Kandilioti and Makropoulos (2011) applied GIS-based multicriteria for the mapping of flood risk in urban areas. This method quantifies the spatial distribution of flood risk and is able to deal with uncertainties in criteria values and to examine their influence on the overall flood risk assessment. It can further assess the spatially variable reliability of the resulting maps on the basis of the choice of method used to develop the maps. The approach is applied to the Greater Athens area and validated for its central and most urban part. A GIS database of economic, social, and environmental criteria contributing to flood risk was created. Three different multicriteria decision rules (Analytical Hierarchy Process, Weighted Linear Combination and Ordered Weighting Averaging) were applied, to produce the overall flood risk map of the area. To implement this methodology, the IDRISI Andes GIS software was adapted and used. It is concluded that the results of the analysis are a reasonable representation of actual flood risk, on the basis of their comparison with historical flood events.

Chen, Hill, and Urbano (2009) used a GIS-based urban flood inundation model (GUFIM) to describe a case study analysis of an urban university of a main campus of the University of Memphis. The model consists of two components: a storm runoff model and an inundation model. Cumulative surface runoff, output of the storm runoff model, serves as input to the inundation model. The storm runoff model adapts the Green–Ampt model to compute infiltration based on rainfall characteristics, soil properties, and drainage infrastructure conveyance. The basis of the inundation model is a flat water model. This effort uses publicly available elevation data, storm data, and insurance claim data to develop, implement and verify the model approach. GUFIM is an alternative to physical-based dynamic models characterized by accurate results, efficient performance, and reasonable input and hardware requirements.

Kenyon (2007) developed a new participant-led multi-criteria method to evaluate flood risk management options in Scotland. The results show that participants preferred regeneration or planting of native woodland to other flood management options, and least preferred building flood walls and embankments. The design of the workshops allowed a rich dataset to reveal the thinking behind such results and provided a deeper understanding of why participants came to these conclusions.

McColl and Aggett (2007) integrated a land use predicting model with a rainfall runoff model in support of improving land use policy formulation at the watershed scale. The models selected for integration are loosely coupled, structured upon a common GIS platform that facilitates data exchange. The hydrologic model HEC-HMS is calibrated for a specific storm event that occurred within central Washington State. The land use forecasting model, What If? is implemented to forecast future spatial distributions of low-density residential land uses under low and high population growth estimates. Forecasted land use distribution patterns for the years 2015, 2025, and 2050 are then used as land use data input for the calibrated hydrologic model, keeping all other parameters constant. Impacts to the stream discharge hydrograph are predicted as the study area becomes increasingly developed as forecasted by What If?. The initial results of this integration process demonstrate the synergy that can be generated through the linkage of the selected models. The ability to quantifiably forecast the potential hydrologic implications of proposed land use policies before their implementation offers land use decision makers a valuable tool for discerning which proposed land-use alternatives will be effective at minimizing storm water runoff.

Rattanakom and Ongsomwang (2008) applied GIS model to analyze flood risk area in Ubon Ratchathani province. In the study, simple additive weighting (SAW) method of index model was applied for flood risk assessment based on the importance of factors, which included the amount of rainfall, elevation, land use types, soil drainage, stream proximity, slope, and drainage density, affecting the probability of flooding. Herewith, analytical hierarchy process (AHP) method was used for weighting important factors. The results revealed a notably consistency between the high risk flooding zone and number of risky flood villages.

Sinha, Bapalu, Singh, and Rath (2008) integrated the hydrological analysis under GIS-based for flood risk mapping of Kosi basin. This studied flood risk analysis follows a multi-parametric approach using Analytical Hierarchy Process (AHP) and integrates geomorphological, land cover, topographic and social (population density) parameters to propose a Flood Risk Index (FRI). The flood risk map is validated with long-term inundation maps and offers a cost-effective solution for planning mitigation measures in flood-prone areas.

Bapalu and Sinha (2005) used GIS to define the flood hazard areas in the Kosi River Basin, North Bihar, India. They have used one of the multi-criteria decision-making techniques, Analytical Hierarchical Process (AHP) which provides a systematic approach for assessing and integrating the impact of various factors, involving several levels of dependent and independent, qualitative and quantitative information. They present a novel methodology for computing a composite index of flood hazard derived from topographical, land cover, geomorphic and population related data. All data are finally integrated in a GIS environment to prepare a final flood hazard map.

As results from the reviews, important flooding factors based on Rattanakom and Ongsomwang (2008) are selected and modified for potential flood analysis in this study.

CHAPTER III

RESEARCH METHODOLOGY

The main focuses of this research are to study land use/land cover change, urban growth, environmental impact and land use planning in the future is schematically represented in Figure 3.1. Details of research methodology are described in the following sections.

3.1 Data collection and preparation

Two major tasks which include data collection and preparation are implemented under this component. Herewith remotely sensed data, GIS data, maps and documents related to the research are firstly identified and collected as summary by analysis and modeling in Table 3.1. Then, the collected data are prepared for data analysis and modeling as shown in Table 3.2

3.2 LULC assessment and its change

The main operations of this component include image preprocessing, LULC interpretation, accuracy assessment and LULC change detection and urban growth analysis are displayed as a schematic diagram in Figure 3.2.

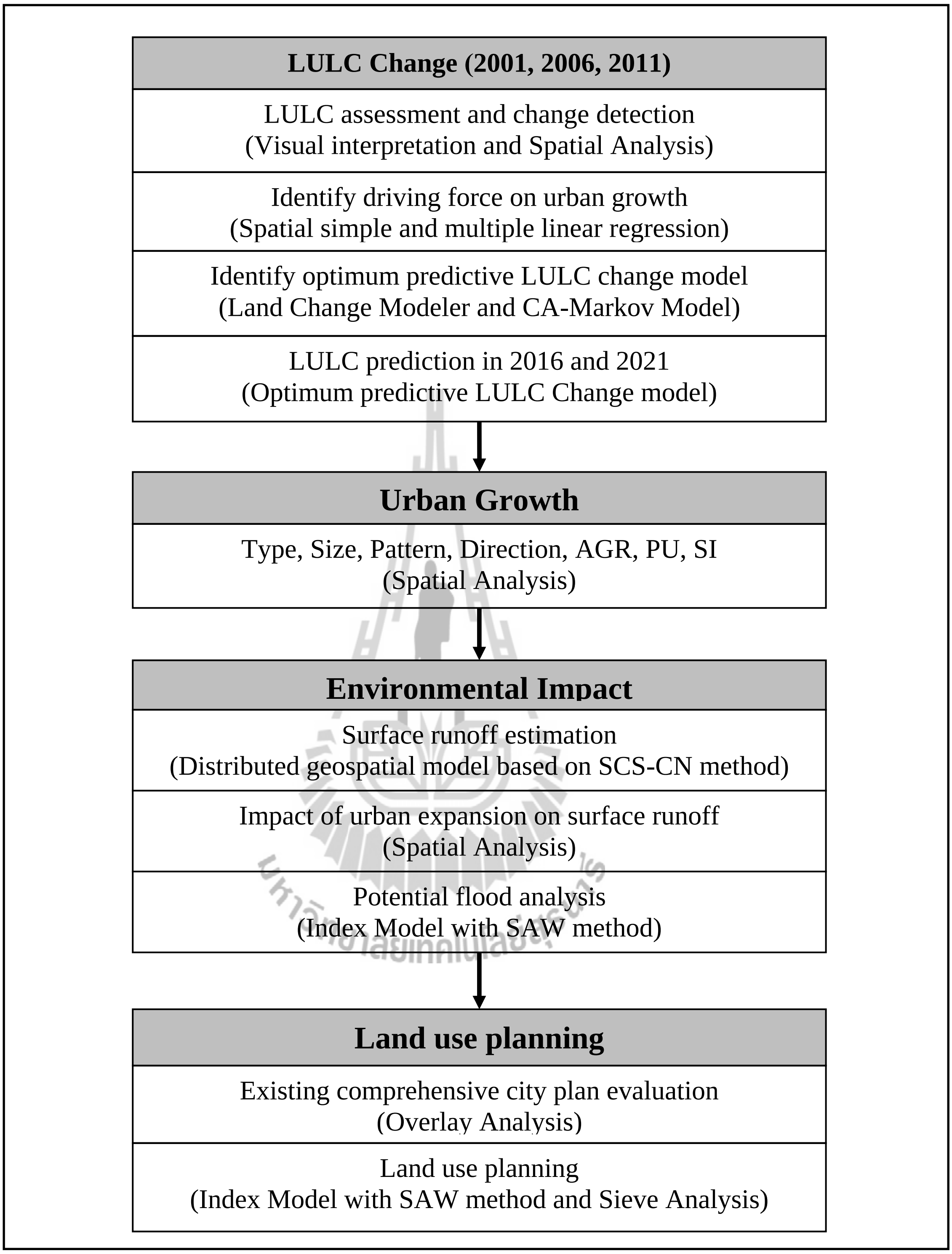


Figure 3.1 Framework of research methodology.

Table 3.1 List of data collection for analysis and modeling in the study.

Analysis and Modeling	Collective data	Scale	Source
LULC assessment and change detection	Color orthophoto data in 2001	1:10,000*	LDD
	SPOT data in 2006	1:10,000*	GISTDA
	THEOS data in 2011	1:10,000*	GISTDA
Driving force on urban growth by spatial regression analysis	DEM	30 x 30 m	CU
	Road network	1:10,000	PSO of MOT
	Per capita income	No scale	CDD
	Land value	1:4,000	TD
	Size of population	No scale	DOPA
	Size of household	No scale	DOPA
	Comprehensive city plan	1:4,000	DPT
	Existing urban area	1:10,000*	By visual interpretation
	Boundary of new MSU campus	1:10,000*	THEOS data
Surface runoff by SCS-CN method	30 years (1981-2010) climatological data	No scale	TMD
	Soils series data	1:100,000	LDD
Potential flood analysis	DEM	30 x 30 m	CU
	Road network	1:10,000	MOT
	River network	1:50,000	DEQP
Existing comprehensive city plan evaluation	Comprehensive city plan map	1:4,000	DPT
Potential urban and built-up area development	Road network	1:10,000	PSO of MOT
	Location of college/university	1:10,000	THEOS data
	Location of public service	1:50,000	DEQP
Potential agricultural and conservation area development	River network	1:50,000	DEQP
Potential residential area development	Location of school	1:50,000	DEQP
Potential institution area development	Road network (major road)	1:10,000	PSO of MOT

* Digitized scale on the screen for visual interpretation

Table 3.2 List of data preparation for analysis and modeling in the study.

Analysis and Modeling	Prepared data	Operation
LULC assessment and change detection	Interpreted LULC in 2001	Visual interpretation
	Interpreted LULC in 2006	Visual interpretation
	Interpreted LULC in 2011	Visual interpretation
Driving force on urban growth by spatial regression analysis	Slope classification	Extraction from DEM
	Distance to road network	Buffering by distance
	Average per capita income in each sub-district	Average per capita income extraction
	Average land value in each land value zone	Average land value extraction for each land value zone
	Population density in each sub-district	Population density calculation
	Household density in each sub-district	Household density calculation
	Comprehensive city plan	Extraction from the existing comprehensive city plan
	Existing urban area	Extraction from LULC data
	New MSU campus	Buffering by distance from new MSU campus
LULC Prediction using CA-Markov model	Interpreted LULC in 2001	By visual interpretation
	Interpreted LULC in 2006	By visual interpretation
LULC Prediction using Land Change Modeler	Interpreted LULC in 2001	By visual interpretation
	Interpreted LULC in 2006	By visual interpretation
	Three driving forces on urban growth	Spatial multiple linear regression analysis
Surface runoff estimation and prediction by SCS-CN method	Interpreted and predicted LULC data (2001, 2006, 2011, 2016, 2021)	By visual interpretation and prediction
	Soil texture class	Extraction from soil series data
	Maximum rainfall surface data	Interpolation from maximum rainfall data during 1981 to 2010
Potential flood analysis	Distance to rivers	Buffering by distance
	Elevation classification	Extraction from DEM
	Surface runoff in 2011	SCS-CN surface runoff model
	River density	Calculation from river length and catchment area
	Road network density	Calculation from road length and catchment area
	Slope classification	Extraction from DEM
Existing comprehensive city plan evaluation	Comprehensive city plan	Extraction from the existing comprehensive city plan
	Interpreted LULC in 2011	By visual interpretation
	Predicted LULC in 2016	By prediction

Table 3.2 (Continued).

Analysis and Modeling	Prepared data	Operation
Potential urban and built-up area development analysis	LULC in 2021	By prediction
	Potential flood data	Potential flood analysis
	Distance to major road	Buffering by distance
	Distance to college and university	Buffering by distance
	Distance to public service	Buffering by distance
Potential agricultural and conservation area development analysis	Potential urban and built-up area development	Reclassification
	LULC in 2021	By prediction
	Distance to reservoir	Buffering by distance
	Distance to river	Buffering by distance
	Distance to residential area	Buffering by distance
Potential residential area development analysis	Potential agricultural and conservation area development	Reclassification
	Potential flood data	Potential flood analysis
	LULC in 2021	By prediction
	Distance to residential areas	Buffering by distance
	Distance to schools	Buffering by distance
Potential institution area development analysis	Potential agricultural and conservation area development	Reclassification
	LULC 2021	By prediction
	Potential flood data	Potential flood analysis
	Distance to major road	Buffering by distance
Potential commercial area development analysis	Potential agricultural and conservation area development	Reclassification
	Potential flood data	Potential flood analysis
	LULC 2021	By prediction
	Distance to commercial areas	Buffering by distance
Sieve analysis for land use planning	High suitability for agricultural and conservation area development	Extraction from potential agricultural and conservation area development
	High suitability for residential area development	Extraction from potential residential area development
	High suitability for institution area development	Extraction from potential institution area development
	High suitability for commercial area development	Extraction from potential commercial area development
	Existing water body and mash land	Extraction from LULC in 2021

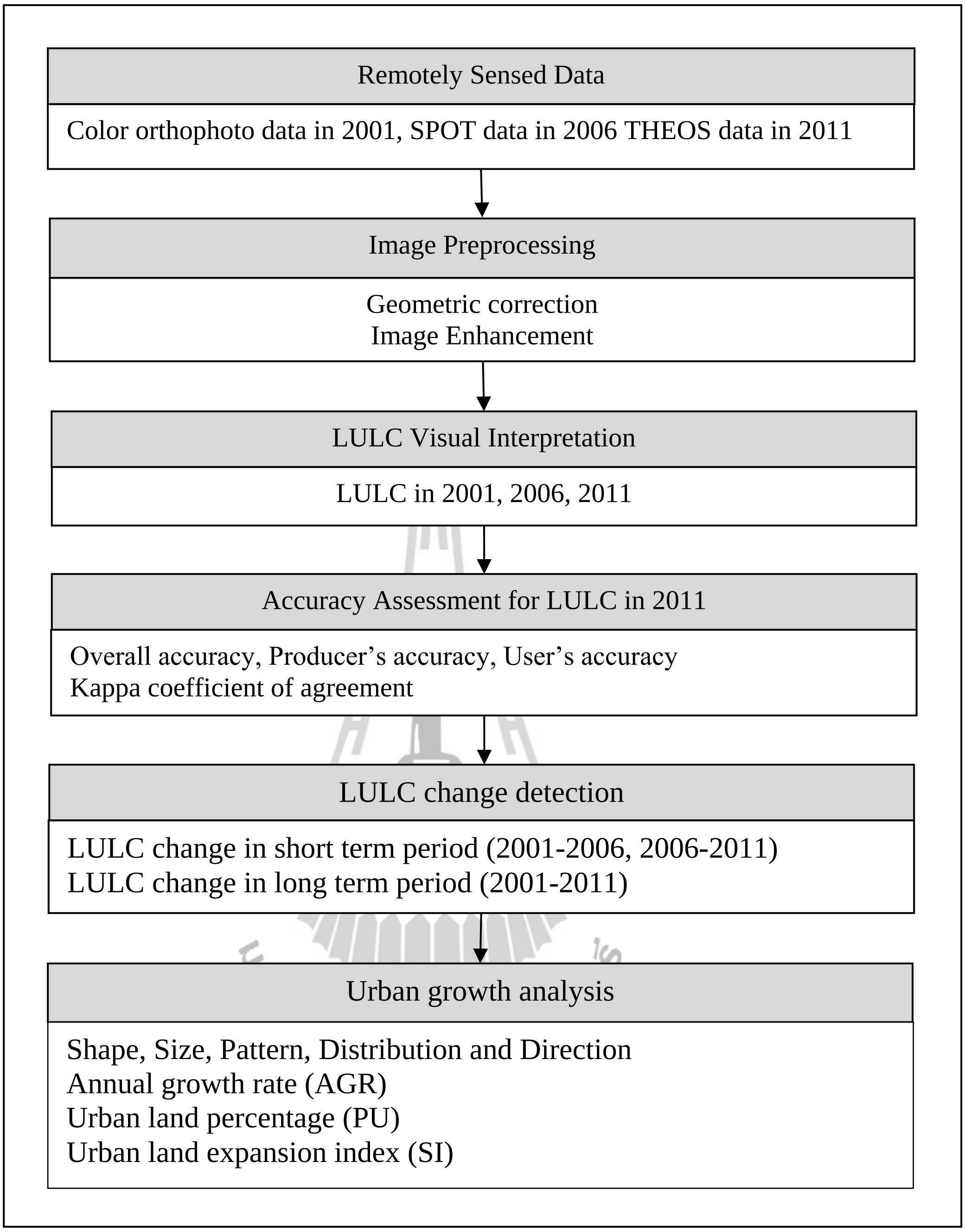


Figure 3.2 Main operations for land use and land cover assessment and its change and urban growth analysis.

3.2.1 Image preprocessing

SPOT and THEOS data are geometrically corrected using image to image rectification based on color orthophoto data. Herein, the second order of polynomial transformation for spatial interpolation and nearest neighbor re-sampling for intensity interpolation are applied for image rectification with RMSE less than 1 pixel. In this study, Universal Transverse Mercator (UTM) Zone 48 is utilized for map projection and World Geodetic System 1984 (WGS 84) is exercised for geodetic datum. In addition, standard image enhancement is exercised to remotely sensed data during visual interpretation.

3.2.2 LULC visual interpretation

LULC classes in 2001, 2006, and 2011 are visually interpreted from the remotely sensed data by mean of on-screen digitizing at the scale of 1:10,000. In this study LULC classification system is modified from standard land use classification of LDD (2009) as shown in Table 3.3.

3.2.3 Accuracy assessment for LULC map in 2011

Traditional accuracy assessment is performed based on error matrix between an interpreted LULC in 2011 and field surveying in 2011/2012 using simple descriptive statistics (overall accuracy, producer's accuracy and user's accuracy) and multivariate statistics (Kappa analysis).

Table 3.3 LULC classification system for visual interpretation.

LULC classification		Remark
Level 1	Level 2	
Urban and built-up area (U)	Commercial area*	Separate from urban and commercial area (U1) of LDD standard
	City and village*	Combine urban (city) with village (U2) of LDD standard
	Institution (U3)	LDD standard
	Dormitory*	New LULC type which is separated from urban and commercial area (U1) of LDD standard
	Real estate*	New LULC type which is separated from urban and commercial area (U1) of LDD standard
Agricultural land (A)	Paddy field (A1)	LDD standard
	Field crop (A2)	LDD standard
	Perennial tree (A3)	LDD standard
	Orchard (A4)	LDD standard
Forest land (F)	Secondary forest	New LULC type which is modified from disturbed deciduous forest (F200) of LDD standard
	Eucalyptus plantation (F5)	New LULC type which is modified from forest plantation (F5) of LDD standard
Water body (W)		Combine natural and artificial water body (W1 and W2) of LDD standard
Miscellaneous land (M)	Development land*	New LULC type which is modified from landfill (M405) of LDD standard
	Marsh land (M2)	LDD standard

* Modified from standard land use classification of LDD (2009)

3.2.4 LULC change detection

Evaluation of LULC change using the post-classification comparison algorithm for explanation from-to change information is conducted for historical record (2001-2006, 2006-2011, and 2001-2011) and future trend (2011-2016 and 2016-2021).

3.2.5 Urban growth analysis

Results from LULC assessment and its change are used to analyze the spatial growth of urban areas in term of size, shape, pattern, distribution, and direction. These characteristics are used to explain the urban growth in this study. Herein, the urban growth pattern includes compact, scattered, linear strip, polynucleated and leapfrogging development as suggested by Batty, Besussi, and Chin (2003) is identified as shown in Figure 3.3.

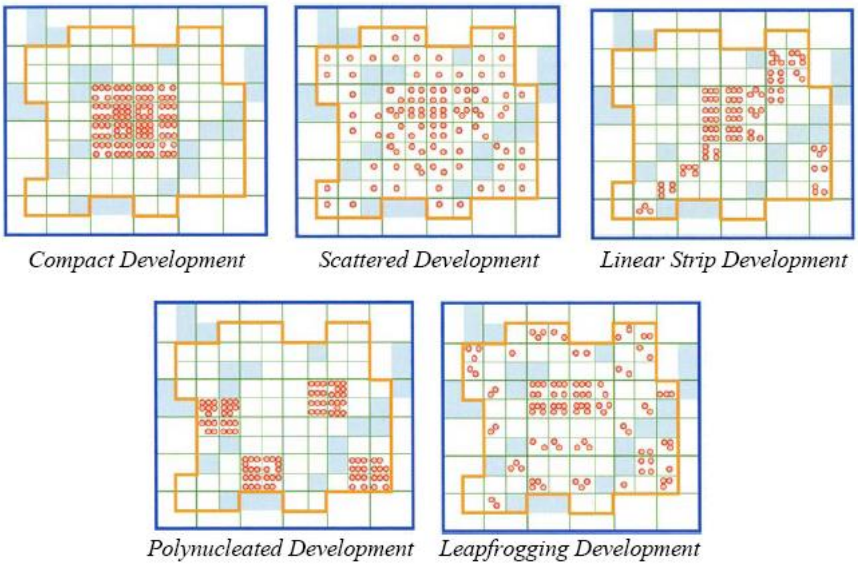


Figure 3.3 Physical patterns defining of urban growth (Batty et al., 2003).

In addition, urban growth rate (AGR) that describes the degree of differentiation of urban expansion in different directions and denotes the growth of the urban areas of a spatial unit as a percentage of the total area of the land unit is calculated as:

$$AGR = \frac{UA_{n+i} - UA_i}{nTA_{n+i}} \times 100\ \%, \tag{3.1}$$

where AGR is annual urban growth rate, TA_{n+i} is the total land area of the target unit at the time point of i+n; UA_{n+i} and UA_i is the urban and built-up area in the target unit at time i+n and i, respectively and n is the interval of the calculating period (in years) (Zhao-ling, Pei-Jun, and Da-zhi, 2007).

Also, urban land percentage (PU) that describes the percentage of urban areas of the total areas is calculated as:

$$PU = \frac{UL}{UT} \times 100\ \%, \tag{3.2}$$

where PU is urban land percentage (%), UL is urban land area (sq. km) and UT is total land area (sq. km) (Tian et al., 2005).

Furthermore, urban land expansion index (SI) that represents index for urban development is calculated as:

$$SI = \frac{UL_j - UL_i}{UT} \times 100\ \%, \tag{3.3}$$

where SI is urban expansion index from period i to j, UL_i is urban land area in period i (sq. km) UL_j is urban land area in period j (sq. km) and TL is total land area (sq. km) (Tian et al., 2005).

3.3 Driving force for urban growth

Spatial simple and multiple linear regressions are here applied to analyze driving force for urban growth. Major driving force clusters for urban growth, which are here reviewed from Zondag and Borsboom (2009) and Thapa and Murayama (2010), include (1) physical condition, (2) public service accessibility, (3) economy, (4) demography, (5) plans and policies and (6) existing land use pattern. Variables in each driving force cluster in this study are summarized as shown in Table 3.4.

In practice, selected driving force variables for urban growth as independent variables and existing urban pattern (urban and non-urban areas) in 2001, 2006, and 2011 are firstly prepared (as mentioned in Section 3.1) and then used to analyze spatial simple and multiple linear regression under IDRISI software (Figure 3.4). For spatial multiple linear regression analysis, dependent and independent variables are firstly normalized and independent variables are then orderly combined based on the significant ranking from the spatial simple linear regression for an optimal multiple linear equation identification. Three dominant driving forces from an optimal multiple linear equations are selected and applied in Land Change Modeler for LULC in 2011 prediction.

Table 3.4 Driving force for urban growth.

Driving force cluster	Variables
Physical conditions	Slope
Public service accessibility	Road network
Economy	Per capita income
	Land value
Demography	Size of population
	Size of household
Plans and policy	Existing comprehensive city plan
Existing land use pattern	Existing urban area
	New MSU campus

Modified from Zondag and Borsboom (2009) and Thapa and Murayama (2010).

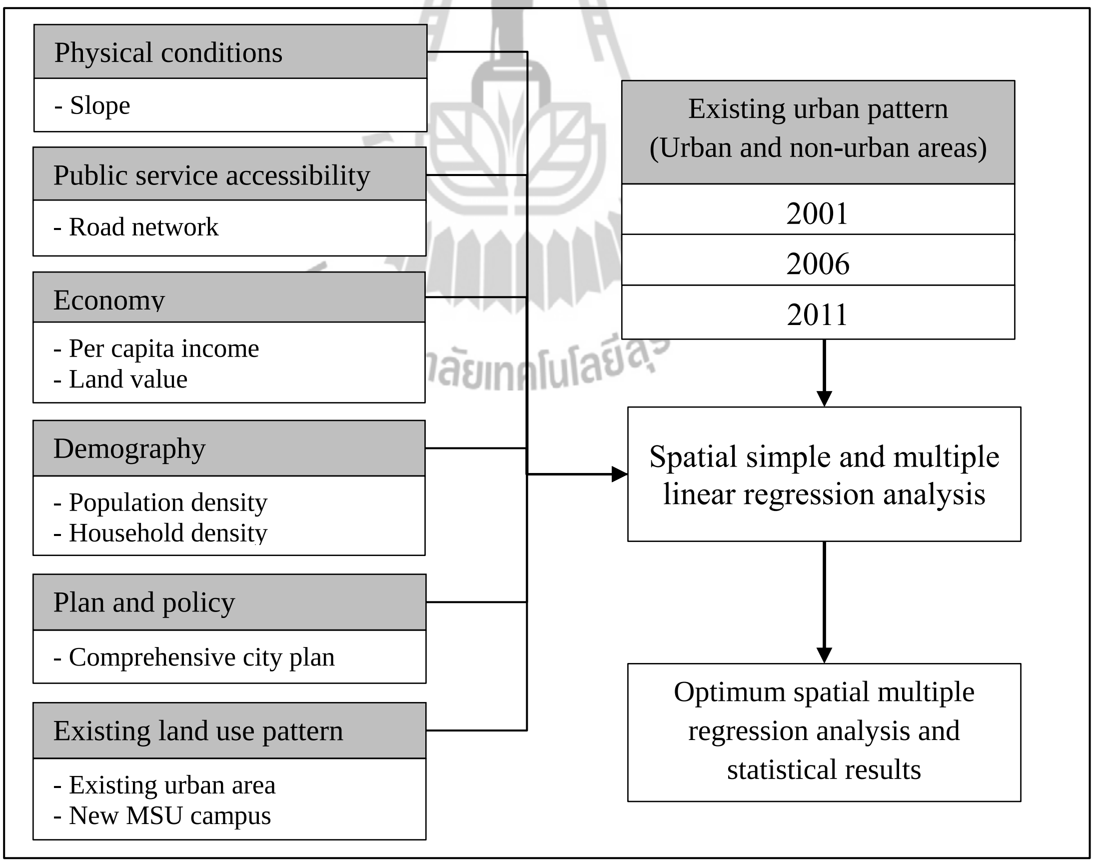


Figure 3.4 Main operations of the driving force for urban growth.

3.4 LULC prediction

LULC prediction is firstly used CA-Markov model and Land Change Modeler to predict LULC in 2011 based on LULC data in 2001 and 2006. Results of both predictive LULC models are then compared with an interpreted LULC in 2011 using overall accuracy and Kappa coefficient of agreement. After that the model which provides higher accuracy values is applied for LULC in 2016 and 2021 prediction (Figure 3.5).

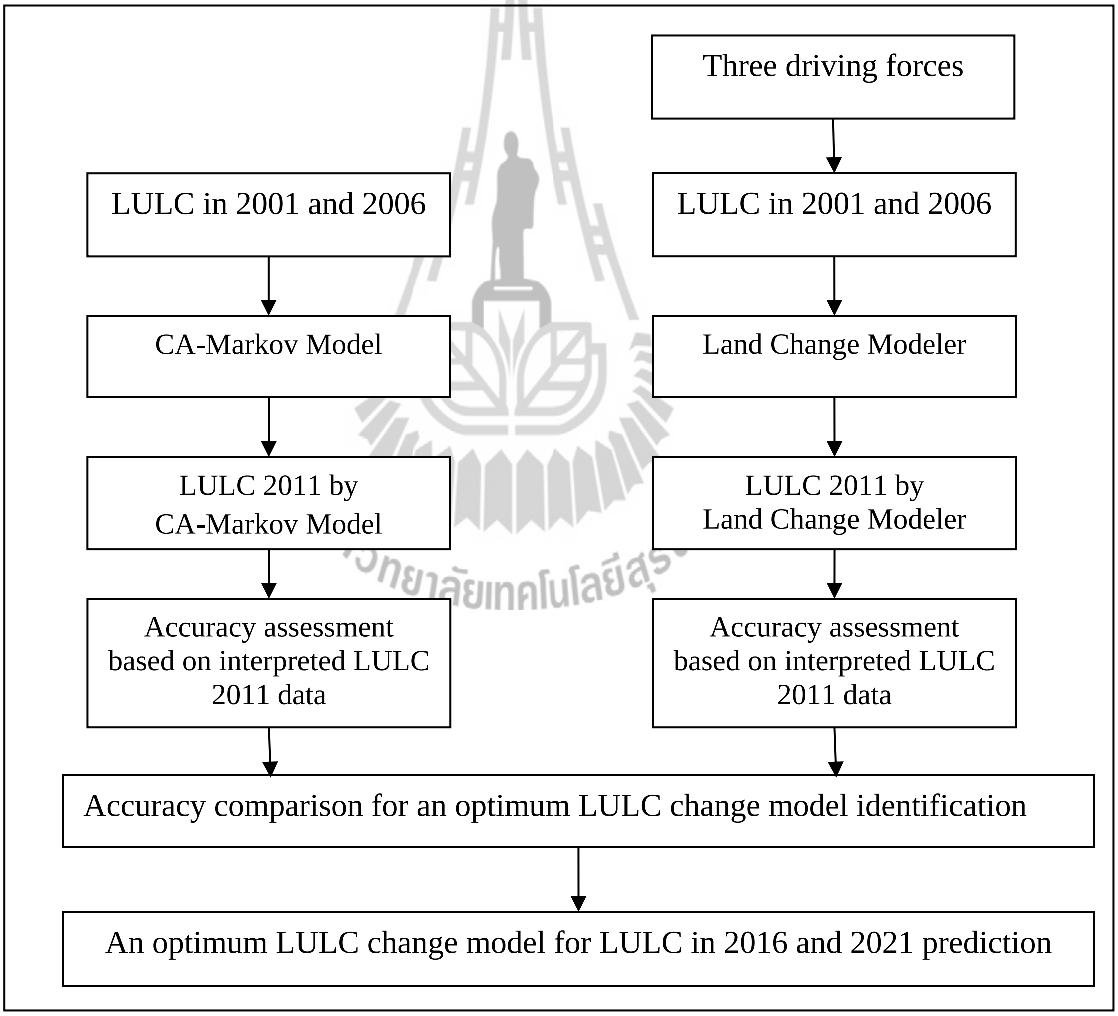


Figure 3.5 Main operations for LULC evaluation and prediction.

3.4.1 CA-Markov model

Under this operation, two basic processes are required include Markov process, and Cellular Automata (CA).

(1) Markov process

Markov process is considered in discrete time and characterized by variables that can be in one of N states from S = {S1, S2, …, SN}. The set T of transition rules is substituted by a matrix of transition probabilities (P) and this is reflective of the stochastic nature of the process:

$$P= \left\| p_{ij} \right\| = \left\| \begin{matrix} P_{1,1} & P_{1,2} & \cdots & P_{1,N} \\ P_{2,1} & P_{2,2} & \cdots & P_{2,N} \\ \cdots & \cdots & \cdots & \cdots \\ P_{N,1} & P_{N,2} & \cdots & P_{N,N} \end{matrix} \right\|, \tag{3.4}$$

where pij is the conditional probability that the state of a cell at moment t+1 will be Sj, given it is Si at moment t:

$$\text{Prob}(Si \rightarrow Sj) = pij. \tag{3.5}$$

The Markov process as a whole is given by a set of status S and a transition matrix P. By definition, in order to always be "in one of the state" for each i, the condition $\sum_j P_{ij} = 1$ should hold (Benenson and Torrens, 2004).

(2) Cellular Automata

Cellular automata are dynamic models being discrete in time, space and state. A simple of cellular automata A is defined by a lattice (L), a state space (Q), a neighborhood template (δ) and a local transition function (f):

$$A = (L, Q, \delta, f). \tag{3.6}$$

Each cell of L can be in a discrete state out of Q. The cells can be linked in different ways. Cells can change their states in discrete time-steps. Usually cellular automata are synchronous, i.e. all cells change their states simultaneously. The fate of a cell is dependent on its neighborhood and the corresponding transition function (Balzter, Braun, and Köhler, 1998).

In practice, predictive LULC in 2011 is modeled using CA-Markov model based on an interpreted LULC data in 2001 and 2006 under IDRISI software. Herewith, Markov module is firstly used to generate a transition areas matrix, a transition probability matrix and a set of conditional probability data of LULC between 2001 and 2006. Then, the extracted result is used to predict LULC in 2011 based on Markov chain analysis and multi-criteria evaluation/multi-objective land allocation routines under CA-Markov module.

3.4.2 Land Change Modeler

Predictive LULC in 2011 by Land Change Modeler is also performed under IDRISI software based on an interpreted LULC data in 2001 and 2006 with major driving forces derived from Step 3.3. Basically, 3 modules of Land Change Modeler include: (1) change analysis, (2) transition potential, and (3) change prediction required for LULC prediction.

(1) Change analysis module. Two LULC dataset are used to calculate transitional LULC change matrix for loss and gain evaluation and change map generation.

(2) Transition potential module. Potential for transitional change between LULC type are firstly identify to generate variable transformation with specific transformation type (e.g. evidence likelihood). Then dominant driving forces

are added to transition sub-model for MLP Neural Network operation to generate a potential transition map as from-to change detection.

(3) Change prediction module. Under this module, LULC are predicted for specific period using change demand modeling (Markov chain) and change allocation conditions.

3.4.3 The optimum predictive model for urban growth prediction

Result of predictive LULC in 2011 from CA-Markov model and Land Change Modeler are here compared with an interpreted LULC in 2011 based on overall accuracy and Kappa coefficient of agreement. After that the model which provides higher accuracy is used for LULC prediction in 2016 and 2021.

3.5 Surface runoff estimation and prediction

Under this component, SCS-CN method is used to estimate relative surface runoff in 2001, 2006 and 2011 and to predict relative surface runoff in 2016 and 2021 based on CN values, which is derived from LULC and soil data, and annual maximum rainfall from 30 year climatology data of Thailand (1981-2010). In this study, grid based operation with cell size of 30 x 30 m is applied for relative surface runoff estimation and prediction using Model Builder of ArcGIS environment (Figure 3.6).

In practice, major steps under this component include: (1) analysis of hydrologic soil group-land cover complex, (2) calculation of potential maximum storage, (3) interpolation of rainfall data, and (4) surface runoff calculation can be here summarized as follows.

3.5.1 Analysis of hydrologic soil group–land cover complex

Soil series data of the LDD and the extracted LULC are firstly overlaid to generate hydrologic soil cover complex with the aid of the standard SCS table and then they are assigned an appropriate CN value according hydrologic soil group (Group A, B, C, and D) with antecedent moisture condition II (AMC II).

3.5.2 Calculation of potential maximum storage (S)

By using the map algebra function of the GIS, a potential maximum storage (S) is computed for each pixel by using the following equation:

$$S = 25.4 \times \frac{1000}{CN} - 10, \qquad (3.7)$$

where

S is potential maximum storage in mm, and

CN is runoff curve number of hydrologic soil group–land cover complex.

In this stage, potential maximum storage is separately created for year 2001, 2006, 2011, 2016, and 2021. These data are further overlaid with maximum rainfall data to create a surface runoff in each year.

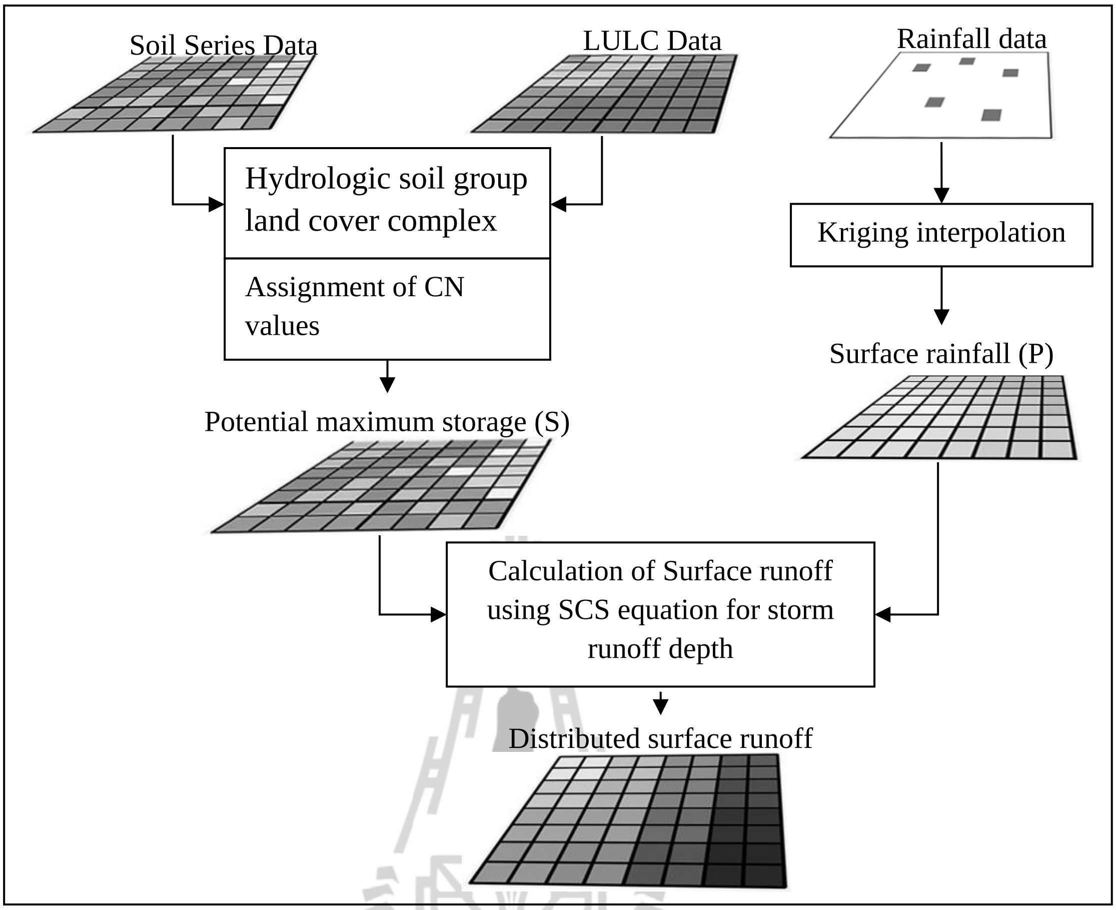


Figure 3.6 Flowchart of surface runoff estimation using SCS-CN method.

3.5.3 Surface rainfall interpolation

Maximum rainfall data based on 30 years climatological data of Thailand (1981-2010) of Kosum Pisai meteorological station and 8 neighboring stations surrounding the study area are used to interpolate surface rainfall event using kriging method. This interpolated rainfall data is further used to estimate and predict a relative surface runoff in 2001, 2006, 2011, 2016, and 2021 using SCS CN method.

3.5.4 Surface runoff calculation

Surface runoff in each cell are generate based on runoff curve numbers (CN) according to potential maximum storage (S) and rainfall (P) values in each cell (USDA 1986) using Model Builder of ArcGIS environment. The SCS equation for storm runoff depth is mathematically expressed in Equation 3.8.

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}, \tag{3.8}$$

where

Q = direct runoff (mm),

P = rainfall (mm), and

S = potential maximum retention after runoff begins (mm).

3.6 Impact of urban growth on surface runoff

Under this operation, impact of urban growth on surface runoff will be investigated include: (1) impact of urban growth on surface runoff, (2) spatial relationship between urban growth and surface runoff change, and (3) spatial relationship between urbanization and surface runoff.

3.6.1 Impact of urban growth on surface runoff change

The impact of urban growth on surface runoff change are examined by comparing of surface runoff change in the past (2001-2011) and in the future (2011-2021) and LULC change in these periods, especially urban area change.

3.6.2 Spatial relationship between urban growth and surface runoff change

Zonation of surface runoff changes are used to examine the spatial relationship with urban growth by spatial simple linear regression analysis of IDRISI software. The derived correlation coefficient (R) and coefficient of determination (R^2) values are used to explain the relationship between urban growth and surface runoff change.

3.6.3 Spatial relationship between urbanization and surface runoff change

Spatial relationship between urbanization and surface runoff change are here examined by simple linear regression analysis of IDRISI software. The derived correlation coefficient (R) and coefficient of determination (R^2) values are used to explain the relationship between urbanization and surface runoff change.

3.7 Potential flood analysis

Under this component, potential flood analysis due to urban growth is investigated using indexing model with SAW method (Malczewski, 1999). The reviewed factors for potential flood analysis include: (1) distance to river, (2) elevation, (3) predicted surface runoff in 2011, (4) river densities, (5) road network densities, and (6) slope, which are modified from Rattanakom and Ongsomwang (2008). The scores and weights with straight rank method of each factor are summarized in Table 3.5.

In practice, systematic classification of each factor is prepared for index model operation as follows:

(1) distance to river by distance buffering;

(2) elevation using by extraction from DEM;

(3) predicted surface runoff by equal interval classification;

(4) river density by calculation from river length and catchment area;

(5) road network density by calculation from road length and catchment area; and

(6) slope by extraction from DEM.

Table 3.5 Scores and weights for potential flood analysis.

Factor	**Classification**	**Score**	**Rank**	**Weight**
Distance to river	Very low: < 1,000 m.	10	1	0.29
	Low: 1,000-1,500 m.	8		
	Moderate: 1,500-2,000 m.	5		
	High: > 2,000 m.	2		
Elevation	Very low: < 150 m. above MSL.	10	2	0.24
	Low: 150-170 m. above MSL.	8		
	Moderate: 170-190 m. above MSL.	5		
	High > 190 m. above MSL.	2		
Surface runoff in 2011 (Equal interval classification)	Very low	2	3	0.19
	Low	5		
	Moderate	8		
	High	10		
River density	Very low: < 0.35	2	4	0.14
	Low: 0.35-0.70	5		
	Moderate: 0.70-1.0	8		
	High: > 1	10		
Road network density	Very low: < 1	2	5	0.09
	Low: 1-2	5		
	Moderate: 2-3	8		
	High: > 3	10		
Slope	Very low: 0-2%	10	6	0.05
	Low: 2-8 %	8		
	Moderate: 8-16%	5		
	High: > 16%	2		

3.8 Evaluation of the existing comprehensive city plan and land use planning

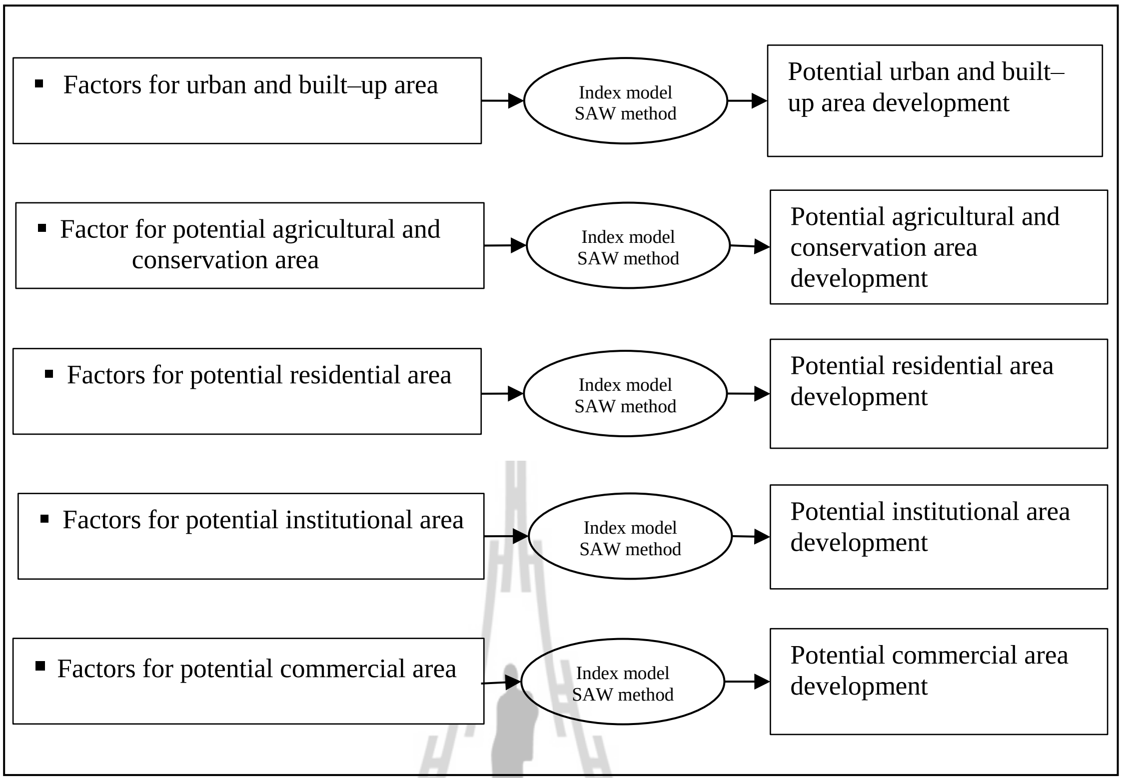
Two main tasks are implemented in this component include evaluation of the existing comprehensive city plan and land use plan in 2021. Each task is briefly described in the next section.

3.8.1 Evaluation of the existing comprehensive city plan

LULC in 2011 and 2016 are used to compare with the existing comprehensive city plan in the study area using post-classification change detection algorithm. This transition matrix is then be used to explain the gains and losses of all categories in the existing comprehensive city plan include: (1) commercial and high density residential area, (2) moderate density residential area, (3) low density residential areas, (4) conservation for residential area, (5) industrial area, (6) rural and agricultural area, (7) conservation for rural and agricultural area, (8) barren land for recreation and environmental quality area, (9) education, (10) barren land for environmental quality area, (11) religion, (12) government and infrastructure, and (13) conservation for cultural. In this study, the existing comprehensive city plan of Tha Khon Yang-Kham Reang community and Mueang Maha Sarakham between 2012 and 2016 are used as sample case for this operation. The outputs are used for explanation about urban growth impact on the existing comprehensive city plan, especially the limiting percentage for specific land use in specific area.

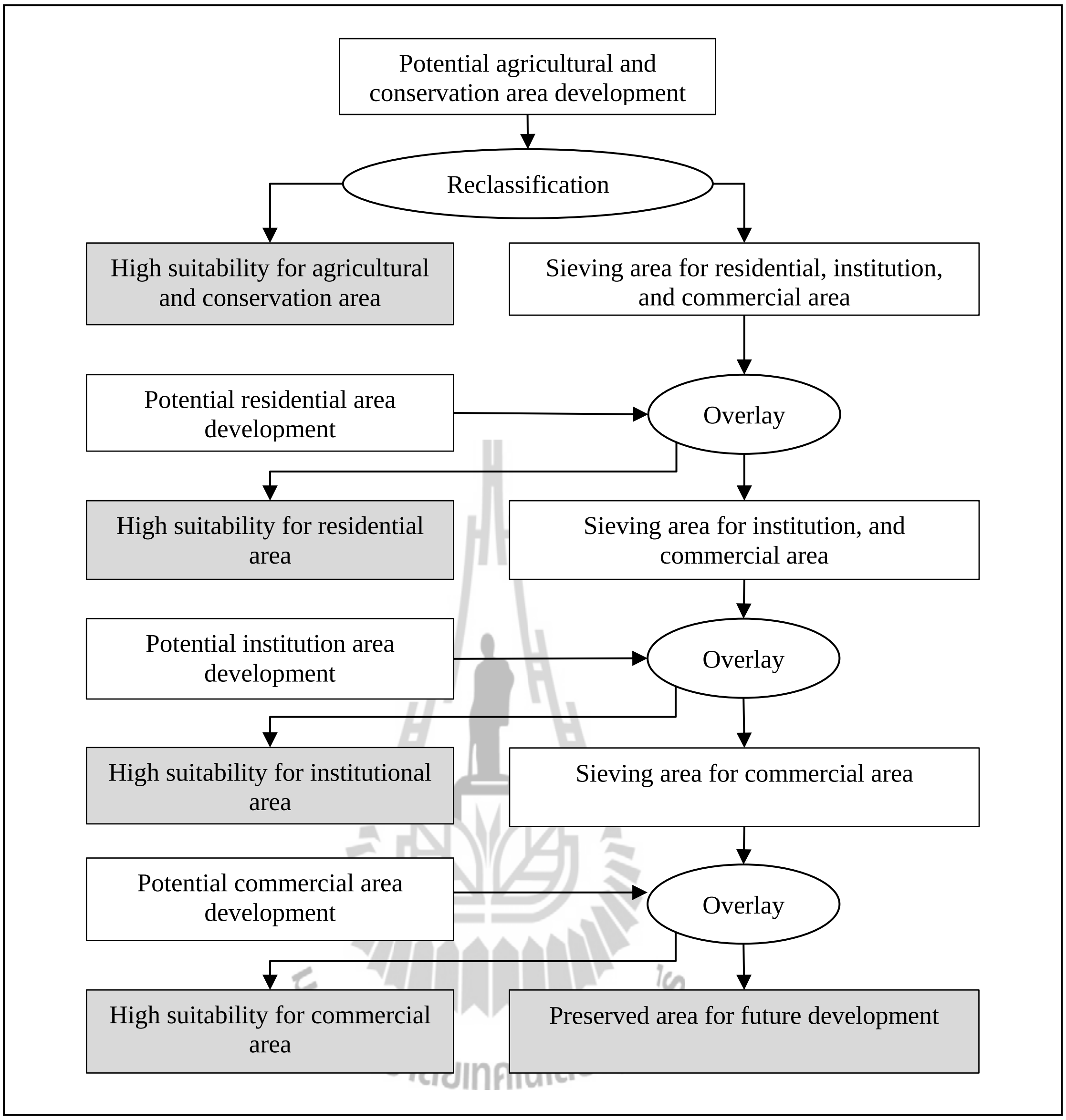
3.8.2 Land use planning

The predictive LULC and surface runoff in 2021 with potential flooding data are used to create a future land use plan of Muang Maha Sarakhan district and Kantharawichai district for flooding mitigation. The major land use types in the land use plan in 2021 include: (1) agricultural and conservation area, (2) residential area, (3) institutional area, and (4) commercial area. These major land use types are firstly prepare by potential surface analysis using index model with SAW method (Malczewski, 1999) as shown in Figure 3.7. The relevant factors for potential surface analysis of main land use types in 2021 are not only physical factor as suggested by Department of Public Works and Town & Country Planning (2010) but also include LULC in 2021 as socio-economic factor and potential flood analysis for flood mitigation. Details of factors with factor score and weighting for potential surface analysis for each land use type are shown in Table 3.6 to Table 3.10. After that, sieve analysis is applied for land use type allocation based on the important land use type as shown in Figure 3.8. In this study, marsh land and water body are directly superimposed after sieve analysis.



Source: Modified from Department of Public Works and Town & Country Planning (2010).

Figure 3.7 Potential surface analysis for land use planning.



Source: Modified from Department of Public Works and Town & Country Planning (2010).

Figure 3.8 Sieve analysis for land use plan.

Table 3.6 Factors for potential urban and built-up area development.

Factors	**Factors score**	**Weight score**
1. Land use data in 2021		0.33
Urban and built-up area	9	
Miscellaneous land	5	
Agricultural land	3	
Forest land	1	
2. Potential flood area		0.27
Very high potential	1	
High potential	3	
Medium potential	5	
Low potential	7	
Very low potential	9	
3. Distance to major road		0.20
0-100 m.	9	
100-500 m.	7	
500-1,000 m.	5	
1,000-1,500 m.	3	
More than 1,500 m.	1	
4. Distance to college and university		0.13
0-500 m.	9	
500-1,500 m.	7	
1,500-3,000 m.	5	
3,000-5,000 m.	3	
More than 5,000 m.	1	
5. Distance to public service		0.07
0-500 m.	9	
500-1,500 m.	7	
1,500-3,000 m.	5	
3,000-5,000 m.	3	
More than 5,000 m.	1	

Table 3.7 Factors for potential agricultural and conservation area development.

Factors	**Factors score**	**Weight score**
1. Potential urban and built-up area development		0.33
Very high potential	3	
High potential	5	
Medium potential	7	
Low potential	9	
2. Land use data in 2021		0.27
Agricultural land	9	
Miscellaneous land	1	
3. Distance to reservoir		0.20
0-250 m.	9	
250-500 m.	7	
500-1000 m.	5	
1,000-2,000 m.	3	
More than 2,000 m.	1	
4. Distance to river		0.13
0-100 m.	9	
100-250 m.	7	
250-500 m.	5	
500-1,000 m.	3	
More than 500 m.	1	
5. Distance to residential area		0.07
0-500 m.	9	
500-1,000 m.	7	
1,000-2,000 m.	5	
2,000-5,000 m.	3	
More than 5,000 m.	1	

Table 3.8 Factors for potential residential area development.

Factors	Factors score	Weight score
1. Potential agricultural and conservation area development		0.33
High potential	5	
Medium potential	7	
Low potential	9	
2. Potential flood area		0.27
Very high potential	1	
High potential	3	
Medium potential	5	
Low potential	7	
Very low potential	9	
3. Land use data in 2021		0.20
City and village area	9	
Agricultural land	7	
Miscellaneous land	5	
Commercial area	3	
Forest land	1	
4. Distance to residential area		0.13
0-100 m.	9	
100-500 m.	7	
500-1,000 m.	5	
1,000-1,500 m.	3	
More than 1,500 m.	1	
5. Distance to school		0.07
0-100 m.	9	
100-500 m.	7	
500-1,000 m.	5	
1,000-1,500 m.	3	

Table 3.9 Factors for potential institutional area development.

Factors	**Factors score**	**Weight score**
1. Potential agricultural and conservation area development		0.40
High potential	5	
Medium potential	7	
Low potential	9	
2. Land use data in 2021		0.30
Institution area	9	
Miscellaneous land	5	
Agriculture land	3	
Forest land	1	
3. Potential flood area		0.20
Very high potential	1	
High potential	3	
Medium potential	5	
Low potential	7	
Very low potential	9	
4. Distance to major road		0.10
0-500 m.	9	
500-1,000 m.	5	
1,000-2,000 m.	3	
More than 2,000 m.	1	

Table 3.10 Factors for potential commercial area development.

Factors	Factors score	Weight score
1. Potential agricultural and conservation area development		0.40
High potential	5	
Medium potential	7	
Low potential	9	
2. Potential flood area		0.30
Very high potential	1	
High potential	3	
Medium potential	5	
Low potential	7	
Very low potential	9	
3. Land use data in 2021		0.20
Commercial area	9	
City and village area	7	
Agricultural land	5	
Miscellaneous land	3	
Forest land	1	
4. Distance to commercial area		0.10
0-100 m.	9	
100- 500 m.	7	
500-1,000 m.	5	
1,000-1,500 m.	3	
More than 1,500 m.	1	

CHAPTER IV

RESULTS AND DISCUSSIONS

Results and discussions of the study included (1) to quantify the characteristics of LULC and urban growth; (2) to identify urban growth impact on surface runoff and potential flood analysis; and (3) to evaluate the existing comprehensive city plan for land use planning. Details of major results were described in the following sections.

4.1 LULC assessment and its change

4.1.1 LULC assessment

LULC assessment in 2001, 2006, and 2011 were extracted from visualized interpretation of remotely sensed data under GIS environment. The distribution of LULC pattern was presented in Figures 4.1-4.3 while area and percentage of LULC types were reported in Table 4.1. Visual interpretation keys for each LULC type were presented in Appendix A.

The dominate LULC type in 2001, 2006, and 2011 were agricultural land included paddy field, field crops, perennial trees, and orchards. Meanwhile, urban and built-up area included commercial, city and village, institution, dormitory, and real estate had been continuously increased in these periods. Especially, percentage of increasing for dormitory and real estate between 2001 and 2006 were about 789 and 200, respectively while percent of increasing for dormitory and real estate between

2006 and 2011 were about 140% and 222% (Figure 4.4). These phenomena are corresponded with the increasing of registered students at MSU.

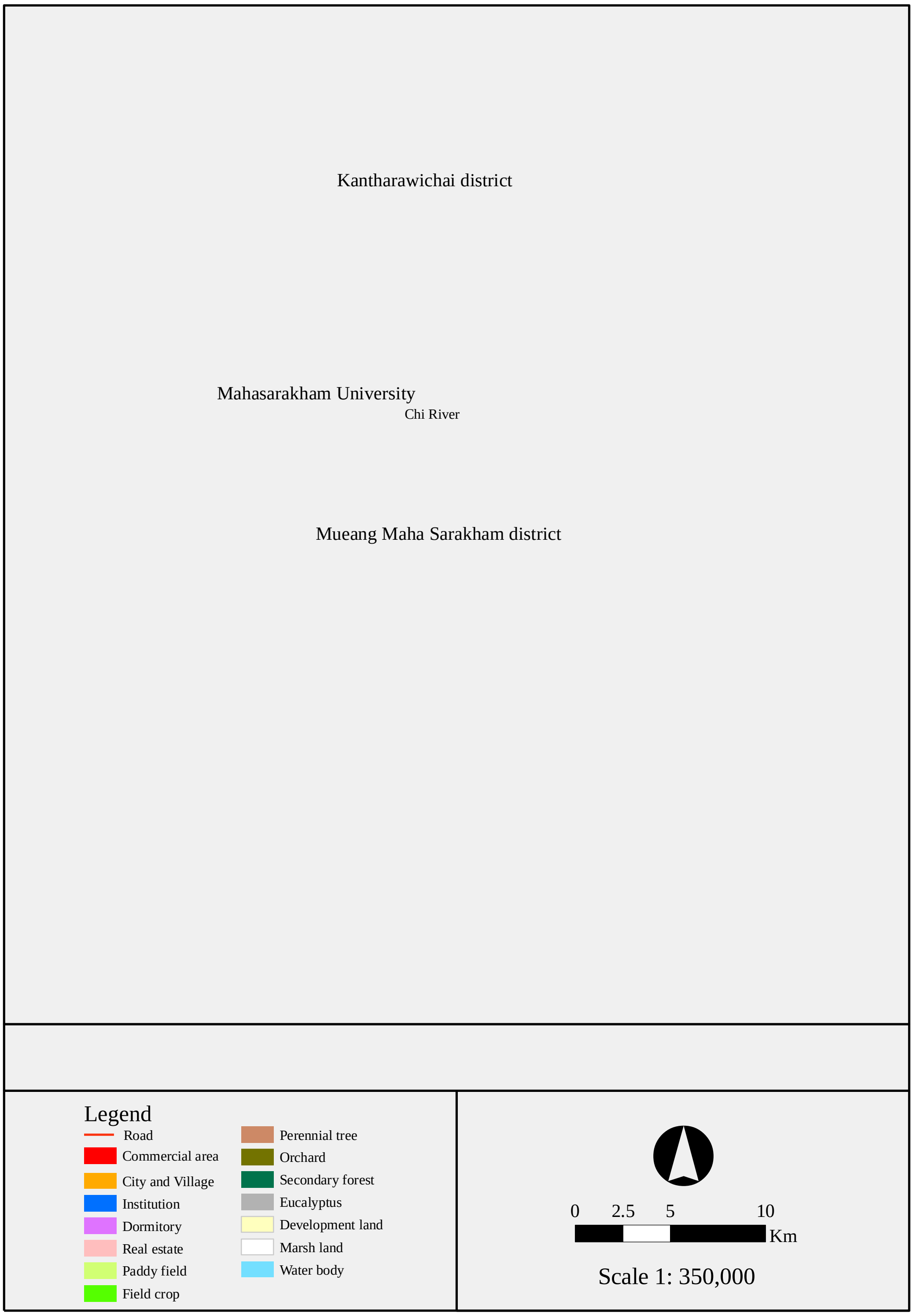


Figure 4.1 Distribution of LULC pattern in 2001.

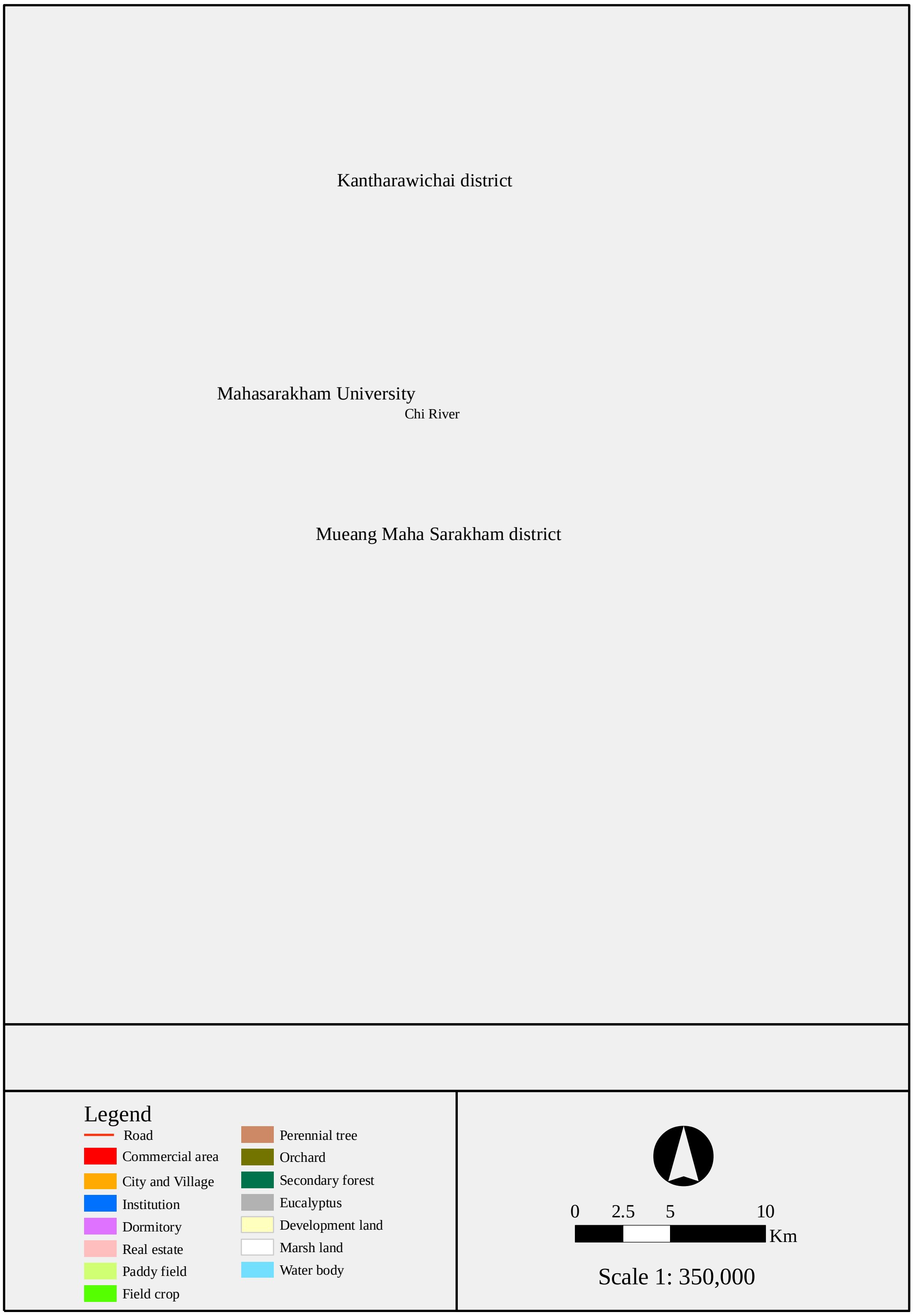


Figure 4.2 Distribution of LULC pattern in 2006.

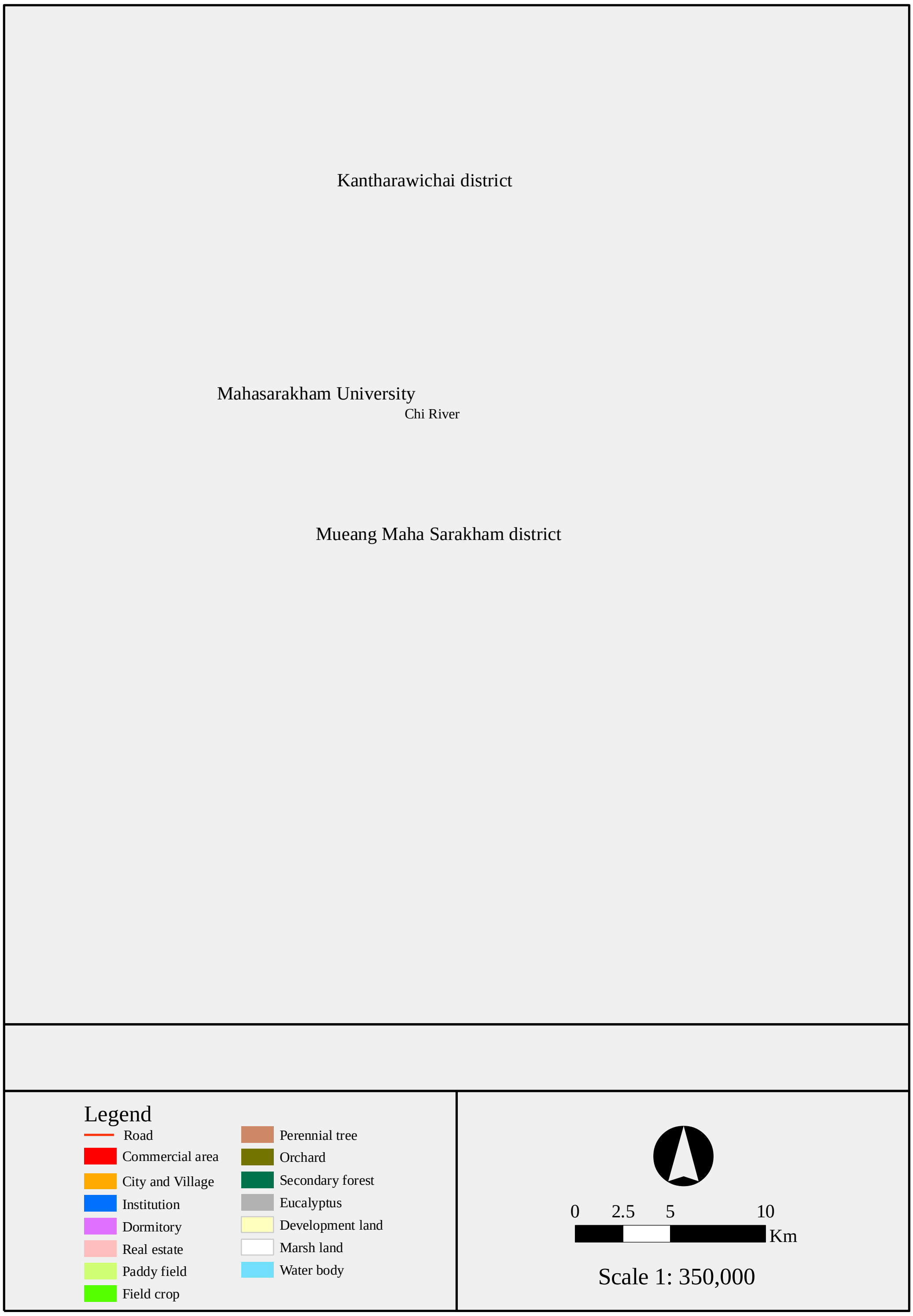


Figure 4.3 Distribution of LULC pattern in 2011.

Table 4.1 Area and percentage of LULC types in 2001, 2006, and 2011.

LULC	2001		2006		2011	
	sq.km	%	sq.km	%	sq.km	%
Commercial (U1)	1.56	0.16	2.36	0.24	3.38	0.35
City and village (U2)	42.02	4.30	42.84	4.38	47.34	4.84
Institution (U3)	10.11	1.03	10.62	1.09	10.94	1.12
Dormitory (U4)	0.09	0.01	0.80	0.08	1.92	0.20
Real estate (U5)	0.12	0.01	0.36	0.04	1.16	0.12
Paddy field (A1)	704.74	72.12	703.23	71.97	699.90	71.63
Field crop (A2)	80.36	8.22	81.41	8.33	79.69	8.16
Perennial tree (A3)	0.57	0.06	0.52	0.05	0.57	0.06
Orchard (A4)	7.92	0.81	7.76	0.79	7.18	0.73
Secondary forest (A5)	63.39	6.49	60.66	6.21	54.90	5.62
Eucalyptus (A6)	12.24	1.25	12.09	1.24	14.33	1.47
Development land (M1)	12.09	1.24	12.69	1.30	12.38	1.27
Marsh land (M2)	3.45	0.35	3.06	0.31	4.86	0.50
Water body (W)	38.50	3.94	38.76	3.97	38.61	3.95
Total	**977.16**	**100.00**	**977.16**	**100.00**	**977.16**	**100.00**

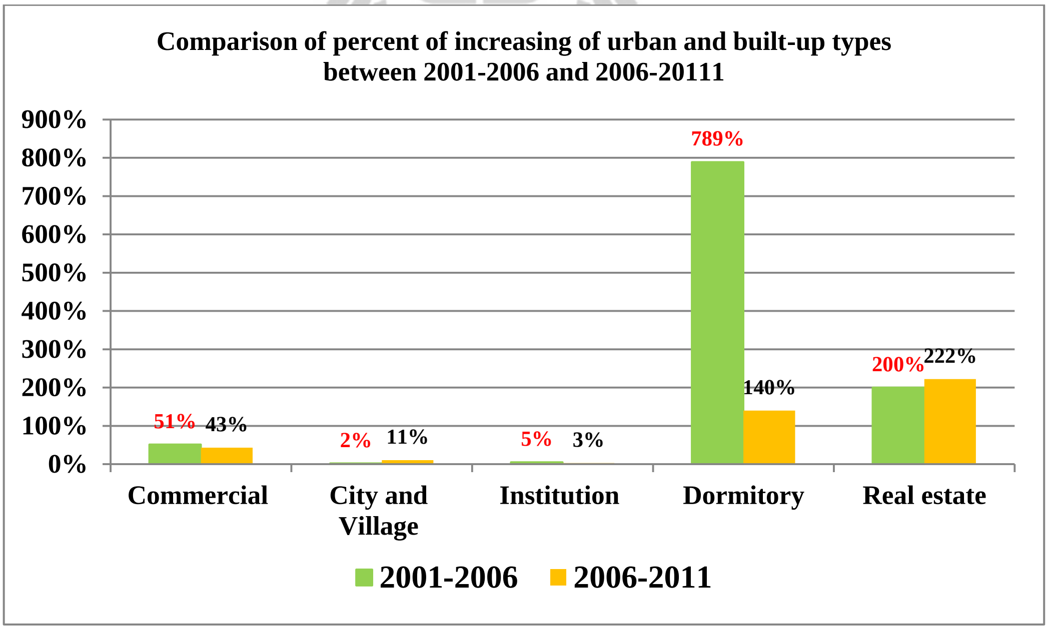


Figure 4.4 Comparison of percent of increasing of urban and built-up types between 2001-2006 and 2006-2011.

4.1.2 LULC change

LULC changes in short term period (2001-2006 and 2006-2011) and long term period (2001-2011) were here extracted using the post classification comparison algorithm. LULC change pattern in these periods were displayed in Figures 4.5-4.7 and transitional change matrices were presented in Tables 4.2-4.4.

As results urban and built-up areas in 2006 and 2011 included commercial, city and village, institution, dormitory, and real estate were converted from agricultural land and forest land. Annual increment of commercial, city and village, institution, dormitory and real estate between 2001 and 2006 were 0.16, 0.16, 0.10, 0.14, and 0.05 sq.km, respectively while annual increment of them between 2006 and 2011 were 0.21, 0.90, 0.06, 0.22, 0.16 sq.km, respectively. It revealed that most of urban and built-up area sub-classes had continuously increased except institution area (Figure 4.8).

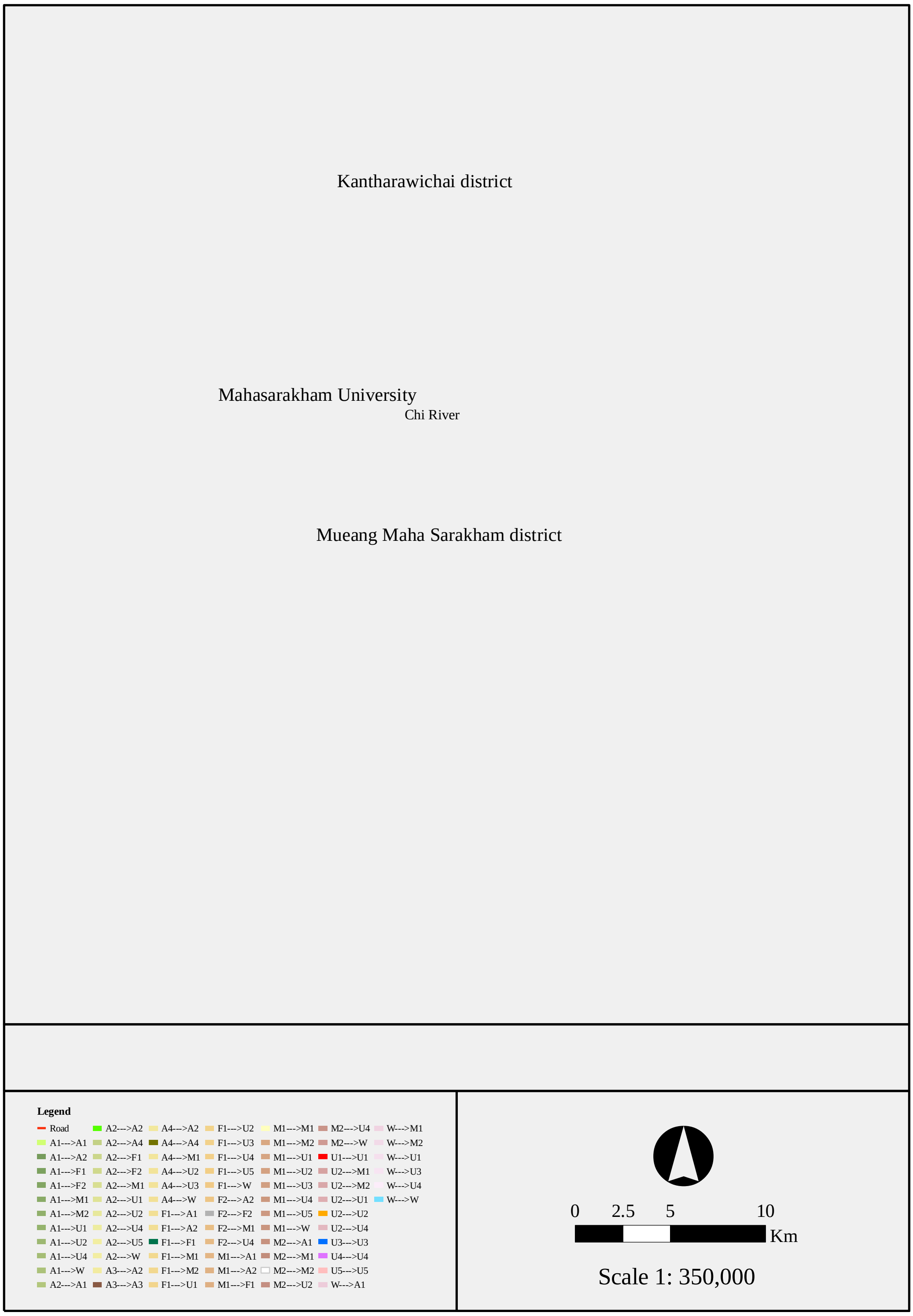


Figure 4.5 Distribution of LULC change pattern between 2001 and 2006.

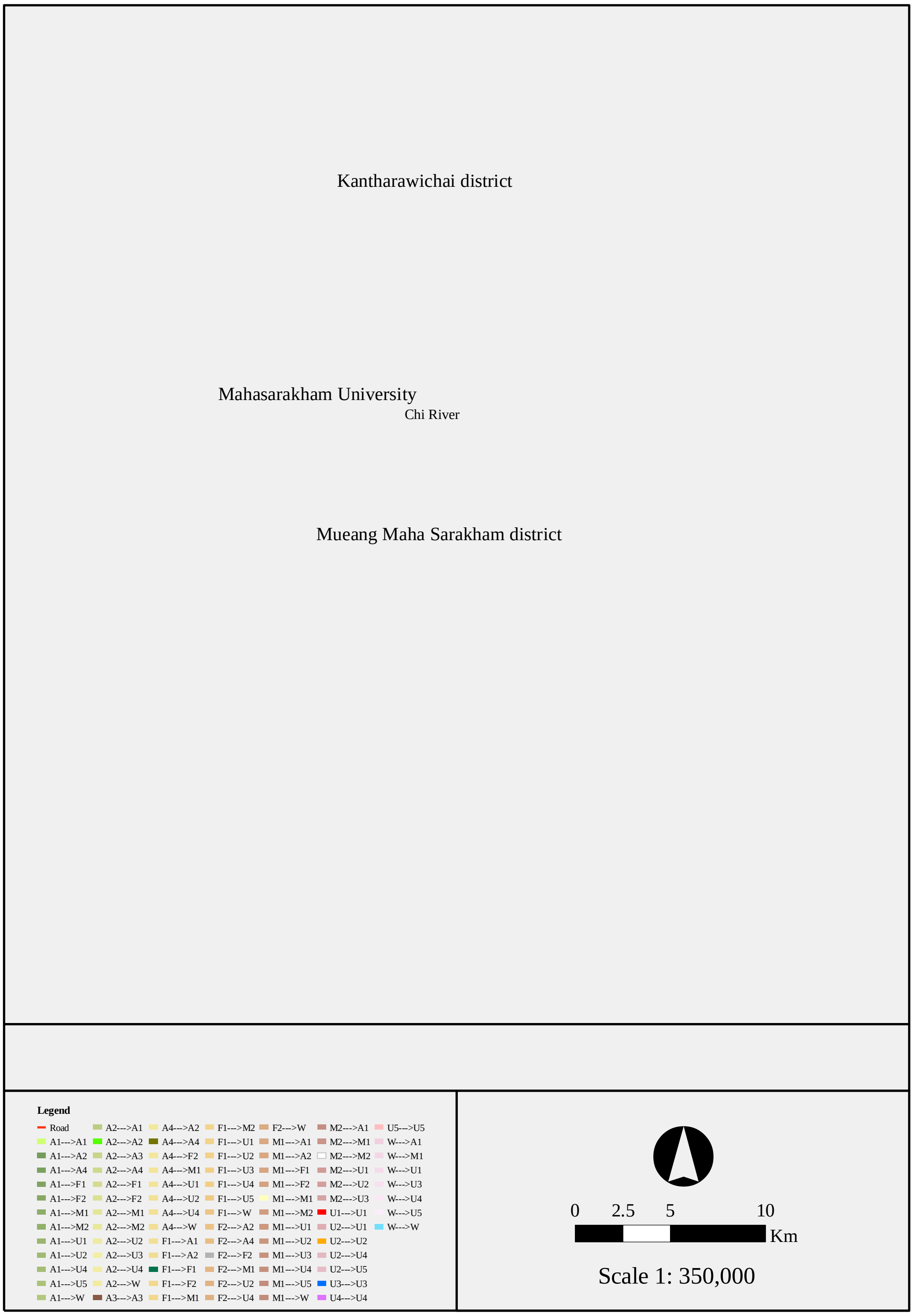


Figure 4.6 Distribution of LULC change pattern between 2006 and 2011.

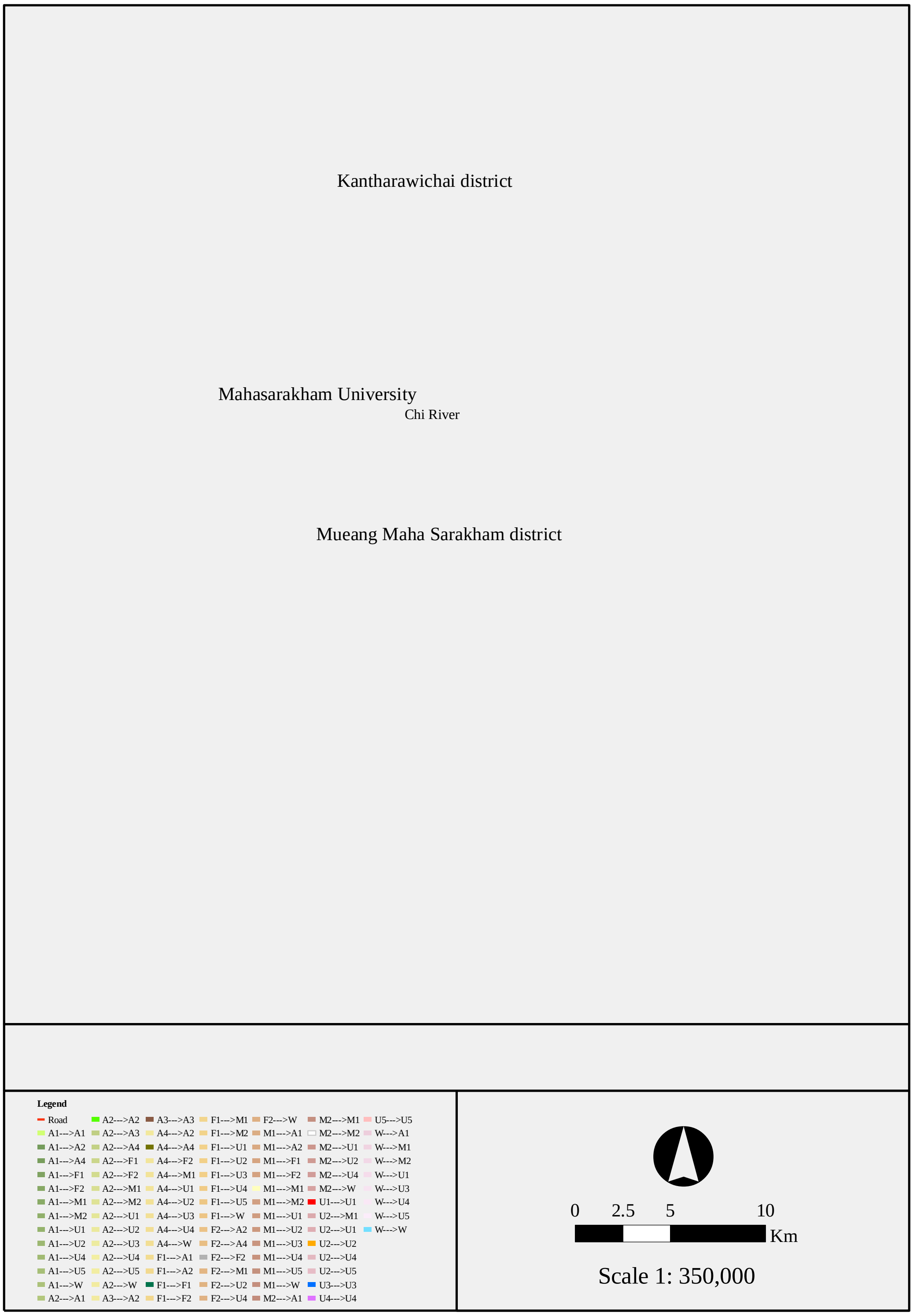


Figure 4.7 Distribution of LULC change pattern between 2001 and 2011.

Table 4.2 LULC change between 2001 and 2006.

(Unit: sq.km)

LULC 2001	LULC 2006														
	U1	**U2**	**U3**	**U4**	**U5**	**A1**	**A2**	**A3**	**A4**	**F1**	**F2**	**M1**	**M2**	**W**	**Total**
Commercial (U1)	1.56	-	-	-	-	-	-	-	-	-	-	-	-	-	**1.56**
City and village (U2)	0.37	41.49	-	0.10	-	-	-	-	-	-	-	0.03	0.03	-	**42.02**
Institution (U3)	-	-	10.11	-	-	-	-	-	-	-	-	-	-	-	**10.11**
Dormitory (U4)	-	-	-	0.09	-	-	-	-	-	-	-	-	-	-	**0.09**
Real estate (U5)	-	-	-	-	0.12	-	-	-	-	-	-	-	-	-	**0.12**
Paddy field (A1)	0.23	0.49	-	0.43	-	701.41	0.48	-	-	0.01	0.05	0.98	0.23	0.42	**704.74**
Field crop (A2)	0.02	0.09	-	0.10	0.08	0.11	79.30	-	0.02	0.10	0.40	0.13	-	0.03	**80.36**
Perennial tree (A3)	-	-	-	-	-	-	0.05	0.52	-	-	-	-	-	-	**0.57**
Orchard (A4)	-	0.09	0.01	-	-	-	0.06	-	7.74	-	-	0.01	-	0.01	**7.92**
Secondary forest (F1)	0.03	0.15	0.30	0.05	0.03	0.92	0.87	-	-	60.53	-	0.50	0.01	0.02	**63.39**
Eucalyptus (F2)	-	-	-	0.00	-	-	0.58	-	-	-	11.65	0.01	-	-	**12.24**
Development land (M1)	0.14	0.40	0.19	0.02	0.13	0.17	0.07	-	-	0.02	-	10.50	0.43	0.02	**12.09**
Marsh land (M2)	-	0.13	-	0.01	-	0.35	-	-	-	-	-	0.53	2.33	0.11	**3.45**
Water (W)	0.01	-	0.02	0.00	-	0.29	-	-	-	-	-	0.00	0.02	38.14	**38.50**
Total	**2.36**	**42.84**	**10.62**	**0.80**	**0.36**	**703.24**	**81.41**	**0.52**	**7.76**	**60.66**	**12.09**	**12.69**	**3.06**	**38.76**	**977.16**
Area of change (sq.km)	**0.80**	**0.81**	**0.51**	**0.71**	**0.24**	**-1.50**	**1.04**	**-0.05**	**-0.16**	**-2.73**	**-0.15**	**0.60**	**-0.38**	**0.26**	
Area per annum (sq.km)	**0.16**	**0.16**	**0.10**	**0.14**	**0.05**	**-0.30**	**0.21**	**-0.01**	**-0.03**	**-0.55**	**-0.03**	**0.12**	**-0.08**	**0.05**	

Table 4.3 LULC change between 2006 and 2011.

(Unit: sq.km)

LULC 2006	LUCL 2011														
	U1	U2	U3	U4	U5	A1	A2	A3	A4	F1	F2	M1	M2	W	Total
Commercial (U1)	2.36	-	-	-	-	-	-	-	-	-	-	-	-	-	**2.36**
City and village (U2)	0.38	42.35	-	0.09	0.01	-	-	-	-	-	-	-	-	-	**42.84**
Institution (U3)	-	-	10.62	-	-	-	-	-	-	-	-	-	-	-	**10.62**
Dormitory (U4)	-	-	-	0.80	-	-	-	-	-	-	-	-	-	-	**0.80**
Real estate (U5)	-	-	-	-	0.36	-	-	-	-	-	-	-	-	-	**0.36**
Paddy field (A1)	0.30	2.33	-	0.39	0.35	694.74	0.59	-	0.03	0.14	0.86	1.99	1.20	0.32	**703.24**
Field crop (A2)	-	0.67	0.02	0.08	-	1.31	75.31	0.05	0.22	0.33	2.73	0.43	0.17	0.09	**81.41**
Perennial tree (A3)	-	-	-	-	-	-	-	0.52	-	-	-	-	-	-	**0.52**
Orchard (A4)	0.00	0.43	-	0.01	-	-	0.31	-	6.93	-	0.01	0.07	-	0.00	**7.76**
Secondary forest (F1)	0.01	0.50	0.15	0.12	0.01	2.72	2.02	-	-	54.38	0.06	0.54	0.08	0.08	**60.66**
Eucalyptus (F2)	-	0.02	-	0.02	-	-	1.30	-	0.01	-	10.64	0.08	-	0.00	**12.09**
Development land (M1)	0.29	0.92	0.08	0.38	0.42	0.64	0.16	-	-	0.04	0.04	8.85	0.83	0.05	**12.69**
Marsh land (M2)	0.05	0.11	0.03	-	-	0.08	-	-	-	-	-	0.22	2.58	-	**3.06**
Water (W)	0.00	-	0.04	0.02	0.00	0.42	-	-	-	-	-	0.20	-	38.07	**38.76**
Total	**3.38**	**47.34**	**10.94**	**1.92**	**1.16**	**699.91**	**79.69**	**0.57**	**7.18**	**54.90**	**14.33**	**12.38**	**4.86**	**38.61**	**977.16**
Area of change (sq.km)	**1.03**	**4.50**	**0.32**	**1.11**	**0.80**	**-3.33**	**-1.71**	**0.05**	**-0.58**	**-5.76**	**2.24**	**-0.31**	**1.80**	**-0.15**	
Area per annum (sq.km)	**0.21**	**0.90**	**0.06**	**0.22**	**0.16**	**-0.67**	**-0.34**	**0.01**	**-0.12**	**-1.15**	**0.45**	**-0.06**	**0.36**	**-0.03**	

Table 4.4 LULC change between 2001 and 2011.

(Unit: sq.km)

LULC 2001	LULC 2011														
	U1	**U2**	**U3**	**U4**	**U5**	**A1**	**A2**	**A3**	**A4**	**F1**	**F2**	**M1**	**M2**	**W**	**Total**
Commercial (U1)	1.56	-	-	-	-	-	-	-	-	-	-	-	-	-	**1.56**
City and village (U2)	0.72	41.06	-	0.20	0.00	-	-	-	-	-	-	0.05	-	-	**42.02**
Institution (U3)	-	-	10.11	-	-	-	-	-	-	-	-	-	-	-	**10.11**
Dormitory (U4)	-	-	-	0.09	-	-	-	-	-	-	-	-	-	-	**0.09**
Real estate (U5)	-	-	-	-	0.12	-	-	-	-	-	-	-	-	-	**0.12**
Paddy field (A1)	0.58	2.89	-	1.12	0.44	693.71	0.82	-	0.03	0.04	0.92	2.25	1.23	0.72	**704.74**
Field crop (A2)	0.02	0.75	0.02	0.16	0.08	1.22	73.87	0.05	0.24	0.23	3.02	0.41	0.17	0.11	**80.36**
Perennial tree (A3)	-	-	-	-	-	-	0.05	0.52	-	-	-	-	-	-	**0.57**
Orchard (A4)	0.00	0.53	0.02	0.01	-	-	0.37	-	6.91	-	0.01	0.07	-	0.01	**7.92**
Secondary forest (F1)	0.03	0.66	0.50	0.22	0.04	3.72	2.59	-	-	54.57	0.06	0.79	0.09	0.11	**63.39**
Eucalyptus (F2)	-	0.02	-	0.03	-	-	1.76	-	0.01	-	10.28	0.13	-	0.00	**12.24**
Development land (M1)	0.38	1.21	0.24	0.05	0.48	0.53	0.23	-	-	0.05	0.04	8.07	0.76	0.05	**12.09**
Marsh land (M2)	0.07	0.21	-	0.01	-	0.05	-	-	-	-	-	0.45	2.59	0.07	**3.45**
Water (W)	0.01	-	0.06	0.02	0.00	0.68	-	-	-	-	-	0.17	0.02	37.53	**38.50**
Total	**3.38**	**47.34**	**10.94**	**1.92**	**1.16**	**699.91**	**79.69**	**0.57**	**7.18**	**54.90**	**14.33**	**12.38**	**4.86**	**38.61**	**977.16**
Area of change (sq.km)	**1.82**	**5.32**	**0.83**	**1.82**	**1.04**	**-4.83**	**-0.67**	**-0.01**	**-0.74**	**-8.50**	**2.09**	**0.30**	**1.41**	**0.11**	
Area per annum (sq.km)	**0.18**	**0.53**	**0.08**	**0.18**	**0.10**	**-0.48**	**-0.07**	**-0.00**	**-0.07**	**-0.85**	**0.21**	**0.03**	**0.14**	**0.01**	

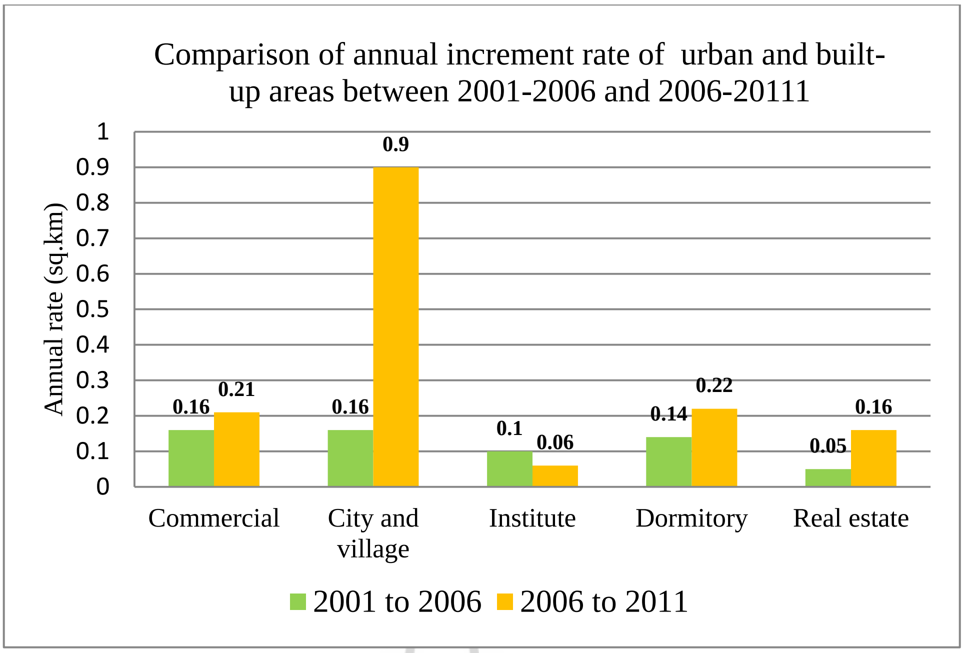


Figure 4.8 Comparison of annual increment rate of urban and built-up area between 2001-2006 and 2006-2011.

4.1.3 Accuracy assessment for LULC 2011

In this study, 862 randomly stratified sampling points based on the multinomial distribution theory with desired level of confident 85% and a precision of 5% were used for accuracy assessment (See detail in Appendix B). The overall accuracy was 98.03% and the Kappa coefficient of agreement was 95.85%. According to Landis and Koch (1977) Kappa coefficient of agreement value more than 80% represents strong agreement or accuracy between the classification map and the ground reference information. Details of accuracy assessment including producer's accuracy and user's accuracy were summarized in Table 4.5.

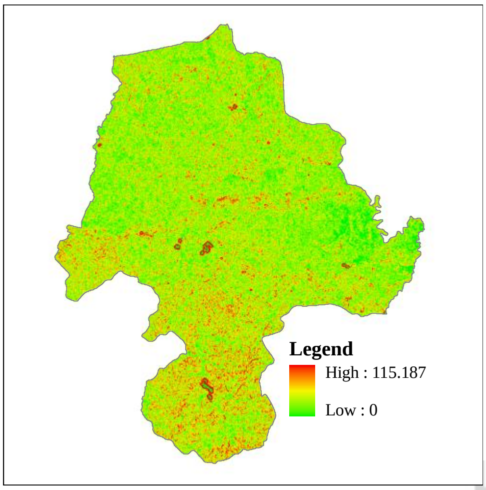
As shown in Table 4.5, the value of producer's accuracy was varied between 50% and 100%. Herewith, the highest accurate LULC types for visual interpretation were city and village (U2), institution (U3), dormitory (U4), perennial tree, (A3), secondary forest (F1), and water body (W) while the lowest accurate LULC type for visual interpretation were real estate (U5), and marsh land (M2). Meanwhile user's accuracy ranged between 81.82 and 100.00%. The highest accurate LULC types for user's reliability were commercial (U1), institution (U3), dormitory (U4), real estate (U5), perennial tree (A3), orchard (A4), and marsh land (M2) while the lowest LULC type for user's reliability was development land (M1).

4.2 Driving force for urban growth

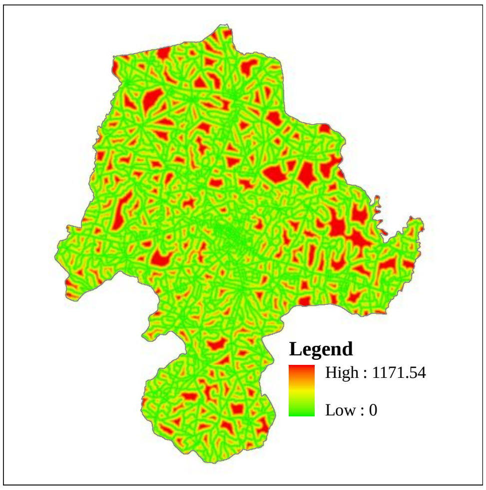
Based on selected driving force for urban growth as independent variables including slope, road network, per capita income, land value, population density, household density, existing comprehensive city plan, existing urban area, and new MSU campus, were linearly regressed with existing urban pattern (urban and non-urban areas) in 2001, 2006, and 2011 as dependent variable using spatial simple linear regression and multiple linear regression. Distribution of the independent variables and dependent variable in 2001, 2006, and 2011 were presented in Figures 4.9 to 4.11 and Figure 4.12, respectively. While an original values of independent variables in 2001, 2006, and 2011, which were normalized into standard score (0-1) for spatial multiple linear regression, were summarized as shown in Tables 4.6 to 4.8, respectively. Results of spatial simple and multiple linear regression analysis were separately described in the following sections.

Table 4.5 Accuracy assessment of LULC in 2011.

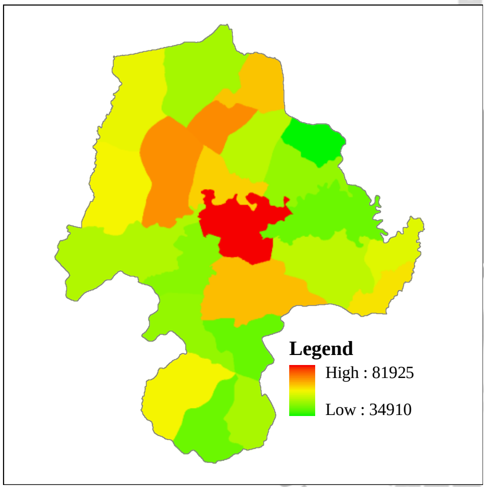
LULC in 2011	Ground truth data														
	U1	**U2**	**U3**	**U4**	**U5**	**A1**	**A2**	**A3**	**A4**	**F1**	**F2**	**M1**	**M2**	**W**	**Total**	**UA (%)**
Commercial (U1)	3														**3**	**100.00**
City and village (U2)	1	38			1	1			1						**42**	**90.48**
Institution (U3)			10												**10**	**100.00**
Dormitory (U4)				2											**2**	**100.00**
Real estate (U5)					1										**1**	**100.00**
Paddy field (A1)						613	1					1	2		**617**	**99.35**
Field crop (A2)							68		1		1				**70**	**97.14**
Perennial tree (A3)								1							**1**	**100.00**
Orchard (A4)									6						**6**	**100.00**
Secondary forest (F1)							1		1	45	1				**48**	**93.75**
Eucalyptus (F2)							1				12				**13**	**92.31**
Development land (M1)						1						9	1		**11**	**81.82**
Marsh land (M2)													4		**4**	**100.00**
Water (W)													1	33	**34**	**97.06**
Total	**4**	**38**	**10**	**2**	**2**	**615**	**71**	**1**	**9**	**45**	**14**	**10**	**8**	**33**	**862**	
PA (%)	**75.00**	**100.00**	**100.00**	**100.00**	**50.00**	**99.67**	**95.77**	**100.00**	**66.67**	**100.00**	**85.71**	**90.00**	**50.00**	**100.00**		
Overall accuracy (%)	**= 98.03**															
Kappa coefficient (%)	**= 95.85**															



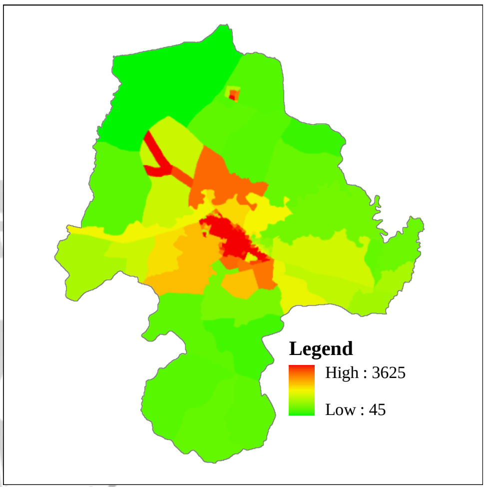
(a) Slope



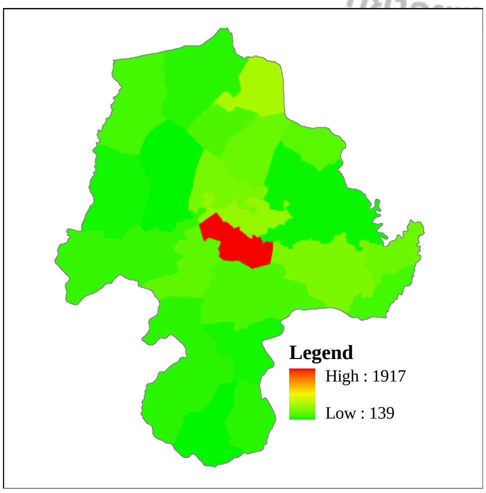
(b) Road network



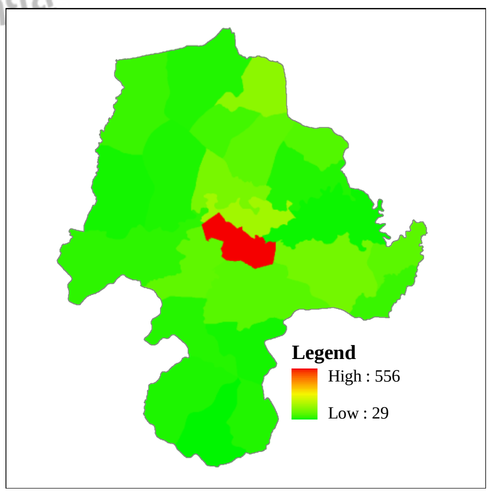
(c) Per capita income



(d) Land value



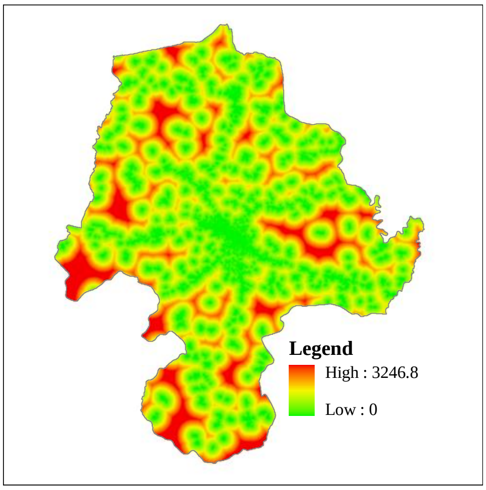
(e) Population density



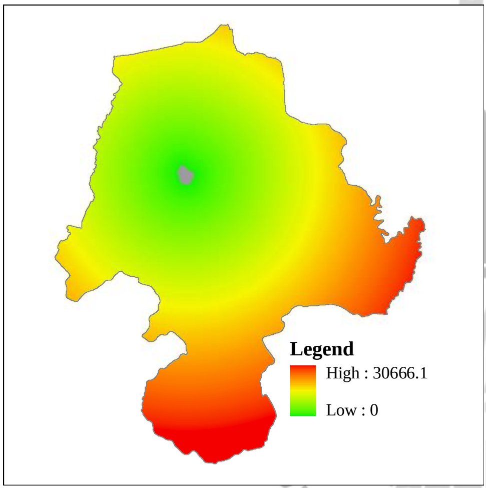
(f) Household density

Figure 4.9 Driving force for urban growth in 2001.

(g) Existing comprehensive city plan

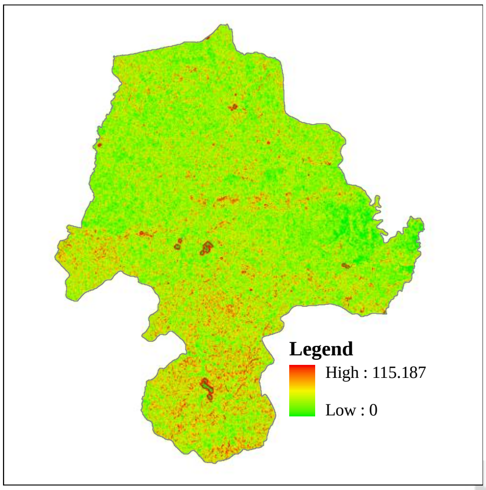


(h) Existing urban area

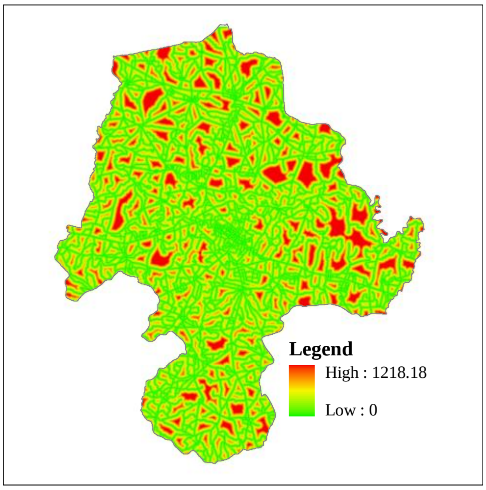


(i) New MSU campus

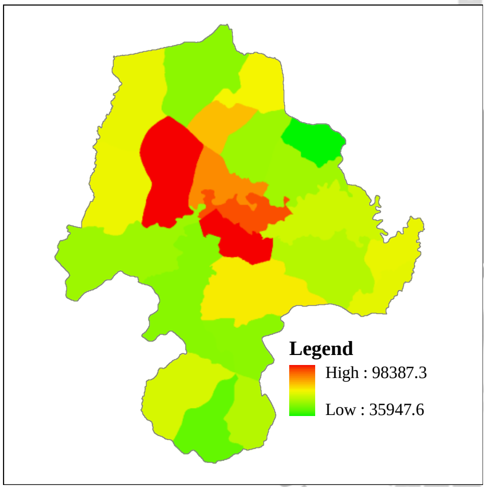
Figure 4.9 (Continued).



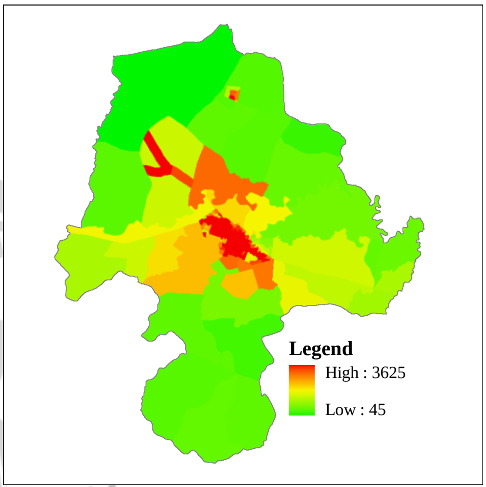
(a) Slope



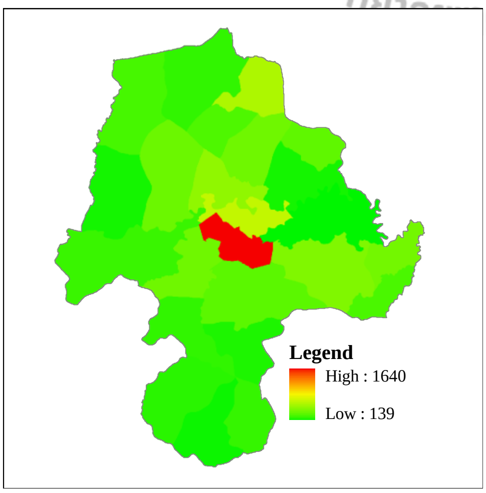
(b) Road network



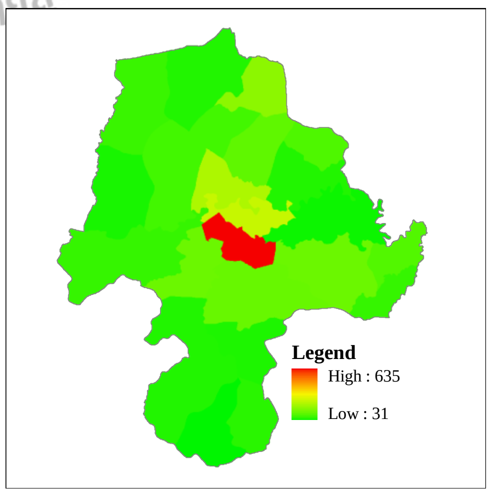
(c) Per capita income



(d) Land value



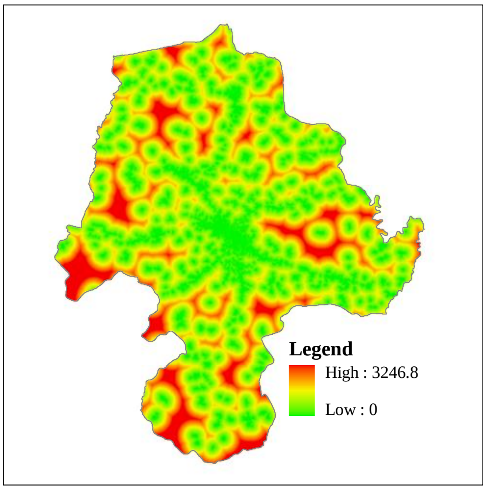
(e) Population density



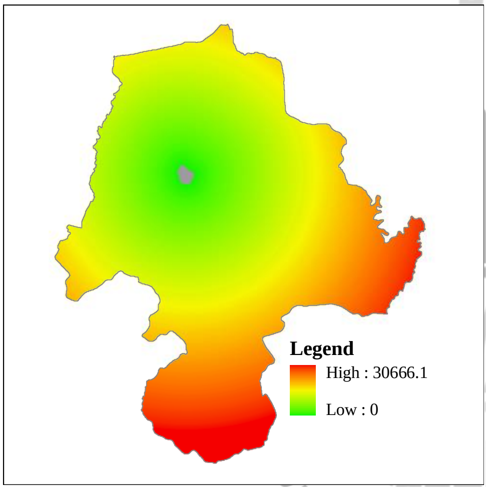
(f) Household density

Figure 4.10 Driving force for urban growth in 2006.

(g) Existing comprehensive city plan

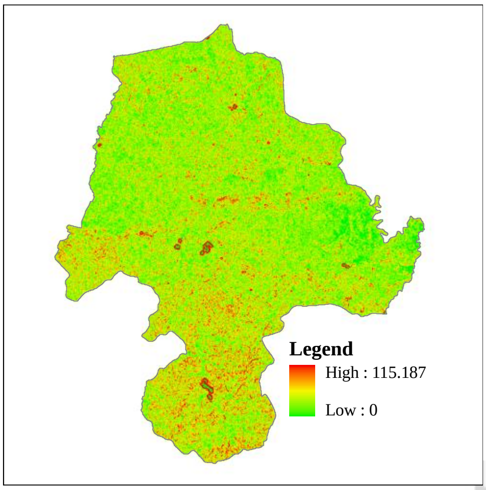


(h) Existing urban area

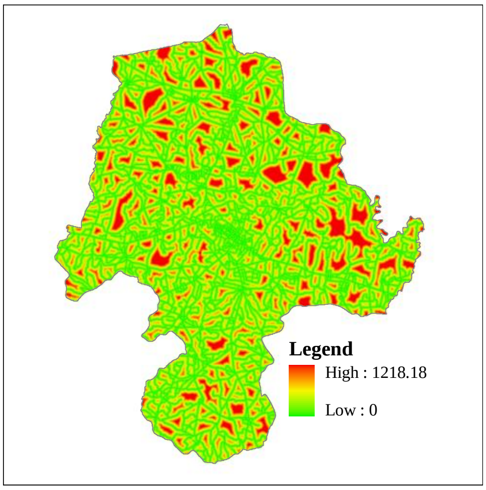


(i) New MSU campus

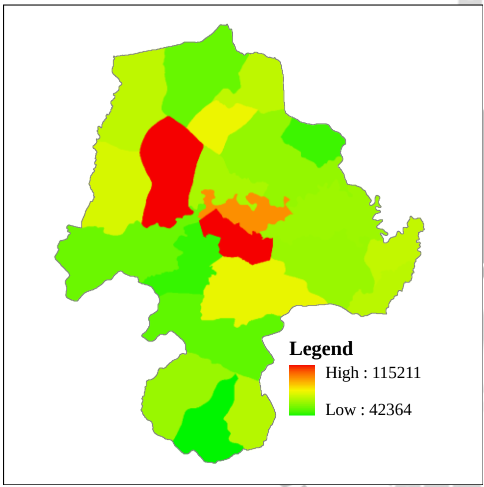
Figure 4.10 (Continued).



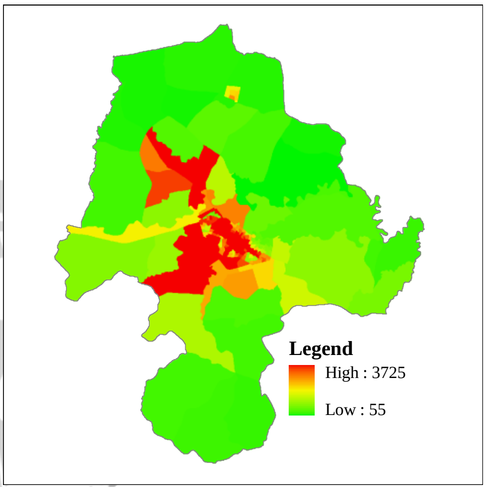
(a) Slope



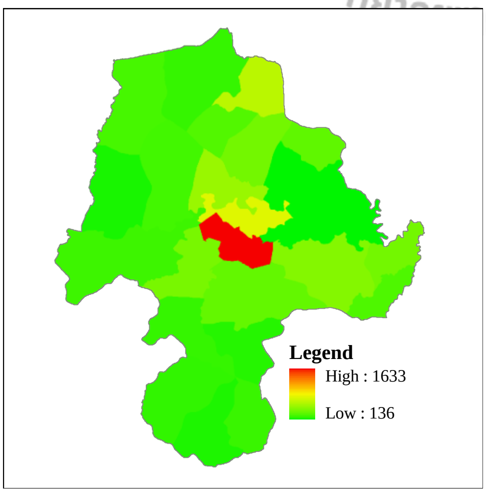
(b) Road network



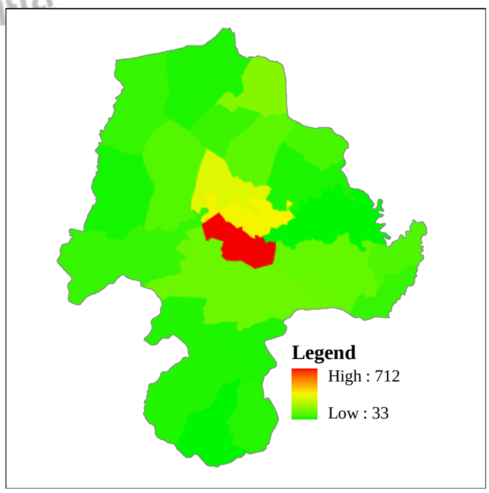
(c) Per capita income



(d) Land value

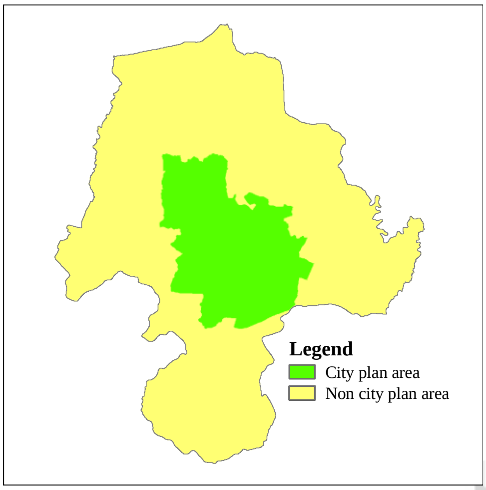


(e) Population density

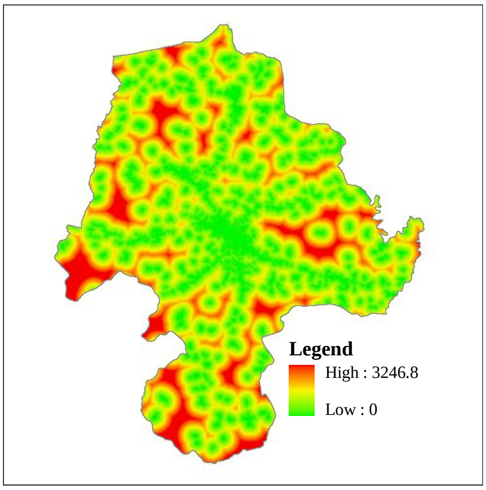


(f) Household density

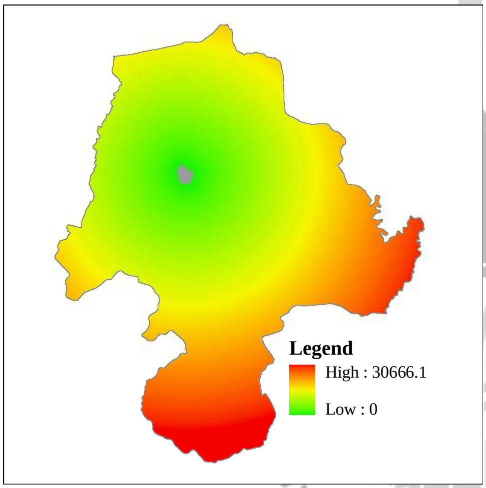
Figure 4.11 Driving force for urban growth in 2011.



(g) Existing comprehensive city plan

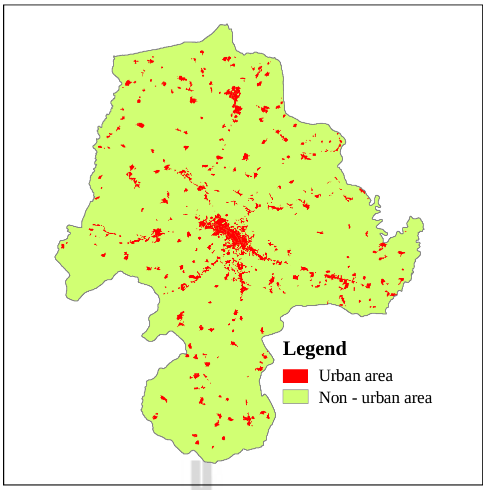


(h) Existing urban area

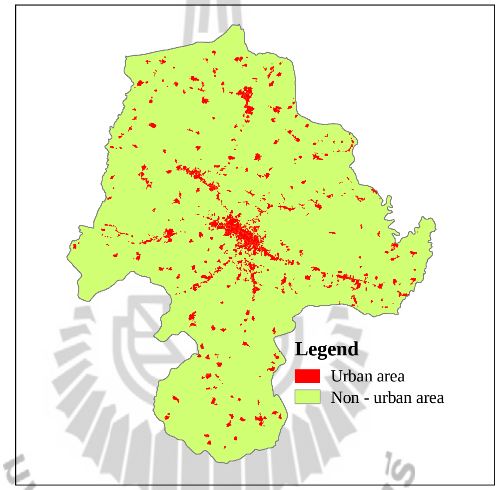


(i) New MSU campus

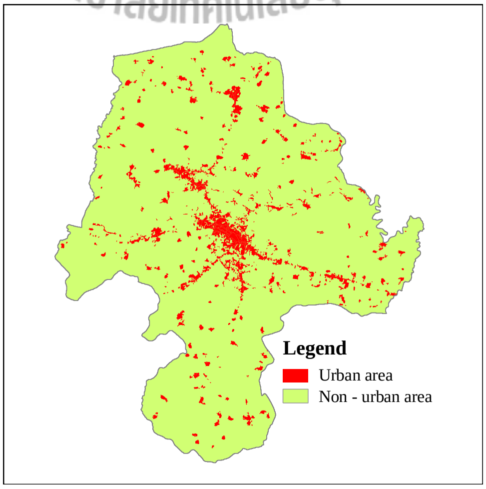
Figure 4.11 (Continued).



(a) Existing urban pattern (urban and non-urban areas) in 2001



(b) Existing urban pattern (urban and non-urban areas) in 2006



(c) Existing urban pattern (urban and non-urban areas) in 2011

Figure 4.12 Existing urban pattern in 2001, 2006, and 2011.

Table 4.6 Original value of independent variables as driving force for urban pattern in 2001.

Independent Variable	Data type	Original value	
		Minimum	**Maximum**
Slope (%)	Continuous	0	115.19
Road network (meter)	Continuous	0	1,171.54
Per capita income (baht)	Zonation by sub-district	34,910	81,925
Land value (baht per sq. m)	Land value zonation	45.50	3,625
Population density (persons)	Zonation by sub-district	139	1,917
Household density (household)	Zonation by sub-district	29	556
Existing comprehensive city plan	Binary	1	2
Existing urban area (meter)	Continuous	0	3,246.8
New MSU campus (meter)	Continuous	0	30,666.1

Table 4.7 Original value of independent variables as driving force on urban pattern in 2006.

Independent Variable	Data type	Original value	
		Minimum	**Maximum**
Slope (%)	Continuous	0	115.19
Road network (meter)	Continuous	0	1,218.18
Per capita income (baht)	Zonation by sub-district	35,947	983,871
Land value (baht per sq. m)	Land value zonation	45.50	3,625
Population density (persons)	Zonation by sub-district	139	1,640
Household density (household)	Zonation by sub-district	31	635
Existing comprehensive city plan	Binary	1	2
Existing urban area (meter)	Continuous	0	3,246.8
New MSU campus (meter)	Continuous	0	30,666.1

Table 4.8 Original value of independent variables as driving force on urban pattern in 2011.

Independent Variable	Data type	Original value	
		Minimum	**Maximum**
Slope (%)	Continuous	0	115.19
Road network (meter)	Continuous	0	1,218.18
Per capita income (baht)	Zonation by sub-district	42,364	115,211
Land value (baht per sq. m)	Land value zonation	55.75	3,725
Population density (persons)	Zonation by sub-district	136	1,633
Household density (household)	Zonation by sub-district	33	712
Existing comprehensive city plan	Binary	1	2
Existing urban area (meter)	Continuous	0	3,246.8
New MSU campus (meter)	Continuous	0	30,666.1

4.2.1 Spatial simple linear regression analysis

The result of spatial simple linear regression analysis based on driving forces factors and urban pattern (urban and non-urban areas) in 2001, 2006, and 2011 were summarized as equation forms in Tables 4.9 to 4.11. Details of spatial simple linear regression analysis were also presented in Appendix C.

Refer to Tables 4.9-4.11, it was found that all driving forces included slope, road network, per capita income, land value, population density, household density, existing comprehensive city plan, existing urban area, and new MSU campus, were positively relate to urban pattern (urban and non-urban areas). The highest significant driving factor on urban pattern in 2001, 2006, and 2011 based on correlation coefficient (R) and coefficient of determination (R^2) was per capita income, which were 95.04% and 90.33% in 2001, respectively. While the lowest significant driving factor on urban pattern in 2001, 2006 and 2011 was existing comprehensive city plan, which were 6.63% and 0.44% in 2006, respectively. In addition, top three dominant driving forces on urban pattern between 2001, 2006, and 2011 were (1) per capita income, (2) new MSU campus, and (3) existing urban area.

Discussion

As results, it was revealed that the ranking of driving force on urban pattern in 2001 and 2006 was identity. However, the ranking of driving force on urban pattern in 2011 was slightly different from year 2001 and 2006. Based on the correlation coefficient (R) and coefficient of determination (R^2) values, per capita income, new MSU campus, or existing urban area can be applied to explain the spatial linear relationship with urban pattern more than 50%. In opposite, slope, road network, land value, population density, household density, or the existing comprehensive city plan can be used to explain the spatial linear relationship with urban pattern less than 50%. In addition, the best predictor of spatial linear regression for urban pattern was per capita income while the worst predictor of spatial linear regression for urban pattern was the existing comprehensive city plan. These results imply that economy and existing land use pattern factors play an important role on urban growth pattern in the study area.

Table 4.9 Summary of spatial simple linear regression model for driving force on urban pattern in 2001.

Driving Force	Model	Correlation coefficient (R) (%)	Coefficient of determination (R^2) (%)	Rank
Slope	Y = 0.631110 + 0.245289X	57.8553	33.47	5
Road network	Y = 0.579977 + 0.004091X	63.5994	40.45	4
Per capita income	Y = 0.062237 + 0.000038X	95.0438	90.33	1
Land value	Y = 0.637210 + 0.004306X	55.6682	30.99	6
Population density	Y = 0.733423 + 0.002039X	46.4090	21.54	7
Household density	Y = 0.803732 + 0.005962X	38.3178	14.68	8
Existing comprehensive city plan	Y = 0.957150 + 0.604711X	6.7805	0.46	9
Existing urban area	Y = 0.491516 + 0.001458X	71.0105	50.42	3
New MSU campus	Y = 0.335539 + 0.000096X	79.9574	63.93	2

Table 4.10 Summary of spatial simple linear regression model for driving force on urban pattern in 2006.

Driving Force	Model	Correlation coefficient (R) (%)	Coefficient of determination (R^2) (%)	Rank
Slope	Y = 0.630116 + 0.244873X	57.8069	33.42	5
Road network	Y = 0.578751 + 0.004082X	63.6433	40.50	4
Per capita income	Y = 0.091046 + 0.000032X	93.3633	87.17	1
Land value	Y = 0.636209 + 0.001071X	55.5011	30.80	6
Population density	Y = 0.667919 + 0.002617X	52.6983	27.77	7
Household density	Y = 0.800628 + 0.005199X	38.4451	14.78	8
Existing comprehensive city plan	Y = 0.955759 + 0.590991X	6.6324	0.44	9
Existing urban area	Y = 0.495327 + 0.001454X	70.7204	50.01	3
New MSU campus	Y = 0.333734 + 0.000096X	80.0576	64.09	2

Table 4.11 Summary of spatial simple linear regression model for driving force on urban pattern in 2011.

Driving Force	Model	Correlation coefficient (R) (%)	Coefficient of determination (R^2) (%)	Rank
Slope	Y = 0.627465 + 0.243928X	57.7102	33.30	5
Road network	Y = 0.574539 + 0.004085X	63.8289	40.74	4
Per capita income	Y = 0.108346 + 0.000030X	92.0348	84.70	1
Land value	Y = 0.726149 + 0.002101X	46.4119	21.54	7
Population density	Y = 0.669741 + 0.002570X	51.8894	26.93	6
Household density	Y = 0.805869 + 0.004408X	36.9721	13.67	8
Existing comprehensive city plan	Y = 0.858090 + 0.984085X	30.3998	9.24	9
Existing urban area	Y = 0.504916 + 0.001458X	69.9755	48.97	3
New MSU campus	Y = 0.329943 + 0.000096X	80.2147	64.34	2

4.2.2 Spatial multiple linear regression analysis

In practice, the driving forces as independent variables were here systematically combined by its ranking from the simple linear regression analysis to identify an optimum spatial multiple linear regression analysis. Tables 4.12 to 4.14 were reported the change of the correlation coefficient (R) and coefficient of determination (R^2) from each combination in spatial multiple linear regression analysis about driving force on urban pattern in 2001, 2006, and 2011, respectively. Meanwhile Figures 4.13 to 4.15 were displayed the change of the coefficient of determination (R^2) under spatial multiple linear regression analysis for year 2001, 2006, and 2011, respectively.

Results of the optimum spatial multiple linear regression analysis based on identified driving force and urban pattern in 2001, 2006 and 2011 were summarized as multiple linear regression equation form (intercept and coefficients) as shown in Table 4.15. Details of multiple linear regression analysis with the predicted and regression residual images were presented in Appendix D.

Discussion

As results, it was found that five independent variables including (1) per capita income, (2) new MSU campus, (3) existing urban area, (4) road network, and (5) slope was applied in the optimum spatial multiple linear regression for explanation about driving force on urban pattern in 2001 and 2006. While, six independent variables including (1) per capita income, (2) new MSU campus, (3) existing urban area, (4) road network, (5) slope, and (6) population density was applied in the optimum spatial multiple linear regression for explanation about driving force on urban pattern in 2011. These results revealed that the common driving forces as predictors of spatial multiple linear regression for urban pattern included (1) per capita income, (2) new MSU campus, (3) existing urban area, (4) road network, and (5) slope. These findings from spatial multiple linear regression also implies that major clusters of urban growth driving force in the study area are: (1) economic factor (per capita income), and (2) existing land use pattern (existing urban area and new MSU campus).

Table 4.12 Change of correlation coefficient and coefficient of determination from multiple linear regression analysis for urban pattern in 2001.

Independent variable	Ranking	Combination	R (%)	R^2 (%)
Per capita income	1			
New MSU campus	2	1&2	89.2148	79.5928
Existing urban area	3	1&2&3	91.3986	83.5370
Road network	4	1&2&3&4	92.1413	84.9001
Slope	5	1&2&3&4&5	92.4831	85.5312
Land value *	6	1&2&3&4&5&6	92.4847	85.5343
Population density *	7	1&2&3&4&5&6&7	93.6340	87.6733
Household density *	8	1&2&3&4&5&6&7&8	93.7817	87.9501
Existing comprehensive city plan *	9	1&2&3&4&5&6&7&8&9	93.8497	88.0777

* These factors are excluded from the optimum spatial multiple linear regression.

Table 4.13 Change of correlation coefficient and coefficient of determination from multiple linear regression analysis for urban pattern in 2006.

Independent variable	Ranking	Combination	R (%)	R^2 (%)
Per capita income	1			
New MSU campus	2	1&2	90.1300	81.2342
Existing urban area	3	1&2&3	91.9325	84.5159
Road network	4	1&2&3&4	92.5272	85.6127
Slope	5	1&2&3&4&5	92.8710	86.2502
Land value *	6	1&2&3&4&5&6	92.8784	86.2640
Population density *	7	1&2&3&4&5&6&7	93.6819	87.7630
Household density *	8	1&2&3&4&5&6&7&8	93.6998	87.7966
Existing comprehensive city plan *	9	1&2&3&4&5&6&7&8&9	94.1123	88.5713

* These factors are excluded from the optimum spatial multiple linear regression.

Table 4.14 Change of correlation coefficient and coefficient of determination from multiple linear regression analysis for urban pattern in 2011.

Independent variable	Ranking	Combination	R(%)	R^2 (%)
Per capita income	1			
New MSU campus	2	1&2	94.9003	90.0607
Existing urban area	3	1&2&3	95.6513	91.4917
Road network	4	1&2&3&4	95.8536	91.8792
Slope	5	1&2&3&4&5	95.9216	92.0096
Population density	6	1&2&3&4&5&6	96.8392	93.7784
Land value *	7	1&2&3&4&5&6&7	96.8447	93.7890
Household density *	8	1&2&3&4&5&6&7&8	97.2251	94.5273
Existing comprehensive city plan *	9	1&2&3&4&5&6&7&8&9	97.2455	94.5668

* These factors are excluded from the optimum spatial multiple linear regression.

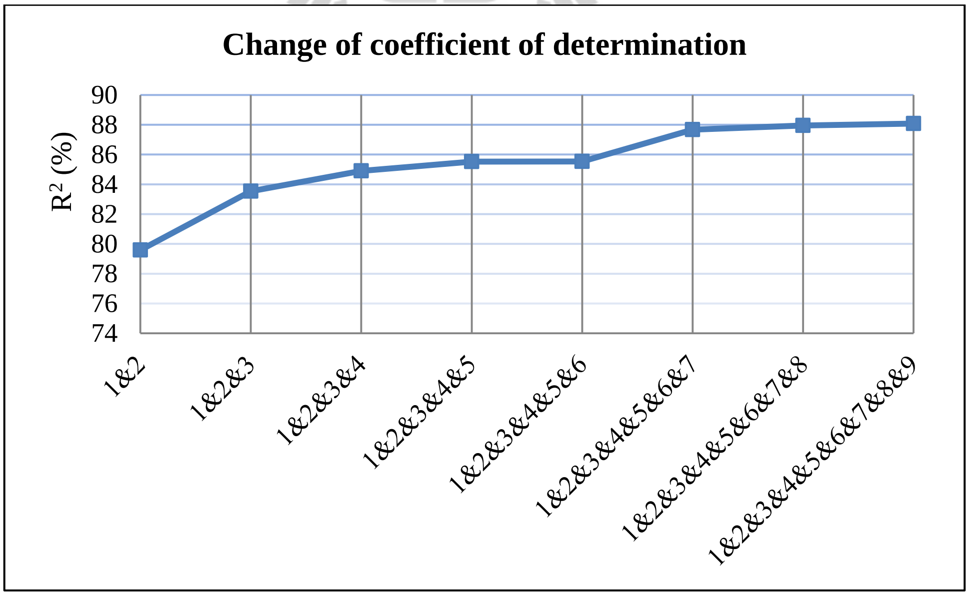


Figure 4.13 Change of the coefficient of determination for an optimum multiple linear regression identification about driving force on urban pattern in 2001.

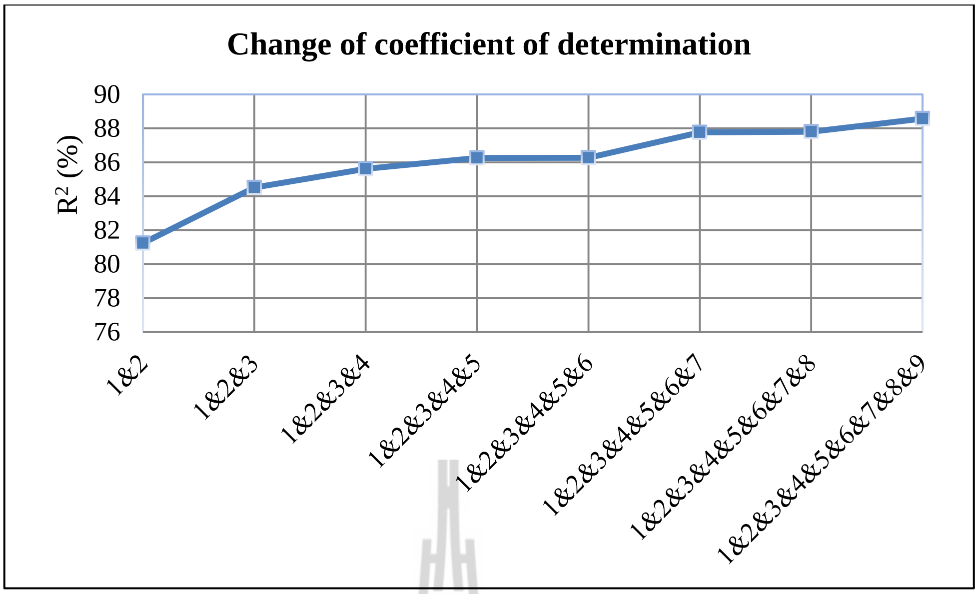


Figure 4.14 Change of the coefficient of determination for an optimum multiple linear regression identification about driving force on urban pattern in 2006.

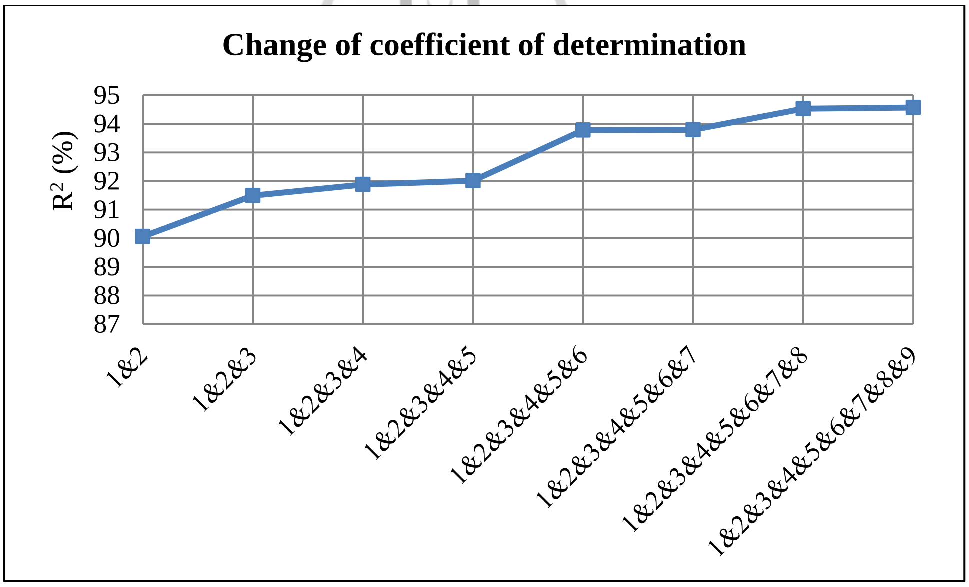


Figure 4.15 Change of the coefficient of determination for an optimum multiple linear regression identification about driving force on urban pattern in 2011.

Table 4.15 Summary of spatial multiple linear regression model for urban pattern prediction.

Driving force	**Regression coefficients**		
	Urban pattern in 2001	Urban pattern in 2006	Urban pattern in 2011
Intercept	0.122636	0.114545	0.036709
Per capita income	1.846407	1.792075	3.092953
New MSU campus	1.454314	1.529551	0.789725
Existing urban area	1.331710	1.242943	0.604527
Road network	1.136072	1.023389	0.474570
Slope	4.702027	4.709027	1.685796
Population density	n. a.	n. a.	-1.687732
Correlation coefficient (%)	**92.4831**	**92.8710**	**96.8392**
Coefficient of determination (%)	**85.5312**	**86.2502**	**93.7784**

Furthermore, the top three dominant driving forces based on its coefficient value from the multiple linear regression equation (Table 4.15), which influence urban pattern, were (1) per capita income, (2) population density, and (3) slope. These factors were further used in Land Change Modeler for LULC prediction in 2011.

4.3 LULC prediction

Two LULC prediction models, CA-Markov and Land Change Modeler were here applied to predict the LULC in 2011 and then compared their results with the interpreted LULC in 2011. After that, an optimum model was selected to predict LULC in 2016 and 2021 based on overall accuracy and kappa coefficient of agreement.

4.3.1 LULC in 2011 prediction using CA-Markov

In practice, LULC in 2001 and 2006 that were selected for predictive LULC in 2011 by Markov chain model were employed to generate a transition probability matrix and a transition area matrix as shown in Table 4.16 and Table 4.17, respectively. Such transition probability matrix was then used to predict LULC in 2011 with Cellular automata model. The predicted LULC in 2011 was shown in Figure 4.16 while area and percentage of predictive LULC 2011 was presented in Table 4.18.

4.3.2 LULC in 2011 prediction using Land Change Modeler

In practice, LULC in 2001 and 2006 were also used for predictive LULC in 2011 by Land Change Modeler. Herein Change analysis module, Transition potential module and Change prediction module were operated for LULC prediction. The predicted LULC in 2011 using Land Change Modeler was shown in Figure 4.17 while area and percentage of predictive LULC 2011 was presented in Table 4.19.

Table 4.16 Transition probability matrix of land use and land cover change between 2001 and 2006.

LULC 2001	LULC 2006													
	U1	**U2**	**U3**	**U4**	**U5**	**A1**	**A2**	**A3**	**A4**	**F1**	**F2**	**M1**	**M2**	**W**
Commercial (U1)	1	0	0	0	0	0	0	0	0	0	0	0	0	0
City and village (U2)	0.0088	0.9873	0	0.0025	0	0	0	0	0	0	0	0.0007	0.0007	0
Institution (U3)	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Dormitory (U4)	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Real estate (U5)	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Paddy field (A1)	0.0003	0.0007	0	0.0006	0	0.9953	0.0007	0	0	0	0.0001	0.0014	0.0003	0.0006
Field crop (A2)	0.0002	0.0012	0	0.0012	0.001	0.0013	0.9868	0	0.0003	0.0012	0.0049	0.0016	0	0.0004
Perennial tree (A3)	0	0	0	0	0	0	0.0925	0.9075	0	0	0	0	0	0
Orchard (A4)	0	0.0117	0.0011	0	0	0	0.0076	0	0.9773	0	0	0.0008	0	0.0015
Secondary forest (F1)	0.0004	0.0023	0.0047	0.0007	0.0004	0.0144	0.0137	0	0	0.9548	0	0.008	0.0002	0.0004
Eucalyptus (F2)	0	0	0	0.0004	0	0	0.0473	0	0	0	0.9518	0.0006	0	0
Development land (M1)	0.0116	0.0327	0.0155	0.0014	0.0111	0.0141	0.0057	0	0	0.0019	0	0.8689	0.0357	0.0014
Marsh land (M2)	0	0.0376	0	0.0016	0	0.1008	0	0	0	0	0	0.1525	0.677	0.0305
Water (W)	0.0003	0	0.0005	0.0001	0	0.0076	0	0	0	0	0	0.0001	0.0005	0.9908

Table 4.17 Transition area matrix of land use and land cover change between 2006 and 2011.

(Unit: sq.km)

LULC 2006	**LULC 20011**														
	U1	**U2**	**U3**	**U4**	**U5**	**A1**	**A2**	**A3**	**A4**	**F1**	**F2**	**M1**	**M2**	**W**	**Total**
Commercial (U1)	2.36	-	-	-	-	-	-	-	-	-	-	-	-	-	**2.36**
City and village (U2)	0.38	42.29	-	0.11	-	-	-	-	-	-	-	0.03	0.03	-	**42.84**
Institution (U3)	-	-	10.62	-	-	-	-	-	-	-	-	-	-	-	**10.62**
Dormitory (U4)	-	-	-	0.80	-	-	-	-	-	-	-	-	-	-	**0.80**
Real estate (U5)	-	-	-	-	0.36	-	-	-	-	-	-	-	-	-	**0.36**
Paddy field (A1)	0.23	0.49	-	0.43	-	699.91	0.48	-	-	0.01	0.05	0.98	0.23	0.42	**703.24**
Field crop (A2)	0.02	0.10	-	0.10	0.08	0.11	80.33	-	0.02	0.10	0.40	0.13	-	0.03	**81.40**
Perennial tree (A3)	-	-	-	-	-	-	0.05	0.47	-	-	-	-	-	-	**0.52**
Orchard (A4)	-	0.09	0.01	-	-	-	0.06	-	7.58	-	-	0.01	-	0.01	**7.76**
Secondary forest (F1)	0.03	0.14	0.28	0.04	0.03	0.88	0.83	-	-	57.92	-	0.48	0.01	0.02	**60.66**
Eucalyptus (F2)	-	-	-	0.00	-	-	0.57	-	-	-	11.51	0.01	-	-	**12.09**
Development land (M1)	0.15	0.41	0.20	0.02	0.14	0.18	0.07	-	-	0.02	-	11.02	0.45	0.02	**12.69**
Marsh land (M2)	-	0.12	-	0.00	-	0.31	-	-	-	-	-	0.47	2.07	0.09	**3.06**
Water (W)	0.01	-	0.02	0.00	-	0.30	-	-	-	-	-	0.00	0.02	38.40	**38.76**
Total	**3.17**	**43.64**	**11.13**	**1.51**	**0.60**	**701.68**	**82.39**	**0.47**	**7.61**	**58.05**	**11.95**	**13.13**	**2.82**	**39.00**	**977.16**

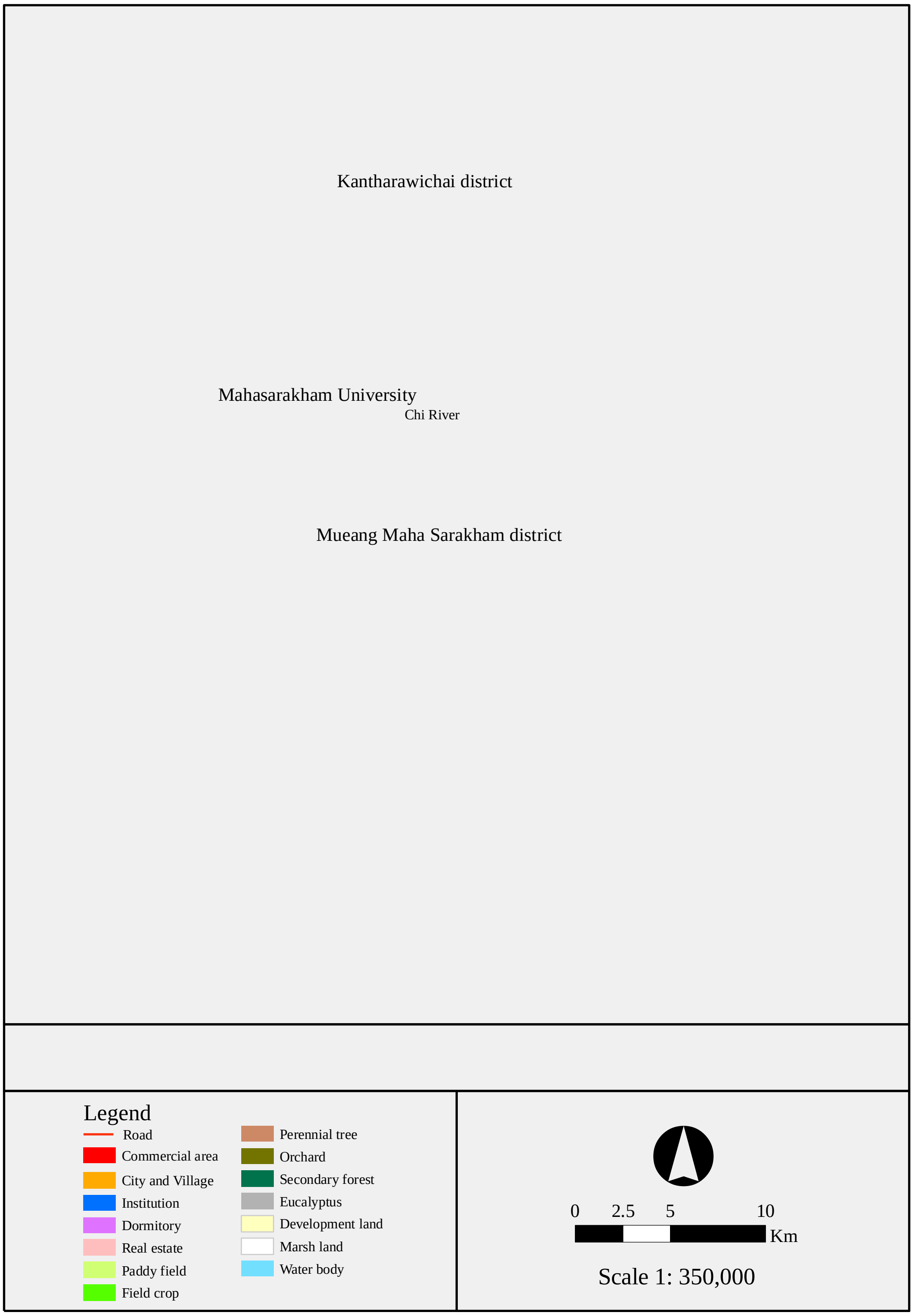


Figure 4.16 Predictive land use and land cover in 2011 using CA-Markov model.

Table 4.18 Area and percentage of predictive LULC in 2011 using CA-Markov model.

LULC Type	Area	
	sq.km	**%**
Commercial	2.48	0.25
City and village	43.34	4.43
Institution	10.91	1.12
Dormitory	0.80	0.08
Real estate	0.38	0.04
Paddy field	704.27	72.07
Field crop	82.38	8.43
Perennial tree	0.48	0.05
Orchard	7.63	0.78
Secondary forest	58.65	6.00
Eucalyptus	11.94	1.22
Development land	12.29	1.26
Marsh land	2.81	0.29
Water body	38.80	3.97
Total	**977.16**	**100.00**

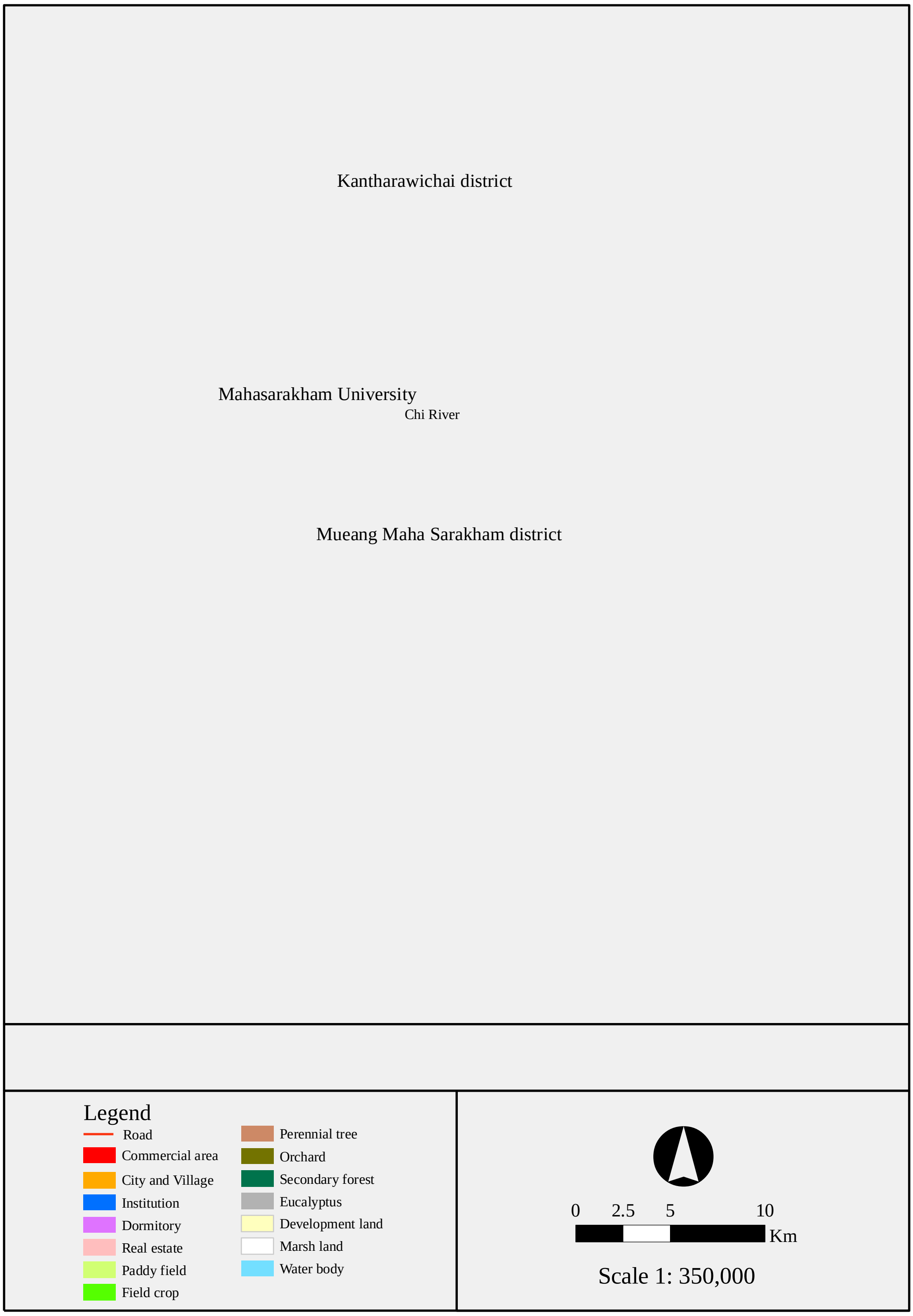


Figure 4.17 Predictive land use and land cover in 2011 using Land Change Modeler.

Table 4.19 Area and percentage of predictive LULC in 2011 using Land Change Modeler.

LULC type	Area	
	Sq.km	%
Commercial	3.10	0.32
City and village	44.16	4.52
Institution	11.13	1.14
Dormitory	1.46	0.15
Real estate	0.60	0.06
Paddy field	701.69	71.81
Field crop	82.40	8.43
Perennial tree	0.47	0.05
Orchard	7.61	0.78
Secondary forest	58.04	5.94
Eucalyptus	11.97	1.23
Development land	12.71	1.30
Marsh land	2.79	0.29
Water body	39.01	3.99
Total	977.16	100.00

4.3.3 Optimum LULC prediction model

An optimum LULC prediction model between CA-Markov and Land Change modeler for LULC in 2016 and 2021 prediction was here justified based on overall accuracy and kappa coefficient based on an interpreted LULC in 2011.

It was found that overall accuracy and Kappa coefficient for predictive LULC in 2011 using CA-Markov model was 96.84 and 93.27%, respectively (Table 4.20). While, overall accuracy and Kappa coefficient for predictive LULC in 2011 using Land Change Modeler was 96.04 and 91.60%, respectively (Table 4.21). Therefore, CA-Markov model that provides higher overall accuracy and Kappa coefficient was here used for LULC prediction in 2016 and 2021. This finding is mostly relevant to the identified optimum predictive model for urban growth prediction by Ongsomwang and Suravisutra (2011).

Table 4.20 Accuracy assessment of predictive LULC using CA-Markov model.

Interpreted LULC 2011	Predicted LULC 2011 by CA-Markov model														
	U1	**U2**	**U3**	**U4**	**U5**	**A1**	**A2**	**A3**	**A4**	**F1**	**F2**	**M1**	**M2**	**W**	**Total**	UA (%)
Commercial (U1)	2.38	0.38	-	-	-	0.30	-	-	-	0.01	-	0.26	0.05	-	**3.38**	**70.34**
City and village (U2)	0.09	42.38	0.02	-	-	2.34	0.67	-	0.42	0.50	0.02	0.84	0.07	-	**47.34**	**89.52**
Institution (U3)	-	0.01	10.68	-	-	-	0.02	-	-	0.13	-	0.05	0.02	0.04	**10.94**	**97.60**
Dormitory (U4)	-	0.09	-	0.80	-	0.39	0.08	-	0.01	0.12	0.02	0.38	-	0.02	**1.92**	**41.99**
Real estate (U5)	-	0.02	0.02	-	0.36	0.35	-	-	-	0.01	-	0.39	-	-	**1.16**	**31.52**
Paddy field (A1)	-	0.01	-	-	-	694.91	1.31	-	-	2.55	-	0.63	0.06	0.43	**699.91**	**99.29**
Field crop (A2)	-	-	-	-	-	0.60	75.39	-	0.31	1.96	1.28	0.15	-	-	**79.69**	**94.60**
Perennial tree (A3)	-	-	-	-	-	-	0.09	0.48	-	-	-	-	-	-	**0.57**	**83.97**
Orchard (A4)	-	0.08	-	-	-	0.03	0.25	-	6.81	-	0.01	-	-	-	**7.18**	**94.89**
Secondary forest (F1)	-	-	0.05	-	-	0.91	1.03	-	-	52.66	-	0.26	-	-	**54.90**	**95.93**
Eucalyptus (F2)	-	-	-	-	-	0.86	2.85	-	0.01	0.06	10.52	0.04	-	-	**14.33**	**73.43**
Development land (M1)	0.02	0.28	0.11	-	0.02	2.00	0.43	-	0.07	0.53	0.08	8.42	0.22	0.20	**12.38**	**68.04**
Marsh land (M2)	-	0.09	0.03	-	-	1.26	0.17	-	-	0.05	-	0.82	2.40	0.04	**4.86**	**49.41**
Water (W)	-	-	-	-	-	0.32	0.09	-	-	0.08	-	0.05	-	38.07	**38.61**	**98.61**
Total	**2.48**	**43.34**	**10.91**	**0.80**	**0.38**	**704.27**	**82.38**	**0.48**	**7.63**	**58.65**	**11.94**	**12.29**	**2.81**	**38.80**	**977.16**	
PA (%)	**95.76**	**97.79**	**97.90**	**100.00**	**95.97**	**98.67**	**91.52**	**100.00**	**89.32**	**89.79**	**88.10**	**68.55**	**85.29**	**98.13**		
Overall accuracy (%)	**= 96.84**															
Kappa coefficient (%)	**= 93.27**															

Table 4.21 Accuracy assessment of predictive LULC using Land Change Modeler.

Interpreted LULC 2011	Predicted LULC 2011 by Land Change Modeler															
	U1	**U2**	**U3**	**U4**	**U5**	**A1**	**A2**	**A3**	**A4**	**F1**	**F2**	**M1**	**M2**	**W**	**Total**	**UA (%)**
Commercial (U1)	2.37	0.38	-	-	-	0.30	-	-	-	0.01	-	0.27	0.05	-	**3.38**	**70.15**
City and village (U2)	0.04	42.35	0.01	0.01	-	2.31	0.67	-	0.43	0.50	0.03	0.87	0.12	0.01	**47.34**	**89.46**
Institution (U3)	-	0.01	10.62	-	-	-	0.02	-	-	0.14	-	0.07	0.03	0.04	**10.94**	**97.10**
Dormitory (U4)	0.02	0.11	-	0.81	-	0.38	0.08	-	0.01	0.12	0.02	0.32	0.02	0.02	**1.92**	**42.27**
Real estate (U5)	0.01	0.02	-	-	0.36	0.34	-	-	-	0.01	-	0.39	0.02	-	**1.16**	**31.05**
Paddy field (A1)	0.22	0.49	0.01	0.41	-	691.60	1.78	-	-	2.68	0.08	1.53	0.28	0.83	**699.91**	**98.81**
Field crop (A2)	0.02	0.11	0.02	0.10	0.09	0.73	74.41	-	0.32	2.05	1.61	0.21	0.01	0.02	**79.69**	**93.37**
Perennial tree (A3)	-	-	-	-	-	-	0.09	0.47	-	-	-	-	-	-	**0.57**	**83.33**
Orchard (A4)	-	0.07	0.01	-	-	0.03	0.28	-	6.77	-	0.01	0.01	-	0.01	**7.18**	**94.27**
Secondary forest (F1)	0.02	0.14	0.28	0.04	0.03	0.95	1.12	-	-	51.76	-	0.53	0.01	0.02	**54.90**	**94.29**
Eucalyptus (F2)	-	0.01	0.01	0.01	0.01	0.86	3.19	-	-	0.06	10.14	0.04	-	-	**14.33**	**70.79**
Development land (M1)	0.35	0.34	0.16	0.07	0.11	2.11	0.50	-	0.07	0.55	0.08	7.33	0.49	0.22	**12.38**	**59.21**
Marsh land (M2)	0.03	0.13	0.01	0.01	0.01	1.48	0.17	-	-	0.08	-	1.10	1.75	0.09	**4.86**	**35.96**
Water (W)	0.01	-	0.02	0.01	-	0.61	0.09	-	-	0.07	-	0.05	0.02	37.73	**38.61**	**97.72**
Total	**3.10**	**44.16**	**11.13**	**1.46**	**0.60**	**701.69**	**82.40**	**0.47**	**7.61**	**58.04**	**11.97**	**12.71**	**2.79**	**39.01**	**977.16**	
PA (%)	**76.48**	**95.91**	**95.42**	**55.32**	**59.38**	**98.56**	**90.30**	**100.00**	**89.00**	**89.18**	**84.70**	**57.67**	**62.55**	**96.72**		
Overall accuracy (%)	**= 96.04**															
Kappa coefficient (%)	**= 91.60**															

4.3.4 LULC prediction

Predictive LULC in 2016 and 2021 were created using CA-Markov model and presented in Figure 4.18 and Figure 4.19. While area and percentage of predictive LULC types in 2016 and 2021 were reported in Table 4.22.

4.3.5 LULC change in the past and in the future

Refer to LULC assessment in 2001, 2006, and 2011 in the past (Table 4.1) and LULC prediction in 2016 and 2021 (Table 4.22), area of LULC and its change during 2001 to 2021 can be summarized as shown in Table 4.23. It was found that during 2001 to 2011 most of sub-classes of urban and built-up area had continuously increased except dormitory. In contrast, most of sub-classes of agricultural land had continuously decreased except field crop and sub-classes of forest land had continuously decreased in these periods. Meanwhile, for miscellaneous land marsh land had trended to decrease but development land had trended to increase in the future. At the same times, water body was unpredictable. Gains and losses of LULC's areas in 4 periods (2001-2006, 2006-2011, 2011-2016, and 2016-20121) were presented in Figure 4.20.

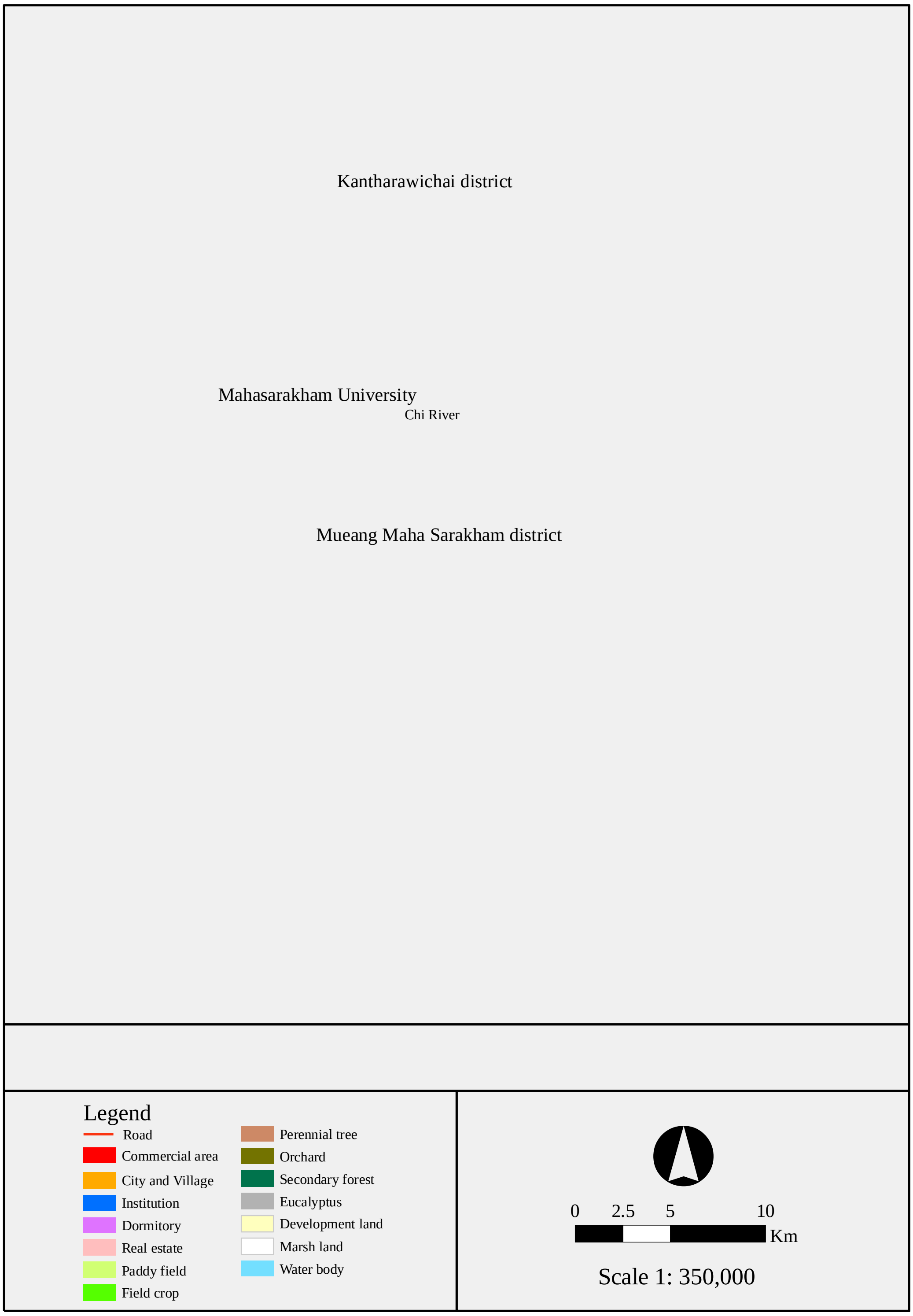


Figure 4.18 Distribution of predictive LULC pattern in 2016.

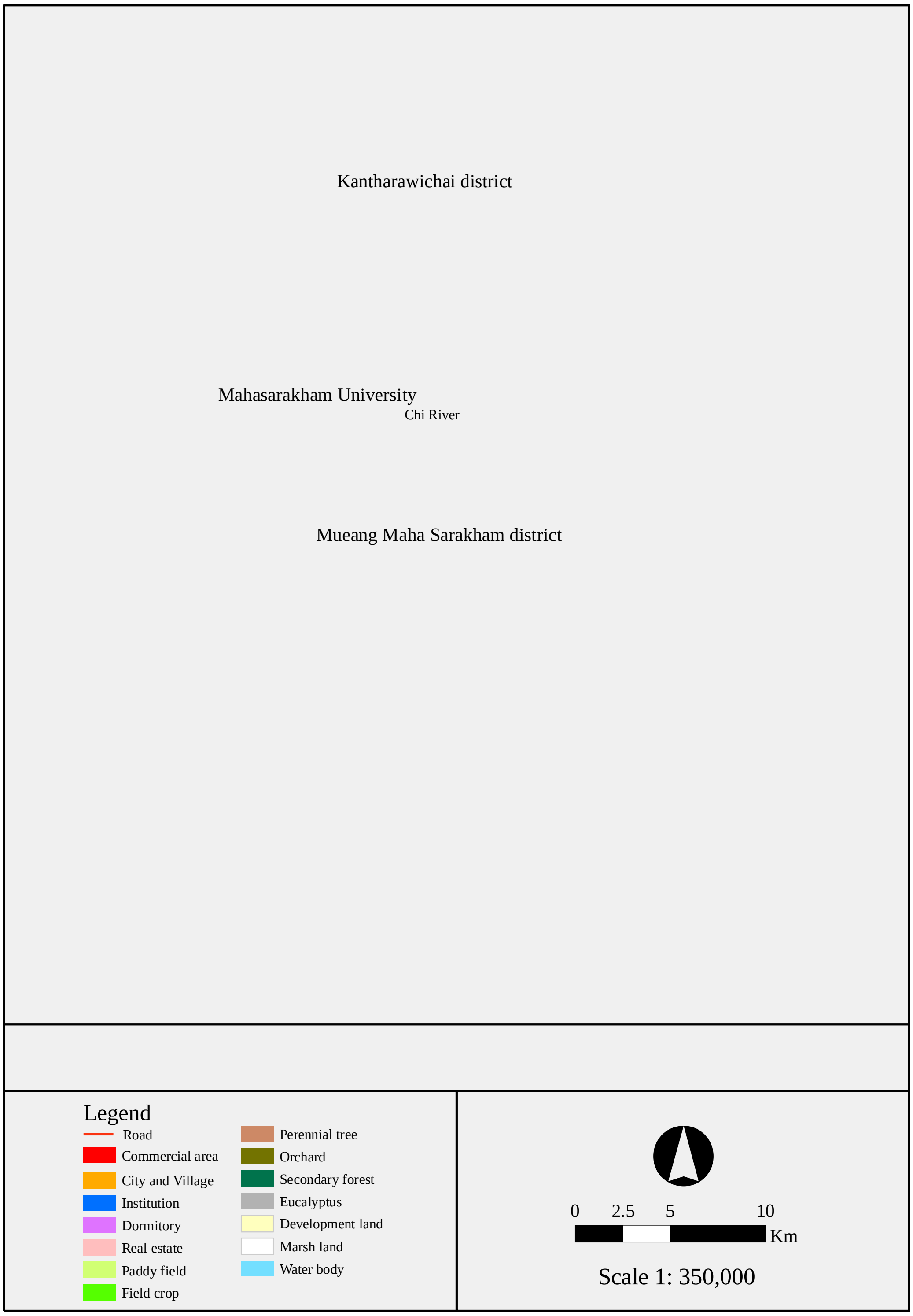


Figure 4.19 Distribution of predictive LULC pattern in 2021.

Table 4.22 Area and percentage of predictive LULC type in 2016 and 2021.

LULC type	2016		2021	
	Area (sq.km)	Percent (%)	Area (sq.km)	Percent (%)
Commercial	3.79	0.39	4.62	0.47
City and village	49.76	5.09	51.08	5.23
Institution	10.95	1.12	11.51	1.18
Dormitory	2.23	0.23	1.98	0.20
Real estate	1.59	0.16	1.63	0.17
Paddy field	702.20	71.86	700.48	71.68
Field crop	78.28	8.01	79.31	8.12
Perennial tree	0.57	0.06	0.56	0.06
Orchard	6.66	0.68	6.57	0.67
Secondary forest	50.46	5.16	48.53	4.97
Eucalyptus	16.48	1.69	15.89	1.63
Development land	10.54	1.08	11.74	1.20
Marsh land	5.10	0.52	4.68	0.48
Water body	38.55	3.94	38.58	3.95
Total	**977.16**	**100.00**	**977.16**	**100.00**

Table 4.23 Development of LULC area during 2001 to 2021.

(Unit: sq.km)

No	LULC	2001	2006	Change	2011	Change	2016	Change	2021	Change
1	Commercial	1.56	2.36	0.8	3.38	1.02	3.79	0.41	4.62	0.83
2	City and village	42.02	42.84	0.82	47.34	4.5	49.76	2.42	51.08	1.32
3	Institution	10.11	10.62	0.51	10.94	0.32	10.95	0.01	11.51	0.56
4	Dormitory	0.09	0.8	0.71	1.92	1.12	2.23	0.31	1.98	-0.25
5	Real estate	0.12	0.36	0.24	1.16	0.8	1.59	0.43	1.63	0.04
6	Paddy field	704.74	703.23	-1.51	699.9	-3.33	702.2	2.3	700.48	-1.72
7	Field crop	80.36	81.41	1.05	79.69	-1.72	78.28	-1.41	79.31	1.03
8	Perennial tree	0.57	0.52	-0.05	0.57	0.05	0.57	0	0.56	-0.01
9	Orchard	7.92	7.76	-0.16	7.18	-0.58	6.66	-0.52	6.57	-0.09
10	Secondary forest	63.39	60.66	-2.73	54.9	-5.76	50.46	-4.44	48.53	-1.93
11	Eucalyptus	12.24	12.09	-0.15	14.33	2.24	16.48	2.15	15.89	-0.59
12	Development land	12.09	12.69	0.6	12.38	-0.31	10.54	-1.84	11.74	1.2
13	Marsh land	3.45	3.06	-0.39	4.86	1.8	5.1	0.24	4.68	-0.42
14	Water body	38.5	38.76	0.26	38.61	-0.15	38.55	-0.06	38.58	0.03
Total		**977.16**	**977.16**	**0.00**	**977.16**	**0.00**	**977.16**	**0.00**	**977.16**	**0.00**

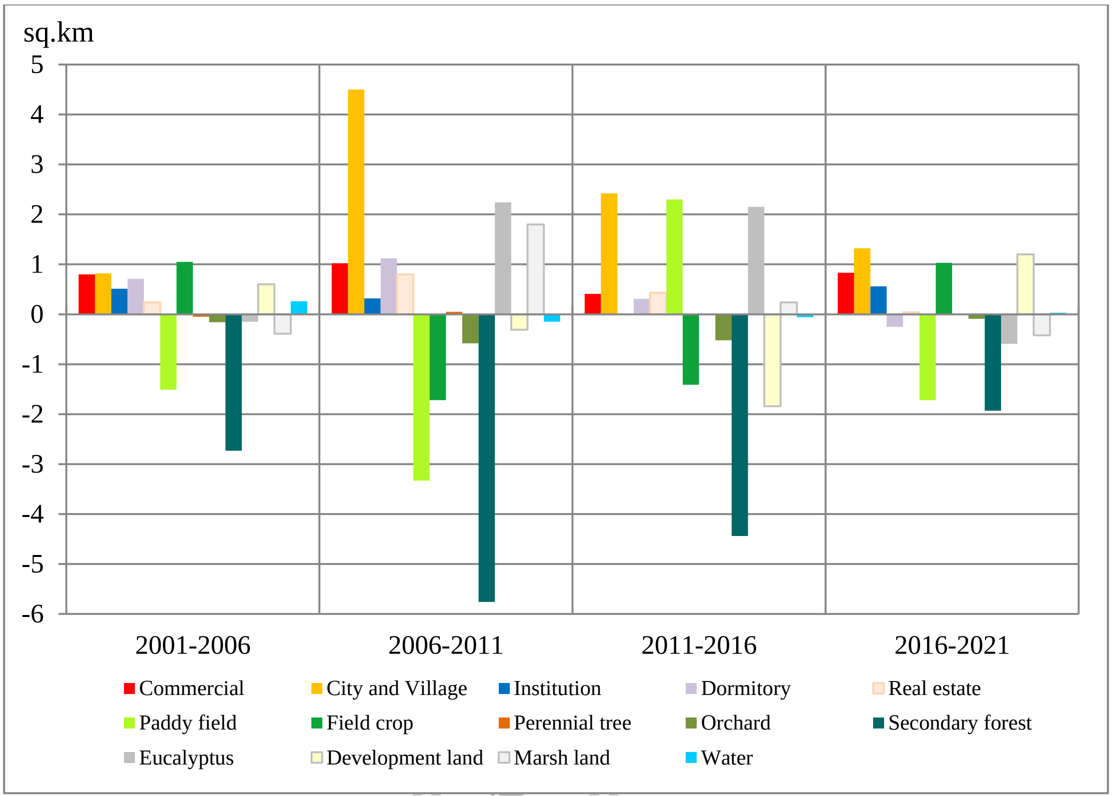


Figure 4.20 Change of LULC during 2001 to 2021 as gains and losses.

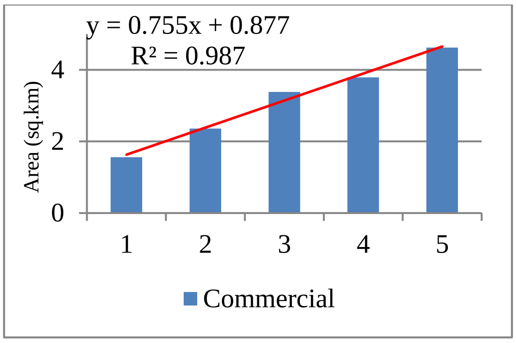
In addition, future trend of sub-classes of urban and built-up areas can be estimated using regression analysis by Trend Analysis of MS-Excel as summary in Table 4.24 and Figure 4.21. As results, it was found the best fit for commercial, city and village, institution and real estate areas were linear regression type while the best fit for dormitory was logarithmic regression type according coefficient of determination (R^2). The predictive area of sub-classes of urban and built-up areas in 2046 was reported in Table 4.25.

Table 4.24 Predicted model for sub-classes of the urban and built-up areas by Trend Analysis.

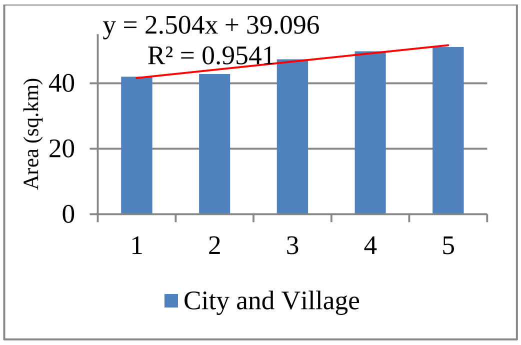
LULC type	**Model Type**	**Equation**	**R^2**
Commercial areas	Linear regression	Y = 0.755X + 0.877	98.70
City and village areas	Linear regression	Y = 2.504X + 39.096	95.41
Institution areas	Linear regression	Y = 0.313X + 9.887	93.19
Dormitory	Logarithm regression	Y = 1.3744ln(X) + 0.088	90.51
Real estate	Linear regression	Y = 0.425X - 0.303	92.60

Table 4.25 Predictive area of sub-classes of urban and built-up areas in 2046 by Trend Analysis.

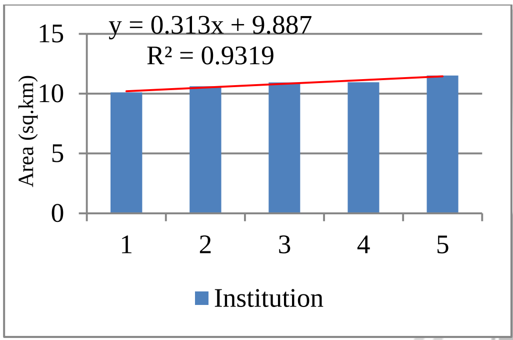
LULC Types	**Area in sq.km in Year**				
	2026	**2031**	**2036**	**2041**	**2046**
Commercial	5.41	6.16	6.92	7.67	8.43
City and village	54.12	56.62	59.13	61.63	64.14
Institution	11.77	12.08	12.39	12.70	13.02
Dormitory	2.55	2.76	2.95	3.11	3.25
Real estate	2.25	2.67	3.10	3.52	3.95



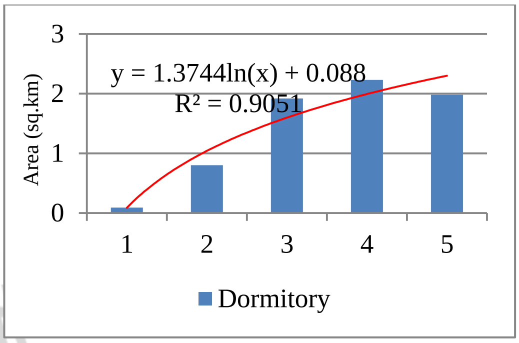
(a) Commercial



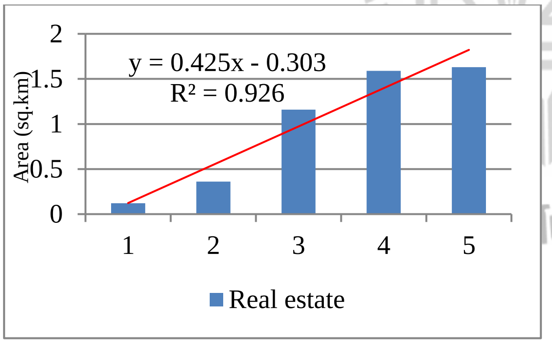
(b) City and village



(c) Institution



(d) Dormitory



(e) Real estate

Note for X-axis explanation:

1 is year in 2001;

2 is year in 2006;

3 is year in 2011;

4 is year in 2016;

5 is year in 2021.

Figure 4.21 Simple regression analysis of sub-classes of urban and built-up areas.

4.4 Urban growth characteristics

Based on interpreted and predicted LULC data, distribution of existing urban area in the past, present and future were extracted as shown in Table 4.26 and Figure 4.22. Major characteristic of urban growth in the study area were further investigated included:

(1) urban growth pattern,

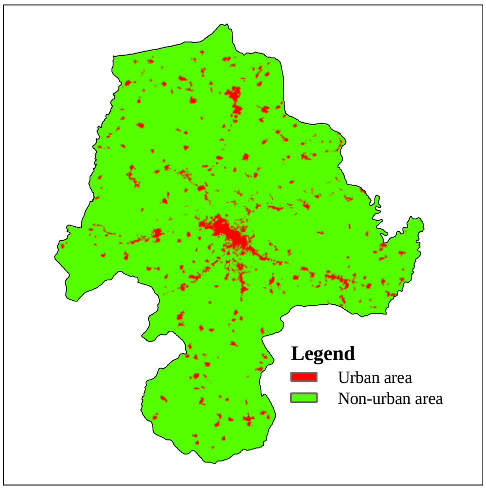
(2) annual Growth Rate (AGR),

(3) urban land percentage (PU), and

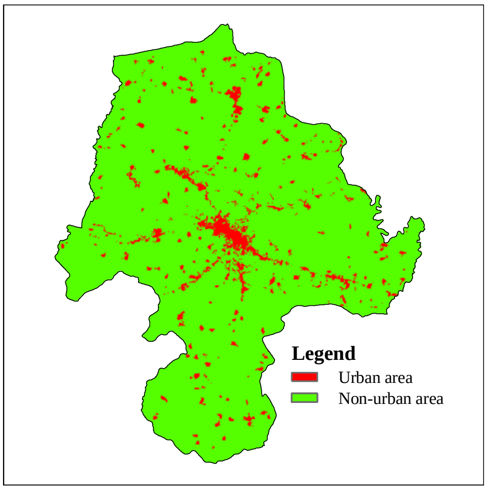
(4) urban land expansion index (SI).

Table 4.26 Area and percentage of urban areas in 2001 to 2021.

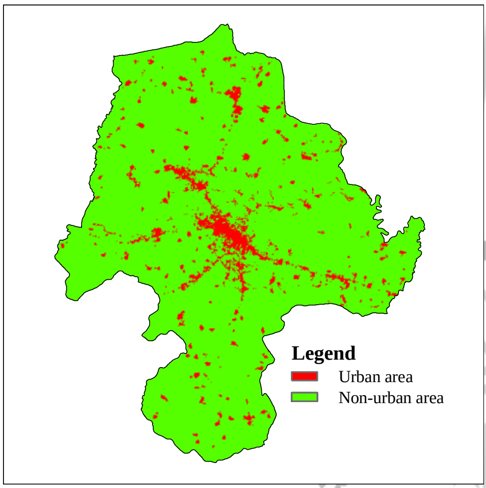
Year	Area (sq.km)	Percentage of study area (%)
Urban area in 2001	53.91	5.52
Urban area in 2006	56.98	5.83
Urban area in 2011	64.73	6.62
Urban area in 2016	68.32	6.99
Urban area in 2021	70.82	7.25



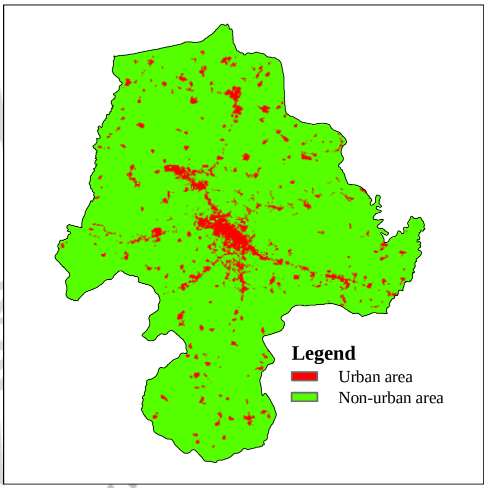
(a) Urban area in 2001



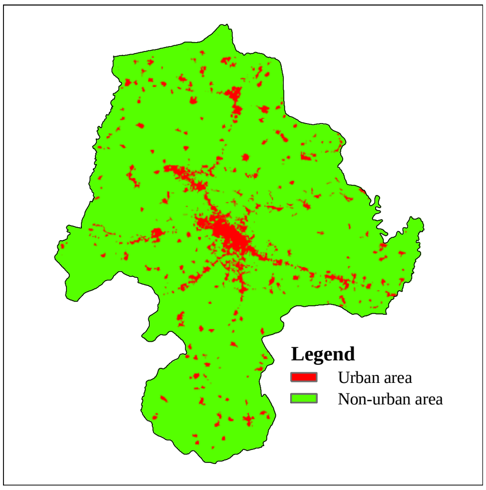
(b) Urban area in 2006



(c) Urban area in 2011



(d) Urban area in 2016



(e) Urban area in 2021

Figure 4.22 Distribution of the existing urban areas.

4.4.1 Urban growth pattern

Urban growth pattern occurred in the past, present, and future was here extracted using overlay analysis.

In the past time, it was found that urban growth pattern between 2001 and 2006 was linear strip development (Figure 4.23). Most of urban growth areas in this period were expanded along the main road through new campus of MSU at Kham Reang and Mueang Maha Sarakham Municipality. In contrast urban growth pattern between 2006 and 2011was changed to be a scattered development pattern. Most of urban growth areas were expanded from urban areas in 2006 (Figure 4.24).

In the future time, newly urban growth areas between 2011 and 2016 and between 2016 and 2021 were still scattered areas and some of them were developed to be newly emerging community areas (Figures 4.25 and 4.26).

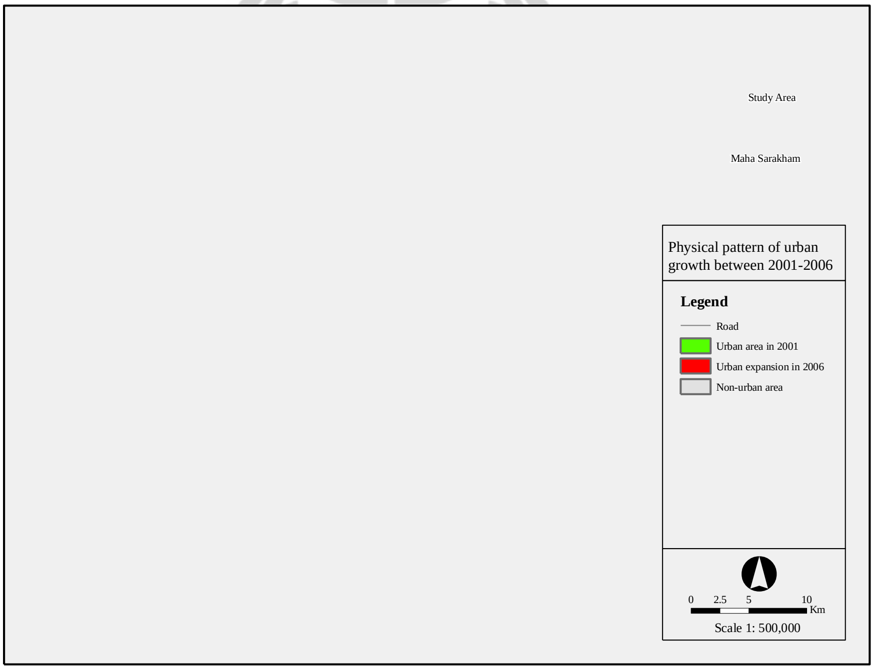


Figure 4.23 Physical pattern of urban growth between 2001 and 2006.

Figure 4.24 Physical pattern of urban growth between 2006 and 2011.

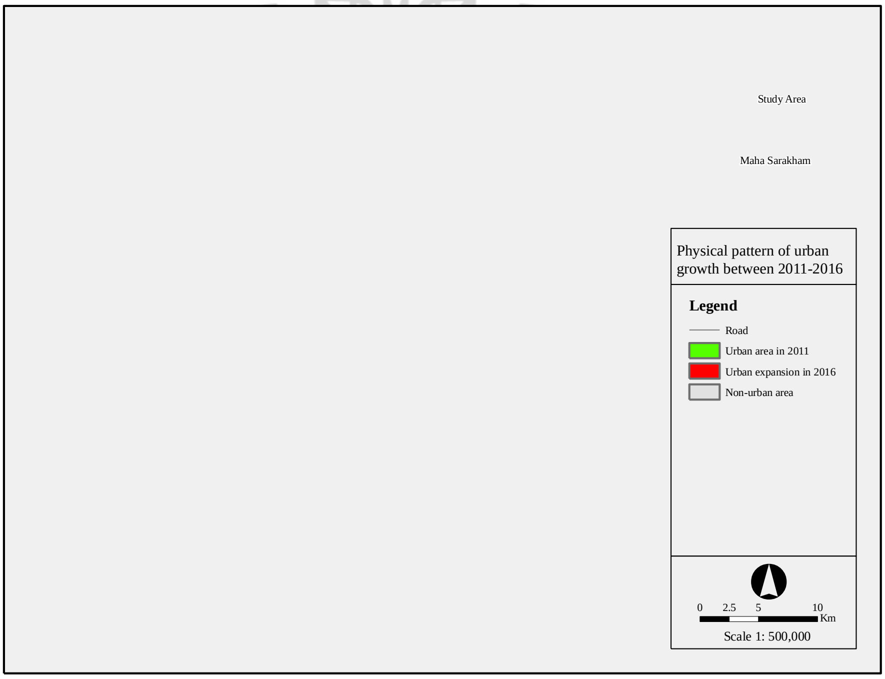


Figure 4.25 Physical pattern of urban growth between 2011 and 2016.

Figure 4.26 Physical pattern of urban growth between 2016 and 2021.

4.4.2 Annual growth rate (AGR)

Annual growth rate (AGR) by sub-district in the study area was here calculated to identify type of urban growth similar to Zhao-ling et al. (2007). Table 4.27 presented the statistics of the AGR for 24 sub-districts in four periods (2001-2006, 2006-2011, 2011-2016, and 2016-2021). In the meantime Figure 4.27 showed spatial AGR classification of each sub-district in each period as follows:

(1) AGR < 0.25% represents an area with slow expansion;

(2) 0.25% ≤ AGR < 0.5% represents an area with slow-speed expansion;

(3) 0.5% ≤ AGR < 0.75% represents an area with medium-speed expansion;

(4) 0.75% ≤ AGR < 1.0% represents an area with fair-speed expansion; and

(5) 1.0% ≤ AGR represents an area with high-speed expansion.

Table 4.27 Annual growth rate (AGR) in each sub-district in four periods.

Sub-district	Annual growth rate between (%)			
	2001-2006	**2006-2011**	**2011-2016**	**2016-2021**
Sri Suk	0.3655	0.0174	0.2291	0.0049
Na Si Nuan	0.0000	0.0298	0.0669	0.1573
Kok Pra	0.0000	0.0923	0.0497	0.1172
Kan Ta Rat	0.0000	0.0443	0.0298	0.0489
Kham Tao Pattana	0.0000	0.0757	0.0306	0.0366
Kham Reang	0.0036	0.3702	0.1690	-0.0523
Kud Sai Jor	0.0048	0.1837	0.0631	0.0801
Ma Kha	0.0070	0.0569	0.0043	0.0158
Kwao Yai	0.0074	0.0159	0.0281	0.0220
Tha Khon Yang	0.0075	0.7624	0.1939	-0.0249
Lat Pattana	0.0081	0.0416	0.0060	0.0326
Kerng	0.0083	0.6142	0.3739	0.1376
Tha Song Khon	0.0089	0.1320	0.0375	0.0319
Tha Tum	0.0110	0.0071	0.0063	0.0379
Kaeng Lerng Chan	0.0112	0.3783	0.0807	0.0414
Kwao	0.0134	0.1310	0.0255	0.0535
Waeng Nang	0.0201	0.2057	0.0347	0.0755
Huai Aeng	0.0316	0.0699	0.0000	0.0196
Nong No	0.0384	0.0171	0.0020	0.0181
Nong Pling	0.0586	0.0021	0.0027	0.0180
Kok Kor	0.1551	0.0127	0.0042	0.0208
Don Whan	0.2622	0.0066	0.0042	0.0348
Bua Khor	0.3022	0.0171	0.0024	0.0171
Ta Lad	0.3320	1.2568	0.5261	0.5253

(a) Annual growth rate (AGR) in 2001-2006

(b) Annual growth rate (AGR) in 2006-2011

(c) Annual growth rate (AGR) in 2011-2016

(d) Annual growth rate (AGR) in 2016-202.

Figure 4.27 Annual Growth Rate (AGR) in each sub-district in four periods.

Four sub-districts had AGR with slow speed expansion while 20 sub-districts had AGR with slow expansion between 2001 and 2006. In contrary, AGR between 2006 and 2011 included all 5 classes of urban expansion: 19 sub-districts with slow expansion, 2 sub-districts with slow-speed expansion, 1 sub-district with medium-speed expansion, 1 sub-district with fair-speed expansion and 1 sub-district with high-speed expansion. This period showed a dramatic expansion of the urban and built-up area in the study. In fact, area of urban and built-up area in 2006 was about 56.98 sq.km were increased into 64.74 sq.km in 2011. However, urban expansion in the future (2011-2016 and 2016–2021) showed only 1 sub-district with medium-speed expansion in both period, and 1 sub-district with slow-speed expansion between 2011 and 2016. The rate of the rest in both periods was slow expansion.

As results, it revealed that most of sub-districts during 2001 to 2021 had expanded at slow speed level which has AGR between 0.25 and 0.5%. However, many urban areas were dramatic expanded between 2006 and 2011.

4.4.3 Urban land percentage (PU)

Urban land percentage (PU), which represents the proportion of urban area to a total area, was firstly extracted using sub-district boundary and then reclassified into 5 grades based on Tian et al. (2005) as:

(1) PU < 0.001% represents an area with very low urbanization;

(2) 0.001% ≤ PU < 1% represents an area with low urbanization;

(3) 1% ≤ PU < 5% represents an area with moderate urbanization;

(4) 5% ≤ PU < 10% represents an area with high urbanization; and

(5) 10% ≤ PU represents an area with very high urbanization.

The result of PU in each sub-district in the study area was summarized as shown in Table 4.28 while, distribution of PU during 2001 to 2021 was presented in Figure 4.28.

Table 4.28 Urban land percentage (PU) in each sub-district during 2001 to 2021.

Sub-district	Urban land percentage (PU) in (%)				
	2001	2006	2011	2016	2021
Sri Suk	4.2167	4.2574	4.3446	5.4900	5.5147
Na Si Nuan	3.6399	3.6751	3.8240	4.1587	4.9450
Kok Pra	9.4419	9.4834	9.9450	10.1935	10.7794
Kan Ta Rat	5.6727	5.6727	5.8943	6.0432	6.2877
Kham Tao Pattana	4.1657	4.3237	4.7024	4.8554	5.0385
Kham Reang	3.7697	5.5973	7.4480	8.2930	8.0314
Kud Sai Jor	5.9552	5.9997	6.9180	7.2336	7.6341
Ma Kha	2.1738	2.1977	2.4820	2.5035	2.5823
Kwao Yai	2.9912	3.0284	3.1080	3.2485	3.3585
Tha Khon Yang	5.0051	6.3162	10.1283	11.0976	10.9734
Lat Pattana	2.6841	2.7390	2.9469	2.9768	3.1398
Kerng	7.9025	9.5623	12.6331	14.5028	15.1909
Tha Song Khon	3.9293	4.0298	4.6899	4.8772	5.0367
Tha Tum	3.9011	3.9681	4.0036	4.0352	4.2245
Kaeng Lerng Chan	8.1497	8.9252	10.8165	11.2200	11.4269
Kwao	6.4526	6.6448	7.2999	7.4276	7.6951
Waeng Nang	6.7508	7.0437	8.0724	8.2459	8.6235
Huai Aeng	4.9879	5.0251	5.3744	5.3744	5.4722
Nong No	2.9296	2.9858	3.0714	3.0812	3.1717
Nong Pling	3.5766	3.5766	3.5873	3.6005	3.6907
Kok Kor	3.6197	3.6197	3.6833	3.7045	3.8087
Don Whan	4.0288	4.0468	4.0797	4.1007	4.2746
Bua Khor	2.6430	2.6430	2.7285	2.7404	2.8259
Ta Lad	43.8140	45.3249	51.6089	54.2392	56.8658

(a) Distribution of urban land percentage in 2001

(b) Distribution of urban land percentage in 2006

(c) Distribution of urban land percentage in 2011

(d) Distribution of urban land percentage in 2016

(e) Distribution of urban land percentage in 2021

Figure 4.28 Distribution of urban land percentage (PU) during 2001 to 2021.

In the past, urban land percentage (PU) in 2001was moderate include 15 sub-districts with moderate urbanization, 8 sub-districts with high urbanization and 1 sub-district with very high urbanization. Later, in 2006 urban land percentage had been increased: 13 sub-districts with moderate urbanization, 10 sub-districts with high urbanization and 1 sub-district with very high urbanization. Meanwhile urban land percentage in 2011 had been still increased: 13 sub-districts with moderate urbanization, 7 sub-districts with high urbanization and 4 sub-districts with very high urbanization.

For future trend, urban land percentage in 2016 had been continuous increased: 12 sub-districts with moderate urbanization, 7 sub-districts with high urbanization and 5 sub-districts with very high urbanization. Meanwhile urban land percentage in 2021 had been continuous increased: 10 sub-districts with moderate urbanization, 9 sub-districts with high urbanization and 5 sub-districts with very high urbanization.

As results, it showed that most of sub-districts during 2001 to 2021 had urban land percentage at moderate and high urbanization level which had PU between 1 and 10%.

4.4.4 Urban land expansion index (SI)

Similar to AGR, urban land expansion index (SI) was here extracted in each sub-district in four periods (2001-2006, 2006-2011, 2011-2016, and 2016-2021) to explain about urban expansion. Herewith, standard SI classification which was suggested by Tian et al. (2005) was adopted as following:

(1) SI < 0.001% represents an area with no change;

(2) 0.001% ≤SI < 0.1% represents an area with low development;

(3) 0.1% ≤SI < 1.0% represents an area with rapid development;

(4) 1.0% ≤SI < 5.0% represents an area with more rapid development; and

(5) 5.0% ≤SI represents an area with dramatic development.

Result of urban land expansion index (SI) and classification of urban land expansion in each sub-district in four periods was displayed in Table 4.29 and Figure 4.29, respectively.

Urban land expansion index between 2001 and 2006 was 4 sub-districts with no change, 11 sub-districts with low development, 5 sub-districts with rapid development and 4 sub-districts with more rapid development. Later, between 2006 and 2011 urban land expansion index had been increased: 8 sub-districts with low development, 10 sub-districts with rapid development, 5 sub-districts with more rapid development and 1 sub-district with dramatic development.

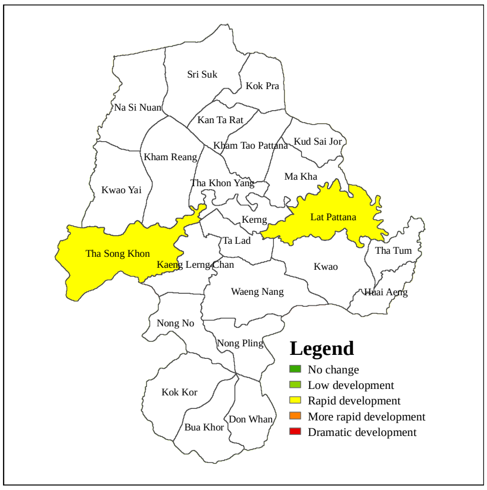
On the contrary urban land expansion index for future trend had been decreased, between 2011 and 2016 included 1 sub-district was SI with no change, 8 sub-districts with low development, 12 sub-districts with rapid development and 3 sub-districts with more rapid development, between 2016 and 2021 included 2 sub-district with no change, 6 sub-districts with low development, 15 sub-districts with rapid development and 1 sub-districts with more rapid development.

As results, it showed that most of urban area in sub-districts during 2001 to 2021 had developed at moderate level which had SI between 0.1 and 1.0%.

Table 4.29 Land expansion index (SI) in each sub–district.

Sub-district	Land expansion index (SI) (%)			
	2001-2006	2006-2011	2011-2016	2016-2021
Sri Suk	0.0407	0.0872	1.1454	0.0247
Na Si Nuan	0.0352	0.1489	0.3347	0.7863
Kok Pra	0.0414	0.4616	0.2486	0.5859
Kan Ta Rat	0.0000	0.2216	0.1490	0.2445
Kham Tao Pattana	0.1580	0.3787	0.1530	0.1831
Kham Reang	1.8276	1.8508	0.8449	-0.2615
Kud Sai Jor	0.0445	0.9184	0.3156	0.4005
Ma Kha	0.0239	0.2843	0.0215	0.0788
Kwao Yai	0.0372	0.0796	0.1405	0.1100
Tha Khon Yang	1.3111	3.8121	0.9693	-0.1243
Lat Pattana	0.0549	0.2079	0.0299	0.1630
Kerng	1.6598	3.0708	1.8697	0.6880
Tha Song Khon	0.1006	0.6601	0.1873	0.1595
Tha Tum	0.0671	0.0355	0.0316	0.1893
Kaeng Lerng Chan	0.7754	1.8914	0.4034	0.2070
Kwao	0.1922	0.6551	0.1276	0.2676
Waeng Nang	0.2929	1.0287	0.1735	0.3776
Huai Aeng	0.0373	0.3493	0.0000	0.0978
Nong No	0.0562	0.0856	0.0098	0.0905
Nong Pling	0.0000	0.0106	0.0133	0.0902
Kok Kor	0.0000	0.0636	0.0212	0.1042
Don Whan	0.0180	0.0330	0.0210	0.1739
Bua Khor	0.0000	0.0855	0.0119	0.0855
Ta Lad	1.5110	6.2839	2.6303	2.6266

(a) Land expansion index (SI) in 2001-2006



(b) Land expansion index (SI) in 2006-2011

(c) Land expansion index (SI) in 2011-2016

(d) Land expansion index (SI) in 2016-2021

Figure 4.29 Classification land expansion index (SI) in each sub-district.

4.5 Surface runoff estimation and prediction

Surface runoff estimation and prediction were here created by SCS-CN method. Basically, relative surface runoff in each cell was generated based on runoff curve numbers (CN) according to hydrological soil-cover complex and maximum rainfall data using Model Builder of ArcGIS environment (Figure 4.30). Runoff curve numbers for hydrologic soil-cover complexes, which were derived from the relationship between LULC types and hydrologic soil groups in the study areas, were presented Table 4.30 and Figure 4.31 demonstrated an example of the runoff curve number based on LULC types in 2011 and soil texture for surface runoff estimation.

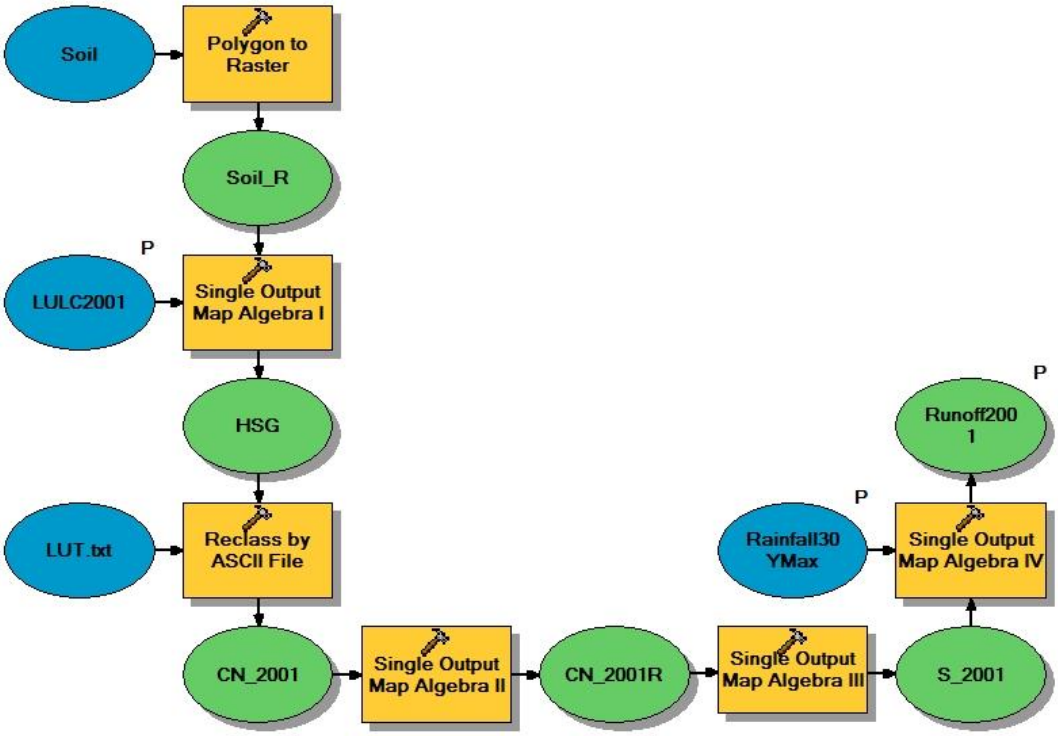


Figure 4.30 Schematic diagram of Model Builder for surface runoff estimation.

Table 4.30 Runoff curve numbers for hydrologic soil-cover complexes.

LULC type	**Hydrology soil group**			
	A	**B**	**C**	**D**
Commercial	89	92	94	95
City and village	89	92	94	95
Institution	89	92	94	95
Dormitory	89	92	94	95
Real estate	89	92	94	95
Paddy field	65	76	84	88
Field crop	72	81	88	91
Perennial tree	43	65	76	82
Orchard	43	65	76	82
Secondary forest	36	60	73	79
Eucalyptus plantation	45	66	77	83
Development land	77	86	91	94
Marsh land	98	98	98	98
Water body	98	98	98	98

Source: Modified from USDA (1986)

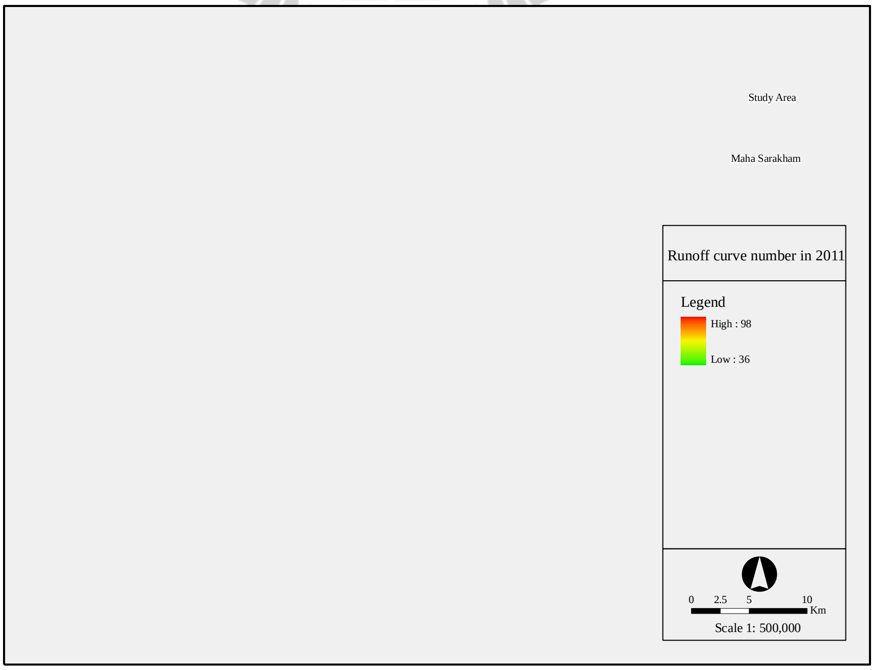


Figure 4.31 Runoff curve numbers (CN) for surface runoff estimation in 2011.

4.5.1 Surface runoff estimation

Distribution of relative surface runoff estimation in 2001, 2006, and 2011 based on maximum rainfall during 30 years (1980-2010) and the interpreted LULC types with soil texture was displayed in Figures 4.32 to 4.34, respectively.

4.5.2 Surface runoff prediction

Distribution of relative surface runoff prediction in 2016 and 2021 based on maximum rainfall during 30 years (1980-2010) and the predicted LULC types with soil texture was displayed in Figure 4.35 and Figure 4.36, respectively.

Figure 4.32 Distribution of estimated relative surface runoff in 2001.

Figure 4.33 Distribution of estimated relative surface runoff in 2006.

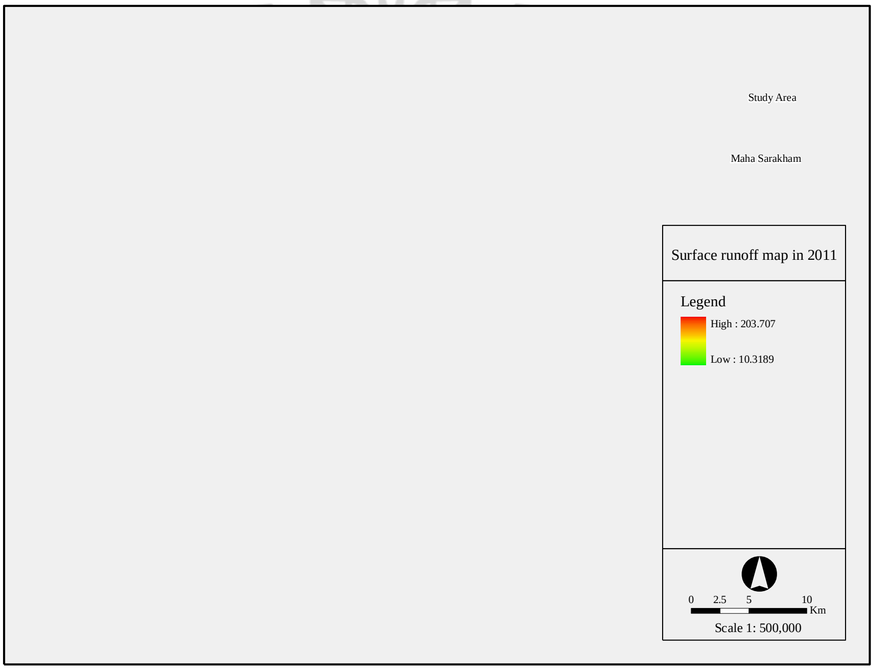


Figure 34 Distribution of estimated relative surface runoff in 2011.

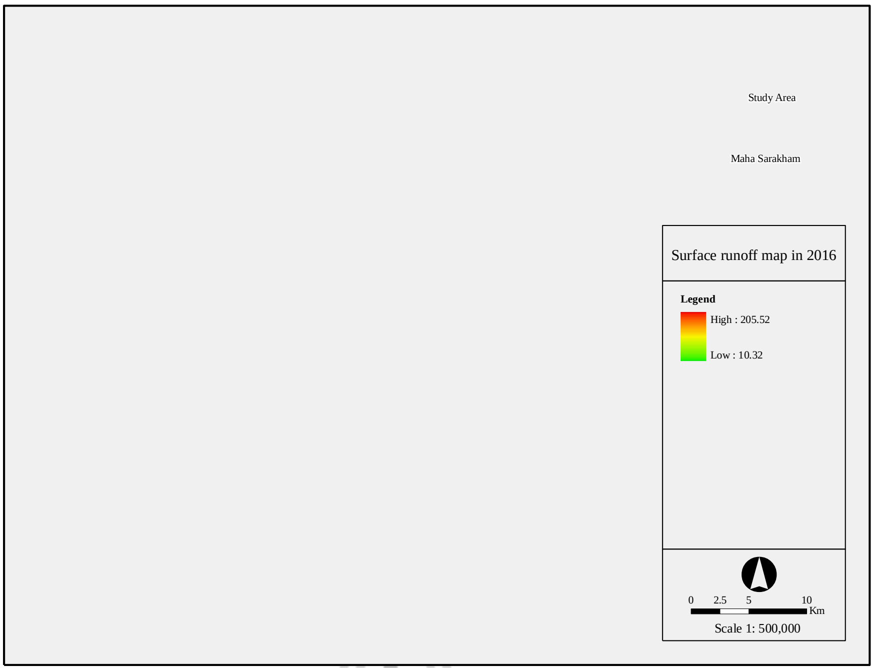


Figure 4.35 Distribution of predicted relative surface runoff in 2016.

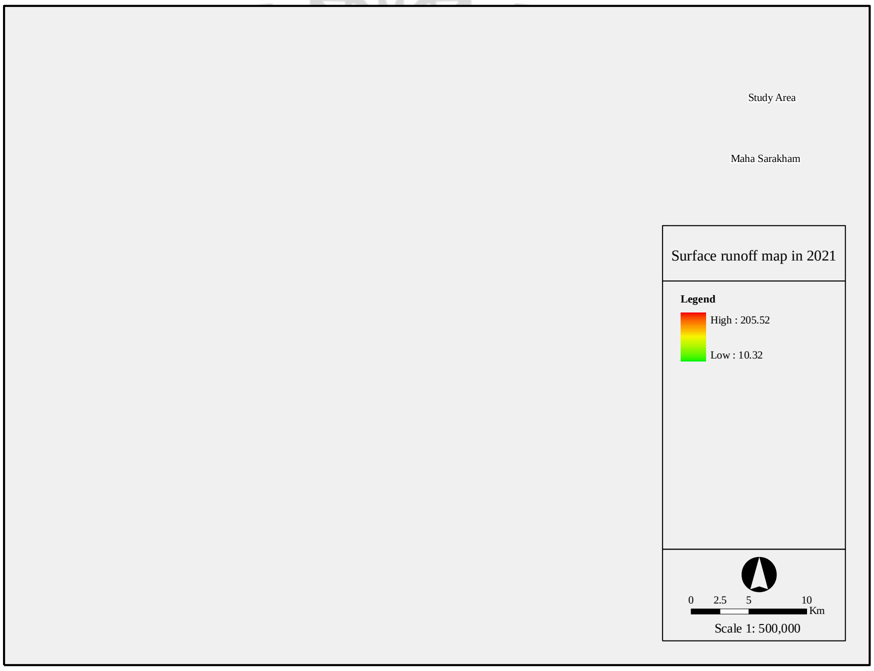


Figure 4.36 Distribution of predicted relative surface runoff in 2021.

The summary of the minimum, mean and maximum values of surface runoff estimation and prediction during 2001 to 2021 was shown in Table 4.31. It was found that characteristics of the minimum and maximum values of surface runoff in 2001 and 2006 and in 2016 and 2021 were similar while the minimum and maximum values of surface runoff in 2011 were dissimilar with others. However, the mean value of surface runoff from these periods was different from each other. The mean value of surface runoff had continuously increased during 2001 to 2021.

Table 4.31 Summary of the minimum, mean and maximum values of surface runoff estimation and prediction during 2001 to 2021.

Year	Surface runoff in mm.		
	Minimum value	**Mean value**	**Maximum value**
2001	10.312	127.721	204.035
2006	10.312	128.073	204.035
2011	10.319	128.645	203.707
2016	10.319	129.252	205.527
2021	10.319	129.481	205.527

4.5.3 Zonation of surface runoff and its change

Zonal analysis was here applied to extract mean value of surface runoff during 2001 to 2021 in each sub-district boundary. After that mean surface runoff in each sub-district was reclassified into 5 zones as follows:

(1) 81 mm > Mean runoff value < 91 mm, very low;

(2) 91 mm ≤ Mean runoff value < 111 mm, low;

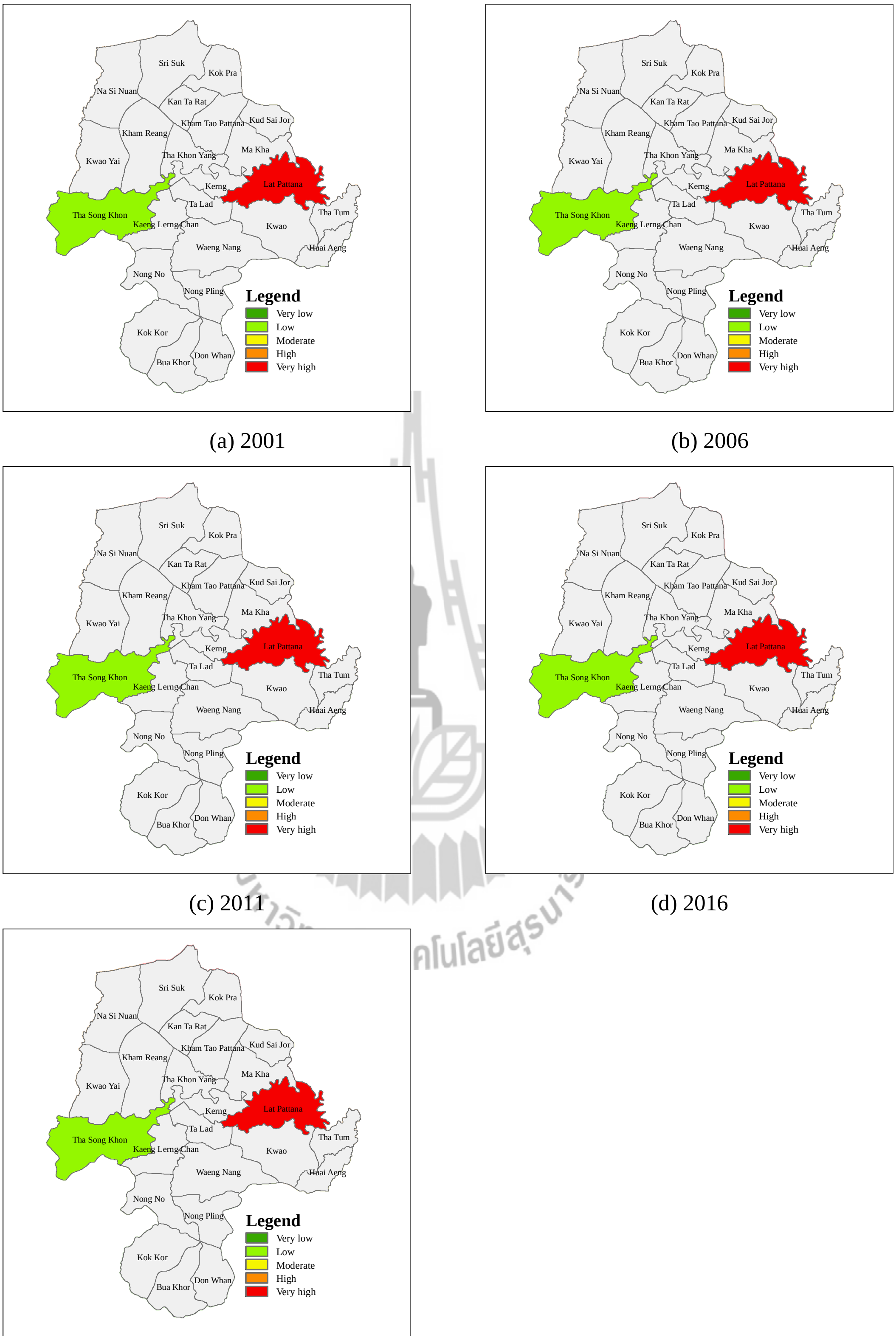
(3) 111 mm ≤ Mean runoff value < 136 mm, moderate;

(4) 136 mm ≤ Mean runoff value < 151 mm, high; and

(5) 151 mm ≤ Mean runoff value, very high.

Results of surface runoff zonation in each sub-district in each year were presented in Figure 4.37. It was found that number of sub-districts in each surface runoff zonation varied due to urban growth during 2001 to 2021 as summary in Table 4.32.

In fact, during 2001 to 2021 4 sub-districts included Ma Kha, Lat Pattana, Kerng, and Ta Lad situated in very high zone and 6 sub-districts included Na Si Nuan, Kham Tao Pattana, Kham Reang, Kwao Yai, Tha Khon Yang, and Tha Tum located in high zone. In contrast, 4 sub-districts included Nong Pling, Kok Kor, Don Whan, and Bau Kor located in very low zone and 2 Sub-districts included Tha Song Khon and Waeng Nang situated in low zone and 2 Sub-districts included Kud Sai Jor and Kaeng Lerng Chan located in moderate zone. These results shown that LULC change during 2001 to 2021 in these sub-districts did not alter their surface runoff zonation. However, LULC change during these periods had effect on surface runoff zonation of 4 sub-districts, namely, Sri Suk, Kok Pra, Kan Ta Rat, and Kwao.



(a) 2001

(b) 2006

(c) 2011

(d) 2016

(e) 2021

Figure 4.37 Surface runoff zonation based on its mean value in each sub-district during 2001 to 2021.

Table 4.32 Classification of surface runoff in each sub-district during 2001 to 2021 by mean value.

Sub-district	Classification of surface runoff				
	2001	2006	2011	2016	2021
Sri Suk	High	Very High	Very High	Very High	Very High
Na Si Nuan	High	High	High	High	High
Kok Pra	High	High	High	Very High	Very High
Kan Ta Rat	High	High	High	High	Very High
Kham Tao Pattana	High	High	High	High	High
Kham Reang	High	High	High	High	High
Kud Sai Jor	Medium	Medium	Medium	Medium	Medium
Ma Kha	Very High	Very High	Very High	Very High	Very High
Kwao Yai	High	High	High	High	High
Tha Khon Yang	High	High	High	High	High
Lat Pattana	Very High	Very High	Very High	Very High	Very High
Kerng	Very High	Very High	Very High	Very High	Very High
Tha Song Khon	Low	Low	Low	Low	Low
Tha Tum	High	High	High	High	High
Kaeng Lerng Chan	Medium	Medium	Medium	Medium	Medium
Kwao	Medium	High	High	High	High
Waeng Nang	Low	Low	Low	Low	Low
Huai Aeng	Low	Low	Low	Medium	Medium
Nong No	Very Low	Low	Low	Low	Low
Nong Pling	Very Low	Very Low	Very Low	Very Low	Very Low
Kok Kor	Very Low	Very Low	Very Low	Very Low	Very Low
Don Whan	Very Low	Very Low	Very Low	Very Low	Very Low
Bua Khor	Very Low	Very Low	Very Low	Very Low	Very Low
Ta Lad	Very high	Very High	Very high	Very High	Very high

4.6 Impact of urban growth on surface runoff

Impact of urban growth on surface runoff was here described included (1) impact of urban growth on surface runoff change, (2) spatial relationship between urban area change and surface runoff change, and (3) spatial relationship between urbanization and surface runoff zonation.

4.6.1 Impact of urban growth on surface runoff change

Change of surface runoff during 2001 to 2021 was here extracted using image differencing techniques and then reclassified into 5 zones as:

(1) 0 mm > Runoff change value, no change

(2) 0 mm ≤ Runoff change value < 50 mm, low change;

(3) 50 mm ≤ Runoff change value < 100 mm, moderate change;

(4) 100 mm ≤ Runoff change value < 150 mm, high change; and

(5) 150 mm ≤ Runoff change value, very high change.

Results of surface runoff change zonation in each sub-district in four periods (2001-2006, 2006-2011, 2011-2016, and 2016-2021) were presented in Figure 4.38.

The resulting surface runoff image of “change” indicated that the annual runoff volume had continuously increased during 2001 to 2021 owing to urban growth in each period. The highest annual runoff change occurred between 2006 and 2011 with the annual change rate of 138.17 mm (Table 4.33).

In addition, surface runoff change and urban area change in these periods were also compared as summary in Table 4.34. Meanwhile, the relationship between urban area change and surface runoff change was linearly regressed by Trend Analysis of MS-Excel as presented in Figure 4.39. The linear relationship between urban area change and surface runoff change was positive with the coefficient of determination (R^2) was 87.82% as shown in the following equation:

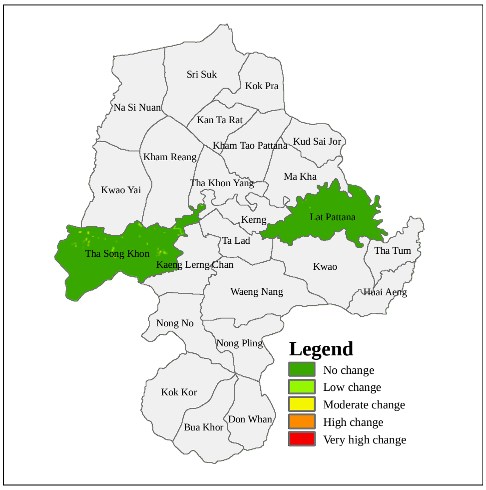
$$Y = 99404 + 0.0668\ X,$$

where Y is surface runoff change in mm and X is urban area change in sq. m.

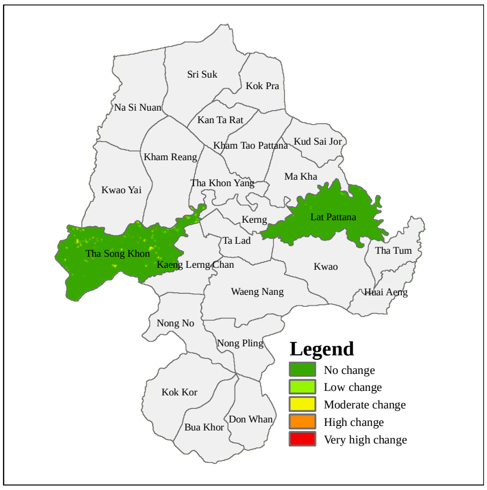
This equation implies that when urban area increases then surface runoff increase.

Table 4.33 Surface runoff change due to LULC change in four periods (2001-2006, 2006-2011, 2011-2016, and 2016-2021).

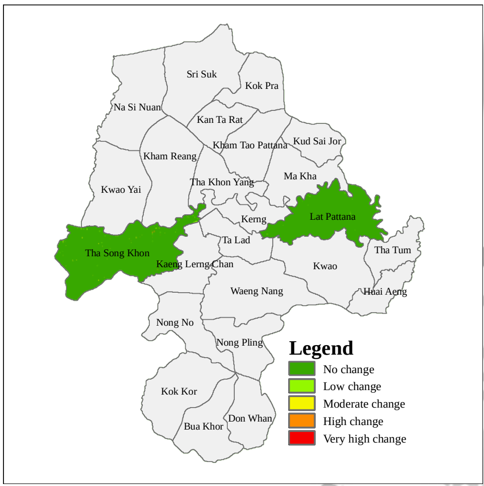
LULC change	Surface runoff change (mm)	Annual change rate (mm)	Urban area change (sq.m)
2001-2006	382,477.59	85.00	3,070,000
2006-2011	621,753.81	138.17	7,750,000
2011-2016	274,893.03	61.09	3,590,000
2016-2021	247,626.16	55.03	2,500,000



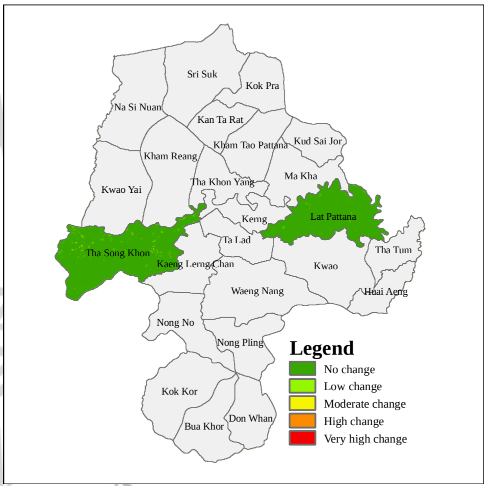
(a) Surface runoff change between 2001 and 2006



(b) Surface runoff change between 2006 and 2011



(c) Surface runoff change between 2011 and 2016



(d) Surface runoff change between 2016 and 2021

Figure 4.38 Surface runoff change zonation by sub-district in four periods: 2001-2006, 2006-2011, 2011-2016, and 2016-2021.

Table 4.34 Comparison of surface runoff and urban area changes during 2001-2021.

Period	Surface runoff change (mm)	Urban area change (sq.m)
2001-2006	382,478	3,070,000
2006-2011	621,754	7,750,000
2011-2016	274,893	3,590,000
2016-2021	247,626	2,500,000

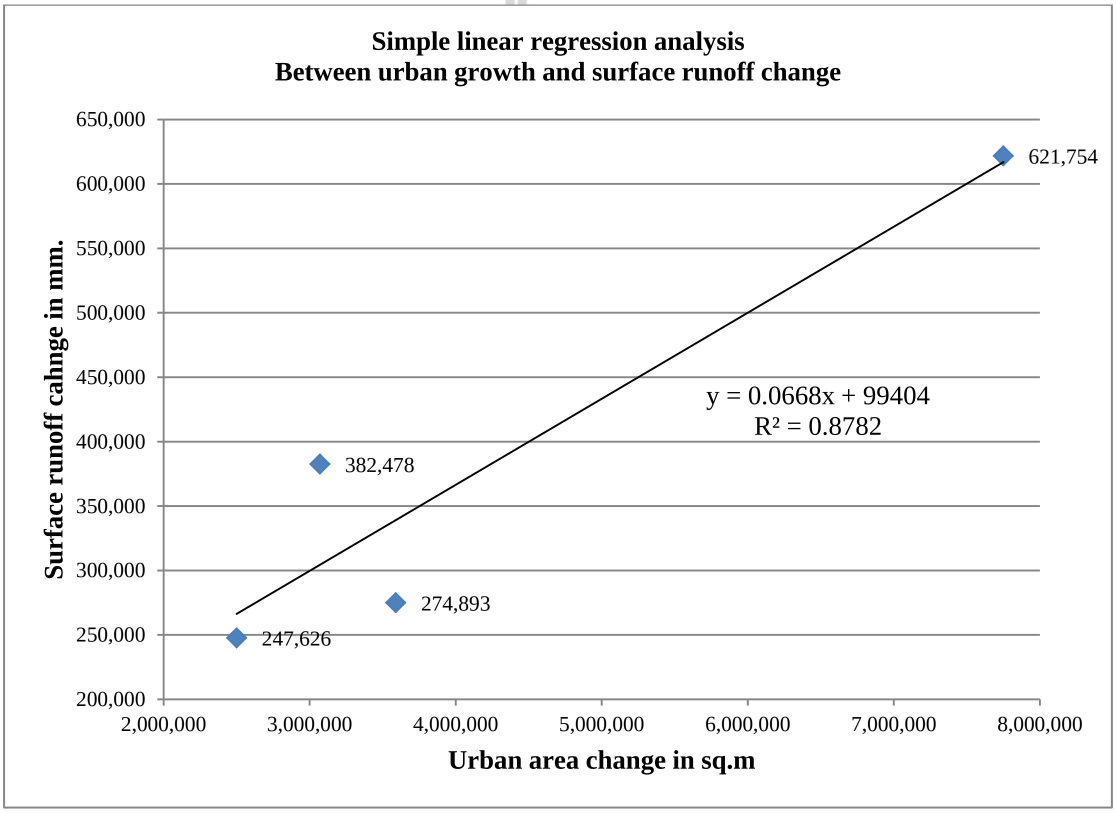
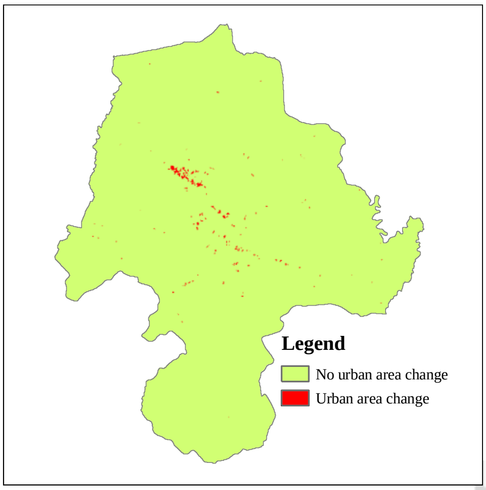


Figure 4.39 Simple linear regression analysis between urban area change and surface runoff change.

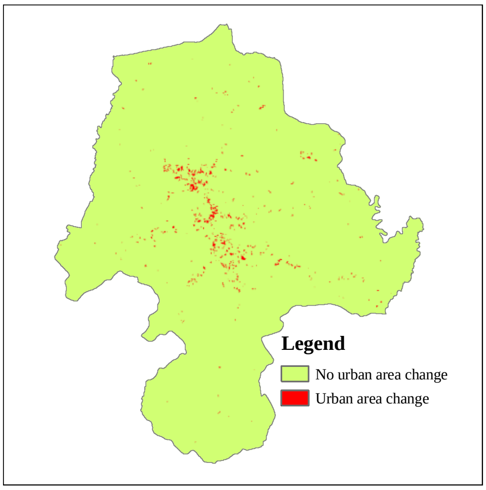
4.6.2 Spatial relationship between urban area change and surface runoff change

Spatial linear regression analysis was here conducted to identify the relationship between urban area change and surface runoff change in four periods (2001-2006, 2006-2011, 2011-2016, and 2016-2021) as shown in Figure 4.40 and Figure 4.41, respectively. It was found that spatial urban area change strongly related with surface runoff change in the study area in all periods. As results, the spatial linear relationship between urban area change and surface runoff change during 2016 to 2021 provided the highest correlation coefficient (R) and coefficient of determination (R^2), which were 99.56% and 99.12%, respectively. Meanwhile the spatial linear relationship between urban area change and surface runoff change during 2006 to 2011 provided the lowest correlation coefficient (R) and coefficient of determination (R^2), which were 98.62% and 97.26%, respectively (Table 4.35). Details of spatial simple linear regression analysis between urban area change and surface runoff change was presented in Appendix E.

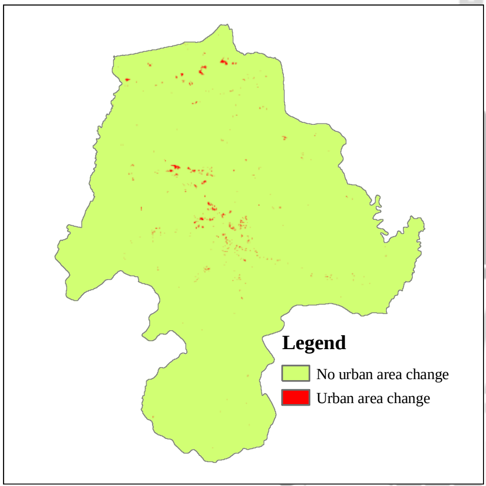
As results it can be concluded that when urban area was expanded, the surface runoff will be increased.



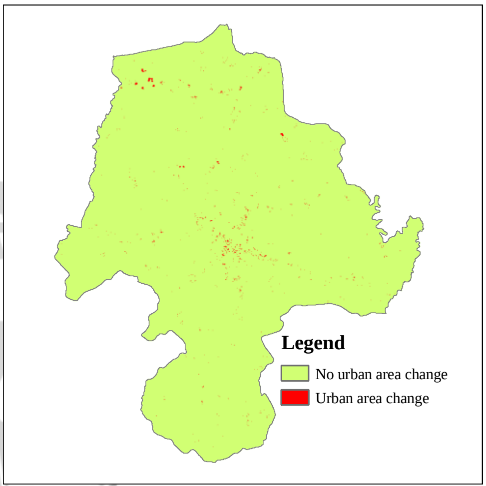
(a) Urban area change between 2001 and 2006



(b) Urban area change between 2006 and 2011

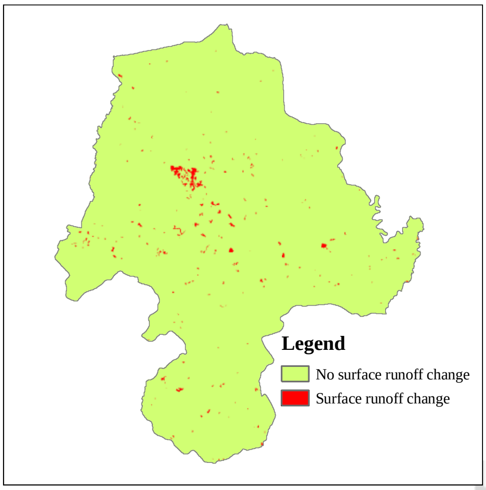


(c) Urban area change between 2011 and 2016

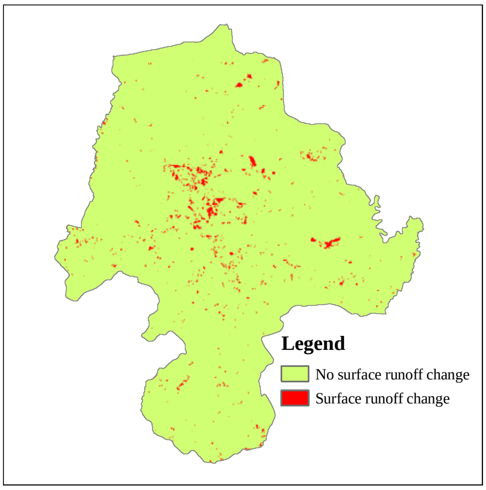


(d) Urban area change between 2016 and 2021

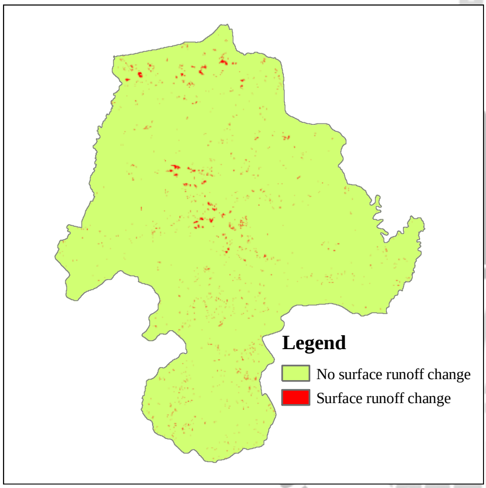
Figure 4.40 Urban area change in four periods: 2001-2006, 2006-2011, 2011-2016, and 2016-2021.



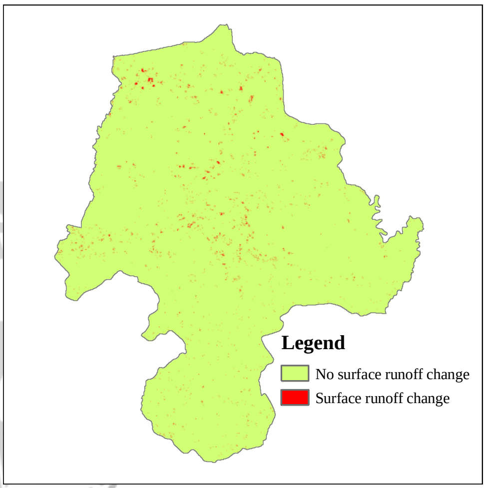
(a) Surface runoff change 2001 and 2006



(b) Surface runoff change 2006 and 2011



(c) Surface runoff change 2011 and 2016



(d) Surface runoff change 2016 and 2021

Figure 4.41 Surface runoff change in four periods: 2001-2006, 2006-2011, 2011-2016, and 2016-2021.

Table 4.35 Summary of spatial simple linear regression model between urban area change and surface runoff change.

Period	Model	Correlation Coefficient (R) (%)	Coefficient of determination (R^2) (%)	Rank
2001-2006	Y = 0.001034 + 1.002404X	99.37	98.74	3
2006-20011	Y = 0.002388 + 1.005359X	98.62	97.26	4
2011-2016	Y = 0.000158 + 1.004559X	99.51	99.02	2
2016-2021	Y = 0.000331 + 1.003252X	99.56	99.12	1

Note: X = Urban growth, Y= Surface runoff change

4.6.3 Spatial relationship between urbanization and surface runoff zonation

Spatial linear regression analysis was here conducted to identify the relationship between urban land percentage as urbanization (see Figure 4.28) and mean surface runoff zonation by sub-district in 2001, 2006, 2011, 2016, and 2021 as shown in Figure 4.37. It was found that urbanization strongly correlated with mean surface runoff zonation by sub-district. Because the spatial pattern between urbanization, which describes the percentage of urban areas of the total sub-district areas, and surface runoff zonation, which creates by mean value in each sub-district, was similar. As results the highest correlation coefficient (R) and coefficient of determination (R^2) was 87.80% and 77.09% in year 2016 while the lowest correlation coefficient (R) and coefficient of determination (R^2) was 84.98% and 72.21% in year 2001 (Table 4.36). Details of spatial linear regression analysis between urbanization and surface runoff zonation were presented in Appendix F.

As results it can be concluded that when urbanization is taken place, the surface runoff will be increased.

Table 4.36 Summary of spatial simple linear regression model between urbanization and mean surface runoff zonation.

Year	Model	Correlation Coefficient (R) (%)	Coefficient of determination (R^2) (%)	Rank
2001	Y = 0.036044 + 0.908790X	84.98	72.21	5
2006	Y = 0.035703 + 0.858506X	85.85	73.70	3
2011	Y = 0.062702 + 0.854680X	85.47	73.05	4
2016	Y = 0.025225 + 0.907646X	87.80	77.09	1
2021	Y = 0.031557 + 0.882305X	86.90	75.51	2

Note: X = Urbanization (PU), Y= Mean surface runoff zonation

4.7 Potential flood analysis

Under this section, potential flood analysis was evaluated using indexing model with SAW method based on relevant factors for flooding included: (1) distance to river, (2) elevation, (3) predicted surface runoff in 2011, (4) river densities, (5) road network densities, and (6) slope (Figure 4.42).

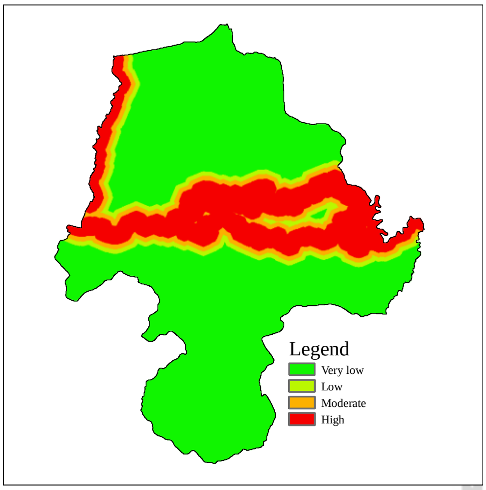
The distribution of potential flood classification by natural break method was presented in Figure 4.43 while area and percentage of potential flood classification in the study area was summarized in Table 4.37. It was found that moderate and high potential flood areas were situated in floodplain and terrace along Chi River covered area about 82.99 sq.km and 198.38 sq.km or about 8.49% and 20.30% of the study area, respectively. On the contrary, no potential flood was located at elevation more than 170 m above MSL.

In addition, area of potential flood classification in each sub-district was also summarized in Table 4.38 while name and number of villages in each potential flood area was reported in Table 4.39. As results, it was found that 13 of 24 sub-districts situated in high potential area and number of villages located in high and moderate potential flood area was 56 and 28 villages.

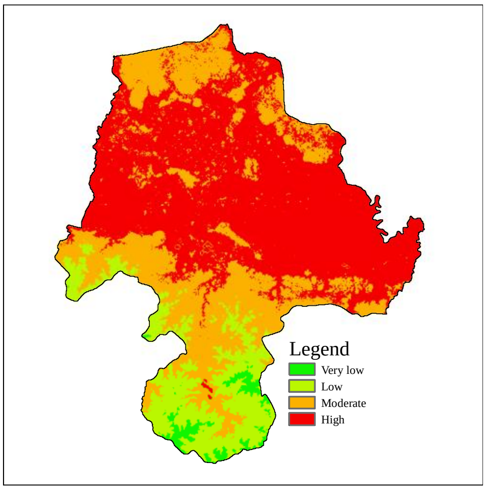
Furthermore, it was found that potential flood classification was highly related with urban land percentage (urbanization) in 2011. The derived correlation coefficient (R) and coefficient of determination (R^2) was 83.96% and 70.49%, respectively. The simple linear regression equation between urban land percentage in 2011 (X) and potential flood classification (Y) was:

$$Y = 0.040530 + 0.795322 X.$$

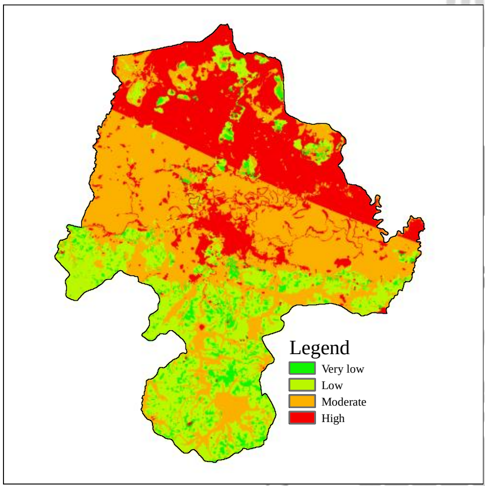
As result it implies that when urbanization is taken place, flood will be potentially increased.



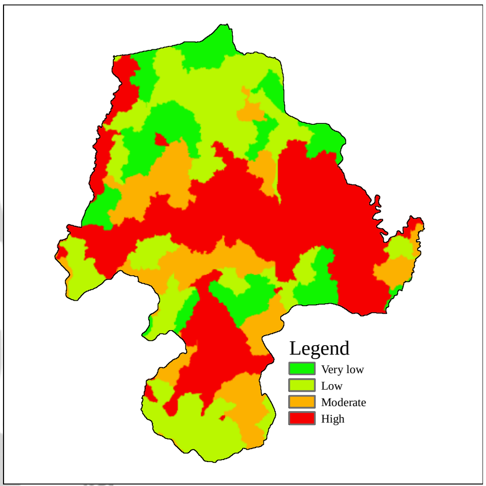
(a) Distance to main river



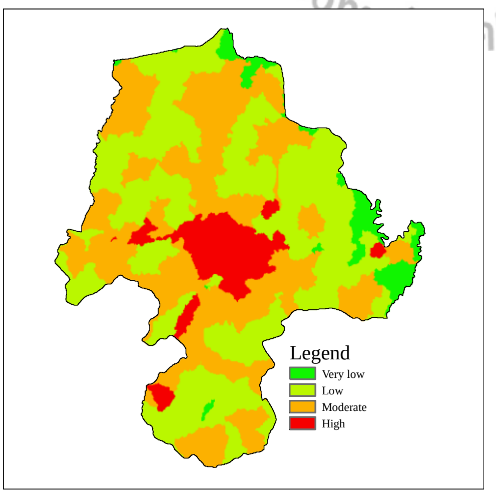
(b) Elevation



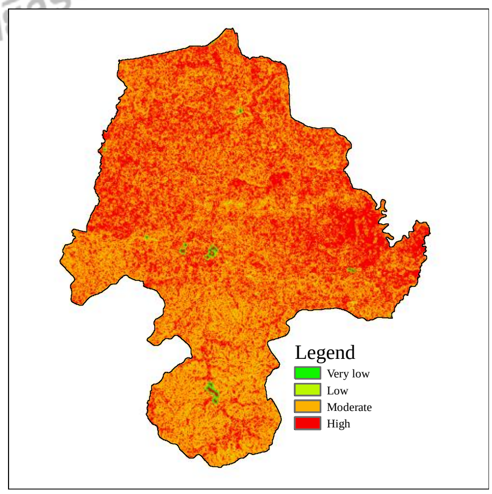
(c) Predicted surface runoff in 2011



(d) River densities



(e) Road network densities



(f) Slope

Figure 4.42 Used factors for potential flood analysis.

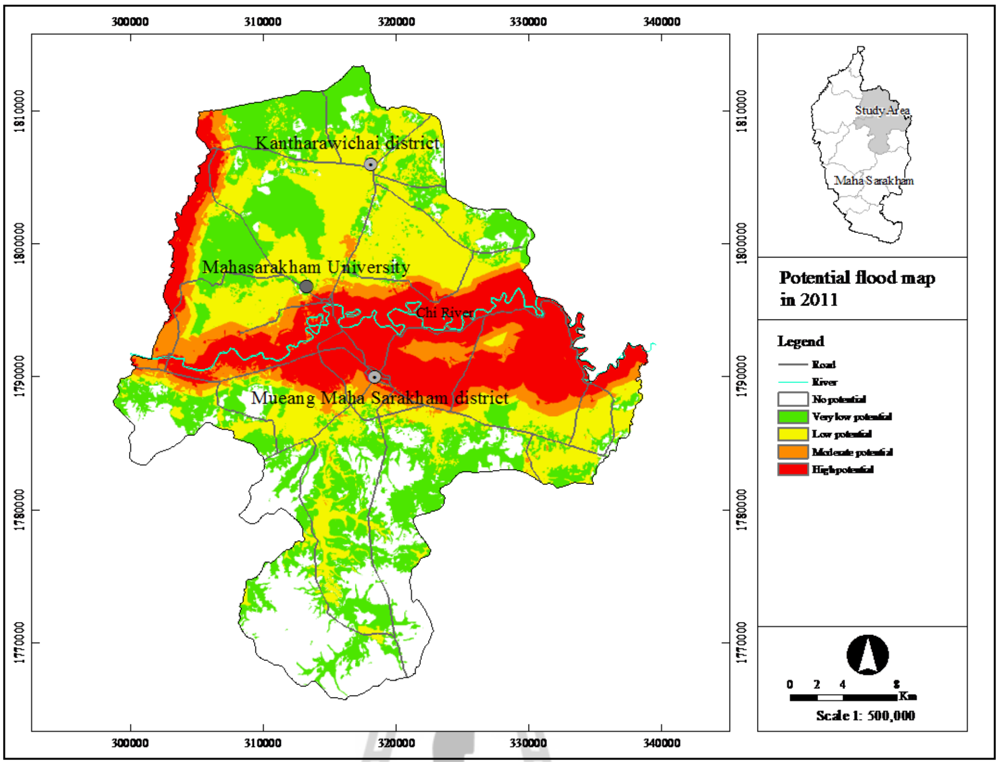


Figure 4.43 Distribution of potential flood classification in the study area.

Table 4.37 Area and percentage of potential flood classification in the study area.

No	Potential flood classification	Area in sq.km	Percentage (%)
1	No potential	166.70	17.06
2	Very low potential	269.84	27.62
3	Low potential	259.25	26.53
4	Moderate potential	82.99	8.49
5	High potential	198.38	20.30
	Total	977.16	100.00

Table 4.38 Area of potential flood classification in each sub-district.

Sub-district	Potential flood (sq.km)					Total	% of high potential
	No potential	Very low	Low	Moderate	High		
Sri Suk	5.02	36.37	20.53	0.00	0.00	61.92	0.00
Na Si Nuan	1.55	24.95	11.45	6.64	11.62	56.20	20.68
Kok Pra	2.57	9.80	18.05	0.00	0.00	30.42	0.00
Kan Ta Rat	0.51	4.63	17.45	0.97	0.00	23.56	0.00
Kham Tao Pattana	1.13	5.91	26.82	1.30	0.72	35.89	2.00
Kham Reang	0.40	19.41	23.34	5.61	9.41	58.16	16.19
Kud Sai Jor	3.16	10.78	8.18	0.12	0.00	22.25	0.00
Ma Kha	0.00	0.43	13.47	4.30	19.48	37.68	51.70
Kwao Yai	0.00	12.05	13.59	14.62	12.91	53.17	24.28
Tha Khon Yang	0.01	1.43	6.86	5.27	15.40	28.97	53.16
Lat Pattana	0.00	0.00	0.96	8.33	44.82	54.12	82.83
Kerng	0.00	0.00	0.00	2.80	20.35	23.15	87.90
Tha Song Khon	20.57	20.54	12.42	9.70	14.63	77.85	18.79
Tha Tum	0.32	1.30	7.89	4.91	8.39	22.82	36.78
Kaeng Lerng Chan	0.93	7.59	14.48	3.59	7.78	34.36	22.63
Kwao	3.78	11.72	18.92	8.02	16.09	58.53	27.49
Waeng Nang	18.90	30.62	14.23	1.09	0.00	64.83	0.00
Huai Aeng	1.66	5.75	11.90	0.02	0.00	19.32	0.00
Nong No	15.48	14.98	6.32	0.03	0.00	36.80	0.00
Nong Pling	9.89	21.08	2.95	0.00	0.00	33.92	0.00
Kok Kor	31.26	13.62	6.09	0.00	0.00	50.97	0.00
Don Whan	22.15	6.54	1.33	0.00	0.00	30.02	0.00
Bua Khor	27.42	10.34	0.14	0.00	0.00	37.90	0.00
Ta Lad	0.00	0.01	1.90	5.67	16.78	24.36	68.88
Total	**166.70**	**269.84**	**259.25**	**82.99**	**198.38**	**977.16**	**20.30**

Table 4.39 Number and name of villages and potential flood classification.

No.	Village	Sub-district	District	Potential flood
1	Don Du	Kwao	Mueang Maha Sarakham	High
2	Nhong Tuen	Kwao	Mueang Maha Sarakham	Moderate
3	Lhoa Noi	Kwao	Mueang Maha Sarakham	Moderate
4	Mho	Kwao	Mueang Maha Sarakham	High
5	Tio	Kwao	Mueang Maha Sarakham	High
6	Non Kwao Noi	Kwao	Mueang Maha Sarakham	Moderate
7	Santi Suk	Kwao	Mueang Maha Sarakham	High
8	Nong Don	Tha Tum	Mueang Maha Sarakham	Moderate
9	Tha Tum	Tha Tum	Mueang Maha Sarakham	High
10	Nhong Kha	Tha Tum	Mueang Maha Sarakham	Moderate
11	Don Rue	Tha Tum	Mueang Maha Sarakham	High
12	Oiy Chang	Tha Tum	Mueang Maha Sarakham	Moderate
13	Din Dum	Kerng	Mueang Maha Sarakham	High
14	Non Tum	Kerng	Mueang Maha Sarakham	High
15	Tha Pratai	Kerng	Mueang Maha Sarakham	High
16	Wang Yao	Kerng	Mueang Maha Sarakham	High
17	Kerng	Kerng	Mueang Maha Sarakham	High
18	Khong Kud Whai	Kerng	Mueang Maha Sarakham	High
19	Thung Na rao	Kerng	Mueang Maha Sarakham	High
20	Non Somboon	Kerng	Mueang Maha Sarakham	Moderate
21	Non Sawhan	Kerng	Mueang Maha Sarakham	Moderate
22	Charern Suk	Kerng	Mueang Maha Sarakham	Moderate
23	Don Tum	Kaeng Lerng Chan	Mueang Maha Sarakham	High
24	Don Doe	Kaeng Lerng Chan	Mueang Maha Sarakham	High
25	Non Hua Fai	Kaeng Lerng Chan	Mueang Maha Sarakham	High
26	Tha Song Khon	Tha Song Khon	Mueang Maha Sarakham	High
27	Upparat	Tha Song Khon	Mueang Maha Sarakham	Moderate
28	Bor Noi	Tha Song Khon	Mueang Maha Sarakham	High
29	Sawang	Tha Song Khon	Mueang Maha Sarakham	High
30	Non Tan	Tha Song Khon	Mueang Maha Sarakham	High
31	Non Sa-art	Tha Song Khon	Mueang Maha Sarakham	High
32	Non Tae	Tha Song Khon	Mueang Maha Sarakham	Moderate
33	Hin Lat Pattana	Tha Song Khon	Mueang Maha Sarakham	Moderate
34	Tha Ngam	Lat Pattana	Mueang Maha Sarakham	High
35	Tha Charern	Lat Pattana	Mueang Maha Sarakham	High

Table 4.39 (Continued).

No.	Village	Sub-district	District	Potential flood
36	Lad	Lat Pattana	Mueang Maha Sarakham	High
37	Wang Phai	Lat Pattana	Mueang Maha Sarakham	High
38	Kud Sui	Lat Pattana	Mueang Maha Sarakham	High
39	Nhong Whai	Lat Pattana	Mueang Maha Sarakham	High
40	Mueang	Lat Pattana	Mueang Maha Sarakham	High
41	Bung khla	Lat Pattana	Mueang Maha Sarakham	High
42	Lerng Bor	Lat Pattana	Mueang Maha Sarakham	High
43	Kui Poe	Lat Pattana	Mueang Maha Sarakham	High
44	Tha Kor	Lat Pattana	Mueang Maha Sarakham	High
45	Nhong Na Sang	Lat Pattana	Mueang Maha Sarakham	High
46	Pa Chan	Lat Pattana	Mueang Maha Sarakham	High
47	Mueang Maha Sarakham Municipality	Ta Lad	Mueang Maha Sarakham	High
48	Kud Wian	Ma Kha	Kantharawichai	High
49	Pa Yang Hang	Ma Kha	Kantharawichai	High
50	Krai Nun	Ma Kha	Kantharawichai	High
51	Khong Ya Ma	Ma Kha	Kantharawichai	High
52	Khong	Ma Kha	Kantharawichai	High
53	Pueai Noi	Ma Kha	Kantharawichai	High
54	Non Tan	Ma Kha	Kantharawichai	High
55	Tha Khon Yang	Tha Khon Yang	Kantharawichai	High
56	Kud Rong	Tha Khon Yang	Kantharawichai	High
57	Wang Wha	Tha Khon Yang	Kantharawichai	High
58	Krai Nun	Tha Khon Yang	Kantharawichai	High
59	Hua Khua	Tha Khon Yang	Kantharawichai	Moderate
60	Na Si Nuam	Na Si Nuam	Kantharawichai	High
61	Whai	Na Si Nuam	Kantharawichai	Moderate
62	Yhaeng	Na Si Nuam	Kantharawichai	Moderate
63	Kwao Don	Na Si Nuam	Kantharawichai	High
64	Nhong Don	Na Si Nuam	Kantharawichai	Moderate
65	Whai Kam	Na Si Nuam	Kantharawichai	High
66	Tan Pattana	Na Si Nuam	Kantharawichai	Moderate
67	Nhong Khae	Kham Reang	Kantharawichai	Moderate
68	Kok	Kham Reang	Kantharawichai	Moderate
69	Hui San	Kham Reang	Kantharawichai	High

Table 4.39 (Continued).

No.	Village	Sub-district	District	Potential flood
70	Don Na	Kham Reang	Kantharawichai	High
71	Kud Hua Chang	Kham Reang	Kantharawichai	High
72	Khong Kud Wian	Kham Reang	Kantharawichai	High
73	Makok	Kham Reang	Kantharawichai	Moderate
74	Don Ngern	Kwao Yai	Kantharawichai	High
75	Kui Pek	Kwao Yai	Kantharawichai	High
76	Kui Cheuk	Kwao Yai	Kantharawichai	High
77	Bung Bao	Kwao Yai	Kantharawichai	Moderate
78	Khi Lhek	Kwao Yai	Kantharawichai	High
79	Som Hong	Kwao Yai	Kantharawichai	Moderate
80	Don Phoe	Kwao Yai	Kantharawichai	Moderate
81	Nhong No	Kwao Yai	Kantharawichai	Moderate
82	Hin Poon	Kwao Yai	Kantharawichai	Moderate
83	Wang Bua	Kham Tao Pattana	Kantharawichai	Moderate
84	Don Pueai	Kham Tao Pattana	Kantharawichai	Moderate
85	Wang Bua Lhuang	Kham Tao Pattana	Kantharawichai	Moderate

Moreover, potential flood classification was further compared with frequency flood data between 2005 and 2011 from GISTDA, which were extracted from RADARSAT data (Figure 4.44). It was found that most of flooded areas during 2005 to 2011 were located in moderate and high potential flood areas covered area of 37.84 sq.km and 98.29 sq.km, respectively or about 45.60% and 49.57% of its potential flood, respectively. At the same time, some of flooded areas were located in very low and low potential flood areas covered area of 24.46 sq.km and 60.52 sq.km, respectively or about 9.07% and 23.34% of its potential flood, respectively. Meanwhile only 2.12% of no potential flood area was flooded during 2005 to 2011. See detail in Table 4.40. As results, if total flooded area during 2005 to 2011 was only considered, it revealed that flooded areas were located in moderate and high potential flood zones more than 60%. Figure 4.45 displayed the distribution of potential flood area with frequency flood data during 2005 to 2011.

Similarly, when potential flood classification was compared with the biggest flood data in 2011 based on flood data of GISTDA between 2005 and 2011, it was found that most of flooded areas in 2011 were located in moderate and high potential flood areas covered area of 31.46 sq.km and 74.37 sq.km, respectively or about 37.91% and 37.49% of its potential flood, respectively. At the same time, some of flooded areas were located in very low and low flood areas covered area of 14.19 sq.km and 37.23 sq.km, respectively or about 5.26% and 14.36% of its potential flood, respectively. Meanwhile only 1.17% of no potential flood area was flooded in 2011 (Table 4.41). Therefore, if total flooded area in 2011 was considered, it was found that flooded areas were located in moderate and high potential flood zones about 66.47 %.

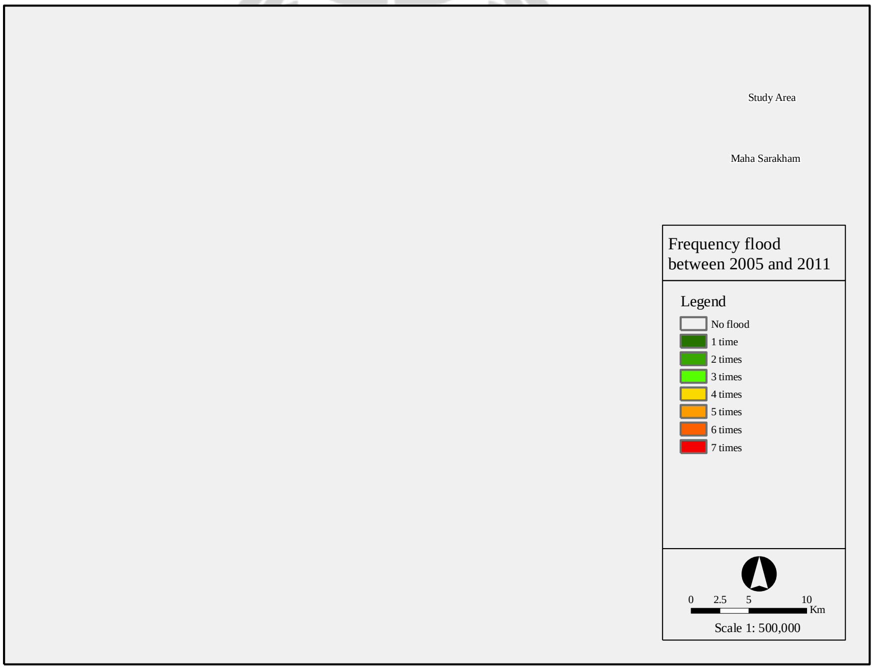


Figure 4.44 Distribution of frequency flood data between 2005 and 2011 by GISTDA.

Table 4.40 Frequency flood data (2005-2011) from GISTDA and potential flood classification.

Potential flood	**Non Flood area (sq.km)**	**Frequency Flood area (sq.km)**								**Per cent (%)**	
		1	**2**	**3**	**4**	**5**	**6**	**7**	**Total**	**Non-flood**	**Flood**
No potential	163.16	2.76	0.61	0.09	0.04	0.04	0.01	0.00	**3.54**	97.88%	2.12%
Very low	245.38	15.14	7.55	0.94	0.23	0.58	0.02	0.00	**24.46**	90.93%	9.07%
Low	198.73	27.19	17.15	6.55	3.68	5.17	0.68	0.10	**60.52**	76.66%	23.34%
Moderate	45.15	7.41	14.27	7.14	3.12	5.12	0.50	0.28	**37.84**	54.40%	45.60%
High	100.09	29.23	23.53	19.54	14.21	11.19	0.58	0.02	**98.29**	50.46%	49.54%
Total	**752.51**	**81.72**	**63.12**	**34.26**	**21.27**	**22.10**	**1.79**	**0.40**	**224.65**	**77.01%**	**22.99%**

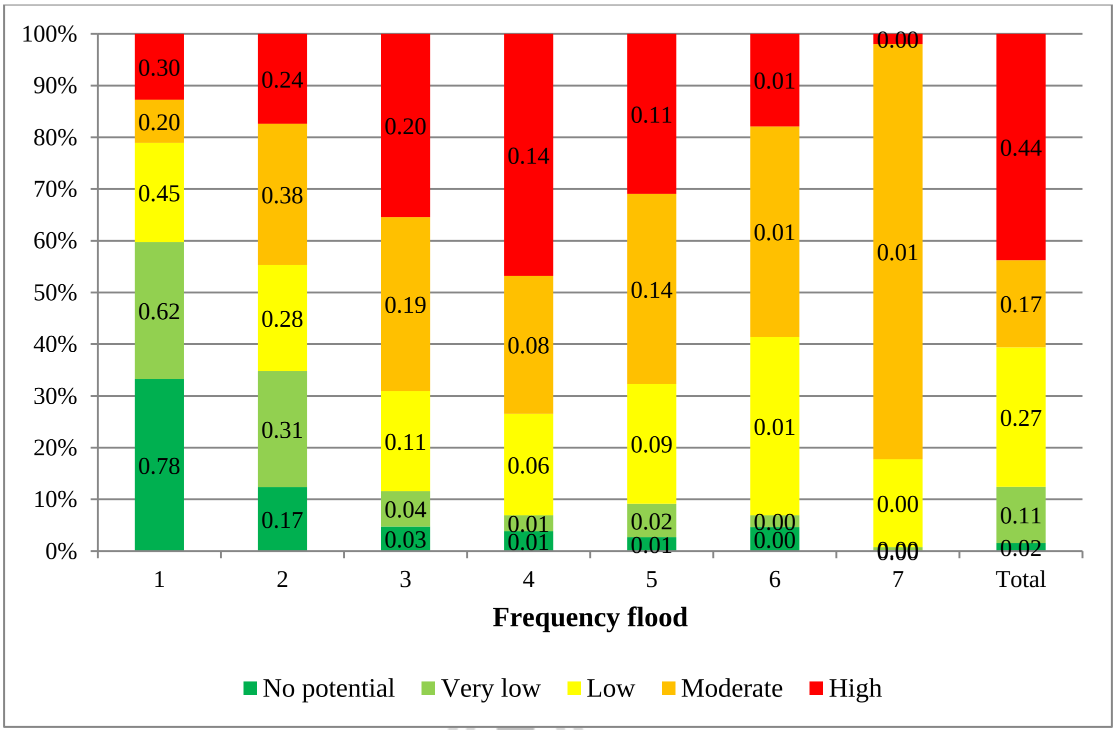


Figure 4.45 Distribution of potential flood area with frequency flood data.

Table 4.41 Flood data in 2011 from GISTDA and potential flood classification.

Potential flood classification	Area in sq.km			Percent (%)	
	Non-flood	**Flood**	**Total**	**Non-flood**	**Flood**
No potential	164.75	1.96	166.70	98.83	1.17
Very low	255.65	14.19	269.84	94.74	5.26
Low	222.02	37.23	259.25	85.64	14.36
Moderate	51.53	31.46	82.99	62.09	37.91
High	124.01	74.37	198.38	62.51	37.49
Total	**817.96**	**159.20**	**977.16**	**83.71**	**16.29**

4.8 Evaluation of the existing comprehensive city plan and land use planning

Under this section, two main results included (1) evaluation of the existing comprehensive city plan, and (2) land use planning were here described and discussed.

4.8.1 Evaluation of the existing comprehensive city plan

LULC in 2011 for present status and 2016 for future status were here used to compare with the existing comprehensive city plan using the post-classification change detection algorithm. This transition matrix was then be used to explain the gains and losses of land use categories in comprehensive city plan include: (1) Commercial and high density residential area, (2) Moderate density residential area, (3) Low density residential areas, (4) Conservation for residential area, (5) Industrial area, (6) Rural and agricultural area, (7) Conservation for rural and agricultural area, (8) Barren land for recreation and environmental quality area, (9) Education, (10) Barren land for environmental quality area, (11) Religion, (12) Government and infrastructure, and (13) Conservation for cultural. In this study, comprehensive city plan of Tha Khon Yang-Kham Reang community and Mueang Maha Sarakham between 2012 and 2016 (Figure 4.46 and Table 4.42) were used as sample case for this operation. The output of transitional matrix between LULC in 2011 and 2016 (see Figure 4.3 and Figure 4.18) and comprehensive city plans were presented in Table 4.43 and Table 4.44, respectively.

Figure 4.46 Comprehensive city plan of Tha Khon Yang-Kham Reang community and Mueang Maha Sarakham between 2011 and 2016.

Table 4.42 Area and percentage of the existing comprehensive city plan (2012-2016).

No	Land use categories in comprehensive city plan	Area (sq.km)	Per cent (%)
1	Commercial and high density residential area	1.80	0.89
2	Moderate density residential area	4.31	2.13
3	Low density residential area	22.39	11.07
4	Conservation for residential area	0.44	0.22
5	Industrial area	0.37	0.18
6	Rural and agricultural area	142.26	70.33
7	Conservation for rural and agricultural area	6.79	3.36
8	Barren land for recreation and environmental quality area	3.95	1.95
9	Education	5.20	2.57
10	Barren land for environmental quality area	7.43	3.67
11	Religion	1.56	0.77
12	Government and infrastructure	5.60	2.77
13	Conservation for culture	0.19	0.09
	Total	**202.28**	**100.00**

Table 4.43 Comparison between LULC type in 2011 and land use category in comprehensive city plan (2012-2016).

LULC 2011	Land use category in comprehensive city plan (2012-2016) (Unit: sq.km)																
	CHDR	MDR	LDR	CR	Edu	Rel	Gov	CC	Sub_total	RA	CA	Sub_total	BLR	BLE	Sub_total	Ind	Total
Commercial	0.76	0.86	1.01	-	0.02	0.03	0.06	-	**2.74**	0.49	-	**0.49**	0.06	-	**0.06**	0.02	**3.31**
City and village	0.73	2.38	5.25	0.23	0.29	0.4	0.13	0.01	**9.42**	9.28	0.1	**9.38**	0.26	0.12	**0.38**	0.01	**19.21**
Institution	0.04	0.12	0.36	-	3.34	0.3	1.82	-	**5.98**	0.23	-	**0.23**	0.12	0.02	**0.14**	-	**6.35**
Dormitory	0.2	0.14	1.3	-	0.05	0	0	-	**1.69**	0.19	-	**0.19**	0.02	-	**0.02**	-	**1.9**
Real estate	-	-	0.86	-	0.01	-	-	-	**0.87**	0.28	-	**0.28**	-	0.01	**0.01**	-	**1.16**
Paddy field	0.02	0.3	8	0.05	0.21	0.11	0.07	0.11	**8.87**	102.2	4.7	**106.9**	0.58	1	**1.58**	0.24	**117.59**
Field crop	-	-	0.23	-	0.05	0.02	3.1	-	**3.4**	8.61	0.07	**8.68**	0.05	0	**0.05**	-	**12.14**
Perennial tree	-	-	-	-	-	-	0.02	-	**0.02**	0.06	-	**0.06**	-	-	**0**	-	**0.08**
Orchard	-	-	0.32	0.02	0.01	0.06	0.03	0	**0.44**	2.29	0.01	**2.3**	-	0	**0**	-	**2.75**
Secondary forest	-	0.01	0.33	0.11	0.5	0.49	0.01	0.01	**1.46**	7.96	1.23	**9.19**	1.04	0.15	**1.19**	0.06	**11.91**
Eucalyptus	-	-	0.01	-	0.01	0.02	0.04	-	**0.08**	1.71	-	**1.71**	0.02	0	**0.02**	-	**1.81**
Development land	0.05	0.38	2.73	-	0.16	0.03	0.17	-	**3.52**	3.97	0.19	**4.16**	0.4	0.02	**0.42**	0.02	**8.12**
Marsh land	0.01	0.08	1.29	-	0.09	0	0.01	-	**1.48**	0.89	-	**0.89**	0.04	0.02	**0.06**	0.02	**2.47**
Water body	-	0.03	0.68	0.02	0.45	0.09	0.15	0.06	**1.48**	4.1	0.48	**4.58**	1.35	6.06	**7.41**	-	**13.48**
Total	**1.8**	**4.31**	**22.39**	**0.44**	**5.2**	**1.56**	**5.6**	**0.19**	**41.45**	**142.26**	**6.79**	**149.04**	**3.95**	**7.43**	**11.38**	**0.37**	**202.28**
Sub-total									**24.22**			**14.73**			**1.03**		
Percent (%)									**58.43%**			**9.88%**			**9.05%**		

Note: CHDR= Commercial and high density residential area, MDR = Moderate density residential area, LDR = Low density residential area, CR = Conservation for residential area, Edu = Education, Rel = Religion, Gov = Government and infrastructure, CC = Conservation for culture, RA = Rural and agricultural area, CA = Conservation for rural and agricultural area, BLR = Barren land for recreation and environmental quality area, BLE = Barren land for environmental quality area, and Ind = Industrial area.

Table 4.44 Comparison between LULC type in 2016 and land use category in comprehensive city plan (2012-2016).

LULC 2016	Land use category in comprehensive city plan (2012-2016) (Unit: sq.km)																
	CHDR	**MDR**	**LDR**	**CR**	**Edu**	**Rel**	**Gov**	**CC**	**Sub_total**	**RA**	**CA**	**Sub_total**	**BLR**	**BLE**	**Sub_total**	**Ind**	**Total**
Commercial	0.79	0.88	1.26	-	0.02	0.03	0.06	-	**3.04**	0.54	-	**0.54**	0.08	-	**0.08**	0.03	**3.68**
City and village	0.73	2.58	5.61	0.24	0.3	0.4	0.14	0.01	**10.01**	9.7	0.1	**9.8**	0.28	0.12	**0.4**	0.01	**20.23**
Institution	0.04	0.12	0.37	-	3.34	0.3	1.82	-	**5.99**	0.23	-	**0.23**	0.12	0.02	**0.14**	-	**6.36**
Dormitory	0.21	0.14	1.58	-	0.05	0.01	0	-	**1.99**	0.22	-	**0.22**	0.02	-	**0.02**	-	**2.22**
Real estate	-	-	1.19	-	0.01	-	0	-	**1.2**	0.37	-	**0.37**	-	0.01	**0.01**	-	**1.58**
Paddy field	0.02	0.3	7.99	0.05	0.22	0.11	0.07	0.11	**8.87**	102.46	4.77	**107.23**	0.58	1	**1.58**	0.24	**117.91**
Field crop	-	-	0.22	-	0.06	0.02	3.1	-	**3.4**	8.6	0.08	**8.68**	0.05	0	**0.05**	-	**12.14**
Perennial tree	-	-	-	-	-	-	0.02	-	**0.02**	0.06	-	**0.06**	-	-	**0**	-	**0.08**
Orchard	-	-	0.28	0.02	0.01	0.06	0.03	0	**0.4**	2.16	0.01	**2.17**	-	0	**0**	-	**2.57**
Secondary forest	-	0.01	0.31	0.11	0.49	0.49	0.01	0.01	**1.43**	7.49	1.14	**8.63**	1.04	0.15	**1.19**	0.06	**11.29**
Eucalyptus	-	-	0.01	-	0.01	0.02	0.04	-	**0.08**	1.85	-	**1.85**	0.03	0	**0.03**	-	**1.96**
Development land	0.01	0.16	1.48	-	0.08	0.03	0.15	-	**1.91**	3.51	0.21	**3.72**	0.37	0.03	**0.4**	0.02	**6.04**
Marsh land	0.01	0.07	1.42	-	0.15	0	0.01	-	**1.66**	0.98	-	**0.98**	0.04	0.02	**0.06**	0.02	**2.73**
Water body	-	0.03	0.68	0.02	0.45	0.09	0.15	0.06	**1.48**	4.1	0.48	**4.58**	1.35	6.06	**7.41**	-	**13.48**
Total	**1.8**	**4.31**	**22.39**	**0.44**	**5.2**	**1.56**	**5.6**	**0.19**	**41.49**	**142.26**	**6.79**	**149.05**	**3.95**	**7.43**	**11.38**	**0.37**	**202.28**
Sub-total									**24.14**			**14.88**			**1.05**		
Percent (%)									**58.18%**			**9.98%**			**9.23%**		

Note: CHDR= Commercial and high density residential area, MDR = Moderate density residential area, LDR = Low density residential area, CR = Conservation for residential area, Edu = Education, Rel = Religion, Gov = Government and infrastructure, CC = Conservation for culture, RA = Rural and agricultural area, CA = Conservation for rural and agricultural area, BLR = Barren land for recreation and environmental quality area, BLE = Barren land for environmental quality area, and Ind = Industrial area.

Refer to Table 4.43, it was found that area of urban and built-up (commercial, city and village, institution, dormitory and real estate) in 2011 was less that area of urban and built-up area in comprehensive city plan about 41.57%. Meanwhile, many LULC types in 2011 were located in rural and agriculture and conservation for rural and agricultural areas about 9.88% and barren land for recreation and environmental quality and barren land for environmental quality areas about 9.05%. Both figures were not more than 10% as suggestion in comprehensive city plan announcement by Public Works and Town & Country Planning in 2012.

Similarly, refer to Table 4.44, it was found that area of predicted urban and built-up (commercial, city and village, institution, dormitory and real estate) in 2016 was less that area of urban and built-up area in comprehensive city plan about 41.52%. Meanwhile, many LULC types in 2016 were located in rural and agriculture and conservation for rural and agricultural areas about 9.98% and barren land for recreation and environmental quality and barren land for environmental quality areas about 9.23%. Both figures were not more than 10% as suggestion in comprehensive city plan announcement by Public Works and Town & Country Planning in 2012.

As results, it implies that comprehensive city plan of Tha Khon Yang-Kham Reang community and Mueang Maha Sarahkam between 2012 and 2016 can support the predicted LULC in 2021.

4.8.2 Land use planning

The predictive LULC and surface runoff in 2021 with potential flooding data were here used to create a future land use plan of Mueang Maha Sarakhan district and Kantharawichai district for environmental impact and flood mitigation. In practice, the potential surface analysis was firstly applied for potential main land use categories using Index model with SAW method using Model Builder under GIS environment (Figure 4.47) and then Sieve Analysis was used for land use type allocation.

For potential surface analysis, distributions of potential urban and built-up area, agricultural and conservation area, institutional area, commercial area, and residential area development were displayed in Figure 4.48 while area and percentage from potential surface analysis for each specific development was summarized as shown in Table 4.45. Meanwhile, the final land use plan in 2021 by Sieve Analysis based on the most suitable areas from potential surface analysis with existing marsh land and water body in 2021 was presented in Figure 4.49 and Table 4.46.

As results, it was found that the most suitable land use allocation was agricultural and conservation area covered area of 811.09 sq.km or 83.00% while the least suitable land use allocation was commercial area covered area of 4.72 sq.km or 0.48%. Additionally, preserved area for future development was allocated in the plan covered area about 23.60 sq.km or 2.41%.

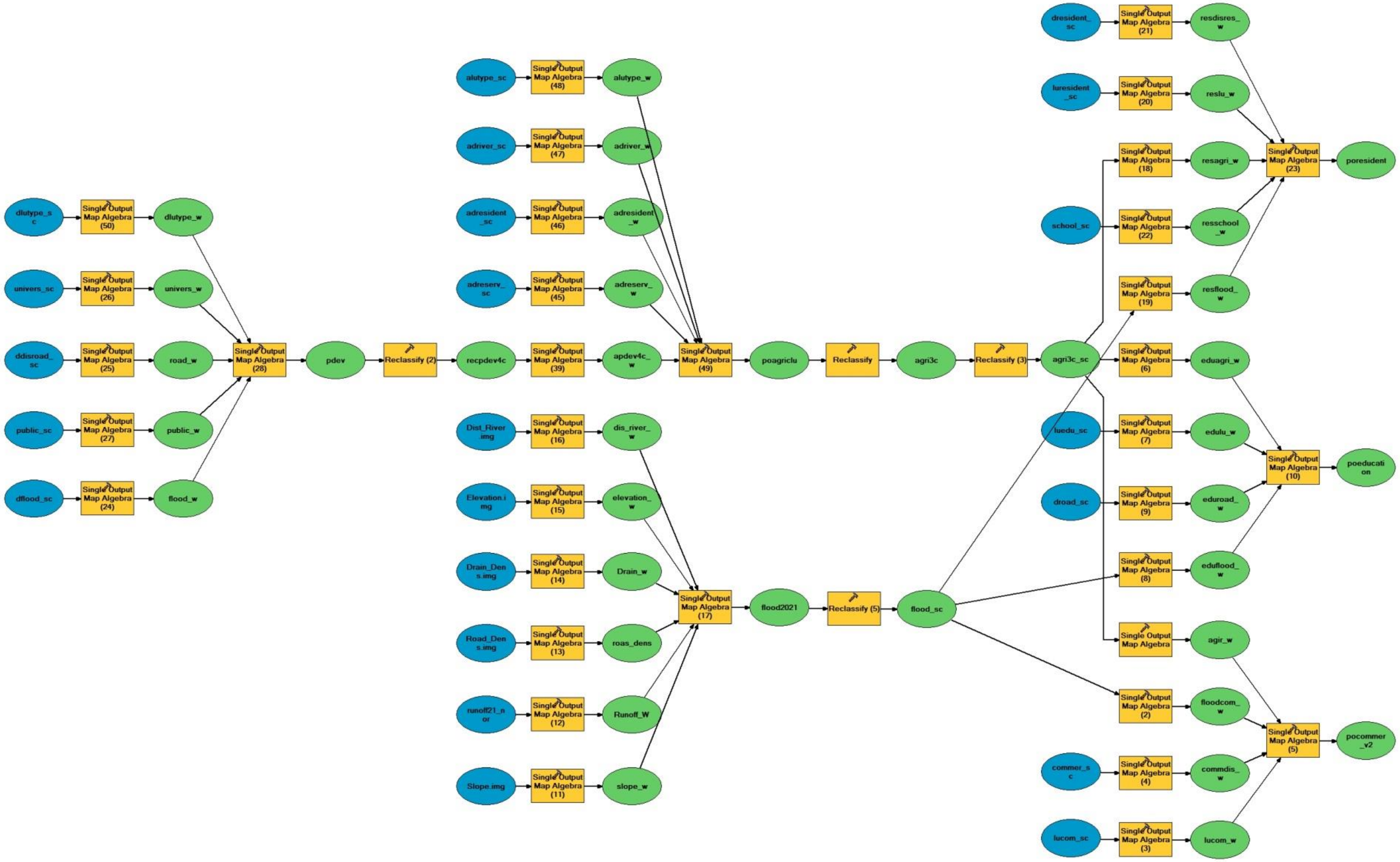


Figure 4.47 Schematic diagram of Model Builder for surface potential analysis.

In addition, when LULC in 2011 compares with land use plan 2021, it was found that most of existing agricultural land (paddy field, field crop, perennial tree and orchard) located in high suitability for agricultural and conservation area about 97.07%. At the same time, 61.40% of city and village, dormitory and real estate situated in the high suitability for residential area and 49.78% and 35.87% of institutional and commercial located in the high suitability for institutional and commercial areas (Table 4.47). However, area of high suitability for agricultural and conservation, residential institutional, and commercial areas in the plan were higher than LULC in 2011.

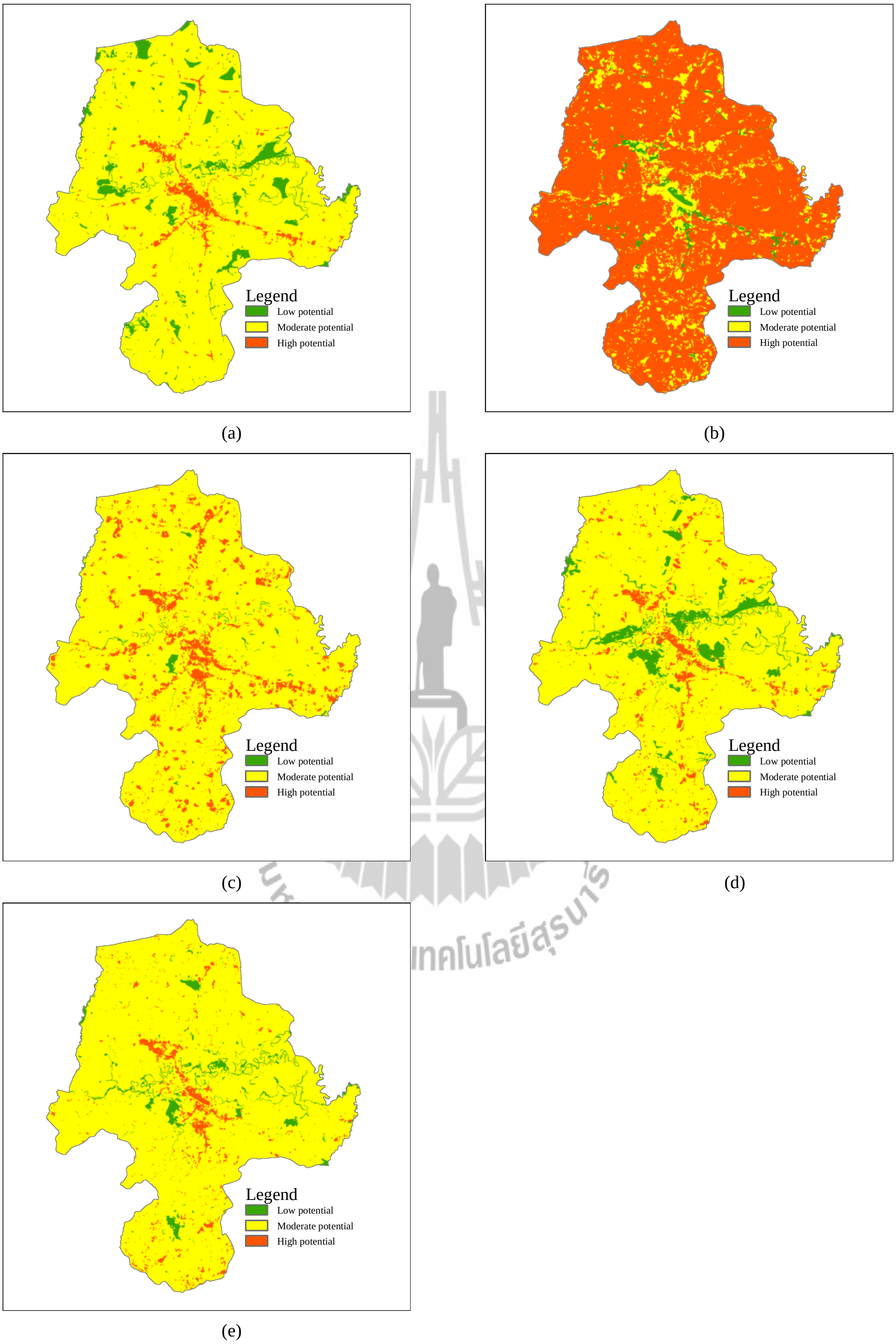


Figure 4.48 Potential surface analysis for development: (a) urban and built-up area (b) agricultural and conservation area, (c) residential area, (d) institutional area, and (e) commercial area.

Table 4.45 Area and percentage of potential surface analysis for development.

Potential suitable class	Urban and built-up area		Agricultural and conservation area		Residential area		Institution area		Commercial area	
	sq.km	%	sq.km	%	sq.km	%	sq.km	%	sq.km	%
Low	66.54	6.81	19.50	2.00	9.23	0.94	66.62	6.82	37.73	3.86
Moderate	874.66	89.51	118.39	12.12	876.89	89.74	861.41	88.15	901.35	92.24
High	35.96	3.68	839.27	85.89	91.04	9.32	49.13	5.03	38.08	3.90
Total	**977.16**	**100.00**	**977.16**	**100.00**	**977.16**	**100.00**	**977.16**	**100.00**	**977.16**	**100.00**

Table 4.46 Area and percentage of land use categories of land use plan in 2021.

Land use type	Area (sq.km)	Per cent (%)
High suitability for agricultural and conservation area	811.09	83.00
High suitability for residential area	79.59	8.14
High suitability for institutional area	14.91	1.53
High suitability for commercial area	4.72	0.48
Water body and marsh land	43.27	4.43
Preserved area for future development	23.60	2.41
Total	**977.16**	**100.00**

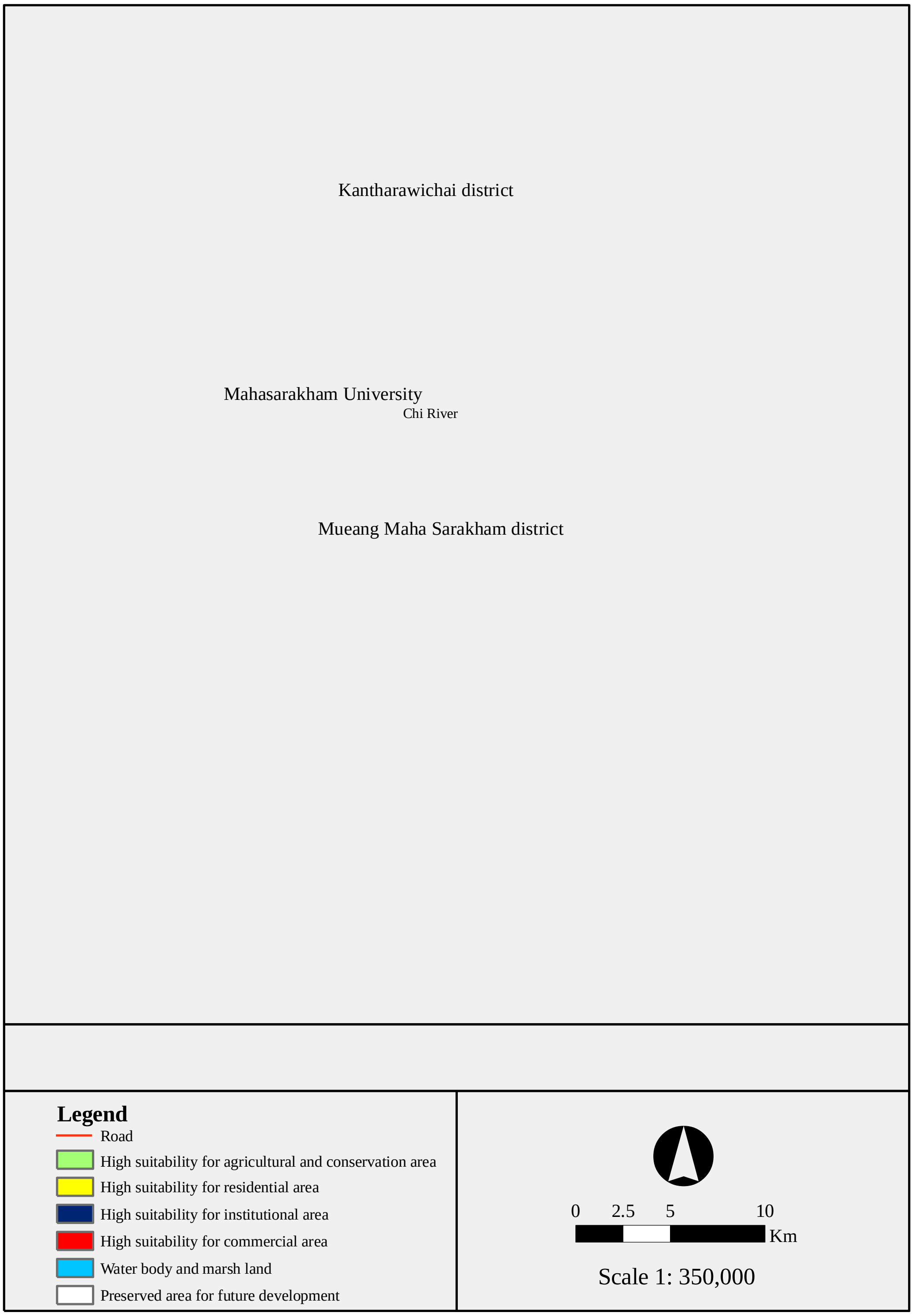


Figure 4.49 Distribution of land use types in land use plan in 2021.

Table 4.47 Transitional change matrix between LULC in 2011 and land use plan in 2021.

LULC in 2011	Land use plan in 2021						
	Agricultural / conservation area	**Residential area**	**Institutional area**	**Commercial area**	**Water body / marsh land**	**Preserved area for future development**	**Total**
Commercial (U1)	0.00	1.69	0.00	1.69	0.00	0.00	**3.38**
City and village (U2)	1.13	45.80	0.00	0.41	0.00	0.00	**47.34**
Institution (U3)	0.33	3.19	7.42	0.00	0.00	0.00	**10.94**
Dormitory (U4)	0.00	1.92	0.00	0.00	0.00	0.00	**1.92**
Real estate (U5)	0.00	1.16	0.00	0.00	0.00	0.00	**1.16**
Paddy field (A1)	699.91	0.00	0.00	0.00	0.00	0.00	**699.91**
Field crop (A2)	79.69	0.00	0.00	0.00	0.00	0.00	**79.69**
Perennial tree (A3)	0.57	0.00	0.00	0.00	0.00	0.00	**0.57**
Orchard (A4)	7.18	0.00	0.00	0.00	0.00	0.00	**7.18**
Secondary forest (F1)	5.72	18.69	4.70	2.20	0.00	23.60	**54.90**
Eucalyptus (F2)	14.33	0.00	0.00	0.00	0.00	0.00	**14.33**
Development land (M1)	2.20	6.84	2.79	0.39	0.16	0.00	**12.38**
Marsh land (M2)	0.00	0.30	0.00	0.04	4.53	0.00	**4.86**
Water (W)	0.02	0.01	0.00	0.00	38.58	0.00	**38.61**
Total	**811.09**	**79.59**	**14.91**	**4.72**	**43.27**	**23.60**	**977.16**
% of LULC	**97.07**	**61.40**	**49.78**	**35.87**	**99.63**	**100.00**	

Similarly, if the predicted LULC in 2021 compares with land use plan 2021, it revealed that most of predicted agricultural land (paddy field, field crop, perennial tree and orchard) located in high suitability for agricultural and conservation area about 96.44%. At the same time, 63.84% of city and village, dormitory and real estate situated in the high suitability for residential area and 53.59% and 53.29% of institutional and commercial located in the high suitability for institutional and commercial areas (Table 4.48). However, area of high suitability for agricultural and conservation, residential, institutional, and commercial areas in the plan were higher than predicted LULC in 2021.

Furthermore, surface runoff prediction based on an allocated land use types of the plan in 2021 was here firstly generated using SCS-CN method as shown in Figure 4.50. This result was then used to compare with a derived surface runoff from a predicted LULC in 2021 by CA-Markov model (see Figure 4.36) for identifying surface runoff change in each sub-district.

As results, it was found that the surface runoff volume deriving from land use plan data had decreased in all sub-districts when compared with data from predicted LULC as shown in Figure 4.51 and Table 4.49 shown surface runoff zonation based on its mean value deriving from land use types in land use plan. These findings imply that a well land use plan can mitigate flooding due to reducing of surface runoff, which is the major source of flooding. In addition, the derived land use plan can be used as a guideline for city plan in the future.

Table 4.48 Compare of LULC predicted in 2021 and land use plan in 2021.

Predicted LULC in 2021	Land use plan in 2021						
	Agricultural / conservation area	Residential area	Institutional area	Commercial area	Water body / marsh land	Preserved area for future development	Total
Commercial (U1)	0.01	2.10	0.00	2.51	0.00	0.00	**4.62**
City and village (U2)	3.85	47.23	0.00	0.00	0.00	0.00	**51.08**
Institution (U3)	0.33	3.19	7.99	0.00	0.00	0.00	**11.51**
Dormitory (U4)	0.00	1.98	0.00	0.00	0.00	0.00	**1.98**
Real estate (U5)	0.04	1.60	0.00	0.00	0.00	0.00	**1.63**
Paddy field (A1)	697.70	2.61	0.04	0.12	0.00	0.00	**700.47**
Field crop (A2)	77.42	1.79	0.02	0.09	0.00	0.00	**79.31**
Perennial tree (A3)	0.56	0.00	0.00	0.00	0.00	0.00	**0.56**
Orchard (A4)	6.57	0.00	0.00	0.00	0.00	0.00	**6.57**
Secondary forest (F1)	5.18	13.61	4.16	1.99	0.00	23.60	**48.53**
Eucalyptus (F2)	15.89	0.00	0.00	0.00	0.00	0.00	**15.89**
Development land (M1)	3.54	5.49	2.70	0.01	0.00	0.00	**11.74**
Marsh land (M2)	0.00	0.00	0.00	0.00	4.68	0.00	**4.68**
Water (W)	0.00	0.00	0.00	0.00	38.58		**38.58**
Total	**811.09**	**79.59**	**14.91**	**4.72**	**43.27**	**23.60**	**977.16**
% of LULC	**96.44**	**63.84**	**53.59**	**53.29**	**100.00**	**100.00**	

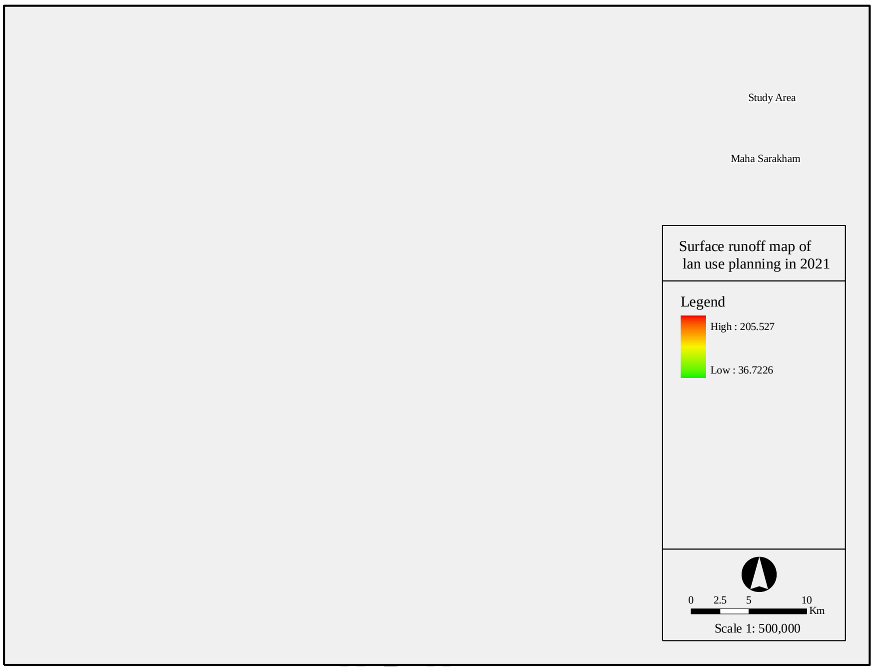


Figure 4.50 Distribution of surface runoff in land use plan in 2021.

Figure 4.51 Surface runoff zonation based on it mean value deriving from land use types in land use plan.

Table 4.49 Compare of surface runoff deriving from LULC prediction data and land use plan data in 2021.

Sub-district	Surface runoff (mm)		
	Predicted LULC data	**Land use plan data in 2021**	**Runoff Change**
Sri Suk	10,509,400	9,528,760	-980,640
Na Si Nuan	9,210,580	8,856,340	-354,240
Kok Pra	5,188,740	4,852,570	-336,170
Kan Ta Rat	3,962,360	3,708,130	-254,230
Kham Tao Pattana	5,904,150	5,530,520	-373,630
Kham Reang	9,659,870	9,147,560	-512,310
Kud Sai Jor	3,348,920	2,934,680	-414,240
Ma Kha	6,733,410	6,416,260	-317,150
Kwao Yai	8,677,800	8,122,350	-555,450
Tha Khon Yang	4,784,070	4,668,560	-115,510
Lat Pattana	9,443,890	8,899,120	-544,770
Kerng	3,992,220	3,841,200	-151,020
Tha Song Khon	8,972,150	7,128,040	-1,844,110
Tha Tum	3,717,570	3,548,050	-169,520
Kaeng Lerng Chan	4,852,160	4,261,250	-590,910
Kwao	9,002,780	8,182,830	-819,950
Waeng Nang	7,471,270	6,675,710	-795,560
Huai Aeng	2,452,870	1,998,600	-454,270
Nong No	3,758,340	3,029,720	-728,620
Nong Pling	3,386,910	2,804,790	-582,120
Kok Kor	4,803,870	3,852,470	-951,400
Don Whan	2,795,670	2,617,670	-178,000
Bua Khor	3,598,270	3,027,970	-570,300
Ta Lad	4,354,450	4,259,220	-95,230
Total	**140,581,720**	**127,892,370**	**-12,689,350**

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Under this chapter, main results according to research objectives included: (1) to quantify the characteristics of LULC and urban growth; (2) to identify urban growth impact on surface runoff and potential flood; and (3) to evaluate the existing comprehensive city plan for land use planning were here summarized. In addition some recommendations were also suggested for future research and development.

5.1 Conclusions

5.1.1 LULC assessment and its change

LULC assessment in 2001, 2006, and 2011, which were extracted from visualized interpretation of remotely sensed data under GIS environment, shown that the dominate LULC type in 2001, 2006, and 2011 were agricultural land included paddy field, field crops, perennial trees and orchards. Meanwhile, urban and built-up area included commercial, city and village, institution, dormitory and real estate had been continuously increased in these periods, especially, dormitory and real estate between 2001 and 2006.

For LULC change, urban and built-up areas in 2006 and 2011 were converted from agricultural land and forest land. Annual increment of commercial, city and village, institution, dormitory and real estate between 2001 and 2006 were about 0.16, 0.16, 0.10, 0.14, and 0.05 sq km, respectively while annual increment of them between 2006 and 2011 were 0.21, 0.90, 0.06, 0.22, and 0.16 sq km, respectively. It was found that most of urban and built-up area sub-classes had continuously increased except institution area.

Meanwhile, for accuracy assessment of LULC in 2011 based on 862 randomly stratified sampling points, it was shown that overall accuracy and Kappa hat coefficient of agreement was 98.03% and 95.85%, respectively. Herein, producer's accuracy varied between 50% and 100% while user's accuracy ranged between 81.82% and 100%.

5.1.2 Driving force for urban growth

The selected driving force for urban growth included slope, road network, per capita income, land value, population density, household density, existing comprehensive city plan, existing urban area, and new MSU campus were here used to regress with urban pattern (urban and non-urban areas) using spatial simple and multiple linear regression analysis.

For spatial simple linear regression analysis, all driving forces for urban growth included slope, road network, per capita income, land value, population density, household density, existing comprehensive city plan, existing urban area, and new MSU campus were positively relate to urban pattern (urban and non-urban areas). The highest significant driving factor in 2001 was per capita income which provided 95.04% of correlation coefficient (R) and 90.33% of coefficient of determination (R^2) while the lowest significant driving factor in 2006 was the existing comprehensive city plan which provided 6.63% of R and 0.44% of R^2. In addition, it was found that per capita income, new MSU campus, or existing urban area can be applied to explain the spatial linear relationship with urban pattern more than 50%. So, it may be here concluded that economy factor (per capita income) and existing land use pattern factor (new MSU campus and existing urban area) play an important role on urban pattern.

For spatial multiple linear regression analysis, it was found that five driving forces including (1) per capita income, (2) new MSU campus, (3) existing urban area, (4) road network, and (5) slope provided an optimum equation for urban pattern prediction in 2001 and 2006. While, six factors including (1) per capita income, (2) new MSU campus, (3) existing urban area, (4) road network, (5) slope, and (6) population density provided an optimum equation for explanation about driving force on urban pattern in 2011. The summary result of spatial multiple linear regression analysis about driving force for urban growth was shown in Table 5.1

Table 5.1 Summary of spatial multiple linear regression analysis.

Driving force	**Regression coefficients**		
	Urban pattern in 2001	Urban pattern in 2006	Urban pattern in 2011
Intercept	0.122636	0.114545	0.036709
Per capita income	1.846407	1.792075	3.092953
New MSU campus	1.454314	1.529551	0.789725
Existing urban area	1.331710	1.242943	0.604527
Road network	1.136072	1.023389	0.474570
Slope	4.702027	4.709027	1.685796
Population density	n. a.	n. a.	-1.687732
Correlation coefficient (%)	**92.4831**	**92.8710**	**96.8392**
Coefficient of determination (%)	**85.5312**	**86.2502**	**93.7784**

5.1.3 LULC prediction

Two LULC prediction models, CA-Markov and Land Change Modeler were here applied to predict the LULC in 2011 and then compared their results with the interpreted LULC in 2011 for an optimum model identification based on overall accuracy and kappa hat coefficient of agreement.

For LULC 2011 prediction using CA-Markov, it was found that overall accuracy and Kappa coefficient of agreement for predictive LULC in 2011 was 96.84% and 93.27%, respectively. At the same time, overall accuracy and Kappa coefficient of agreement for predictive LULC in 2011 using Land Change Modeler was 96.04% and 91.60%, respectively. So, CA-Markov model that provided higher accuracy than Land Change Modeler was used for LULC prediction in 2016 and 2021.

As results of LULC assessment in 2001, 2006, and 2011 and LULC prediction in 2016 and 2021 it was found that during 2001 to 2011 most of sub-classes of urban and built-up area had continuously increased except dormitory. In contrast, most of sub-classes of agricultural land had continuously decreased except field crop and sub-classes of forest land had continuously decreased in these periods. Meanwhile, for miscellaneous land marsh land had trended to decrease but development land had trended to increase in the future. At the same periods, water body was unpredictable.

In addition, future trend of sub-classes of urban and built-up areas can estimated using regression analysis by Trend Analysis of MS-Excel as summary in Table 5.2. As results, it was found the best fit for commercial, city and village, institution and real estate areas were linear regression type while the best fit for dormitory was logarithmic regression type.

Table 5.2 Spatial simple regression analysis for urban and built-up sub-classes prediction.

Urban and built-up Sub-classes	**Model Type**	**Equation**	**R^2**
Commercial areas	Linear regression	Y = 0.755X + 0.877	0.9870
City and village areas	Linear regression	Y = 2.504X + 39.096	0.9541
Institution areas	Linear regression	Y = 0.313X + 9.887	0.9319
Dormitory	Logarithm regression	Y = 1.3744ln(X) + 0.088	0.9051
Real estate	Linear regression	Y = 0.425X - 0.303	0.926

5.1.4 Urban growth characteristics

Based on interpreted and predicted LULC data, major characteristic of urban growth included (1) urban growth pattern, (2) annual growth rate (AGR), (3) urban land percentage (PU), and (4) urban land expansion index (SI) were here summarized.

For urban growth pattern according to Batty et al. (2003), it was shown that in the past urban growth pattern between 2001 and 2006 was linear strip development but urban growth pattern between 2006 and 2011 was changed to be a scattered development. In the future time, urban growth pattern between 2011 and 2016 and between 2016 and 2021 were still scattered development.

For annual growth rate (AGR) assessment and classification at 5 levels: slow, slow-speed, medium-speed, fair-speed, and high-speed expansion, based on Zhao-ling et al. (2007), the AGR in 4 periods can be summarized as shown in the Table 5.3. It was found that most of sub-districts during 2001 to 2021 had expanded at slow speed level which had AGR between 0.25% and 0.5%. However many urban areas were dramatic expanded between 2006 and 2011.

Table 5.3 Change of number of sub-district according to AGR during 2001 to 2021.

Period	Annual growth rate (AGR)				
	Slow	Slow-speed	Medium-speed	Fair-speed	High-speed
2001-2006	20	4	-	-	-
2006-2011	19	2	1	1	1
2011-2016	22	1	1	-	-
2016-2021	23	-	1	-	-

For urban land percentage (PU) assessment and classification at 5 levels: very low, low, moderate, high and very high urbanization, based on Tian et al. (2005), the PU in each year can be summarized in Table 5.4. It was found that most of sub-districts during 2001 to 2021 had urban land percentage at moderate and high urbanization level which had PU between 1% and 10%.

Table 5.4 Change of number of sub-district according to PU during 2001 to 2021.

Year	Urban land percentage (PU)				
	Very low	Low	Moderate	High	Very high
2001	-	-	15	8	1
2006	-	-	13	10	1
2011	-	-	13	7	4
2016	-	-	12	7	5
2021	-	-	10	9	5

Similarly to AGR, for urban land expansion index (SI) assessment and classification at 5 levels: no change, low, rapid, more rapid and dramatic development (Tian et al., 2005), the SI in each period can be summarized as shown in Table 5.5. It was found that most of urban area in sub-districts during 2001 to 2021 had developed at moderate level which SI between 0.1% and 1.0%.

Table 5.5 Change of number of sub-district due to SI during 2001 to 2021.

Period	Urban land expansion index (SI)				
	No change	Low	Rapid	More rapid	Dramatic
2001-2006	4	11	5	4	-
2006-2011	-	8	10	5	1
2011-2016	1	8	12	3	-
2016-2021	2	6	15	1	-

5.1.5 Surface runoff estimation and prediction

Relative surface runoff estimation in 2001, 2006, and 2011 and prediction in 2016 and 2021 was here generated based on runoff curve numbers (CN) according to hydrological soil-cover complex and maximum rainfall data using Model Builder of ArcGIS environment. It was found that the mean value of surface runoff in these periods was different from each other and its value had continuously increased.

In addition, zonal analysis was applied to extract mean value of surface runoff during 2001 to 2021 in each sub-district boundary and was reclassified by the natural break into 5 levels: low, very low, moderate, high, and very high mean surface runoff as summary in Table 5.6. It was found that number of sub-districts in each surface runoff zonation varied due to urban growth during 2001 to 2021.

Table 5.6 Change of number of sub-district due to mean surface runoff change during 2001 to 2021.

Mean surface runoff	Number of Sub-districts				
	2001	2006	2011	2016	2021
Very low	5	4	4	4	4
Low	3	4	4	3	3
Moderate	3	2	2	3	3
High	9	9	9	8	7
Very high	4	5	5	6	7
Total	24	24	24	24	24

5.1.6 Impact of urban growth on surface runoff

Impact of urban growth on surface runoff in four periods (2001-2006, 2006-2011, 2011-2016, and 2016-2021) was here summarized included: (1) impact of urban growth on surface runoff change, (2) spatial relationship between urban area change and surface runoff change, and (3) spatial relationship between urbanization and surface runoff zonation.

For impact of urban growth on surface runoff change, it was indicated that the annual runoff volume had continuously increased during 2001 to 2021 owing urban growth. This finding was confirmed by the simple linear regression analysis between the change of urban area and surface runoff. The predictive equation for surface runoff change due to urban growth with R^2 about 87.82% was obtained as follow:

$$Y = 99404 + 0.0668 X,$$

where Y is surface runoff change in mm and X is urban area change in sq m.

For spatial relationship between urban area change and surface runoff change, by using simple linear regression analysis, it was found that spatial urban area change strongly related with surface runoff change in the study area in all periods. The highest R and R^2 were 99.56% and 99.12%, respectively while the lowest R and R^2 was 98.62% and 97.26%, respectively. As results it can be concluded that when urban area was expanded, the surface runoff will be increased.

For spatial relationship between urbanization and surface runoff zonation, it was found that urbanization strongly correlated with surface runoff change in each period. The highest R and R^2 of simple linear regression was 87.80% and 77.09% from year 2016 while the lowest R and R^2 was 84.98% and 72.21% from year 2001. As results it can be concluded that when urbanization is taken place, the surface runoff change will be increased.

5.1.7 Potential flood analysis

Potential flood analysis was here evaluated using indexing model with SAW method based on relevant factors for flooding included: (1) distance to river, (2) elevation, (3) predicted surface runoff in 2011, (4) river densities, (5) road network densities, and (6) slope. It was found that moderate and high potential flood areas were situated in floodplain and terrace along Chi River covered area about 82.99 sq. km and 198.38 sq. km or about 8.49% and 20.30% of the study area, respectively. In contrary, no potential flood was located at elevation more than 170 m above MSL. Also, it was disclosed that 13 of 24 sub-districts situated in high potential flood area and number of villages located in high and moderate potential flood area was 56 and 28 villages.

In addition, potential flood classification was highly related with urban land percentage (urbanization) in 2011 of each sub-district. The derived R and R^2 was 83.96% and 70.49%, respectively. The simple linear regression equation between urban area percentage (X) and potential flood classification (Y) was:

$$Y = 0.040530 + 0.795322 X.$$

For potential flood data validation, it revealed that extracted frequency flood data of GISTDA during 2005 to 2011 were located in moderate and high potential flood areas more than 60%. In fact, most of flooded areas during 2005 to 2011 were located in moderate and high potential flood areas covered area of 37.84 sq. km and 98.29 sq. km, respectively or about 45.60% and 49.57% of its potential flood area, respectively. At the same time, some of flooded areas were located in very low and low potential flood areas covered area of 24.46 sq. km and 60.52 sq km, respectively or about 9.07% and 23.34% of its potential flood area, respectively. Meanwhile only 2.12% of no potential flood area was flooded during 2005 to 2011.

5.1.8 Evaluation of the existing city plan and land use plan

Evaluation of the existing city plan and land use plan for flooding mitigation using spatial analysis were here summarized.

For the existing city plan evaluation, it was found that area of urban and built-up (commercial, city and village, institution, dormitory and real estate) in 2011 was less that area of urban and built-up area in city plan about 41.57%. Meanwhile, many LULC types in 2011 were located in rural and agriculture and conservation for rural and agricultural areas about 9.88% and barren land for recreation and environmental quality and barren land for environmental quality areas about 9.05%.

Both figures were not more than 10% as suggestion in city plan announcement by Public Works and Town & Country Planning in 2012. Similarly, area of predicted urban and built-up in 2016 was less that area of urban and built-up area in city plan about 41.52%. Meanwhile, many LULC types in 2016 were located in rural and agriculture and conservation for rural and agricultural areas about 9.98% and barren land for recreation and environmental quality and barren land for environmental quality areas about 9.23%. Both figures were not more than 10% as suggestion in city plan announcement too. These results imply that city plan at Tha Khon Yang – Kham Reang community and Mueang Maha Sarakham between 2012 and 2016 could support the growth of predicted LULC in 2021.

For land use planning of Mueang Maha Sarakham and Kantharawichai district in 2021 using Index model with SAW method, it was found that the most of suitable land use allocation was agricultural and conservation area covered area of 811.09 sq km or 83.00%. At the same time, the least suitable land use allocation was commercial area covered area of 4.72 sq km or 0.48%.

In addition, when land use plan 2021 compared with LULC in 2011, most of existing agricultural land was located in high suitability for agricultural and conservation area about 97.07%. At the same time, 61.40% of city and village, dormitory and real estate were situated in the high suitability for residential area while 49.78% and 35.87% of institution and commercial areas were located in the high suitability for institutional and commercial area. However, area of high suitability for agricultural and conservation, residential, institutional, and commercial areas in the plan were higher than predicted LULC in 2021. These phenomena can be also observed when land use plan 2021 compared with predicted LULC in 2021.

Furthermore, when surface runoff deriving from land use plan data and from predicted LULC in 2021 was compared, it was found that the surface runoff volume deriving from land use plan data had decreased in all sub-districts. Similarly, surface runoff zonation based its mean value deriving from land use plan data in each sub-district shown the better result than from predicted LULC in 2021. These findings show that a well land use plan can mitigate flooding because of reducing of surface runoff, which is the major source of flooding.

In conclusion, it appears that the geoinformatics technology can be used as a tool for LULC change and environment impact assessment due to urban growth, especially impact on surface runoff.

5.2 Recommendations

The possible recommendations could be made for future research and development.

(1) Driving force on urban growth analysis. It should be investigated more significant driving factors especially socio-economic and policy. In addition, minimum spatial unit for spatial analysis should be village's boundary instead district's boundary.

(2) Impact of urban growth study. It should include garbage, waste water, dust, and road accident.

(3) Potential flood analysis. The relevant factors deriving from low resolution DEM include as slope, elevation, road network density and river density should be extracted from high resolution DEM.

REFERENCES

REFERENCES

Aguayo, I. M., Wiegand, T., Azocar, D. G., Wiegand, K. and Vega, E. C. (2007). Revealing the driving forces of mid-cities urban growth patterns using spatial modeling: a case study of Los Angeles, Chile. **Ecology and Society**. 12(1): 13.

Balzter, H., Braun, P. W. and Köhler, W. (1998). Cellular automata models for vegetation dynamics. **Ecological Modelling**. 107: 113-125.

Bapalu, G. V. and Sinha, R. (2005). GIS in Flood Hazard Mapping: a case study of Kosi River Basin, India. [On-line]. Available: http://www.gisdevelopment.net/application/natural_hazards/floods/floods001pf.htm.

Batty, M., Xie, Y. and Sun, Z. (1999). Modeling urban dynamics through GIS-based Cellular Automata. **Computers, Environments and Urban Systems**. 233: 205-233.

Batty, M., Besussi, E. and Chin, N. (2003). **Traffic, Urban Growth and Suburban Sprawl**. London, University College London, London.

Benenson, I. and Torrens, M. P. (2004). **Geosimulation: automata-based modeling of urban phenomena**. Hoboken, NJ: John Wiley & Sons.

Bürgi, M., Hersperger, M. A. and Schneeberger, N. (2004). Driving forces of landscape change-current and new directions. **Landscape Ecology**. 19: 857-868.

Camarasa-Belmonte A.M. and Soriano-García J. (2012). Flood risk assessment and mapping in peri-urban mediterranean environments using hydrogeomorphology: Application to ephemeral streams in the Valencia region (eastern Spain). **Landscape and Urban Planning**. 104: 189-200.

Calson, T. N. (2004). Analysis and prediction of surface runoff in an urbanizing watershed using satellite imagery. **Journal of the American Water Resources Association**. 40(4): 1087-1098.

Chen, J., Hill, A. A. and Urbano D. L. (2009). A GIS-based model for urban flood inundation. **Journal of Hydrology**. 373: 184-192.

Clarke, K. C. and Gaydos, L. (1998). Loose-coupling a cellular automaton model and GIS: long-term urban growth prediction for San Francisco and Washington/Baltimore. **International Journal of Geographic Information Science**. 12(7): 699-714.

Department of Public Works and Town & Country Planning (2010). **Database Establish and Analysis for Regional Planning: Ranong, Phang Nga, Phuket, Krabi and Trang Provincial Cluster**. Bangkok, Thailand.

Department of Provincial Administration. (2010). Population statistics. [On-line]. Available: http://stat.dopa.go.th/xstat/popstat.html.

Ebrahimian, M., See, L. F., Ismail, M. H. and Malek, I. A. (2009). Application of Natural Resources Conservation Service-Curve Number method for runoff estimation with GIS in the Kardeh Watershed, Iran. **European Journal of Scientific Research**. 34(4): 575-590.

Elhakeem, M. and Papanicolaou, A. N. (2009). Estimation of the runoff curve number via direct rainfall simulator measurements in the State of Iowa, USA. **Water Resource Management**. 23: 2455-2473.

Fan, F., Wang, Y. and Wang, Z. (2008). Temporal and spatial change detecting (1998-2003) and predicting of land use and land cover in Core corridor of Pearl River Delta (China) by using TM and ETM+ images. **Environmental Monitoring and Assessment**. 137: 127-147.

Fang, S., Gertner, G. Z., Sun, Z. and Anderson, A. (2004). The impact of interactions in spatial simulation of the dynamics of urban sprawl. **Landscape and Urban Planning**. 73: 294-306.

Frumkin, H. (2002). Urban sprawl and public health. **Public Health Reports**. 117: 201-217.

Henriques, C. and Tenedorio, A. J. (2010). Mapping Urban Change to Plan the Future: Maputo City Change Model and the Municipal Structure Plan. **Remote Sensing for Science, Education, and Natural and Cultural Heritage**. 139-146.

Kandilioti, G. and Makropoulos, C. (2011). **Preliminary flood risk assessment: the case of Athens**. National Technical University of Athens. Athens, Greece.

Kenyon, W. (2007). Evaluating flood risk management options in Scotland: A participant-led multi-criteria approach. **Ecological economics**. 64: 70-81.

Land Development Department. (2009). **Land Use Classification**. Bangkok, Thailand.

Landis, J. and Koch, G. (1977). The measurement of observer agreement for categorical data. **Biometrics**. 33: 159-174.

Landis, J. D. (1995). Imagining land use futures: applying the California urban futures model. **Journal of the American Planning Association**. 61(4): 438-457.

Li, X. and Yeh, G. A. (2000). Modelling sustainable urban development by the integration of constrained cellular automata and GIS. **International Journal of Geographical Information Science**. 14(2): 131-152.

Lin, Y., Lin, Y., Wang, Y. and Hong, N. (2008). Monitoring and predicting land-use changes and the hydrology of the Urbanized Paochiao watershed in Taiwan using remote sensing data, urban growth models and a hydrological model. **Sensors**. 8: 658-680.

Liu, X. and Li, J. (2008). Application of SCS model in estimation of runoff from small watershed in Loess Plateau of China. **Chinese Geographical Science**. 18(3): 235-241.

Lopez, E., Bocco, G., Mendoza, M. and Duhau, E. (2001). Predicting land-cover and land-use change in the urban fringe a case in Morelia city, Mexico. **Landscape and Urban Planning**. 55: 271-285.

Ma, Y. and Xu, R. (2010). Remote sensing monitoring and driving force analysis of urban expansion in Guangzhou City, China. **Habitat International**. 34: 228-235.

Mahasarakham University. (2011). Student statistics. [On-line]. Available: http://www.web.msu.ac.th/msumis.

Malczewski, J. (1999). **GIS and Multicriteria Decision Analysis**. New York: John Wiley and Sons.

McColl, C. and Aggett, G. (2007). Land-use forecasting and hydrologic model integration for improved land-use decision support. **Journal of Environmental Management**. 84: 494-512.

Meyer, W. B. and Turner, B. L. (1994). **Changes in land use and land cover : a global perspective**. Cambridge University Press. NY, USA.

Mishra, B. K., Takara, K. and Tachikawa, Y. (2008). **NRCS Curve Number based hydrologic regionalization of Nepalese river basins for flood frequency analysis**. Annuals of Disaster Prevention Research Institute, Kyoto University 51B: 93-102.

Ongsomwang, S. and Suravisutra, A. (2011). Optimum Predictive Model for Urban Growth Prediction. **Suranaree Journal of Science and Technology**. 18(2): 141-152.

Pérez-Vega, A., Jean-Francois, M. and Ligmann-Zielinska, A. (2012). Comparing two approaches to land use/cover change modeling and their implications for the assessment of biodiversity loss in a deciduous tropical forest. **Environmental Modelling & Software**. 29: 11-23.

Rattanakom, R. and Ongsomwang, S. (2008). The Application of GIS for Flood Risk Area Analysis in Ubon Ratchathani Province. **Journal of Remote Sensing and GIS Association of Thailand**. 9(2): 42-48. (in Thai)

Shaw, S. B. and Walter, M. T. (2009). Improving runoff risk estimates: Formulating runoff as a bivariate process using the SCS curve number method. **Water Resources Research**. 45: 1-10.

Sinha, R., Bapalu, G.V., Singh, L. K. and Rath, B. (2008). Flood risk analysis in the Kosi River Basin, North Bihar using multi-parametric approach of analytical hierarchy process (AHP). **Journal of the Indian Society of Remote Sensing**. 36: 335-349.

Tewolde, G. M. and Cabral, P. (2011). Urban Sprawl Analysis and Modeling in Asmara, Eritrea. **Remote Sensing**. 3: 2148-2165.

Thapa, R. B. and Murayama, Y. (2010). Drivers of urban growth in the Kathmandu valley, Nepal: Examining the efficacy of the analytic hierarchy process. **Applied Geography**. 30: 70-83.

Tian, G., Liu, J., Xie, Y., Yang, Z., Zhuang, D. and Niu, Z. (2005). Analysis of spatio-temporal dynamic pattern and driving forces of urban land in China in 1990s using TM images and GIS. **Cities**. 22(6): 400-410.

Tripathi, P. M., Panda, K. R., Pradhan, S. and Sudhakar, S. (2002). Runoff modelling of a small watershed using satellite data and GIS. **Journal of the Indian Society of Remote Sensing**. 30(1-2): 39-52.

U. S. Department of Agriculture. (1986). Urban hydrology for small watersheds: TR-55. Natural Resources Conservation Service, Conservation Engineering Division. [On-line]. Available: ftp://ftp.wcc.nrcs.usda.gov/downloads/hydrology_hydraulics/tr55/tr55.pdf.

Wang, X. and Jin, J. (2001). Assessing the impact of urban growth on flooding with an integrated Curve Number-Flow Accumulation approach. **Water International**. 26(2): 215 -222.

Wang, Y. and Zhang, X. (2001). A dynamic modeling approach to simulating socioeconomic effects on landscape changes. **Ecological Modelling**. 140: 141-162.

Water Science for Schools. (2012). The effects of urbanization on water quality: Urban runoff. [On-line]. Available: http://ga.water.usgs.gov/edu/urbanrun.html.

Weng, Q. (2001). Modeling urban growth effects on surface runoff with the integration of remote sensing and GIS. **Environmental Management**. 28(6): 737-748.

Weng, Q. (2002). Land use change analysis in the Zhujiang Delta of China using satellite remote sensing, GIS and stochastic modeling. **Journal of Environmental Management**. 64: 273-284.

Wu, F. (2002). Calibration of stochastic cellular automata: the application to rural-urban land conversions. **International Journal of Geographical Information Science**. 16(8): 795-818.

Wu, Q., Li, H., Wang, R., Paulussen, J., He, Y., Wang, M., Wang, B. and Wang, Z. (2006). Monitoring and predicting land use change in Beijing using remote sensing and GIS. **Landscape and Urban Planning**. 78: 322-333.

Ye, B. and Bai, Z. (2008). Simulating land use/cover changes of Nenjiang County based on CA-Markov model. **International Federation for Information Processing, Advances in Information and Communication Technology**. 258: 321-329.

Zhao-ling, H., Pei-Jun, D. and Da-zhi, G. (2007). Analysis of Urban Expansion and Driving Forces in Xuzhou City Based on Remote Sensing. **Journal of China University of Mining & Technology**. 17(2): 0267-0271.

Zondag, B. and Borsboom, J. (2009). **Driving forces of land-use change**. Netherlands Environmental Assessment Agency (PBL), NL.

Zoppou, C. (2001). Review of urban storm water models. **Environmental Modelling & Software**. 16: 195-231.

APPENDICES

APPENDIX A

VISUAL INTERPRETATION KEYS

Figure A-1 Characteristics of satellite image and LULC pattern in commercial area (U1).

Figure A-2 Characteristics of satellite image and LULC pattern in city and village (U2).

Figure A-3 Characteristics of satellite image and LULC pattern in institution area (U3).

Figure A-4 Characteristics of satellite image and LULC pattern in dormitory area (U4).

Figure A-5 Characteristics of satellite image and LULC pattern in real estate area (U5).

Figure A-6 Characteristics of satellite image and LULC pattern in paddy field (A1).

Figure A-7 Characteristics of satellite image and LULC pattern in field crop (A2).

Figure A-8 Characteristics of satellite image and LULC pattern in perennial tree (A3).

Figure A-9 Characteristics of satellite image and LULC pattern in orchard (A4).

Figure A-10 Characteristics of satellite image and LULC pattern in secondary forest land (F1).

Figure A-11 Characteristics of satellite image and LULC pattern in eucalyptus area (F2).

Figure A-12 Characteristics of satellite image and LULC pattern in development land (M1).

Figure A-13 Characteristics of satellite image and LULC pattern in marsh land (M2).

Figure A-14 Characteristics of satellite image and LULC pattern in water body (W).

APPENDIX B

SAMPLE POINTS FOR ACCURACY ASSESSMENT

Table B-1 Sample points for LULC accuracy assessment.

ID	X UTM	Y UTM	Visual interpretation	Ground reference
1	315794	1765883	Eucalyptus	Eucalyptus
2	312794	1766783	Paddy field	Paddy field
3	314294	1767143	Paddy field	Paddy field
4	318404	1767143	Paddy field	Paddy field
5	319664	1767293	Field crop	Field crop
6	320384	1767353	Eucalyptus	Eucalyptus
7	318164	1767413	Secondary forest	Secondary forest
8	316844	1767443	Field crop	Field crop
9	318404	1767503	Paddy field	Paddy field
10	314354	1767623	Paddy field	Paddy field
11	314204	1767653	Paddy field	Paddy field
12	320504	1767653	Paddy field	Paddy field
13	319544	1767743	Paddy field	Paddy field
14	319874	1767923	Paddy field	Paddy field
15	318584	1767953	Paddy field	Paddy field
16	314114	1768163	Paddy field	Paddy field
17	314684	1768283	Paddy field	Paddy field
18	318104	1768403	Paddy field	Paddy field
19	319604	1768433	Field crop	Field crop
20	312884	1768523	Paddy field	Paddy field
21	315794	1768553	Paddy field	Paddy field
22	321704	1768553	Paddy field	Paddy field
23	314714	1768613	Paddy field	Paddy field
24	318044	1768703	Paddy field	Paddy field
25	320324	1768703	Paddy field	Paddy field
26	320054	1769213	Paddy field	Paddy field
27	313304	1769393	Secondary forest	Secondary forest
28	311834	1769483	Field crop	Field crop
29	310754	1769663	Paddy field	Paddy field
30	318704	1769813	Paddy field	Paddy field
31	313814	1769933	Paddy field	Paddy field
32	309704	1770173	Paddy field	Paddy field
33	314624	1770233	Field crop	Field crop
34	313904	1770383	Secondary forest	Secondary forest
35	322274	1770413	Paddy field	Paddy field
36	311384	1770503	Field crop	Field crop
37	318344	1770623	Paddy field	Paddy field
38	313514	1770773	Paddy field	Paddy field
39	310724	1770863	Paddy field	Paddy field
40	321914	1770863	City and village	City and village
41	321374	1770953	Paddy field	Paddy field
42	312044	1771073	Paddy field	Paddy field
43	319694	1771073	City and village	City and village
44	321044	1771193	Paddy field	Paddy field
45	317804	1771223	Paddy field	Paddy field
46	317894	1771223	Paddy field	Paddy field
47	320354	1771283	Paddy field	Paddy field
48	315044	1771373	Paddy field	Paddy field

Table B-1 (Continued).

ID	X UTM	Y UTM	Visual interpretation	Ground reference
49	309914	1771403	Field crop	Field crop
50	315044	1771403	Paddy field	Paddy field
51	315284	1771403	Orchard	Orchard
52	322334	1771583	Secondary forest	Secondary forest
53	310934	1771763	Paddy field	Paddy field
54	320774	1771763	Paddy field	Paddy field
55	309704	1771913	Paddy field	Paddy field
56	321554	1771913	Paddy field	Paddy field
57	321704	1772033	Paddy field	Paddy field
58	314654	1772123	Field crop	Field crop
59	310574	1772273	Paddy field	Paddy field
60	318074	1772273	Paddy field	Paddy field
61	310544	1772453	Paddy field	Paddy field
62	309464	1772483	Field crop	Field crop
63	320924	1772633	Paddy field	Paddy field
64	314774	1772723	City and village	City and village
65	312584	1773023	Paddy field	Paddy field
66	315284	1773443	Water	Water
67	316154	1773623	Paddy field	Paddy field
68	312644	1773683	Field crop	Field crop
69	319964	1773743	Field crop	Field crop
70	308834	1773833	Paddy field	Paddy field
71	319904	1773923	Field crop	Field crop
72	315944	1773953	Secondary forest	Secondary forest
73	319934	1773953	Field crop	Field crop
74	313784	1774073	Paddy field	Paddy field
75	310124	1774103	Field crop	Field crop
76	308984	1774163	Field crop	Field crop
77	319544	1774313	Secondary forest	Secondary forest
78	318824	1774343	Field crop	Field crop
79	314084	1774373	Paddy field	Paddy field
80	319394	1774403	Secondary forest	Secondary forest
81	316634	1774613	Secondary forest	Secondary forest
82	317624	1774643	Secondary forest	Secondary forest
83	309464	1774673	Eucalyptus	Eucalyptus
84	311444	1774673	Paddy field	Paddy field
85	320744	1774943	Paddy field	Paddy field
86	319484	1775003	Field crop	Field crop
87	320084	1775033	Paddy field	Paddy field
88	320954	1775063	Paddy field	Paddy field
89	315044	1775333	Paddy field	Paddy field
90	314894	1775363	City and village	City and village
91	312764	1775393	Paddy field	Paddy field
92	318434	1775453	Secondary forest	Secondary forest
93	319814	1775483	Field crop	Field crop
94	320144	1775633	Paddy field	Paddy field
95	311654	1775693	Paddy field	Paddy field

Table B-1 (Continued).

ID	X UTM	Y UTM	Visual interpretation	Ground reference
96	313124	1775873	Paddy field	Paddy field
97	318194	1775903	Paddy field	Paddy field
98	319274	1775903	Eucalyptus	Eucalyptus
99	317204	1775933	Paddy field	Paddy field
100	312824	1775993	Paddy field	Paddy field
101	312794	1776173	Paddy field	Paddy field
102	316004	1776203	Paddy field	Paddy field
103	319634	1776443	Secondary forest	Secondary forest
104	312674	1776473	Field crop	Field crop
105	316364	1776503	Paddy field	Paddy field
106	314234	1776563	Field crop	Field crop
107	320354	1776653	Paddy field	Paddy field
108	313064	1776743	Field crop	Field crop
109	317654	1777133	Paddy field	Paddy field
110	316934	1777163	Paddy field	Paddy field
111	320204	1777193	Paddy field	Paddy field
112	319784	1777253	Secondary forest	Secondary forest
113	321404	1777253	Paddy field	Paddy field
114	313154	1777283	City and village	City and village
115	321434	1777433	City and village	City and village
116	313874	1777463	Paddy field	Paddy field
117	315614	1777463	Paddy field	Paddy field
118	316964	1777463	Paddy field	Paddy field
119	321494	1777523	Paddy field	Paddy field
120	320624	1777763	Secondary forest	Secondary forest
121	313874	1777883	Paddy field	Paddy field
122	319034	1778093	Water	Water
123	317474	1778213	Field crop	Field crop
124	321374	1778543	Field crop	Field crop
125	315464	1778633	Secondary forest	Secondary forest
126	318224	1778723	City and village	City and village
127	313604	1778753	Paddy field	Paddy field
128	314354	1778843	Paddy field	Paddy field
129	316844	1778903	Paddy field	Paddy field
130	320354	1778933	Paddy field	Paddy field
131	320894	1778963	Paddy field	Paddy field
132	319004	1779083	Paddy field	Paddy field
133	314084	1779233	Paddy field	Paddy field
134	319244	1779233	Paddy field	Paddy field
135	321224	1779293	Paddy field	Paddy field
136	313454	1779833	Paddy field	Paddy field
137	310424	1779863	Paddy field	Paddy field
138	322214	1779893	Paddy field	Paddy field
139	312944	1779923	Paddy field	Paddy field
140	312974	1779983	Paddy field	Paddy field
141	315194	1780013	Paddy field	Paddy field
142	310574	1780043	Paddy field	Paddy field
143	323054	1780163	Paddy field	Paddy field

Table B-1 (Continued).

ID	X UTM	Y UTM	Visual interpretation	Ground reference
144	313754	1780223	Paddy field	Paddy field
145	309254	1780403	Secondary forest	Secondary forest
146	318134	1780553	Secondary forest	Secondary forest
147	309554	1780613	Eucalyptus	Field crop
148	318824	1780643	Paddy field	Paddy field
149	320174	1780763	Field crop	Field crop
150	314774	1780793	Paddy field	Paddy field
151	315554	1780793	Paddy field	Paddy field
152	312674	1780823	Field crop	Field crop
153	316214	1780853	Paddy field	Paddy field
154	311384	1781093	Paddy field	Paddy field
155	312104	1781093	Paddy field	Paddy field
156	315794	1781093	Paddy field	Paddy field
157	317474	1781153	Secondary forest	Secondary forest
158	311384	1781183	Paddy field	Paddy field
159	315524	1781183	Secondary forest	Secondary forest
160	320864	1781243	Paddy field	Paddy field
161	310424	1781363	Field crop	Field crop
162	310724	1781393	Paddy field	Paddy field
163	317414	1781423	Field crop	Field crop
164	319184	1781423	Field crop	Field crop
165	317234	1781723	Orchard	Orchard
166	312434	1781783	City and village	City and village
167	319064	1781813	Paddy field	Paddy field
168	312194	1781843	City and village	City and village
169	313574	1781873	Secondary forest	Secondary forest
170	316274	1781933	Paddy field	Paddy field
171	322334	1782053	Paddy field	Paddy field
172	321254	1782083	Paddy field	Paddy field
173	322154	1782113	Paddy field	Paddy field
174	322994	1782113	Paddy field	Paddy field
175	317444	1782143	Field crop	Field crop
176	331214	1782143	Paddy field	Paddy field
177	317264	1782263	Paddy field	Paddy field
178	320474	1782263	Paddy field	Paddy field
179	320534	1782323	Secondary forest	Secondary forest
180	334364	1782323	Water	Water
181	314504	1782473	Paddy field	Paddy field
182	330284	1782503	Paddy field	Paddy field
183	332684	1782713	Field crop	Field crop
184	323504	1782773	Paddy field	Paddy field
185	311624	1782803	Paddy field	Paddy field
186	319844	1782863	Paddy field	Paddy field
187	333794	1782863	City and village	City and village
188	312224	1782953	Paddy field	Paddy field
189	315464	1782953	Paddy field	Paddy field
190	330884	1782983	Paddy field	Paddy field
191	320204	1783043	Paddy field	Paddy field

Table B-1 (Continued).

ID	X UTM	Y UTM	Visual interpretation	Ground reference
192	329174	1783043	Paddy field	Paddy field
193	333434	1783073	Paddy field	Paddy field
194	317384	1783103	Secondary forest	Secondary forest
195	328424	1783133	Institution	Institution
196	329564	1783133	Paddy field	Paddy field
197	326264	1783223	Paddy field	Paddy field
198	322814	1783253	Paddy field	Paddy field
199	313304	1783283	Paddy field	Paddy field
200	314624	1783283	Paddy field	Paddy field
201	332534	1783283	Paddy field	Paddy field
202	333434	1783313	Paddy field	Paddy field
203	333824	1783313	Paddy field	Paddy field
204	329594	1783403	Paddy field	Paddy field
205	331034	1783673	Paddy field	Paddy field
206	327554	1783703	Paddy field	Paddy field
207	332954	1783733	Paddy field	Paddy field
208	311204	1783763	Paddy field	Paddy field
209	318704	1783763	Paddy field	Paddy field
210	334094	1783763	Paddy field	Paddy field
211	317414	1783823	Paddy field	Paddy field
212	321824	1783853	Paddy field	Paddy field
213	323474	1783973	Paddy field	Paddy field
214	331124	1783973	Paddy field	Paddy field
215	327944	1784033	Paddy field	Paddy field
216	300884	1784063	Paddy field	Paddy field
217	321494	1784063	Paddy field	Paddy field
218	324794	1784183	Paddy field	Paddy field
219	320654	1784243	Paddy field	Paddy field
220	331064	1784243	Paddy field	Paddy field
221	314384	1784303	Paddy field	Paddy field
222	310034	1784363	Field crop	Field crop
223	328364	1784423	Paddy field	Paddy field
224	302234	1784483	Field crop	Field crop
225	330104	1784483	Field crop	Field crop
226	335024	1784483	Field crop	Field crop
227	330944	1784513	Paddy field	Paddy field
228	315284	1784633	Paddy field	Paddy field
229	315494	1784633	Paddy field	Paddy field
230	322184	1784633	Orchard	Orchard
231	315014	1784663	Water	Water
232	335744	1784723	Field crop	Field crop
233	327344	1784813	City and village	City and village
234	312434	1784963	Institution	Institution
235	318404	1784963	Paddy field	Paddy field
236	309464	1785083	Paddy field	Paddy field
237	325574	1785083	Field crop	Field crop
238	318914	1785113	Marsh land	Marsh land
239	319844	1785113	City and village	City and village

Table B-1 (Continued).

ID	X UTM	Y UTM	Visual interpretation	Ground reference
240	314774	1785143	Field crop	Field crop
241	334244	1785143	Water	Water
242	327584	1785263	Secondary forest	Secondary forest
243	302114	1785293	Paddy field	Paddy field
244	332174	1785293	Field crop	Field crop
245	329744	1785353	Field crop	Field crop
246	328034	1785413	Paddy field	Paddy field
247	310874	1785443	Paddy field	Paddy field
248	313304	1785443	City and village	City and village
249	316634	1785473	Paddy field	Paddy field
250	304034	1785503	Eucalyptus	Eucalyptus
251	325424	1785533	Field crop	Field crop
252	334904	1785563	Paddy field	Paddy field
253	324074	1785623	Field crop	Field crop
254	330194	1785653	Institution	Institution
255	302084	1785683	Paddy field	Paddy field
256	330884	1785743	Field crop	Field crop
257	331544	1785803	Field crop	Field crop
258	316274	1785833	Paddy field	Paddy field
259	317204	1785863	City and village	City and village
260	332384	1785863	City and village	City and village
261	318794	1785923	City and village	City and village
262	322154	1785923	Field crop	Field crop
263	319094	1785953	Institution	Institution
264	325574	1786043	Field crop	Field crop
265	301904	1786073	Field crop	Field crop
266	312434	1786103	Paddy field	Paddy field
267	317324	1786133	Orchard	Orchard
268	318494	1786133	Field crop	Field crop
269	327344	1786133	Paddy field	Paddy field
270	302054	1786193	Paddy field	Paddy field
271	313094	1786193	Paddy field	Paddy field
272	314294	1786193	City and village	City and village
273	333494	1786193	Paddy field	Paddy field
274	312404	1786223	Paddy field	Paddy field
275	323984	1786223	Field crop	Field crop
276	307814	1786283	Paddy field	Paddy field
277	315944	1786283	Paddy field	Paddy field
278	316934	1786283	Paddy field	Paddy field
279	333974	1786433	Paddy field	Paddy field
280	302114	1786463	Paddy field	Paddy field
281	323624	1786523	Paddy field	Paddy field
282	320354	1786553	Field crop	Field crop
283	302144	1786583	Paddy field	Paddy field
284	327464	1786613	Paddy field	Paddy field
285	302954	1786643	Field crop	Field crop
286	317414	1786643	Paddy field	Paddy field
287	309404	1786703	Paddy field	Paddy field

Table B-1 (Continued)**.**

ID	X UTM	Y UTM	Visual interpretation	Ground reference
288	328334	1786703	Paddy field	Paddy field
289	300734	1786733	Field crop	Field crop
290	302774	1786763	Paddy field	Paddy field
291	302204	1786793	Paddy field	Paddy field
292	309914	1786883	City and village	City and village
293	311804	1786883	Paddy field	Paddy field
294	327134	1786883	Paddy field	Paddy field
295	328994	1786883	Paddy field	Paddy field
296	302894	1786913	Paddy field	Paddy field
297	319634	1786913	Development land	Development land
298	325484	1786913	Water	Water
299	311444	1786943	Paddy field	Paddy field
300	327944	1786943	Paddy field	Paddy field
301	336074	1786943	Paddy field	Paddy field
302	305054	1786973	Paddy field	Paddy field
303	322184	1786973	Paddy field	Paddy field
304	323264	1787003	Paddy field	Paddy field
305	332204	1787063	Paddy field	Paddy field
306	316994	1787093	Paddy field	Paddy field
307	311954	1787183	Paddy field	Paddy field
308	314954	1787183	Paddy field	Paddy field
309	320594	1787183	Paddy field	Paddy field
310	316934	1787213	Paddy field	Paddy field
311	319814	1787213	City and village	City and village
312	314564	1787333	Water	Water
313	322604	1787393	City and village	Real estate
314	324944	1787423	Paddy field	Paddy field
315	335564	1787423	Paddy field	Paddy field
316	300974	1787453	Paddy field	Paddy field
317	332654	1787483	Paddy field	Paddy field
318	299144	1787573	Field crop	Field crop
319	326894	1787603	Paddy field	Paddy field
320	331874	1787603	Paddy field	Paddy field
321	310604	1787633	Paddy field	Paddy field
322	335654	1787693	Paddy field	Paddy field
323	306224	1787723	Paddy field	Paddy field
324	331064	1787723	Paddy field	Paddy field
325	332084	1787723	Paddy field	Paddy field
326	301364	1787783	Field crop	Field crop
327	327134	1787783	Paddy field	Paddy field
328	303974	1787843	Paddy field	Paddy field
329	331814	1787903	Paddy field	Paddy field
330	326354	1787963	Paddy field	Paddy field
331	335774	1787993	Paddy field	Paddy field
332	324824	1788113	Paddy field	Paddy field
333	331184	1788113	Paddy field	Paddy field
334	338054	1788173	Field crop	Field crop
335	314744	1788233	Water	Water

Table B-1 (Continued).

ID	X UTM	Y UTM	Visual interpretation	Ground reference
336	315134	1788353	Paddy field	Paddy field
337	301184	1788383	Field crop	Field crop
338	309584	1788413	Paddy field	Field crop
339	320684	1788443	City and village	City and village
340	310064	1788473	Field crop	Field crop
341	335324	1788473	Paddy field	Paddy field
342	318974	1788533	City and village	City and village
343	319244	1788533	City and village	Commercial
344	328244	1788533	Paddy field	Paddy field
345	337424	1788593	Paddy field	Paddy field
346	318524	1788683	Paddy field	Paddy field
347	332654	1788683	Paddy field	Paddy field
348	305444	1788743	Paddy field	Paddy field
349	311144	1788743	Paddy field	Paddy field
350	312284	1788773	Paddy field	Paddy field
351	300944	1788803	Paddy field	Paddy field
352	337484	1788803	Paddy field	Paddy field
353	317924	1788833	Marsh land	Marsh land
354	324614	1788863	Paddy field	Paddy field
355	327404	1788893	Paddy field	Paddy field
356	331184	1788923	Paddy field	Paddy field
357	315554	1788953	Institution	Institution
358	315314	1788983	Paddy field	Paddy field
359	306854	1789043	Paddy field	Paddy field
360	311234	1789103	Paddy field	Paddy field
361	314414	1789133	Water	Water
362	333044	1789133	Paddy field	Paddy field
363	332054	1789163	Paddy field	Paddy field
364	334484	1789193	Paddy field	Paddy field
365	300824	1789253	Paddy field	Paddy field
366	302024	1789253	Field crop	Field crop
367	324974	1789253	Paddy field	Paddy field
368	325964	1789253	Paddy field	Paddy field
369	313124	1789283	Paddy field	Paddy field
370	302744	1789403	Paddy field	Paddy field
371	314264	1789403	Paddy field	Paddy field
372	326084	1789403	Paddy field	Paddy field
373	330704	1789403	Paddy field	Paddy field
374	306884	1789433	Paddy field	Paddy field
375	313184	1789433	Paddy field	Paddy field
376	301184	1789463	Perennial tree	Perennial tree
377	310574	1789553	Paddy field	Paddy field
378	324824	1789613	Paddy field	Paddy field
379	311684	1789643	Water	Marsh land
380	334604	1789643	Water	Water
381	310964	1789703	Paddy field	Paddy field
382	317834	1789703	Development land	Development land
383	314564	1789733	Water	Water

Table B-1 (Continued).

ID	X UTM	Y UTM	Visual interpretation	Ground reference
384	319214	1789823	Commercial	Commercial
385	334244	1789823	Paddy field	Paddy field
386	299414	1789853	Paddy field	Paddy field
387	330104	1789913	Paddy field	Paddy field
388	333614	1789913	Paddy field	Paddy field
389	329444	1789943	Field crop	Field crop
390	323384	1790003	Paddy field	Paddy field
391	308804	1790063	Secondary forest	Secondary forest
392	323984	1790063	Paddy field	Paddy field
393	332984	1790093	Paddy field	Paddy field
394	320564	1790123	Paddy field	Paddy field
395	327524	1790123	Paddy field	Paddy field
396	311594	1790153	Paddy field	Paddy field
397	316064	1790153	Paddy field	Paddy field
398	306644	1790183	Paddy field	Paddy field
399	333824	1790183	Paddy field	Paddy field
400	323534	1790213	Paddy field	Paddy field
401	308954	1790243	Institution	Institution
402	304544	1790273	Paddy field	Paddy field
403	326144	1790333	Paddy field	Paddy field
404	331064	1790333	Paddy field	Paddy field
405	300554	1790393	Field crop	Field crop
406	310064	1790393	City and village	City and village
407	321284	1790393	Paddy field	Paddy field
408	333734	1790393	Paddy field	Paddy field
409	333434	1790423	Paddy field	Paddy field
410	312284	1790453	Water	Water
411	325064	1790453	Paddy field	Paddy field
412	328064	1790453	Paddy field	Paddy field
413	331154	1790453	Paddy field	Paddy field
414	325334	1790483	Paddy field	Paddy field
415	329114	1790573	Paddy field	Paddy field
416	311594	1790603	Paddy field	Paddy field
417	313574	1790603	Secondary forest	Secondary forest
418	323534	1790633	Paddy field	Paddy field
419	325094	1790693	Paddy field	Paddy field
420	325034	1790723	Paddy field	Paddy field
421	315494	1790753	Paddy field	Paddy field
422	329354	1790753	Paddy field	Paddy field
423	302714	1790783	Paddy field	Paddy field
424	303074	1790783	Paddy field	Paddy field
425	337154	1790783	Paddy field	Paddy field
426	323924	1790813	Paddy field	Paddy field
427	336224	1790843	Secondary forest	Secondary forest
428	306794	1790903	Paddy field	Paddy field
429	325094	1790903	Paddy field	Paddy field
430	326954	1790903	Water	Water
431	334214	1790903	Secondary forest	Secondary forest

Table B-1 (Continued)**.**

ID	X UTM	Y UTM	Visual interpretation	Ground reference
432	310934	1790993	Paddy field	Paddy field
433	301304	1791023	Eucalyptus	Eucalyptus
434	315254	1791023	Water	Water
435	338744	1791023	Paddy field	Paddy field
436	312854	1791083	Paddy field	Paddy field
437	319574	1791083	Paddy field	Paddy field
438	310934	1791113	Paddy field	Paddy field
439	316064	1791143	Commercial	Commercial
440	322214	1791233	Paddy field	Paddy field
441	311384	1791263	Paddy field	Paddy field
442	313664	1791263	Paddy field	Paddy field
443	300554	1791293	Field crop	Field crop
444	314054	1791293	Development land	Development land
445	322034	1791323	Paddy field	Paddy field
446	300764	1791413	Secondary forest	Secondary forest
447	318764	1791413	City and village	City and village
448	311384	1791443	Paddy field	Paddy field
449	316544	1791443	City and village	City and village
450	321674	1791443	Paddy field	Paddy field
451	323324	1791443	Paddy field	Paddy field
452	315074	1791503	Water	Water
453	315194	1791623	Institution	Institution
454	311384	1791683	Paddy field	Marsh land
455	305414	1791743	Paddy field	Paddy field
456	309074	1791743	Paddy field	Paddy field
457	302594	1791803	Paddy field	Paddy field
458	330944	1791833	Paddy field	Paddy field
459	303764	1791863	Paddy field	Paddy field
460	306104	1791893	Paddy field	Paddy field
461	317294	1791923	Institution	Institution
462	318794	1791923	Paddy field	Paddy field
463	325124	1791953	Paddy field	Paddy field
464	332354	1791953	Paddy field	Paddy field
465	317594	1791983	Paddy field	Paddy field
466	319754	1792013	Paddy field	Paddy field
467	317744	1792043	Water	Water
468	313394	1792103	Secondary forest	Secondary forest
469	305174	1792133	Paddy field	Paddy field
470	324224	1792373	Paddy field	Paddy field
471	313694	1792403	Secondary forest	Secondary forest
472	316034	1792403	Development land	Development land
473	312674	1792493	Water	Water
474	325064	1792583	Paddy field	Paddy field
475	312284	1792613	Development land	Marsh land
476	305474	1792673	Paddy field	Paddy field
477	318824	1792703	Paddy field	Paddy field
478	324704	1792703	Water	Water
479	305744	1792763	Water	Water

Table B-1 (Continued)**.**

ID	X UTM	Y UTM	Visual interpretation	Ground reference
480	308834	1792763	Paddy field	Paddy field
481	311444	1792793	Water	Water
482	324374	1792793	Paddy field	Paddy field
483	333194	1792853	Paddy field	Paddy field
484	326384	1792973	Paddy field	Paddy field
485	312464	1793003	Paddy field	Paddy field
486	314204	1793033	Paddy field	Paddy field
487	321044	1793093	Paddy field	Paddy field
488	310874	1793153	Paddy field	Paddy field
489	312434	1793183	Paddy field	Paddy field
490	323024	1793183	Institution	Institution
491	313244	1793213	Secondary forest	Field crop
492	316694	1793243	Dormitory	Dormitory
493	329624	1793243	Paddy field	Paddy field
494	302804	1793273	Paddy field	Paddy field
495	323984	1793273	Paddy field	Paddy field
496	304604	1793303	Paddy field	Paddy field
497	315224	1793333	Paddy field	Paddy field
498	310364	1793453	Secondary forest	Eucalyptus
499	328874	1793483	Paddy field	Paddy field
500	304244	1793513	Paddy field	Paddy field
501	332594	1793513	Paddy field	Paddy field
502	328844	1793543	Paddy field	Paddy field
503	333014	1793573	Paddy field	Paddy field
504	325844	1793663	Institution	Institution
505	326354	1793693	City and village	City and village
506	317114	1793723	Paddy field	Paddy field
507	307454	1793753	Paddy field	Paddy field
508	331604	1793753	Paddy field	Paddy field
509	332294	1793783	Paddy field	Paddy field
510	305114	1793903	Paddy field	Paddy field
511	304484	1793933	Paddy field	Paddy field
512	313604	1793933	Paddy field	Paddy field
513	328964	1793933	Paddy field	Paddy field
514	331214	1793933	Paddy field	Paddy field
515	317954	1793963	Paddy field	Paddy field
516	328364	1794023	Paddy field	Paddy field
517	303884	1794053	Paddy field	Paddy field
518	304364	1794173	Paddy field	Paddy field
519	308294	1794233	Paddy field	Paddy field
520	314444	1794293	Water	Water
521	306074	1794323	Paddy field	Paddy field
522	325784	1794323	Water	Water
523	303374	1794383	Paddy field	Paddy field
524	304544	1794383	Paddy field	Paddy field
525	307394	1794383	Paddy field	Paddy field
526	314744	1794383	Development land	Paddy field
527	316964	1794473	Marsh land	Marsh land

Table B-1 (Continued)**.**

ID	X UTM	Y UTM	Visual interpretation	Ground reference
528	324944	1794503	Water	Water
529	324254	1794533	Water	Water
530	314204	1794563	Secondary forest	Secondary forest
531	331424	1794593	Paddy field	Paddy field
532	311864	1794653	Water	Water
533	328094	1794743	Paddy field	Paddy field
534	307034	1794773	Paddy field	Paddy field
535	324044	1794833	Water	Water
536	310454	1794893	Paddy field	Paddy field
537	318554	1794893	Paddy field	Paddy field
538	326024	1794923	Secondary forest	Secondary forest
539	332174	1794953	Paddy field	Paddy field
540	324014	1795013	Secondary forest	Secondary forest
541	319724	1795133	Paddy field	Paddy field
542	331604	1795193	Paddy field	Paddy field
543	313214	1795253	Secondary forest	Secondary forest
544	305804	1795283	Paddy field	Paddy field
545	313514	1795343	Paddy field	Paddy field
546	313664	1795373	Paddy field	Paddy field
547	313694	1795403	Real estate	Real estate
548	330134	1795403	Secondary forest	Secondary forest
549	308834	1795433	Paddy field	Paddy field
550	321854	1795523	Water	Water
551	310424	1795583	Paddy field	Paddy field
552	302894	1795643	Paddy field	Paddy field
553	314834	1795703	City and village	City and village
554	320444	1795793	Paddy field	Paddy field
555	308594	1795883	Paddy field	Paddy field
556	324254	1795883	Paddy field	Paddy field
557	316544	1795913	Paddy field	Paddy field
558	326714	1795943	Paddy field	Paddy field
559	309764	1795973	Paddy field	Paddy field
560	310304	1795973	Paddy field	Paddy field
561	313574	1795973	Dormitory	Dormitory
562	306944	1796093	Paddy field	Paddy field
563	308054	1796093	Secondary forest	Orchard
564	329504	1796093	Field crop	Eucalyptus
565	316934	1796123	Paddy field	Paddy field
566	328094	1796243	Water	Water
567	329834	1796273	Paddy field	Paddy field
568	318704	1796303	Paddy field	Paddy field
569	318404	1796513	Paddy field	Paddy field
570	307394	1796543	City and village	City and village
571	312584	1796573	Development land	Development land
572	318434	1796603	Paddy field	Paddy field
573	325634	1796633	Paddy field	Paddy field
574	329924	1796633	Paddy field	Paddy field
575	323324	1796663	Paddy field	Paddy field

Table B-1 (Continued).

ID	X UTM	Y UTM	Visual interpretation	Ground reference
576	328304	1796693	Paddy field	Paddy field
577	314234	1796783	Paddy field	Paddy field
578	307334	1796813	Field crop	Field crop
579	315674	1796813	Paddy field	Paddy field
580	308264	1796933	Secondary forest	Secondary forest
581	317714	1796933	Paddy field	Paddy field
582	311714	1796963	Paddy field	Paddy field
583	310604	1797023	Paddy field	Paddy field
584	314204	1797143	Paddy field	Paddy field
585	319574	1797143	City and village	Orchard
586	315344	1797293	Development land	Development land
587	304124	1797353	Paddy field	Paddy field
588	313814	1797383	Commercial	Commercial
589	304604	1797413	Paddy field	Marsh land
590	305594	1797443	Paddy field	Paddy field
591	324404	1797473	Paddy field	Paddy field
592	306464	1797503	Paddy field	Paddy field
593	307994	1797653	Paddy field	Paddy field
594	324764	1797683	Paddy field	Paddy field
595	308354	1797743	Paddy field	Paddy field
596	320714	1797743	Paddy field	Paddy field
597	321314	1797743	Paddy field	Paddy field
598	323444	1797743	Paddy field	Paddy field
599	315374	1797803	Orchard	Orchard
600	316394	1797833	Paddy field	Paddy field
601	305144	1797893	Paddy field	Paddy field
602	317864	1797893	Paddy field	Paddy field
603	325724	1797893	Paddy field	Paddy field
604	303614	1797923	Paddy field	Paddy field
605	321824	1797953	Marsh land	Marsh land
606	322514	1797953	Water	Water
607	311864	1797983	Development land	Development land
608	315974	1797983	City and village	City and village
609	328544	1798073	Paddy field	Paddy field
610	311654	1798103	Development land	Development land
611	307274	1798133	Development land	Development land
612	303824	1798163	Paddy field	Paddy field
613	304274	1798193	Paddy field	Paddy field
614	317264	1798193	Paddy field	Paddy field
615	313064	1798223	Paddy field	Paddy field
616	317684	1798223	Paddy field	Paddy field
617	321824	1798253	Paddy field	Paddy field
618	322904	1798283	Paddy field	Paddy field
619	321974	1798313	Paddy field	Paddy field
620	309884	1798433	Paddy field	Paddy field
621	328544	1798463	Water	Water
622	317744	1798493	Paddy field	Paddy field
623	308624	1798613	Paddy field	Paddy field

Table B-1 (Continued).

ID	X UTM	Y UTM	Visual interpretation	Ground reference
624	309044	1798643	Paddy field	Paddy field
625	328184	1798643	Paddy field	Paddy field
626	329894	1798643	Paddy field	Paddy field
627	313454	1798703	Paddy field	Paddy field
628	316514	1798763	City and village	City and village
629	316784	1798793	City and village	City and village
630	317294	1798823	Water	Water
631	326414	1798823	City and village	City and village
632	317624	1798973	Paddy field	Paddy field
633	317564	1799033	Paddy field	Paddy field
634	305894	1799093	Paddy field	Paddy field
635	305714	1799183	Paddy field	Paddy field
636	315584	1799213	Paddy field	Paddy field
637	320414	1799213	Paddy field	Paddy field
638	309194	1799333	Paddy field	Paddy field
639	320894	1799333	Paddy field	Paddy field
640	315764	1799363	Paddy field	Paddy field
641	320264	1799393	Paddy field	Paddy field
642	312584	1799423	Paddy field	Paddy field
643	313994	1799453	Paddy field	Paddy field
644	328484	1799453	Paddy field	Paddy field
645	325034	1799483	Paddy field	Paddy field
646	307934	1799513	Paddy field	Paddy field
647	329774	1799543	Water	Water
648	308294	1799603	Paddy field	Paddy field
649	319004	1799633	Paddy field	Paddy field
650	307694	1799663	Paddy field	Paddy field
651	319934	1799663	Paddy field	Paddy field
652	317864	1799693	Paddy field	Paddy field
653	319904	1799723	Paddy field	Paddy field
654	311834	1799753	Paddy field	Paddy field
655	305504	1799783	Paddy field	Paddy field
656	323594	1799903	Paddy field	Paddy field
657	302954	1800143	Secondary forest	Secondary forest
658	314564	1800143	Paddy field	Paddy field
659	328364	1800143	Paddy field	Paddy field
660	306644	1800173	Paddy field	Paddy field
661	312134	1800173	Paddy field	Paddy field
662	318584	1800173	Paddy field	Paddy field
663	328994	1800173	Paddy field	Paddy field
664	306554	1800203	Paddy field	Paddy field
665	307874	1800203	Paddy field	Paddy field
666	326144	1800233	Paddy field	Paddy field
667	313244	1800323	Paddy field	Paddy field
668	303974	1800503	Paddy field	Paddy field
669	325544	1800533	City and village	City and village
670	312404	1800623	Paddy field	Paddy field
671	313784	1800623	Paddy field	Paddy field

Table B-1 (Continued)**.**

ID	X UTM	Y UTM	Visual interpretation	Ground reference
672	310124	1800653	Paddy field	Paddy field
673	316514	1800683	Paddy field	Paddy field
674	310964	1800773	Paddy field	Paddy field
675	309344	1800803	Paddy field	Paddy field
676	327524	1800803	Paddy field	Paddy field
677	305204	1800863	Paddy field	Paddy field
678	314114	1800893	Paddy field	Paddy field
679	310184	1800983	Paddy field	Paddy field
680	328694	1801043	Paddy field	Paddy field
681	311294	1801103	Paddy field	Paddy field
682	320954	1801103	Paddy field	Paddy field
683	321914	1801103	Paddy field	Paddy field
684	325694	1801103	Paddy field	Paddy field
685	327884	1801103	Paddy field	Paddy field
686	310964	1801133	Paddy field	Paddy field
687	306044	1801253	Paddy field	Paddy field
688	306674	1801253	Paddy field	Paddy field
689	319124	1801253	Paddy field	Paddy field
690	307784	1801313	Paddy field	Paddy field
691	329624	1801313	Paddy field	Paddy field
692	309254	1801343	Secondary forest	Secondary forest
693	311984	1801343	Paddy field	Paddy field
694	320654	1801373	Paddy field	Paddy field
695	328994	1801463	Paddy field	Paddy field
696	312584	1801493	Paddy field	Paddy field
697	308204	1801583	Paddy field	Paddy field
698	327734	1801583	Paddy field	Paddy field
699	309614	1801613	Paddy field	Paddy field
700	326924	1801673	Paddy field	Paddy field
701	328724	1801733	Paddy field	Paddy field
702	306914	1801823	Paddy field	Paddy field
703	318464	1801853	Paddy field	Paddy field
704	312554	1801913	Paddy field	Paddy field
705	308924	1801943	Paddy field	Paddy field
706	326324	1801943	Paddy field	Paddy field
707	328904	1801943	Paddy field	Paddy field
708	328304	1802003	Paddy field	Paddy field
709	328784	1802003	Paddy field	Paddy field
710	328244	1802123	Paddy field	Paddy field
711	305774	1802153	Paddy field	Paddy field
712	324434	1802213	Paddy field	Paddy field
713	320084	1802243	Paddy field	Paddy field
714	324674	1802243	Paddy field	Paddy field
715	306464	1802273	Paddy field	Paddy field
716	317924	1802363	City and village	Paddy field
717	318254	1802393	Paddy field	Paddy field
718	312854	1802453	Paddy field	Paddy field
719	314444	1802453	Paddy field	Paddy field

Table B-1 (Continued)**.**

ID	X UTM	Y UTM	Visual interpretation	Ground reference
720	324854	1802483	City and village	City and village
721	317804	1802513	Paddy field	Paddy field
722	320864	1802573	Paddy field	Paddy field
723	321764	1802573	Paddy field	Paddy field
724	315254	1802663	Paddy field	Paddy field
725	324884	1802753	Paddy field	Paddy field
726	304574	1802813	Paddy field	Paddy field
727	324224	1802843	Paddy field	Paddy field
728	309854	1802963	Paddy field	Paddy field
729	311984	1803083	Paddy field	Paddy field
730	309314	1803113	Paddy field	Paddy field
731	312554	1803113	Paddy field	Paddy field
732	308144	1803173	Paddy field	Paddy field
733	305924	1803203	Paddy field	Paddy field
734	310514	1803203	Paddy field	Paddy field
735	317114	1803203	Paddy field	Paddy field
736	306704	1803263	Paddy field	Paddy field
737	307274	1803263	Paddy field	Paddy field
738	309104	1803263	Paddy field	Paddy field
739	309104	1803263	Paddy field	Paddy field
740	311744	1803263	Paddy field	Paddy field
741	315914	1803263	Paddy field	Paddy field
742	316484	1803353	Paddy field	Paddy field
743	304514	1803443	Paddy field	Paddy field
744	309704	1803533	Paddy field	Paddy field
745	310694	1803533	Paddy field	Paddy field
746	308354	1803563	Paddy field	Paddy field
747	323414	1803563	Paddy field	Paddy field
748	313964	1803743	Paddy field	Paddy field
749	311954	1803773	Paddy field	Paddy field
750	313604	1803833	Paddy field	Paddy field
751	311564	1804043	Paddy field	Paddy field
752	313814	1804223	Paddy field	Paddy field
753	308354	1804343	Paddy field	Paddy field
754	310214	1804343	Paddy field	Paddy field
755	315824	1804343	Secondary forest	Secondary forest
756	307814	1804373	Paddy field	Paddy field
757	313514	1804373	Paddy field	Paddy field
758	319904	1804373	Paddy field	Paddy field
759	313304	1804433	Paddy field	Paddy field
760	322814	1804523	Paddy field	Paddy field
761	311294	1804643	Paddy field	Paddy field
762	322904	1804733	Paddy field	Paddy field
763	307964	1804853	Paddy field	Development land
764	315044	1804883	Paddy field	Paddy field
765	318764	1804973	Paddy field	Paddy field
766	323624	1804973	Paddy field	Paddy field
767	314924	1805003	Paddy field	Paddy field

Table B-1 (Continued).

ID	X UTM	Y UTM	Visual interpretation	Ground reference
768	306704	1805123	Eucalyptus	Eucalyptus
769	309974	1805153	Secondary forest	Secondary forest
770	322934	1805213	Paddy field	Paddy field
771	307664	1805333	Secondary forest	Secondary forest
772	307004	1805363	Field crop	Field crop
773	311354	1805453	Paddy field	Paddy field
774	311984	1805453	Paddy field	Paddy field
775	312434	1805483	Field crop	Orchard
776	313364	1805513	Water	Water
777	313094	1805543	Secondary forest	Secondary forest
778	311684	1805603	Paddy field	Paddy field
779	309524	1805633	Paddy field	Paddy field
780	307154	1805753	Eucalyptus	Eucalyptus
781	319664	1805783	Paddy field	Paddy field
782	307394	1805813	Eucalyptus	Eucalyptus
783	317684	1805813	City and village	City and village
784	317474	1805933	City and village	City and village
785	315464	1806293	Paddy field	Paddy field
786	317204	1806323	Paddy field	Paddy field
787	309734	1806413	Paddy field	Paddy field
788	316964	1806593	Paddy field	Paddy field
789	312644	1806653	Eucalyptus	Eucalyptus
790	312764	1806653	Eucalyptus	Eucalyptus
791	307514	1806683	Secondary forest	Secondary forest
792	310034	1806803	Paddy field	Paddy field
793	310514	1806833	Orchard	Orchard
794	310274	1807103	Secondary forest	Secondary forest
795	312674	1807433	City and village	City and village
796	311834	1807583	Field crop	Field crop
797	321434	1807583	Paddy field	Paddy field
798	306134	1807643	Eucalyptus	Eucalyptus
799	308354	1807643	Field crop	Field crop
800	311894	1807673	Field crop	Field crop
801	312254	1807733	City and village	City and village
802	320864	1807733	Paddy field	Paddy field
803	323414	1807763	Paddy field	Paddy field
804	312344	1807793	City and village	City and village
805	307874	1807823	Field crop	Field crop
806	308324	1807853	Field crop	Field crop
807	306734	1807883	Paddy field	Paddy field
808	317294	1807883	Paddy field	Paddy field
809	321404	1807913	Paddy field	Paddy field
810	317684	1807973	Paddy field	Paddy field
811	312884	1808033	Secondary forest	Secondary forest
812	320054	1808063	Paddy field	Paddy field
813	314324	1808213	Field crop	Field crop
814	315944	1808273	Paddy field	Paddy field
815	317504	1808303	Paddy field	Paddy field

Table B-1 (Continued).

ID	X UTM	Y UTM	Visual interpretation	Ground reference
816	307994	1808363	Secondary forest	Secondary forest
817	323114	1808363	Paddy field	Paddy field
818	322034	1808453	Paddy field	Paddy field
819	307004	1808633	Paddy field	Paddy field
820	313484	1808753	Paddy field	Paddy field
821	306854	1808843	Paddy field	Paddy field
822	308294	1808843	Paddy field	Paddy field
823	310904	1808843	Paddy field	Paddy field
824	321884	1808873	Paddy field	Paddy field
825	316274	1808933	Paddy field	Paddy field
826	319814	1809113	Paddy field	Paddy field
827	306554	1809233	Paddy field	Paddy field
828	309824	1809353	Paddy field	Paddy field
829	314294	1809473	Paddy field	Paddy field
830	319544	1809503	Paddy field	Paddy field
831	307244	1809713	Paddy field	Paddy field
832	315764	1809713	Paddy field	Paddy field
833	307154	1809743	Paddy field	Paddy field
834	305534	1809833	Paddy field	Paddy field
835	319394	1809833	Paddy field	Paddy field
836	321254	1809833	Paddy field	Paddy field
837	310814	1809893	Paddy field	Paddy field
838	319814	1809893	Paddy field	Paddy field
839	321584	1809983	Paddy field	Paddy field
840	313004	1810133	Paddy field	Paddy field
841	320774	1810163	Paddy field	Paddy field
842	307724	1810193	Paddy field	Paddy field
843	308444	1810193	Paddy field	Paddy field
844	320864	1810193	Paddy field	Paddy field
845	309074	1810253	Paddy field	Paddy field
846	319004	1810253	Paddy field	Paddy field
847	308744	1810283	Paddy field	Paddy field
848	312734	1810403	Paddy field	Paddy field
849	314384	1810493	Paddy field	Paddy field
850	315134	1810643	Paddy field	Paddy field
851	315314	1810733	Paddy field	Paddy field
852	312524	1810793	Paddy field	Paddy field
853	317654	1810853	Paddy field	Paddy field
854	312944	1811003	Paddy field	Paddy field
855	313844	1811033	Paddy field	Paddy field
856	313184	1811063	Paddy field	Paddy field
857	316334	1811153	Paddy field	Paddy field
858	316544	1811333	Paddy field	Paddy field
859	317924	1811483	Paddy field	Paddy field
860	316214	1811753	Paddy field	Paddy field
861	315764	1811903	Paddy field	Paddy field
862	315524	1812053	Paddy field	Paddy field

APPENDIX C

STATISTICAL DATA FROM THE SPATIAL SIMPLE LINEAR REGRESSION ANALYSIS BETWEEN URBAN PATTERN AND DRIVING FORCES FACTORS

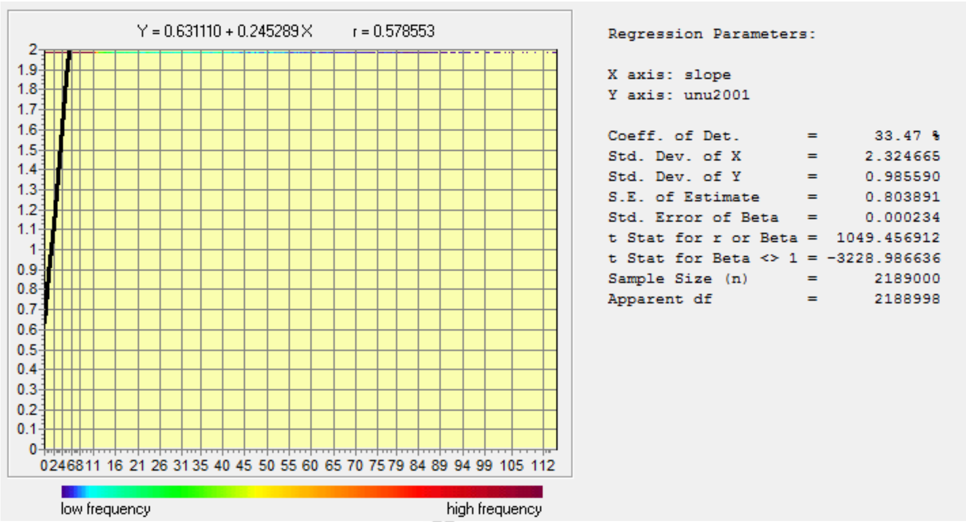


Figure C-1 Spatial simple linear regression analysis between urban pattern in 2001 and slope.

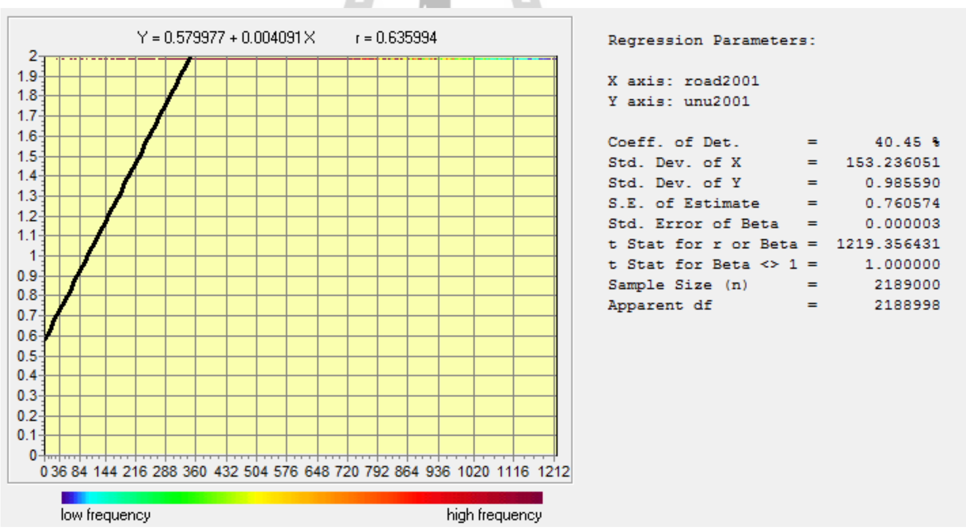


Figure C-2 Spatial simple linear regression analysis between urban pattern in 2001 and road network.

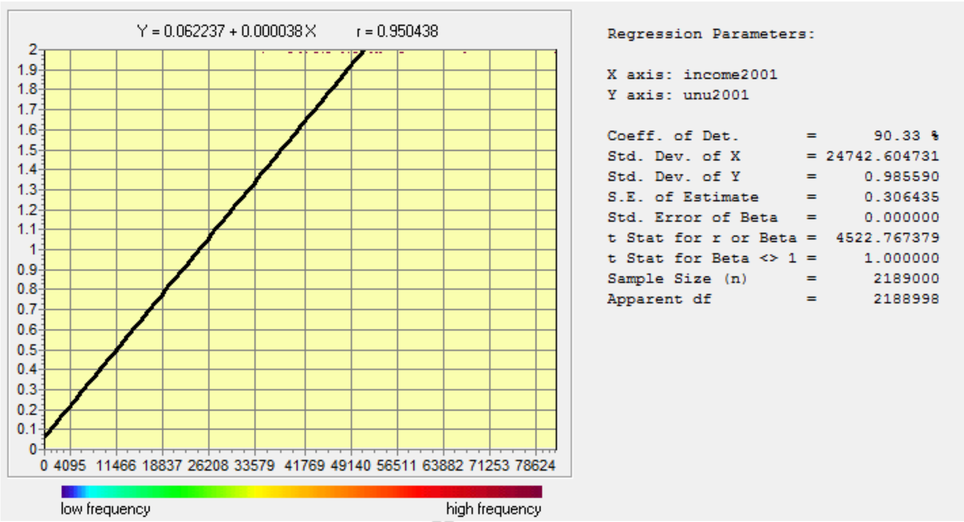


Figure C-3 Spatial simple linear regression analysis between urban pattern in 2001 and per capita income in 2001.

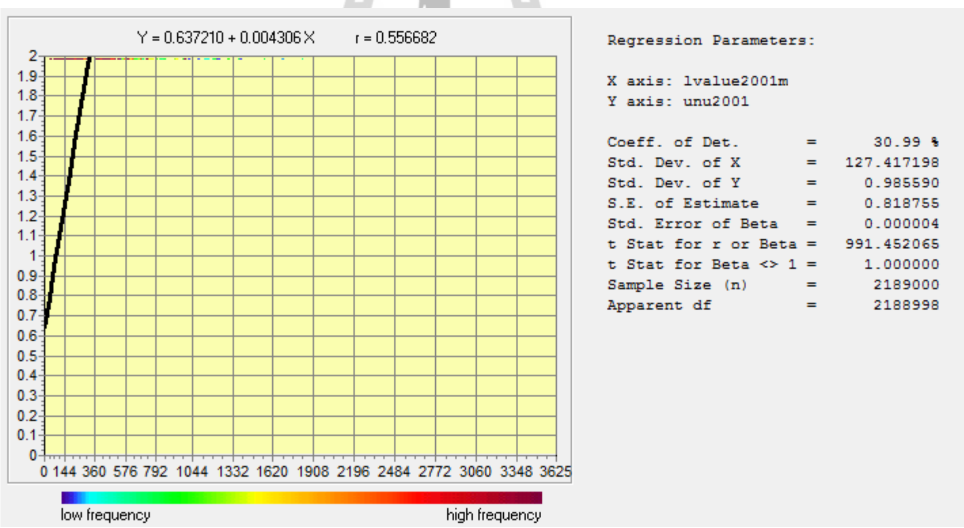


Figure C-4 Spatial simple linear regression analysis between urban pattern in 2001 and land value.

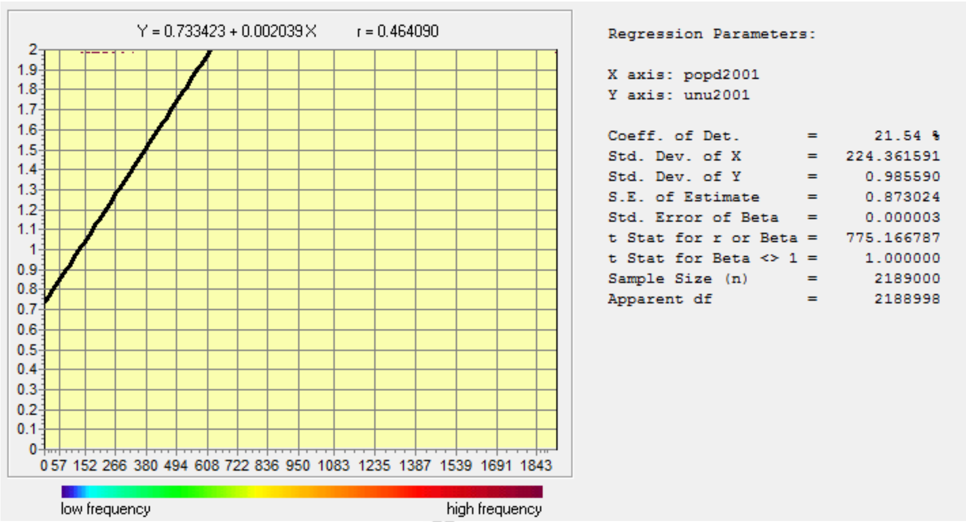


Figure C-5 Spatial simple linear regression analysis between urban pattern in 2001 and population density in 2001.

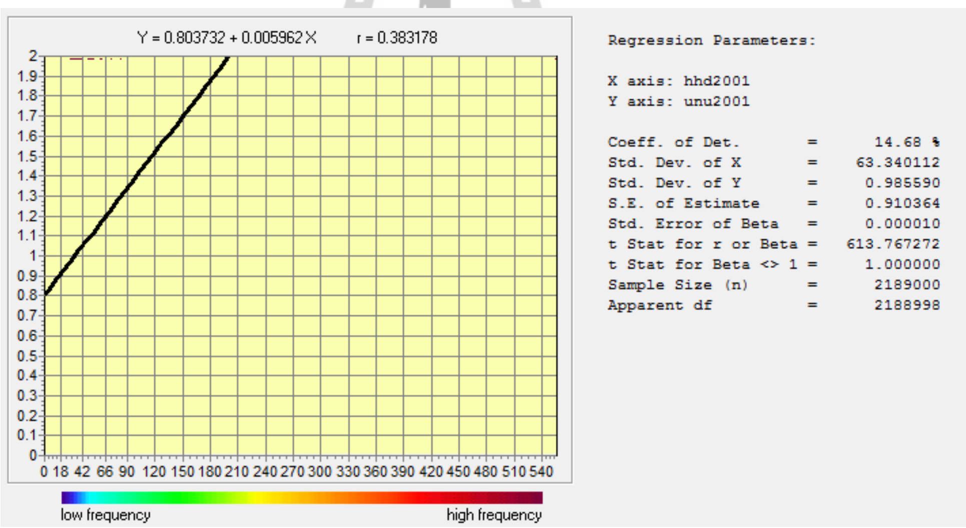


Figure C-6 Spatial simple linear regression analysis between urban pattern in 2001 and household density in 2001.

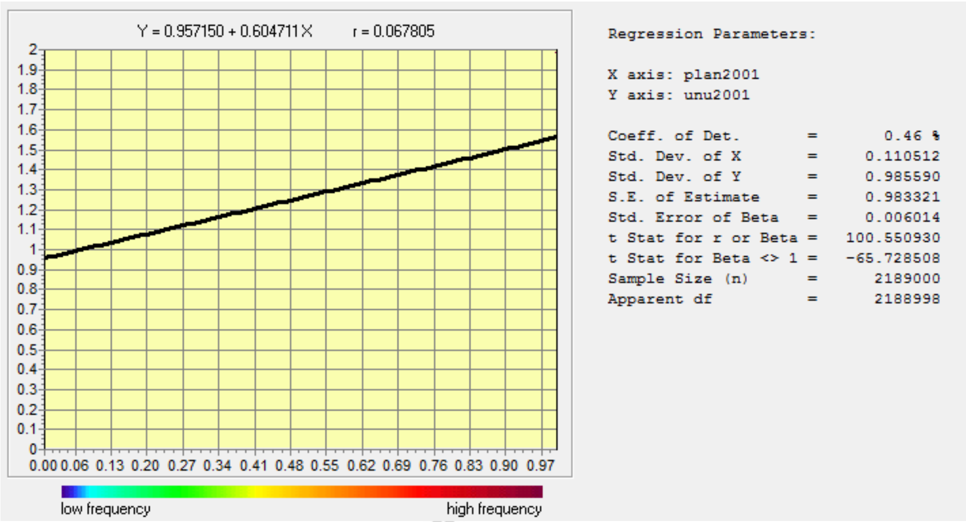


Figure C-7 Spatial simple linear regression analysis between urban pattern in 2001 and the existing comprehensive city plan.

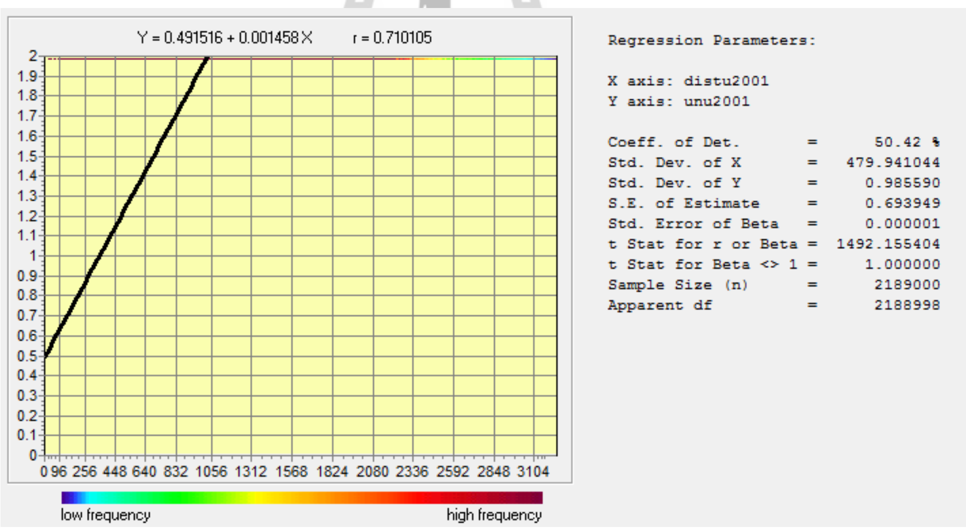


Figure C-8 Spatial simple linear regression analysis between urban pattern in 2001 and existing urban area in 2001.

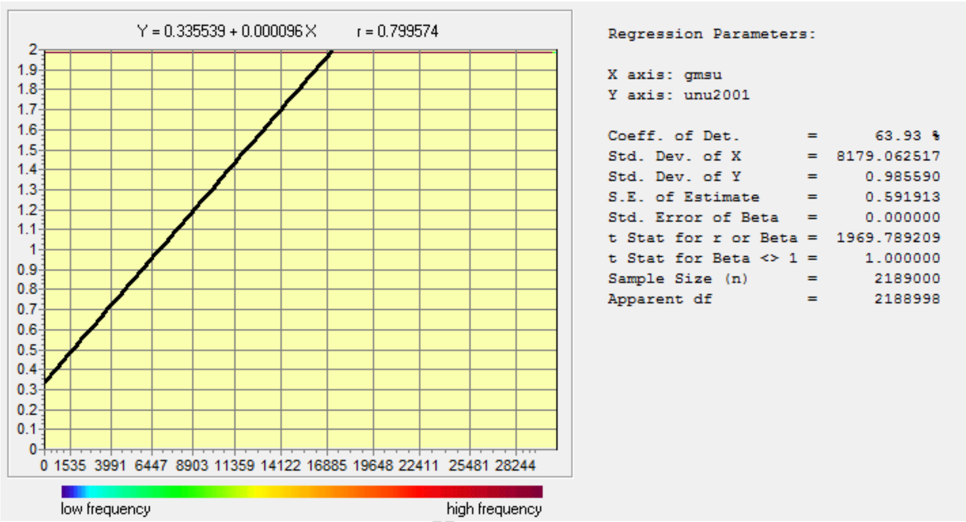


Figure C-9 Spatial simple linear regression analysis between urban pattern in 2001 and new MSU campus.

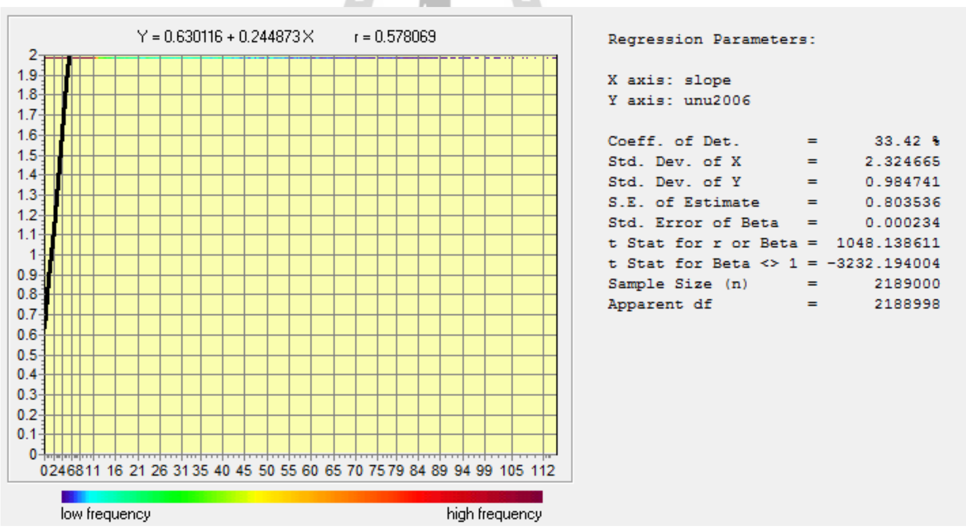


Figure C-10 Spatial simple linear regression analysis between urban pattern in 2006 and slope.

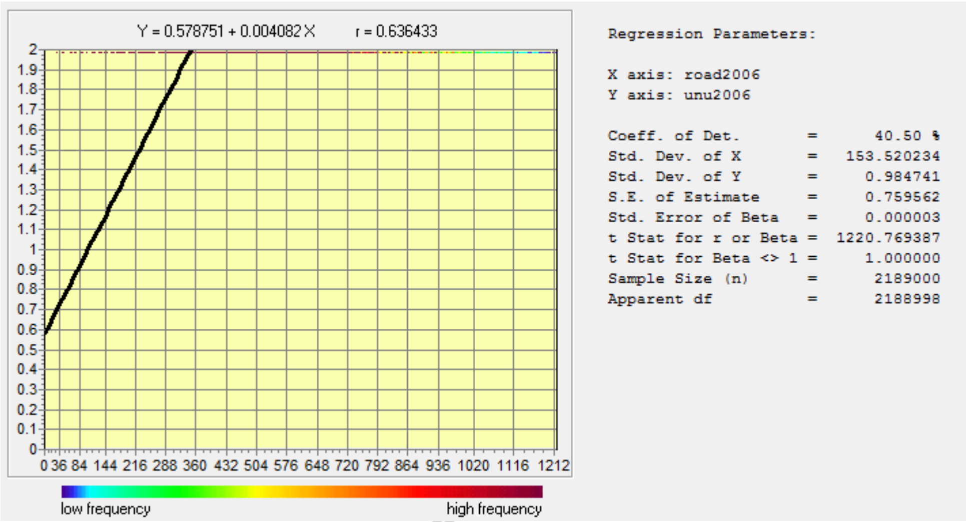


Figure C-11 Spatial simple linear regression analysis between urban pattern in 2006 and road network.

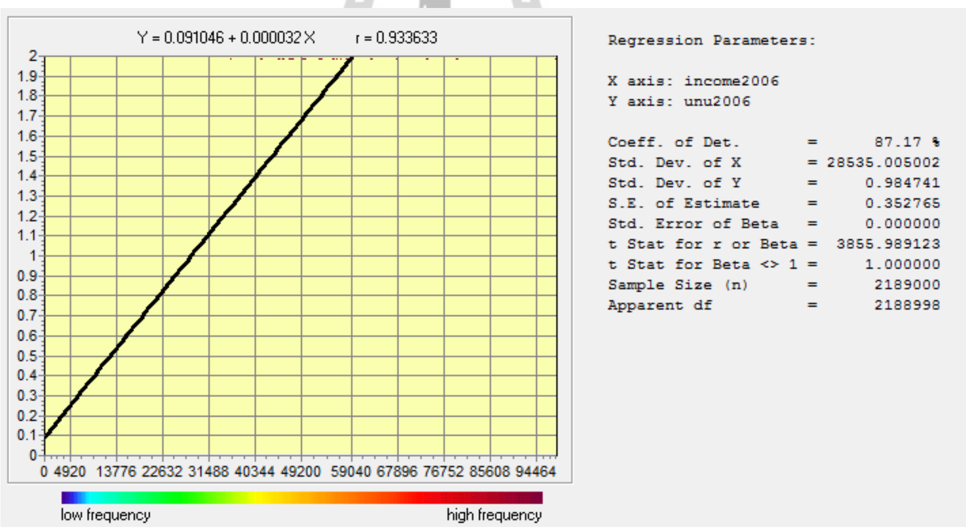


Figure C-12 Spatial simple linear regression analysis between urban pattern in 2006 and per capita income in 2006.

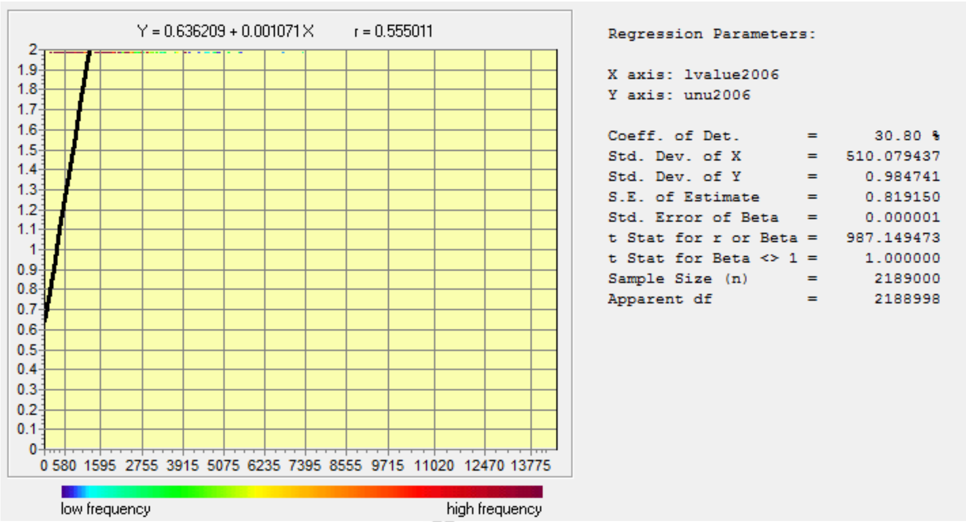


Figure C-13 Spatial simple linear regression analysis between urban pattern in 2006 and land value.

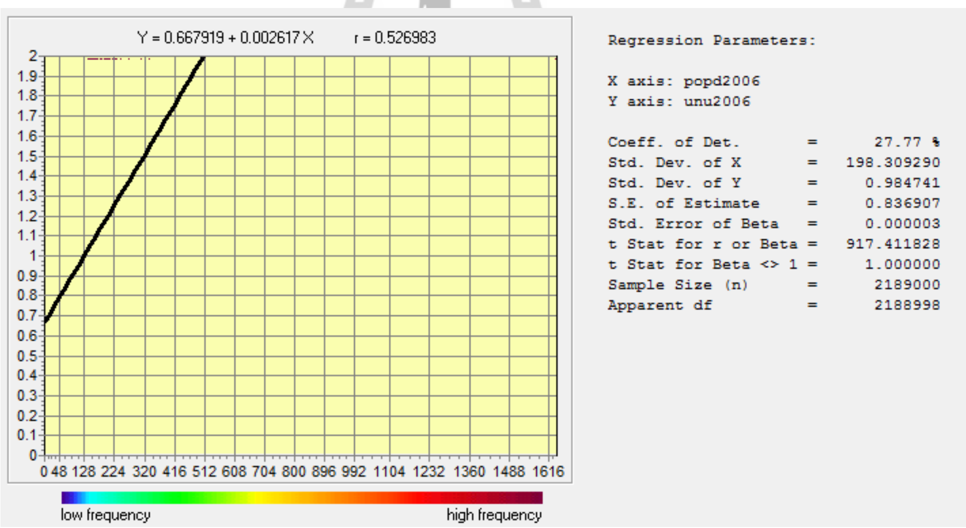


Figure C-14 Spatial simple linear regression analysis between urban pattern in 2006 and population density in 2006.

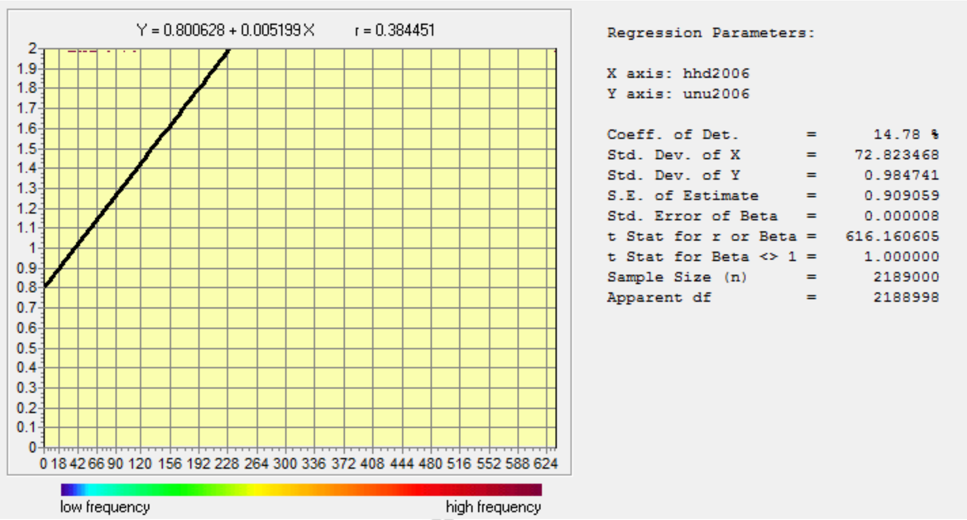


Figure C-15 Spatial simple linear regression analysis between urban pattern in 2006 and household density in 2006.

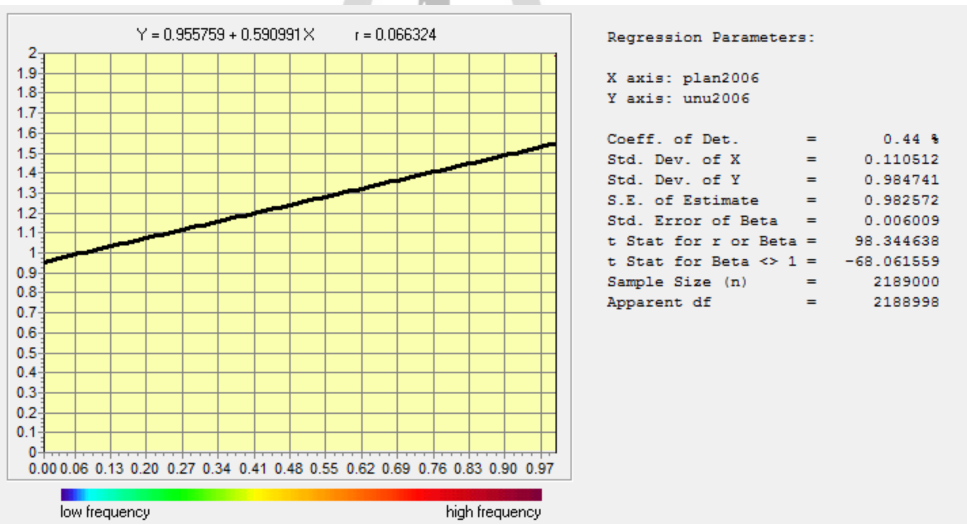


Figure C-16 Spatial simple linear regression analysis between urban pattern in 2006 and the existing comprehensive city plan.

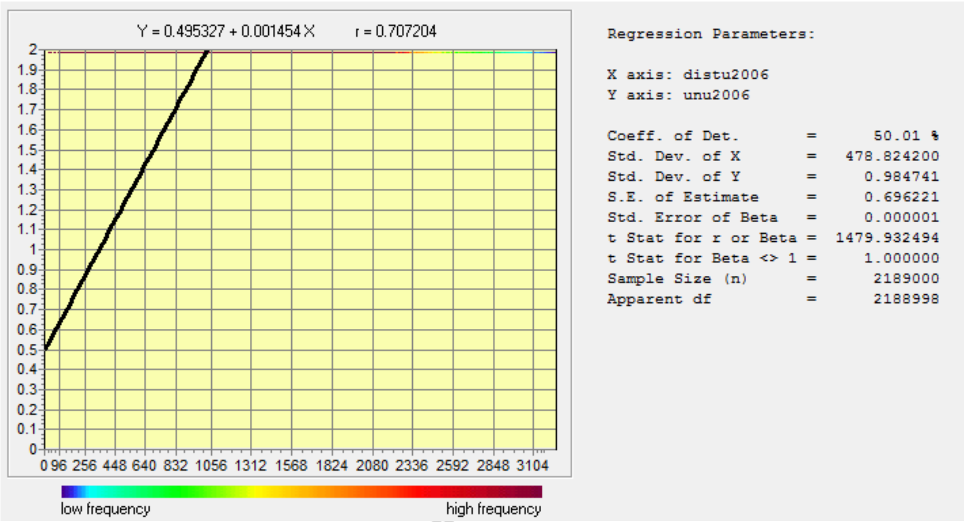


Figure C-17 Spatial simple linear regression analysis between urban pattern in 2006 and existing urban area in 2006.

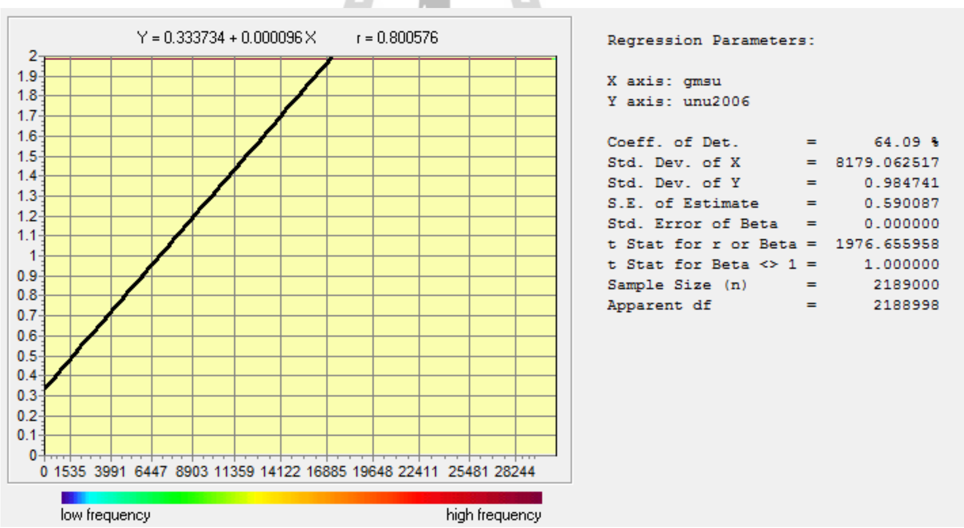


Figure C-18 Spatial simple linear regression analysis between urban pattern in 2006 and new MSU campus.

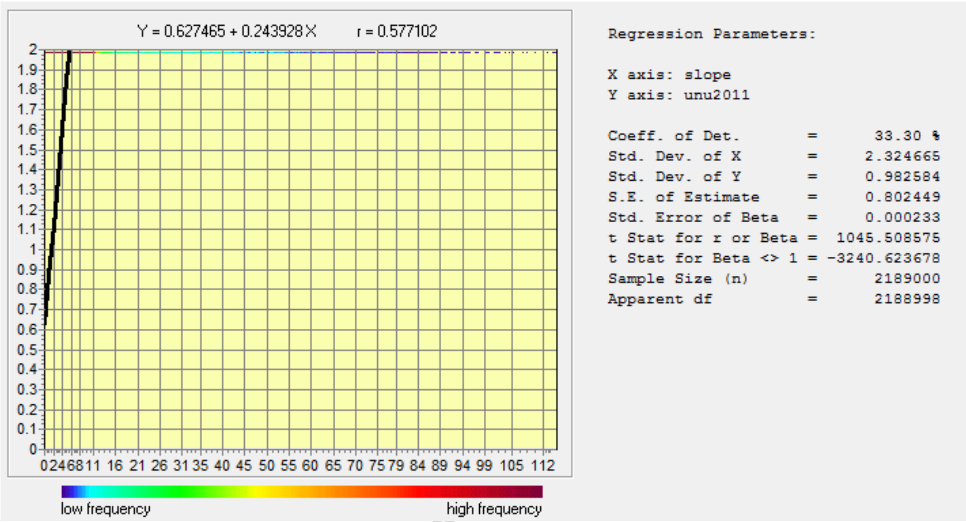


Figure C-19 Spatial simple linear regression analysis between urban pattern in 2011 and slope.

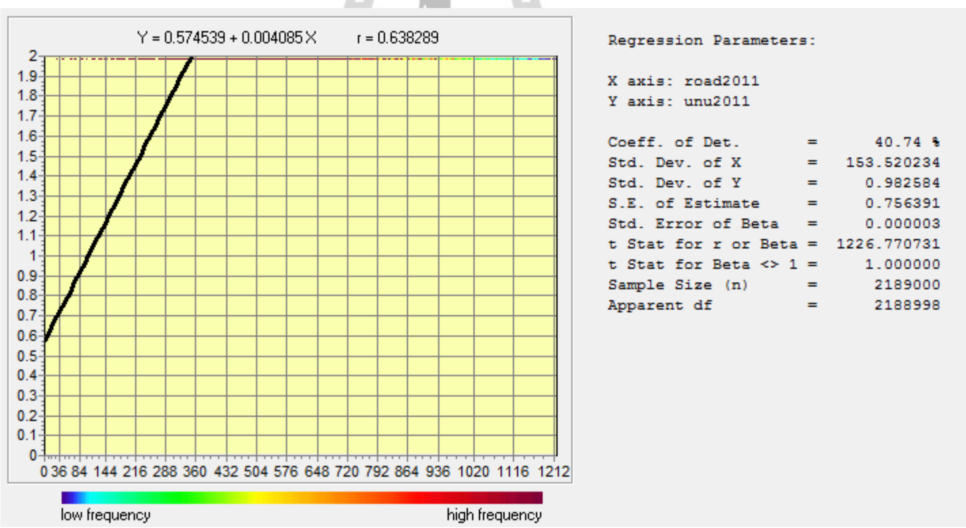


Figure C-20 Spatial simple linear regression analysis between urban pattern in 2011 and road network.

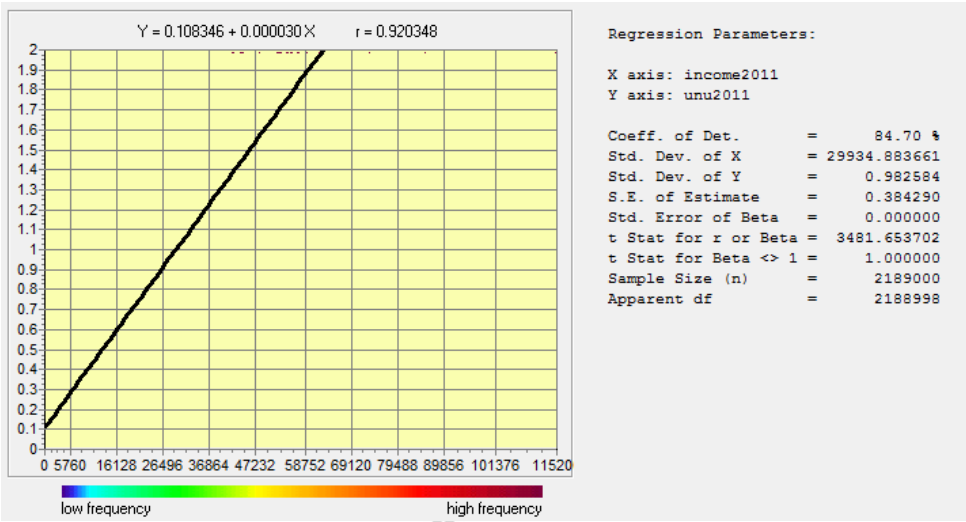


Figure C-21 Spatial simple linear regression analysis between urban pattern in 2011 and per capita income in 2011.

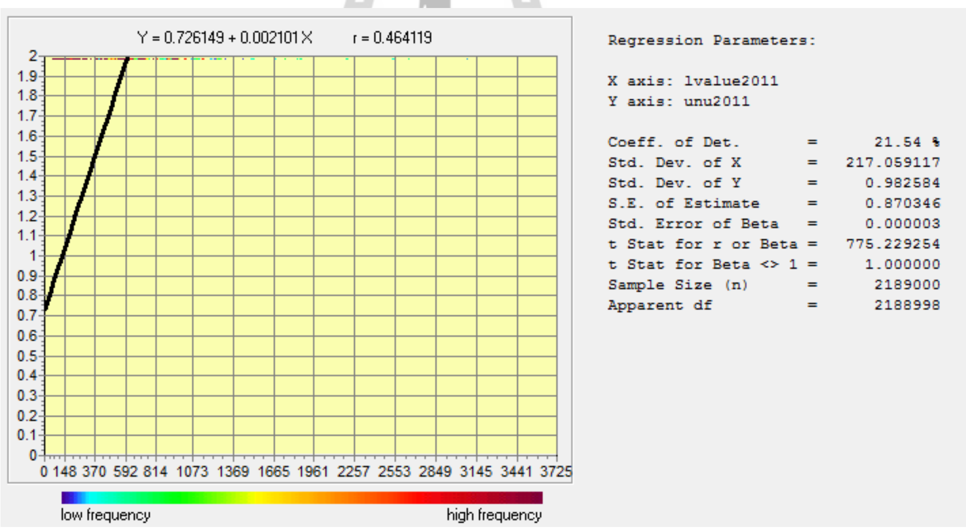


Figure C-22 Spatial simple linear regression analysis between urban pattern in 2011 and land value.

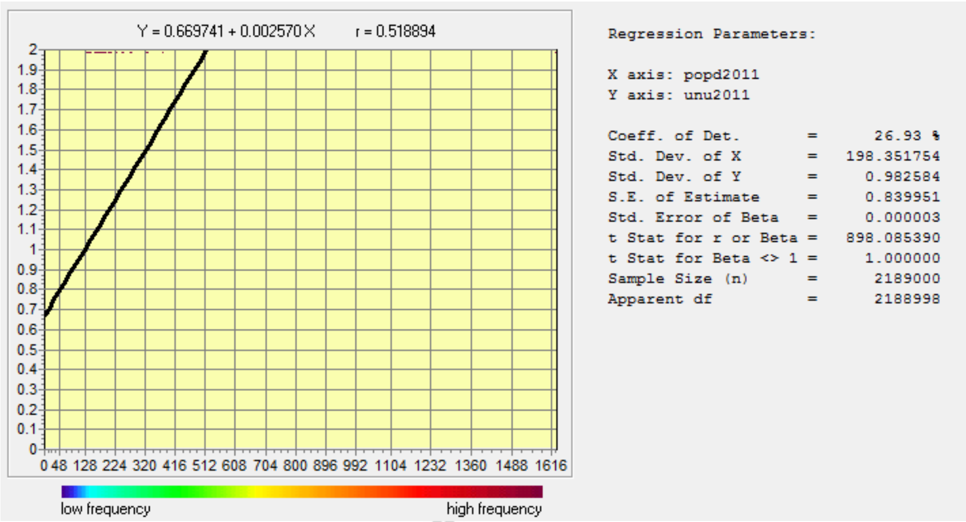


Figure C-23 Spatial simple linear regression analysis between urban pattern in 2011 and population density in 2011.

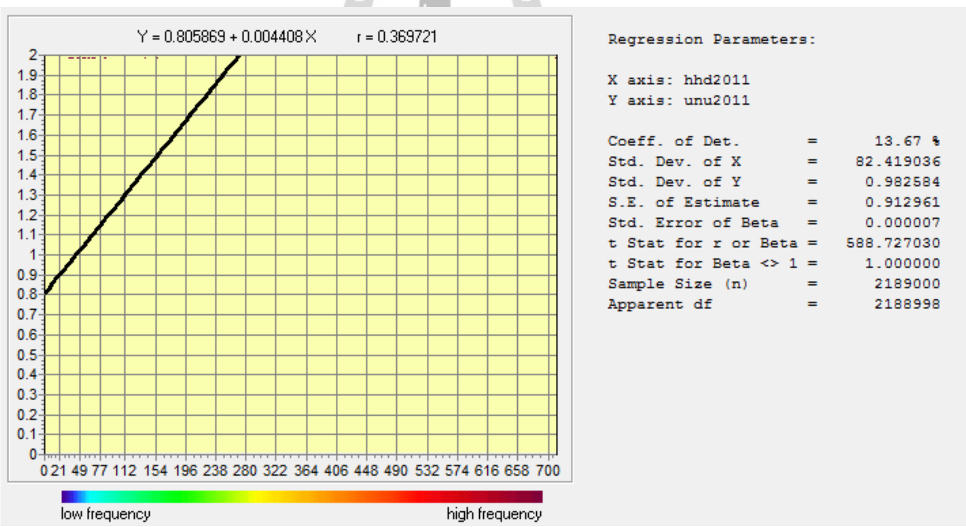


Figure C-24 Spatial simple linear regression analysis between urban pattern in 2011 and household density in 2011.

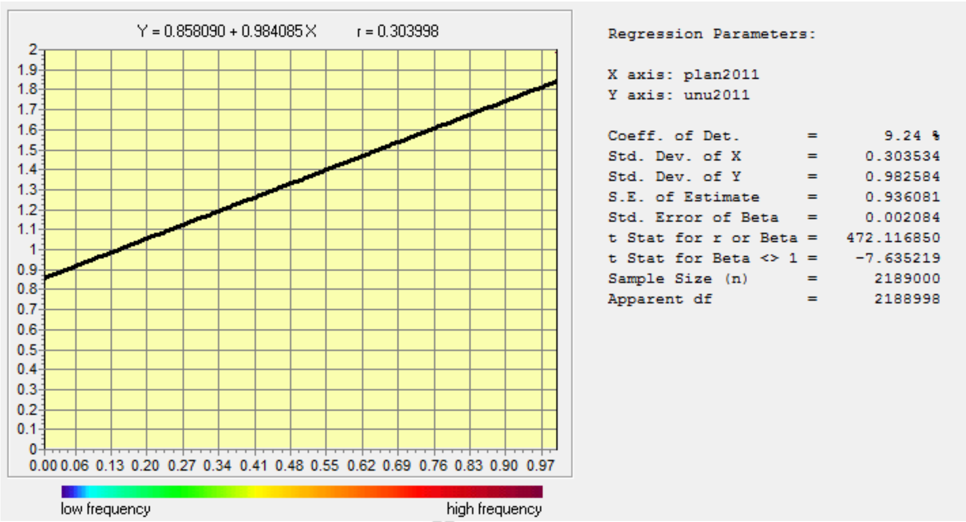


Figure C-25 Spatial simple linear regression analysis between urban pattern in 2011 and the existing comprehensive city plan.

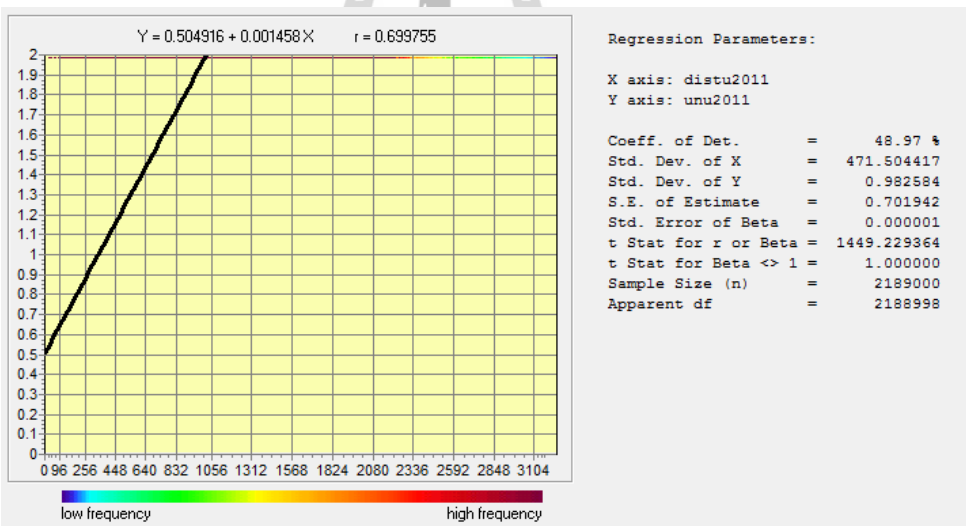


Figure C-26 Spatial simple linear regression analysis between urban pattern in 2011 and existing urban area in 2011.

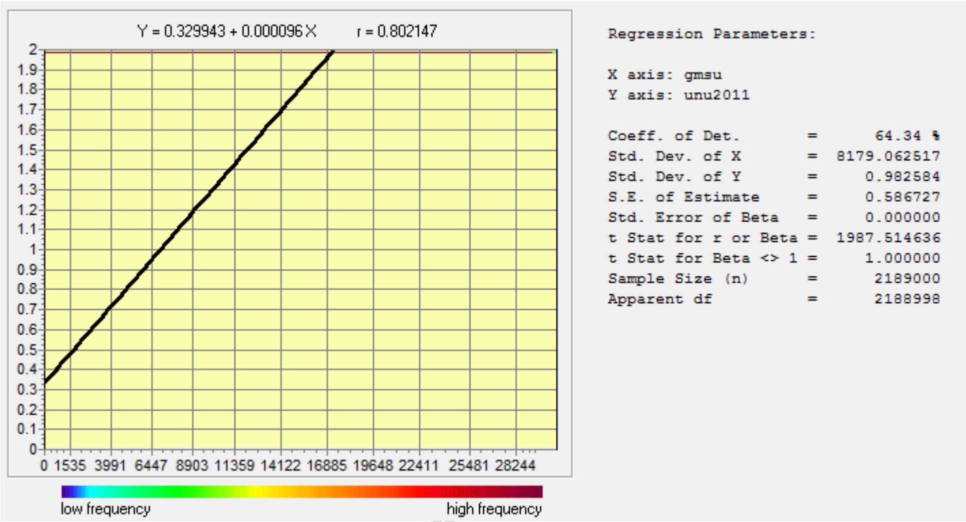


Figure C-27 Spatial simple linear regression analysis between urban pattern in 2011 and new MSU campus.

APPENDIX D

STATISTICAL DATA FROM THE SPATIAL MULTIPLE LINEAR REGRESSION ANALYSIS BETWEEN URBAN PATTERN AND DRIVING FORCE FACTORS

D.1 Spatial multiple linear regression analysis between urban pattern in 2001 and an optimum driving force factors: per capita income, new MSU campus, existing urban area, road network, and slope.

Multiple Regression Results:

Regression Equation :

```
unu2001 = 0.1226 + 1.8464*income2001 + 1.4543*gmsu
          + 1.3317*distu2001 + 1.1361*road2001 + 4.7020*slope
```

Regression Statistics :

```
Apparent R = 0.924831      Apparent R square = 0.855312
Adjusted R = 0.924831      Adjusted R square = 0.855312
F ( 5,     2188994) = 2588013.000000
```

ANOVA Regression Table

Source	apparent degrees of freedom	sum of squares	mean square
Regression	5	1818705.49	363741.09
Residual	2188994	307659.64	0.14
Total	2188999	2126365.12	

Individual Regression Coefficients

	Coefficient	t_test (2188994)
Intercept	0.122636	355.169983
income2001	1.846407	1148.788940
gmsu	1.454314	1076.731689
distu2001	1.331710	562.554443
road2001	1.136072	443.307617
slope	4.702027	308.981110

D.2 Spatial multiple linear regression analysis between urban pattern in 2006 and driving force factors: per capita income, new MSU campus, existing urban area, road network, and slope.

```
Multiple Regression Results:

  Regression Equation :

         unu2006 = 0.1145 + 1.7921*income2006 + 1.5296*gmsu
                    + 1.2429*distu2006 + 1.0234*road2006 + 4.7090*slope

  Regression Statistics :

          Apparent R = 0.928710     Apparent R square = 0.862502
          Adjusted R = 0.928710     Adjusted R square = 0.862502
          F ( 5,     2188994) = 2746235.000000

                     ANOVA Regression Table

                 |  apparent degrees          sum of             mean
  Source         |    of freedom              squares            square
-----------------+---------------------------------------------------------
 Regression      |               5          1830835.39         366167.09
 Residual        |         2188994           291867.81              0.13
 Total           |         2188999          2122703.20
-----------------+---------------------------------------------------------

                   Individual Regression Coefficients

                 |      Coefficient          t_test ( 2188994 )
-----------------+-----------------------------------------
 Intercept       |      0.114545          339.882629
       income2006|      1.792075         1226.385132
             gmsu|      1.529551         1167.180542
        distu2006|      1.242943          537.068237
         road2006|      1.023389          408.582794
            slope|      4.709027          318.558472
-----------------+-----------------------------------------
```

D.3 Spatial multiple linear regression analysis between urban pattern in 2011 and driving force factors: per capita income, new MSU campus, existing urban area, road network, slope, and population density.

```
Multiple Regression Results:

  Regression Equation :

         unu2011 = 0.0367 + 3.0930*income2011 + 0.7897*gmsu
                     + 0.6045*distu2011 + 0.4746*road2011 + 1.6858*slope
                     - 1.6877*popd2011

  Regression Statistics :

          Apparent R = 0.968392     Apparent R square = 0.937784
          Adjusted R = 0.968392     Adjusted R square = 0.937784
          F ( 6,      2188993) = 5499127.000000

                      ANOVA Regression Table

                  |  apparent degrees           sum of             mean
  Source          |     of freedom              squares            square
------------------+-------------------------------------------------------------
 Regression       |               6          1981928.51         330321.41
 Residual         |         2188993           131488.36              0.06
 Total            |         2188999          2113416.87
------------------+-------------------------------------------------------------

                    Individual Regression Coefficients

                  |       Coefficient          t_test ( 2188993 )
------------------+--------------------------------------------
 Intercept        |       0.036709           158.873993
       income2011 |       3.092953          2189.495361
             gmsu |       0.789725          830.920044
        distu2011 |       0.604527          372.154907
         road2011 |       0.474570          276.756744
            slope |       1.685796          167.052582
         popd2011 |      -1.687732          -788.881287
------------------+--------------------------------------------
```

APPENDIX E

STATISTICAL DATA FROM THE SPATIAL SIMPLE LINEAR REGRESSION ANALYSIS BETWEEN URBAN AREA CHANGE AND SURFACE RUNOFF CHANGE

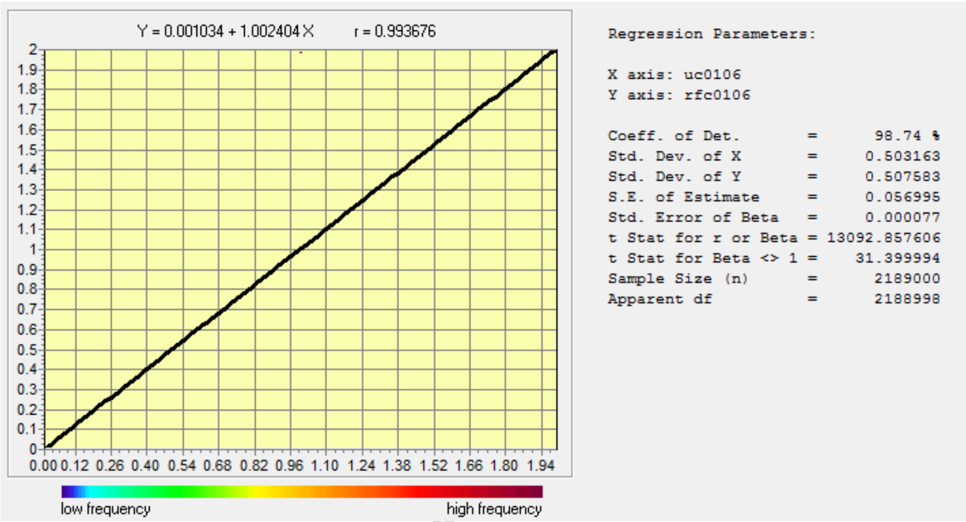


Figure E-1 Spatial simple linear regression analysis between urban area change and surface runoff change between 2001 and 2006.

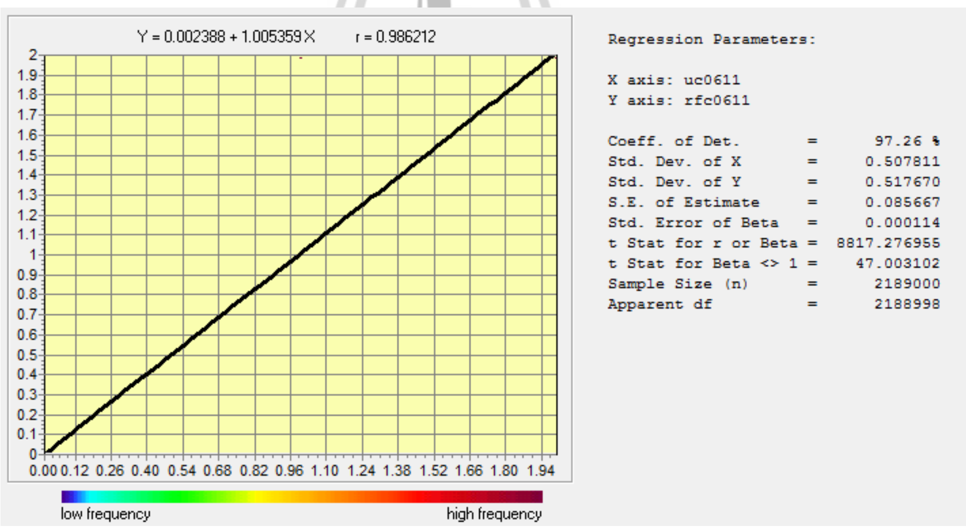


Figure E-2 Spatial simple linear regression analysis between urban area change and surface runoff change between 2006 and 2011.

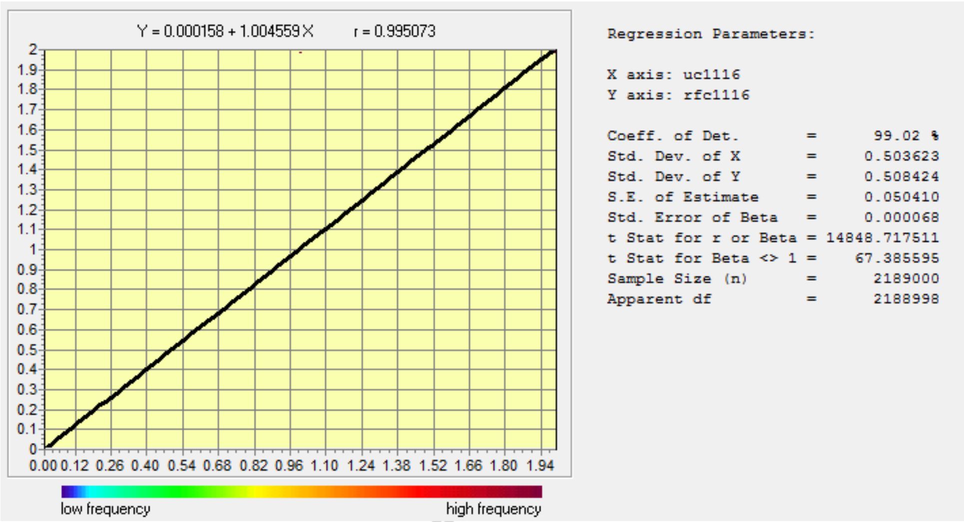


Figure E-3 Spatial simple linear regression analysis between urban area change and surface runoff change between 2011 and 2016.

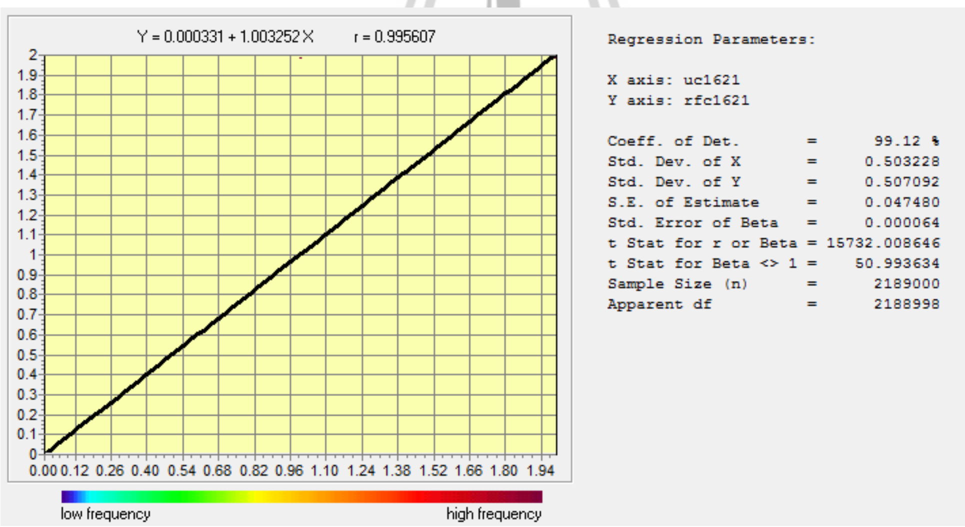


Figure E-4 Spatial simple linear regression analysis between urban area change and surface runoff change between 2016 and 2021.

APPENDIX F

STATISTICAL DATA FROM THE SPATIAL SIMPLE LINEAR REGRESSION ANALYSIS BETWEEN URBANIZATION AND MEAN SURFACE RUNOFF ZONATION

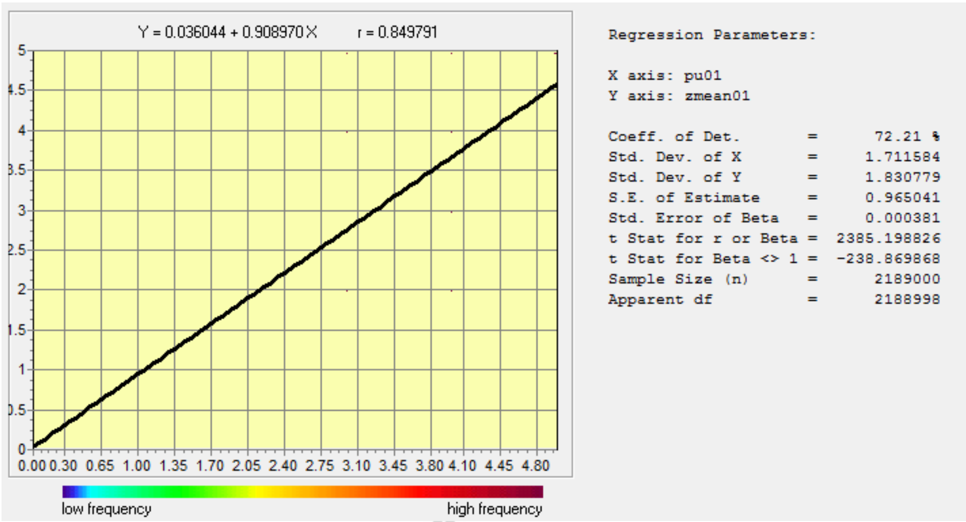


Figure F-1 Spatial simple linear regression analysis between urbanization and mean surface runoff zonation in 2001.

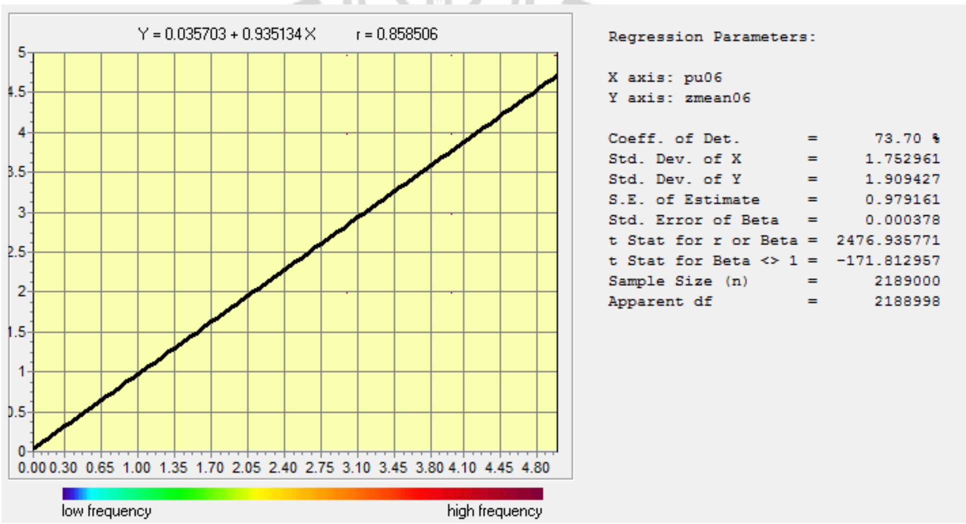


Figure F-2 Spatial simple linear regression analysis between urbanization and mean surface runoff zonation in 2006.

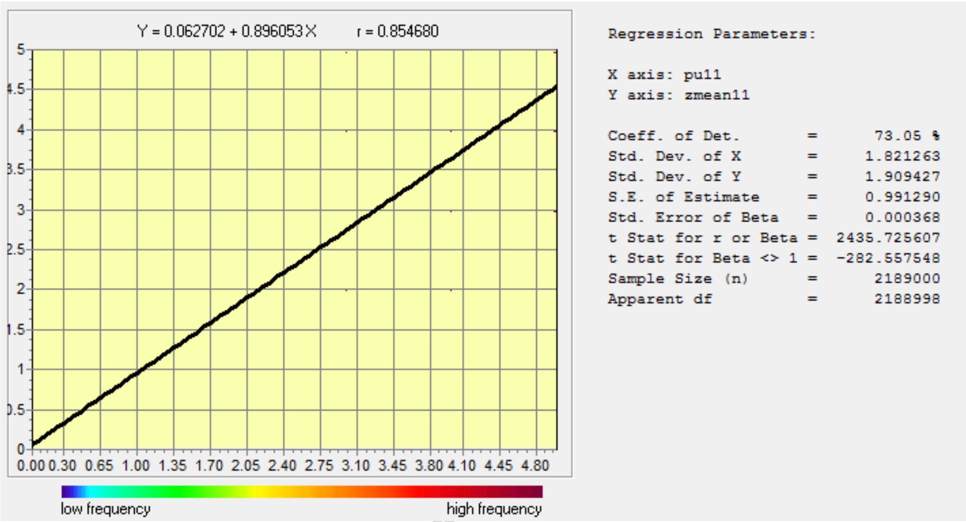


Figure F-3 Spatial simple linear regression analysis between urbanization and mean surface runoff zonation in 2011.

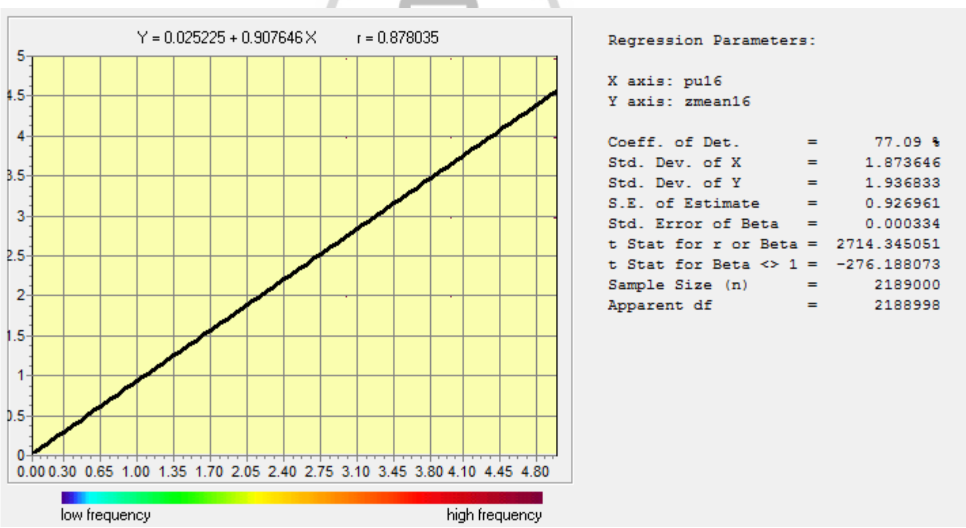


Figure F-4 Spatial simple linear regression analysis between urbanization and mean surface runoff zonation in 2016.

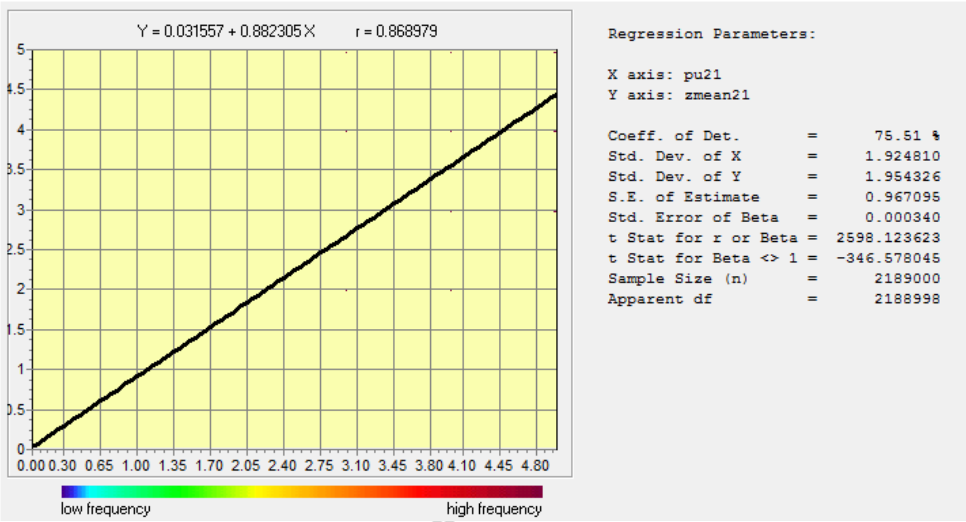


Figure F-5 Spatial simple linear regression analysis between urbanization and mean surface runoff zonation in 2021.

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