ASSESSMENT AND PREDICTION OF AGRICULTURAL AND FOREST LANDSCAPE SUSTAINABILITY IN LAMTAKHONG WATERSHED, NAKHON RATCHASIMA PROVINCE, THAILAND

Siriwan Ruamkaew

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Geoinformatics

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การประเมินและคาดการณ์ความยั่งยืนของภูมิทัศน์ทางการเกษตรและป่าไม้ในลุ่มน้ำลำตะคอง จังหวัดนครราชสีมา ประเทศไทย

นางสาวสิริวรรณ รวมแก้ว

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

Thesis Examining Committee

____

(Asst. Prof. Dr. Sunya Sarapirome)

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____

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สิริวรรณ รวมแก้ว : การประเมินและคาดการณ์ความยั่งยืนของภูมิทัศน์ทางการเกษตรและป่าไม้ในลุ่มน้ำลำตะคอง จังหวัดนครราชสีมา ประเทศไทย (ASSESSMENT AND PREDICTION OF AGRICULTURAL AND FOREST LANDSCAPE SUSTAINABILITY IN LAMTAKHONG WATERSHED, NAKHON RATCHASIMA PROVINCE, THAILAND) อาจารย์ที่ปรึกษา : ผู้ช่วยศาสตราจารย์ ดร.สุวิทย์ อ๋องสมหวัง, 213 หน้า.

การประเมินและคาดการณ์ความยั่งยืนของภูมิทัศน์ทางการเกษตรและป่าไม้ มีความจำเป็นสำหรับ การวางแผน ป้องกัน และ อนุรักษ์ความหลากหลายทางชีวภาพของภูมิทัศน์ในอนาคต วัตถุประสงค์ หลัก ของการศึกษาคือ เพื่อ จำแนก การใช้ประโยชน์ที่ดินและสิ่งปกคลุมดิน และ คาดการณ์การเปลี่ยนแปลงการใช้ประโยชน์ที่ดินและสิ่งปกคลุมดิน เพื่อประเมินรูปแบบ ภูมิทัศน์ของภูมิทัศน์ทางการเกษตรและป่าไม้ และเพื่อประเมินความยั่งยืน ของภูมิทัศน์ทางการเกษตรและป่าไม้โดยใช้แบบจำลองดัชนีความยั่งยืน (Sustainability Indicator model: SUSI Model) และพัฒนาแบบจำลองคาดการณ์ความยั่งยืนของภูมิทัศน์ ในการศึกษา ข้อมูลดาวเทียม Landsat พ.ศ. 2536 พ.ศ. 2544 และ พ.ศ. 2552 ถูกนำมาทำการ จำแนกการ ใช้ประโยชน์ที่ดินและสิ่งปกคลุมดิน ด้วยวิธี การจำแนกแบบผสมผสาน (Hybrid classification) และนำผลที่ได้ไปใช้คาดการณ์การใช้ประโยชน์ที่ดินและสิ่งปกคลุมดิน พ.ศ. 2560 และ พ.ศ. 2568 จากนั้น นำข้อมูลการใช้ประโยชน์ที่ดินและสิ่งปกคลุมดิน ไปจำแนกประเภท ของภูมิทัศน์ และประเมิน รูปแบบ ทางภูมิทัศน์ รวมทั้ง การประเมินความยั่งยืนของ ภูมิทัศน์ทางการเกษตรและป่าไม้ ด้วยดัชนีความยั่งยืน (SUSI) และ พัฒนาแบบจำลองคาดการณ์ความยั่งยืนของภูมิทัศน์

ผลการประเมินการใช้ประโยชน์ที่ดินและสิ่งปกคลุมดิน และการเปลี่ยนแปลง พบว่า ใน พ.ศ. 2536 พ.ศ. 2544 และ พ.ศ. 2552 เมืองและสิ่งปลูกสร้าง พืชไร่ ไม้ยืนต้นและไม้ผล แหล่งน้ำ และพื้นที่เบ็ดเตล็ด มีพื้นที่ เพิ่มขึ้นอย่างต่อเนื่อง ขณะที่ป่าไม้ มีพื้นที่ ลดลง อย่างต่อเนื่อง ทำนองเดียวกัน ใน พ.ศ. 2560 และ พ.ศ. 2568 เมืองและสิ่งปลูกสร้าง พืชไร่ ทุ่งหญ้าเลี้ยงสัตว์ แหล่งน้ำ และพื้นที่เบ็ดเตล็ด มีพื้นที่เพิ่มขึ้นอย่างต่อเนื่อง ขณะที่ป่าไม้ มีพื้นที่ลดลงอย่างต่อเนื่อง สำหรับการพัฒนา การ ของประเภทภูมิทัศน์ใน ระหว่าง พ.ศ. 2536 -2568 พบว่า ภูมิทัศน์เมือง ภูมิทัศน์เกษตร กรรม และภูมิทัศน์เบ็ดเตล็ด มีพื้นที่เพิ่มขึ้นอย่างต่อเนื่ อง ขณะที่ภูมิทัศน์ป่าไม้ มีพื้นที่ลดลงอย่างต่อเนื่อง

การวิเคราะห์รูปแบบภูมิทัศน์ ระหว่าง พ.ศ. 2536-2568 พบว่า ระดับการแตกกระจาย ของภูมิทัศน์เกษตรมีค่า ค่อนข้างต่ำ ขณะที่ความซับซ้อน ความหลากหลาย และการรวมกลุ่ม มีค่า

ปานกลาง ในขณะเดียวกัน การแยกออกจากกันของภูมิทัศน์มีค่าสูง สำหรับ การแตกกระจาย ความหลากหลาย และการรวมกลุ่ม ของภูมิทัศน์ป่าไม้ มีค่าต่ำ ขณะที่ความซับซ้อนใน พ.ศ. 2536 และ พ.ศ. 2544 มีค่าปานกลาง แต่ความซับซ้อนใน พ.ศ. 2552 พ.ศ. 2560 และ พ.ศ. 2568 มีค่าต่ำ อย่างไรก็ตาม ระหว่าง พ.ศ. 2536-2568 การแยกออกจากกันของภูมิทัศน์ป่ามีค่าสูง

การประเมินความยั่งยืนของภูมิทัศน์ พบว่า ความยั่งยืนของภูมิทัศน์ ทางการเกษตรและป่าไม้มีค่าลดลงระหว่าง พ.ศ. 2536-2552 และมีค่าลดลงในอนาคตในระหว่าง พ.ศ. 2552-2560 และ พ.ศ. 2552-2568 นอกจากนี้ ผลการคาดการณ์ความยั่งยืนของภูมิทัศน์ ทางการเกษตรและป่าไม้ใน พ.ศ. 2552 โดยอาศัยแบบจำลองการวิเคราะห์การถดถอยเชิงเส้นแบบพหุสามารถ นำมาใช้อธิบายความสัมพันธ์ระหว่างดัชนีความยั่งยืนของภูมิทัศน์ ทางการเกษตรและป่าไม้ กับค่าดัชนีภูมิทัศน์ได้ประมาณร้อยละ 82 และ 46 ตามลำดับ ความถูกต้องโดยรวมของ การคาดการณ์ความยั่งยืน ของภูมิทัศน์ทางการเกษตรใน พ .ศ. 2560 และ พ.ศ. 2568 เท่ากับ ร้อยละ 81.64 และ 80.08 ตามลำดับ และค่าสัมประสิทธิ์แคปปาเท่ากับ 0.34 และ 0.39 ตามลำดับ ในขณะที่ความถูกต้องโดยรวมของการคาดการณ์ความยั่งยืน ของทางการเกษตรใน พ .ศ. 2560 และ พ.ศ. 2568 เท่ากับ ร้อยละ 81.64 และ 80.08 ตามลำดับ และค่าสัมประสิทธิ์แคปปา เท่ากับ 0.34 และ 0.39 ตามลำดับ ในขณะ ที่การคาดการณ์ความยั่งยืน ของภูมิทัศน์ ป่าไม้ใน พ.ศ. 2560 และ พ.ศ. 2568 มีค่าเท่ากับ ร้อยละ 32.81 และ 35.16 ตามลำดับ และมีค่าสัมประสิทธิ์แคปปาเท่ากับ 0.19 และ 0.11 ตามลำดับ

จากผลการศึกษาสามารถ สรุปได้ว่า ความยั่งยืนของภูมิทัศน์ ทางการเกษตรและป่าไม้สามารถตรวจวัดได้จากระดับความเข้มข้นของการใช้ประโยชน์ที่ดินโดยใช้แบบจำลองดัชนีความยั่งยืน (SUSI model)

สาขาวิชาการรับรู้จากระยะไกล ลายมือชื่อนักศึกษา________________________

ปีการศึกษา 2554 ลายมือชื่ออาจารย์ที่ปรึกษา__________________

SIRIWAN RUAMKAEW : ASSESSMENT AND PREDICTION OF AGRICULTURAL AND FOREST LANDSCAPE SUSTAINABILITY IN LAMTAKHONG WATERSHED, NAKHON RATCHASIMA PROVINCE, THAILAND. THESIS ADVISOR : ASST. PROF. SUWIT ONGSOMWANG, Dr. rer. 213 PP.

LAND USE AND LAND COVER / LANDCSPE ECOLOGY/ LANDCSPE PATTERN / LANDSCAPE SUSTAINABILITY / SUSTAINABILITY INDEX (SUSI)

Assessment and prediction of agricultural and forest landscape sustainability are necessary for planning, protection and conservation of landscape biodiversity in the future. The main objectives of the study were to classify land use and land cover (LULC) and predict land use and land cover change (LULCC), to evaluate landscape pattern of agricultural and forest landscape and to evaluate and agricultural and forest landscape sustainability using Sustainability Indicator model (SUSI model) and develop landscape sustainability predictive model. In practice, Landsat imageries in 1993, 2001 and 2009 were used to LULC classified using hybrid classification method and predict LULC in 2017 and 2025. These LULC data were used to classify landscape types and assess landscape pattern. In addition, agricultural and forest landscape sustainability were evaluated using SUSI and landscape sustainability predictive model developed.

For LULC assessment and change in 1993, 2001 and 2009, urban and built-up area, field crop, perennial and orchard, water body and miscellaneous land had continued increase, while forest land had decreased. While, in 2017 and 2025 urban and built-up area, field crop, pasture, water body and miscellaneous land were

continued increase while forest land was continued to decrease. In addition, change of landscape types during 1993-2025 urban, agricultural and miscellaneous landscapes had continued to increase while forest landscape had successively decreased.

For landscape pattern analysis, during 1993-2025 agricultural landscape fragmentation was rather low while complexity, diversity and adjacency were moderate. Meanwhile, landscape isolation was high. For forest landscape fragmentation, diversity and adjacency were low. While landscape complexity in 1993 and 2001 were moderate but its complexity in 2009, 2017 and 2025 were low. However, during 1993-2025 landscape isolation of forest landscape was high.

For landscape sustainability evaluation, sustainability of agricultural and forest landscape decreased during 1993-2009 and they will be decreased during 2009-2017 and 2009-2025. In addition, predictive agricultural and forest landscape sustainability in 2009 using multiple linear regression model can be used to explains the relationship among agricultural and forest landscape sustainability indexes and landscape metrics about 81 and 41%, respectively. Overall accuracy of predictive agricultural indexes in 2017 and 2025 were 81.64 and 80.08% respectively and Kappa coefficient were 0.34 and 0.39 respectively. Meanwhile, Overall accuracy of predictive forest indexes in 2017 and 2025 were 32.81 and 35.16% respectively and Kappa coefficient were 0.19 and 0.11 respectively.

In conclusion, agricultural and forest landscape sustainability can be measured as a degree of land use intensity using Sustainability Indicator model (SUSI model)

School of Remote Sensing Student’s Signature________________________

Academic Year 2011 Advisor’s Signature________________________

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LIST OF ABBREVIATIONS

A	=	Agricultural Land
ALT	=	Agriculture Landscape Type
ANN	=	Artificial Neural Network Models
CA	=	Cellular Automata Models
DEM	=	Digital Elevation Model
ETM+	=	Enhanced Thematic Mapper Plus
F	=	Forest Land
FC	=	Field Crop
FLT	=	Forest Landscape Type
GIS	=	Geographic Information System
GISTDA	=	Geo-Informatics and Space Technology Development Agency (public organization)
IJI	=	Interspersion Juxtaposition Index
km	=	Kilometer
LDD	=	Land Development Department
LULC	=	Land Use and Land Cover
LULCC	=	Land Use and Land Cover Change
M	=	Miscellaneous Land
MA	=	Multi-agent System
MLT	=	Miscellaneous Landscape Type

LIST OF ABBREVIATIONS (Continued)

NP	=	Number of Patches
MPFD	=	Mean Patch Fractal Dimension Index
MPI	=	Mean Proximity Index
PF	=	Paddy Field
PO	=	Perennial and Orchard
PS	=	Pasture
SHDI	=	Shannon's Diversity Index
SUSI	=	Sustainability Indicator
SUT	=	Suranaree University of Technology
TM	=	Thematic Mapper
U	=	Urban and Built-up Area
ULT	=	Urban Landscape Type
USDA	=	United States Department of Agriculture
W	=	Water Body
WCED	=	World Commission on Environment and Development

CHAPTER I

INTRODUCTION

1.1 Significant of the problem

Lamtakhong watershed is one of the most important watersheds in Nakhon Ratchasima province, northeast region of Thailand. It covers area of 3,315.07 km^2 or about 16.15% of the total area of Nakhon Ratchasima province. The main river of this watershed is Lamtakhong river which is originated in Khao Yai national park. It flows through Sikhio and Mueang Nakhon Ratchasima districts and joins with the Mun River in Chaloem Phra kiat district. During the past decades, Land use and land cover (LULC) in Lamtakhong watershed was rapidly changed by human activities such as building, road construction, deforestation and many other anthropogenic activities. As a result there has been an increased demand for land and modified in the status of LULC over time.

The watershed is a sensitive area affected by land use and land cover change (LULCC), improper land use practices, lack of appropriate land use planning and the measures for sustainable development adversely affects many natural processes that lead to terrestrial biodiversity change, habitat destruction, soil erosion, land degradation, and water pollution. It is identified as major cases of environmental degradation (Apan, Raine and Paterson, 2000). The problem from LULCC will be continued and has relationship with natural resources and environment degradation and result on declines in standards of living of peoples in the watershed.

Moreover, LULCC also play a major role in the dynamics and change of landscape pattern (Kim, Zerbe and Kowarik, 2002; Fu, Hu, Chen, Honnay and Gulinck, 2006). The removal of small biotopes or changes in the patch size of land use parcels to large units can therefore be seen as an unsustainable development (Renetzeder et al., 2010). The shape and spatial distribution of landscape element induced a variation of the landscape spatial pattern and a variety of ecological phenomena, including animal movements, water runoff and erosion, which further leads to the changes of the ecological sustainability of landscape (Fu et al., 2006). However, the study on LULCC only focused on area changes and conversions of various land use types, with little attention to shape changes and spatial distribution of landscape elements. While the study on landscape ecology emphasizes macroscopic properties, such as landscape pattern, ecological process, and temporal-spatial scale, providing a new tool for performing the LULCC study (Sun et al., 2003).

Landscape pattern or landscape structure refer to the number, size, and juxtaposition of landscape elements or patches, which are important contributors to overall landscape pattern and interpret action of the ecological processes (Gardner, Milne, Turner and O'Nell 1987; O'Neill et al., 1988). Monitoring and detecting the change of landscape patterns under disturbance, especially anthropogenesis disturbance is a critical issue for watershed management and sustainable development (Spies, Ripple and Bradshaw, 1994). The pattern and process are the fundamental components in the analysis and management of watershed and landscape.

Landscape ecological concepts and applied metrics are likely to be useful to understand the relationship between landscape pattern and change in environmental conditions due to human land use (Gustafson, 1998). Investigating landscape metrics and it change a prerequisite to the study of ecosystem functions and processes, sustainable resource management and effective land use planning because landscape pattern can predicator ecological sustainability (Peterseil et al., 2004). Landscape structure has not only been used to evaluate the ecological value of landscapes but also used to measure ecological aspect of the sustainability of land use pattern (Wrbka et al., 2004).

Remote Sensing (RS) and Geographic Information System (GIS) are providing new tools for advanced ecosystem management, land use mapping, and planning (Mark and Kudakwashe, 2010). In particular, LULC information derived from a variety of sensor systems has been particularly useful in better understanding landscape change (Liverman, Moran, Rindfuss, and Stern, 1998). In a GIS context, the use of pattern metrics for quantifying spatial composition and configuration aids in the inference of landscape, whether natural or human induced. The integration of RS and GIS have been coupled to landscape ecology theory to study the distribution pattern of communities and ecosystem, human and environmental processes that effect these patterns, and changes in pattern and process over time.

The purpose of this study is to classify LULC and predict LULCC, to measure evaluate agricultural and forest landscape patterns and to evaluate and develop agricultural and forest landscape sustainability model in Lamtakhong watershed. This assessment can be used as a tool to estimate the impact of past and present human land use practices. It could aid in the administration of public natural resources by assessing spatial and temporal changes and planning future land uses. Moreover, the assessment of landscape sustainability plays a vital role to maintain the ecological security and promote regional ecological sustainable development. The result of the research will benefit decision makers and natural resource managers for conservation planning and protection for land, natural resources and effective ecologically sustainable development into the future.

1.2 Research objectives

The main specific objectives of the study are as follows:

1. To classify land use and land cover in 1993, 2001 and 2009 and their change and predict land use and land cover change in 2017 and 2025;

2. To measure and evaluate agricultural and forest landscape pattern during 1993 to 2025;

3. To evaluate agricultural and forest landscape sustainability during 1993 to 2025 and develop predictive landscape sustainability model.

1.3 Scope and limitations of the study

Scope of the study can be summarized as following.

1. LULC in 1993, 2001 and 2009 are classified from Landsat-TM data using digital image processing with hybrid classification algorithm.

2. LULC in 2017 will be predicted based on transition matrix of LULCC between 2001 and 2009 and predictive LULC in 2025 will be estimated based on transition matrix of LULCC between 1993 and 2009. Both predictive LULC will be created using CA-Markov models.

3. Agricultural and forest landscapes during 1993 to 2025 will be firstly classified based on majority of LULC in grid cell with size of 1 km^2 (landscape cell) and they then used to measure landscape pattern by landscape metrics under Patch Analyst of ArcGIS. Finally, their status and change of agricultural and forest landscape pattern will be evaluated under Spatial Analysis of ArcGIS.

4. For landscape sustainability, hemeroby state in each landscape cell of agricultural and forest landscapes are firstly calculated based on hemeroby value of each LULC type and its proportional area. Sustainability of agricultural and forest landscape during 1993 to 2025 will be then evaluated based on the derived hemeroby state using Sustainability indicator value (SUSI). In addition, the relationship between sustainability of agricultural and forest and their landscape metrics are identified using regression analysis.

1.4 Study area

Lamtakhong watershed is one of the most important water resources for Nakhon Ratchasima province and Northeast region of Thailand. It situates between latitude 14° 22′ to 15° 4′ N and longitude 101° 16′ to 102° 15′ E, covering an area of 3,315.07 km^2 (or 2,071,918 Rai). It encompasses some parts of Pak Chong, Wang Nam Khiao, Sikhio, Dan Khun Thot, Sung Noen, Pak Thong Chai, Kham Thale So, Mueang Nakhon Ratchasima and Chaloem Phra Kiat districts in Nakhon Ratchasima province and Mueang Nakhon Nayok district in Nakhon Nayok province (Figure 1.1).

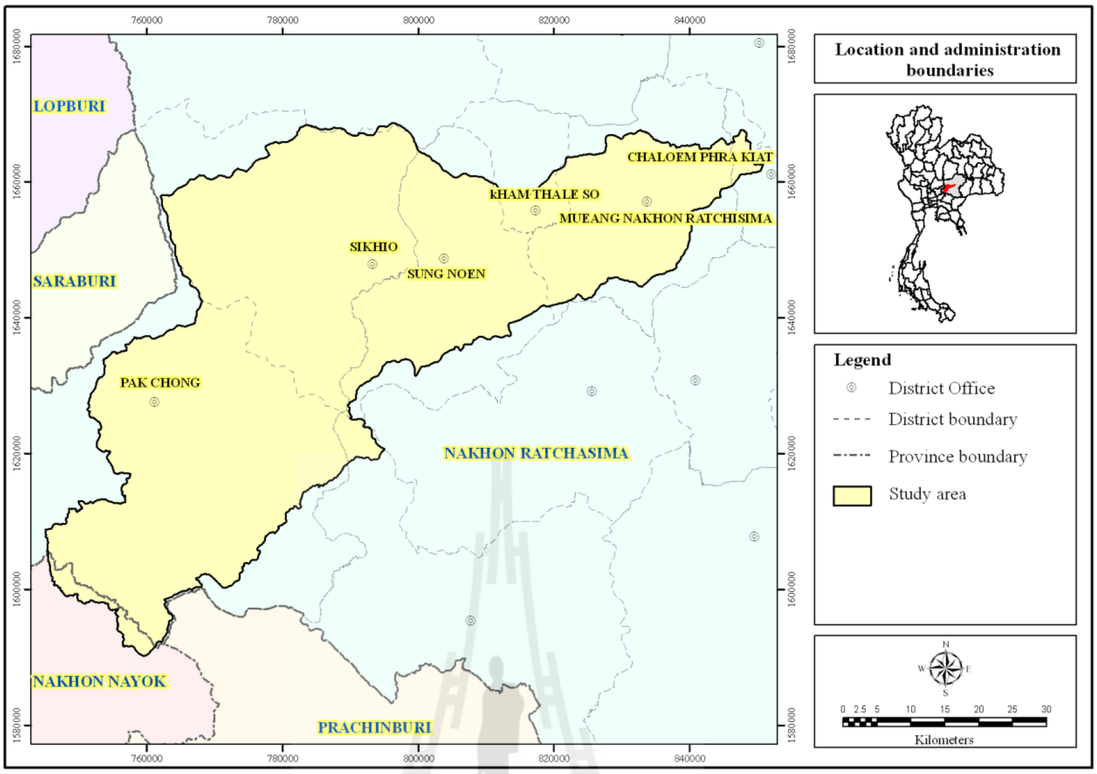


Figure 1.1 Location and administration boundary of the study area.

The elevation of Lamtakhong watershed ranges about form 159 m to 1,300 m above mean sea level (Figure 1.2). The terrain of the study area can be divided in various zones based on their landform. In northeast area, it is characterized by flat areas and gently undulating; most of land use types in this zone are paddy field and field crop. While, in eastern part of the study area, it is characterized by undulating and rolling, this zone is mostly covered by field crop and forest land. At the same time, the hilly zone in the south and mountainous areas in the southeast are covered by forest land. There are three sub watersheds in Lamtakhong watershed including Upper Lamtakhong, Lower Lamtakhong and Huay Hinlab. The main river in Lamtakhong watershed is Lamtakhong river, it has a length of about 220 km, and it flows from west to east of watershed.

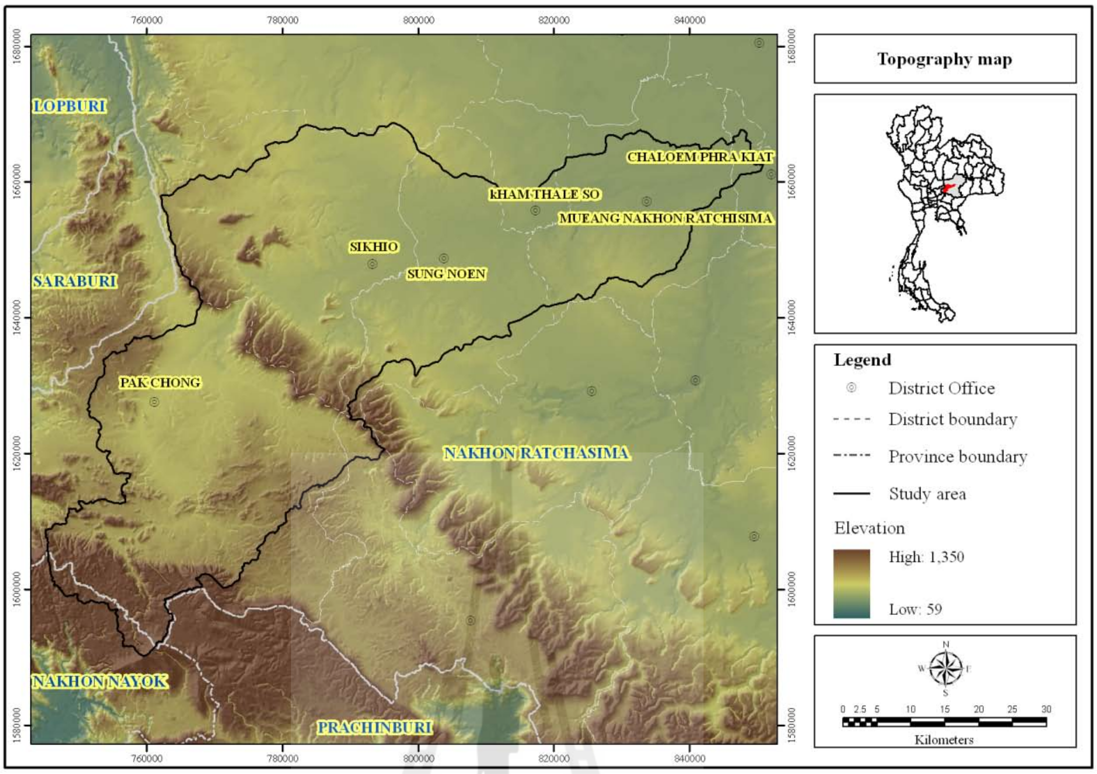


Figure 1.2 Topography of Lamtakhong watershed.

According to report of Land Development Department (LDD) in 2009, annual average temperature is 27.1 °C. The highest temperature in March to April is at 36.6 °C and lower temperature in December is at 17.7 °C. An average annual rainfall is at 1,200.42 mm, the highest rainfall in April to September is at 976.72 mm and lower rainfall is at 223.70 mm in December.

In addition, the main land use type in 2007 in Lamtakhong watershed was agriculture land including paddy field, field crop, perennial, and orchard covered area about 60% of total area. Forest lands were about 20% of total area consisting of dry evergreen forest, dry dipterocarp forest and forest plantation. At the same time, urban and built-up area and water body and miscellaneous land area cover area about 20% of total area (Land Development Department, 2009).

1.5 Benefits of the study

1. To understand LULC status and their multi-period changes and the relationship between landscape pattern and landscape sustainability of agricultural and forest landscape in Lamtakhong watershed. The results can be applied for agricultural and forest land sustainability evaluation.

2. Measurement of sustainability based landscape ecology can be used as a framework for prevention, protection, conservation and restoring land and natural resources to planners, managers and decision makers.

CHAPTER II

RELATED CONCEPTS AND LITERATURE REVIEW

2.1 Land use and land cover

Change of land use and land cover (LULC), as one of the main driving forces of global environmental change, is central to the sustainable development debate. Land use and land cover change (LULCC) have impacts on a wide range of environmental and landscape attributes including the quality of water, land and air resources, ecosystem processes and function, and the climate system itself through greenhouse gas fluxes and surface albedo effects. (Lambin, Rounsevel and Geist, 2000).

LULC are two related land surface characteristics where land use is the way in which, and the purposes for which, human beings employ the land and its resources: for example, farming, mining, or lumbering. Land cover describes the physical state of the land surface: as in cropland, mountains, or forests. The term land cover originally referred to the kind and state of vegetation (such as forest or grass cover), but it has broadened in subsequent usage to include human structures such as buildings or pavement and other aspects of the natural environment, such as soil type, biodiversity, and surface and groundwater (Meyer, 1995).

LULCC means (quantitative) changes in the area extent (increases or decreases) of a given type of LULC, respectively (Briassoulis, 2000). It can be grouped into two broad categories as conversion and modification. Land cover conversion involves a change from one cover type to another. Land cover modification involves alterations of structure or function without a wholesale change from one type to another; it could involve changes in productivity, biomass, or phenology (Briassoulis, 2000; Skole, 1994).

2.2 Land use change models

Singh (2003) classified land use change models as follows:

1. Cellular Automata Models (CA): The approach in this model is 'bottom to top'. The final global structure emerges from purely local interactions among the cells. CA not only offers a new way of thinking for dynamic process modeling it also provides a laboratory for testing the decision making processes. As stated earlier they have natural affinity with GIS and remotely sensed data. One of the most significant properties of CA is perhaps its simplicity.

2. Artificial Neural Network Models (ANN): Artificial Neural network model is taught by sample data taken in real area as a human brain learns, thinks and reacts against stimulus. During the training, initial weights that are assigned to interconnection links are modified repeatedly until the ANN can produce acceptable outputs that matches the original target values even though not exactly the same.

3. Multi-agent (MA) systems are designed as a collection of interacting autonomous agents, each having their own capacities and goals but related to a common environment. This interaction can involve communication, i.e. the passing of information from one agent and environment to another. An agent-based model is one in which the basic unit of activity is the agent. Usually, agents explicitly represent actors in the situation being modeled, often at the individual level. They can be

developers, individuals, state policy etc. their influence can be at different scales. Agents are autonomous in that they are capable of effective independent action, and their activity is directed towards the achievement of defined tasks or goals. They share an environment through agent communication and interaction, and they make decisions that tie behavior to the environment.

4. Spatial statistical models: Although traditional statistical models, e.g. Markov chain analysis, multiple regression analysis, principal component analysis, factor analysis and logistic regression, have been very successful in interpreting socio-economic activities, they needed to have spatial component within themselves so that they can used to their full potential in geography. But even after adding the spatial component, many authors criticized them, as time and spatial domain do not follow standard distribution like normal distribution. Therefore the sampling technique is also questioned.

5. Fractal based model: fractals are spatial objects having properties of (1) self-similarity (scale independent), (2) fractional dimension. They can be formed by repeating themselves. The natural objects like ferns, coastlines etc has been represented by fractals successfully.

2.3 Markov chain model

Markov chain modeling or Markov modeling, derived by the mathematician Andrei A. Markov in 1907. A Markov chains are stochastic process fulfilling the Markov property with a discrete state space and a discrete or continuous parameter space. A Markov model represents system of elements making transitions from one state to another over time. The order of the chain gives the number of time steps in the past influencing the probability distribution of the present state, and can be greater than one (Balzter, 2000).

A first order Markov model assumes that to predict the state of the system at time $t + 1$, one need only know the state of the system at time t. The main of Markov model is the transition probability matrix P, which summarizes the probability that cell in cover i will change to cover type j during a single time step (Usher, 1992).

The conditional probabilities $P(X_t = j|X_s = i) = p_{ij}(s,t)$ are called transition probabilities of order $r = t - s$ from state i to state j for all indices $0 \leq s < t$, with $1 \leq i,j \leq k$. They are denoted as the transition matrix P (Balzter, 2000).

For k states P has the form

$$P = \begin{bmatrix} P_{11} & P_{12} & \ldots & P_{1k} \\ P_{21} & P_{22} & \ldots & P_{2k} \\ \ldots & \ldots & \ldots & \ldots \\ P_{k1} & P_{k2} & \ldots & P_{kk} \end{bmatrix}$$

In this expression, k is the number of land use types in the target area, and is the probability of transition of type i into that of type j from the initiation to the end. The probability in any state varies between zero and one. The summation of row in a transition matrix is always equal to one.

The transition matrix P can also be represented as a graph (a box-and-arrow diagram). An example with tree cover types could be illustrated as in Figure 2.1. Casual inspections of the graph reveals the direction of flow in the system, and suggest a succession from type1, through type 2 to type 3, with some process resetting sites back to the initial stage (Urban and Wallin, 2002).

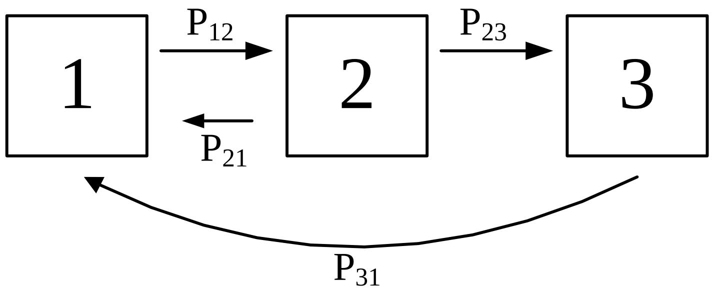


Figure 2.1 A schematic box-and-arrow diagram of transition matrix (Urban and Wallin, 2002).

2.4 Cellular automata model

Cellular Automata model (CA) was first development in the 1940's by two mathematicians working at the Los Alamos National Laboratory, Stanislaw M. Ulam and John von Neumann (Ungerer, 2000). As a frame work of CA was investigating the logical underpinnings of life. They were attempting to explore the possibility of using purely mathematical formulation to reproduce biological automata (Torrens, 2000).

CA is a cellular entity that independently varies its state based on its previous state and that of its immediate neighbors according to a specific rule. Clearly there is a similarity here to a Markovian process. The only difference is application of a transition rule that depends not only upon the previous state, but also upon the state of the local neighborhood (Eastman, 2006).

CA is perhaps the simple models of dynamics spatial model. Singh (2003) described five elements of CA included:

1. Cell Space: The cell space is composed of individual cell. Theoretically, these cells may be in any geometric shape. Yet, most CAs adopts regular grids to represent such a space, which make CA very similar to a raster GIS.

2. Cell states: The states of each cell may represent any spatial variable, e.g., the various types of land use.

3. Time steps: A CA will evolve at a sequence of discrete time steps. At each step, the cells will be updated simultaneously based on transition rules.

4. Transition rules: These rules are the heart of a CA that guides its dynamic evolution. A transition rule normally specifies the states of cell before and after updating based on its neighborhood conditions.

5. Neighborhood: A neighborhood consists of a CA cell itself and any number of cells in a given configuration around the cell. Each cell has two neighbors in one-dimensional cellular automata, whereas in two dimensional cellular automata model there are two ways to define it. Von Neumann has considered four neighboring cells as neighbors; Moore considered eight neighboring cells as neighbors (Figure 2.2).

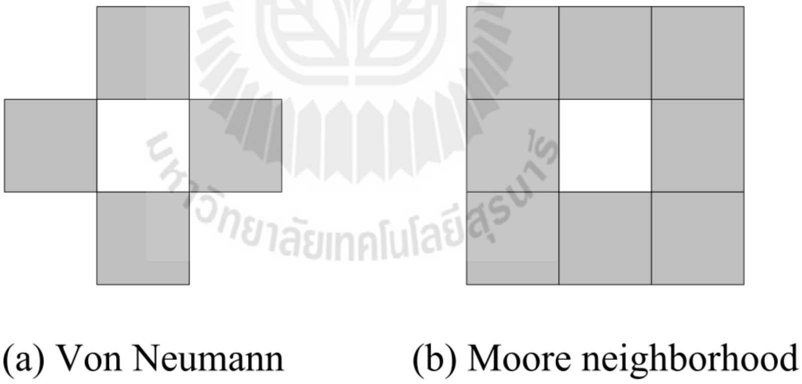


Figure 2.2 Cell and neighborhood (a) Von Neumann's neighborhood (b) Moore's neighborhood (Singh, 2003).

2.5 Landscape ecology

Concept and definition of landscape ecology scale and hierarchy theory and landscape metrics which are the framework for this study are here briefly explained.

2.5.1 Concepts and definitions of landscape ecology

The term of landscape ecology was first introduced by the German bio-geographer Carl Troll in 1939, arising from European tradition of regional geography and vegetation science and motivated particularly by the novel perspective offered by aerial photography (Turner, Gardner and O'Neill, 2001). Landscape ecology is the study of the structure, function, and changes in heterogeneous land areas composed of interacting organisms. It is the study of the interaction between landscape patterns and ecological processes, especially the influence of landscape on the flows of water, energy, nutrients, and biota (Bourgeron and Jensen, 1994). Landscape ecology emphasizes large areas and the ecological effects of the spatial patterning of ecosystems. Specifically, it considers (1) the development and dynamics of spatial heterogeneity, (2) interactions and exchanges across heterogeneous landscapes, (3) the influences of spatial heterogeneity on biotic and abiotic processes, and (4) the management of spatial heterogeneity (Risser, Karr and Forman, 1984).

The main object of landscape ecology is the landscape, Forman and Godron (1986) defined the term of landscape as a heterogeneous land area composed of a cluster of interacting ecosystems (landscape elements) that is repeated in similar form, various sizes, shapes, and spatial relationships. The term ecosystem is a relatively homogeneous area of organisms interacting with their environment. This can be applied at any scale (Forman, 1995).

Landscape ecology focuses on three useful characteristics of the landscape:

1. Structure refers to the distribution of energy, materials, and species. The spatial relationships of landscape elements are characterized as landscape pattern in two ways. First, the simple number and amount of different spatial elements within a landscape is generally defined as landscape composition. Second, the arrangement, position, shape, and orientation of spatial elements within a landscape are generally defined as landscape configuration (McGarigal and Marks, 1995).

2. Function refers to flow of energy, material, and species and the interactions between the mosaic elements (Forman, 1995). Examples, range from fundamental abiotic process, such as cycling of water, carbon, and minerals, to biotic process, including forest succession (Oliver and Larson, 1996), and the dispersal and gene flow of wildlife.

3. Change refers to alteration in the structure and function of the ecological mosaic through time (Forman and Godron, 1986). The main processes or flows generating landscape structure formation and landscape change over time can be considered as natural and anthropogenic disturbances (e.g. wildfire and harvesting); biotic processes (e.g. succession, birth, death, and dispersal); and environmental conditions (e.g. soil quality and climate) (Levin, 1978).

2.5.2 Landscape element

The basic of a landscape is the landscape element (Figure 2.3). A convenient and popular model for conceptualizing and representing the elements a categorical map pattern is known as the patches-corridors-matrix model (Forman, 1995). The concept is based on the analysis of the spatial arrangement of landscape elements. In other words, the structural pattern of patches, corridors and the matrix is used as major determinate of functional flows and movements in and through the landscape. The change in landscape pattern is used as an indication for process changes over time. According to patch-corridor-matrix model, a landscape mosaic is composed of three main types of spatial elements (Forman, 1995):

1. Patch is a homogenous nonlinear area that differs from its surroundings. For example, a woodlot surrounded by farmland and a wetland immersed in upland habitat. Intense human activity often results in simpler, less-convoluted patch shape. Landscapes are composed of a mosaic of patches.

2. Corridor is a form of patch in that they differ from the surrounding areas. However, they are usually identified as strips or linear that can be defined on structure or function. Corridors are areas that link patches together, serving as highways or conduits for organisms to transfer or move from patch to patch.

3. Matrix is the most extensive component of the landscape, is background ecosystem or land use type in a mosaic that is characterized by extensive cover, high connectivity and major control over dynamics (e.g. cultivated fields in agricultural landscape)

A mosaic is a collection of different patches comprising an area where there is no dominant matrix (O'Keefe, Elliott and Naiman, 2012).

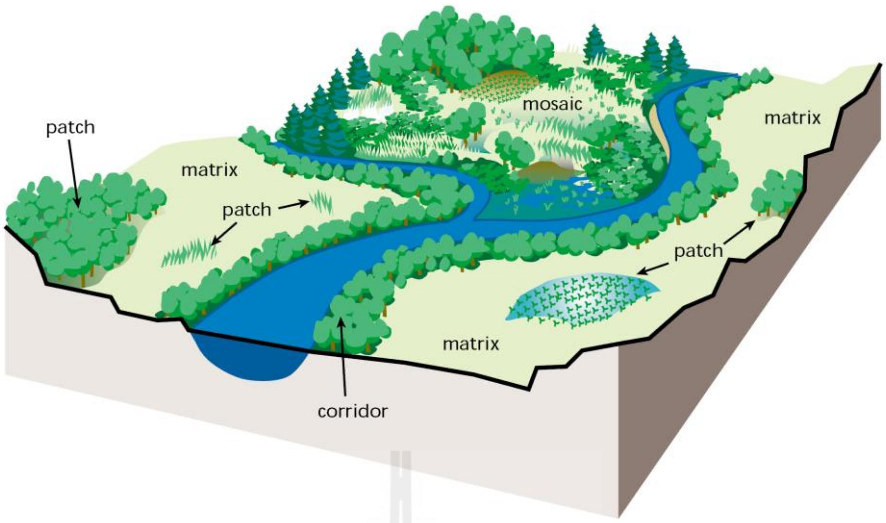


Figure 2.3 Landscapes elements (United States Department of Agriculture, 1998).

2.5.3 Scale and Hierarchy theory

The developments in hierarchy theory demonstrate how processes and constraints change across scales. Thus, the scale at which the landscape exhibits patchiness is important for understanding ecological processes (Wiens, 1986; Maurer, 1985).

Scale is a main concept in landscape ecology, it was that represents the real world as translated onto a map, in the relationship between distance on a map image and the corresponding distance on earth (Malczewski, 1999). Scale is also the spatial or temporal resolution of an object or a process, or level or degree of spatial resolution (Forman, 1995). Scale is measured by two factors: grain and extent. The grain is the determined by the finest level of resolution possible with the given data set; e.g., pixel size for raster data. The extent is established by the size of the study area or the duration of time under consideration (Turner, Dale and Gardner, 1989; Gergel and Turner, 2002).

Hierarchy theory helps explain the connections between complex landscape patterns and the scale of the many processes that influence these patterns. When applied to landscape ecology, this theory allows the components of an ecosystem, or set of ecosystems, to be defined, their patterns and processes identified, and the linkages between the different scales of ecological organization traced (Bourgeron and Jensen, 1994). Determining status and trends in the pattern of landscape is critical to understanding the overall condition of ecological resources. Landscape patterns thus provide a set of indicators (e.g. pattern shape, dominance, connectivity, configuration) that can be use to assess ecological status and trends at a variety of scales (Jensen, 2007).

2.5.4 Landscape metrics

Landscape metrics are algorithms that quantify specific spatial characteristics of patches, classes of patches, or entire landscape mosaics. The plethora of metrics has been developed to quantify categorical map patterns (McGarigal and Marks, 1995).

(1) Level of landscape metrics

Landscape metrics or indices can be divided into three levels: patch level metrics, class level metrics and landscape level metrics (McGarigal and Marks, 1995).

- Patch-level metrics are defined for individual patches, and characterize the spatial character and context of patch.

- Class-level metrics are integrated over all the patches of a given type (class).

- Landscape-level metrics are integrated over all patch type or classes over the full extent of the data (i.e. the entire landscape).

(2) Component of landscape metric

Landscape metrics can be divided into two general categories: those that quantify the landscape composition and/or landscape configuration:

- Landscape composition refers to number, proportional frequency and diversity of patch types represented on a landscape. In other words, landscape composition encompasses the variety and abundance of patch types within a landscape but not the placement or location of patches within the landscape mosaic.

- Landscape configuration refers the spatial character and arrangement, position, or orientation of patches within the class or landscape or the physical distribution or spatial character of patches within the landscape. For example, patch isolation or patch contagion, are measured of the placement of patch types relative to other patch types, the landscape boundary, or other features of interest.

The different types of landscape metrics can be separated into eight major groups (MaGarigal and Marks, 1994 and Häusler et al., 2000).

- Area metrics describe the extent of patches, classes or the total landscape. This can be done in absolute value, as mean values or in percentages.

- Edge metrics describe the number of occurring edges between patches or classes. This is done by perimeter calculations of each patch. In that way, these indices can give information about the spatial variance of an area. A high number of edges can indicate variable ecological conditions, which is e.g. necessary for the occurrence of specific species. Low edge frequencies typically indicate monotonous conditions for the subject/species of interest.

- Shape metrics are based on perimeter-area relationships of the patches, where e.g. the perimeter of a patch is compared to the perimeter of a square with the same area (Frohn, 1998). High values may indicate the occurrence of many patches with complex and convoluted shapes, while low value represent the dominance of simple geometric shapes, like rectangular or circular shapes.

- Core area metrics, core area defined as the area within a patch beyond certain edge distance or buffer width. Core area metrics compute statistics regarding the inner/central parts of patches relative to the total patches. These metrics can give information about habitat quality for certain species.

- Patch metrics describe the total number of patches and their relative proportion (if more classes are present) in a given area.

- Nearest-Neighbor metrics are based on the distances from patches to the nearest neighboring patch of the same type/class. These indices are calculated by using the minimum distance measured as edge to edge distance from one patch to the nearest neighboring patch of the same class type. These measures can be used for describing migration possibilities of species or species interaction of separated populations.

- Diversity metrics measure landscape composition and area function of the richness and evenness of the patch types in the landscape.

- Contagion/interspersion metrics are calculated using the actual rate of adjacency of each occurring class type with all other class types. The resulting values express the probability of adjacency of different class types. Herewith, contagion can give an idea about the extent of aggregation or clumping of patches. High values indicate big continuous areas, while small values represent many small, dissected areas. On the other hand, juxtaposition and interspersion metrics indicate how "well mixed" the patches in the landscape.

Examples of the landscape metrics values for each group can be illustrated in Figure 2.4

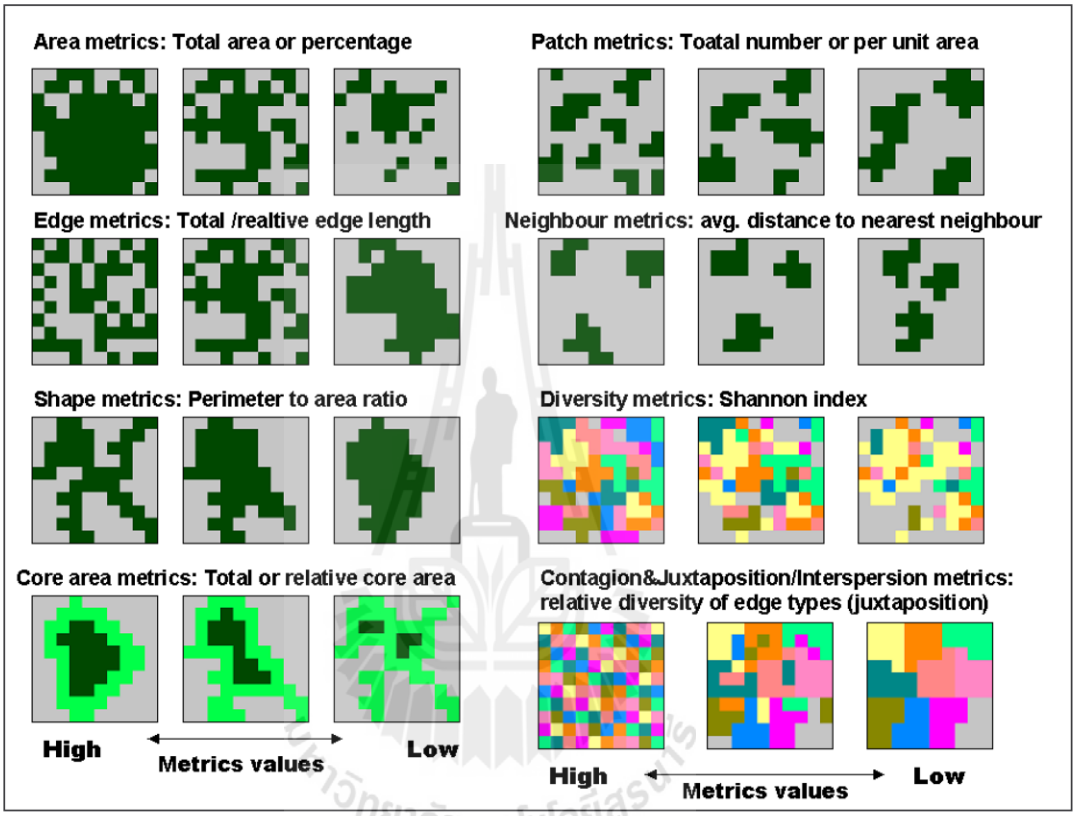


Figure 2.4 Example of the landscape metrics values (Nielsen, 2001).

2.6 Landscape sustainability development

Sustainability originally coined by forestry in the 19th century has become a central term in environmental planning and policy since the late 1980s. The definition of sustainable as development that meets the needs of the present without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development, 1987).

The principles of sustainable development imply that in developing land, ecological, social and economical functions are balanced in space and time to maintain their potential to deliver goods and services to future generations (World Commission on Environment and Development, 1987; Linehan and Gross, 1998). Therefore, in the context of sustainable development, decisions on landscape change must take into account the three dimensions of the landscape concept, each of them representing a different way of looking at the function and pattern of landscapes (Leitão and Ahern, 2002; Opdam, Steingr and Van, 2006). These dimensions are: the eco-physical dimension, defined by geographical patterns and ecological processes; the social dimension, defined by parameters of human perception, land use and physical and mental health; the economic dimension, defined by the landscape's capacity to produce economical values.

In the ecological research, the concept of sustainability is focused in two different ways, an ecosystem research sees sustainable development in terms of material and energy flows within ecosystems. Modern landscape ecological research expands this concept by the spatial and temporal dimension of landscapes (Forman and Godron 1986; Forman, 1995). Sustainable landscape is one which is able to maintain the outputs of ecosystem goods and services that people value or need, and that the key research focus for Landscape Ecology is to understand the biophysical, social and economic boundaries of the space in which this is possible (Potschin and Young, 2006).

Austrian Landscape Research Program developed "Concept of the Relative Deviance" for landscape sustainability assessment (Figure 2.5). The concept is based idea that landscapes can be assessed relative to the sum of other landscapes which belong to the same landscape type. The hemerobiotic state describes and compares the intensity of land use of landscape within a certain landscape type. The deviation of landscape in comparison to the average hemerobiotic state of the according landscape type can be used as indicator for sustainability in ecological terms (Wrbka et al., 2003).

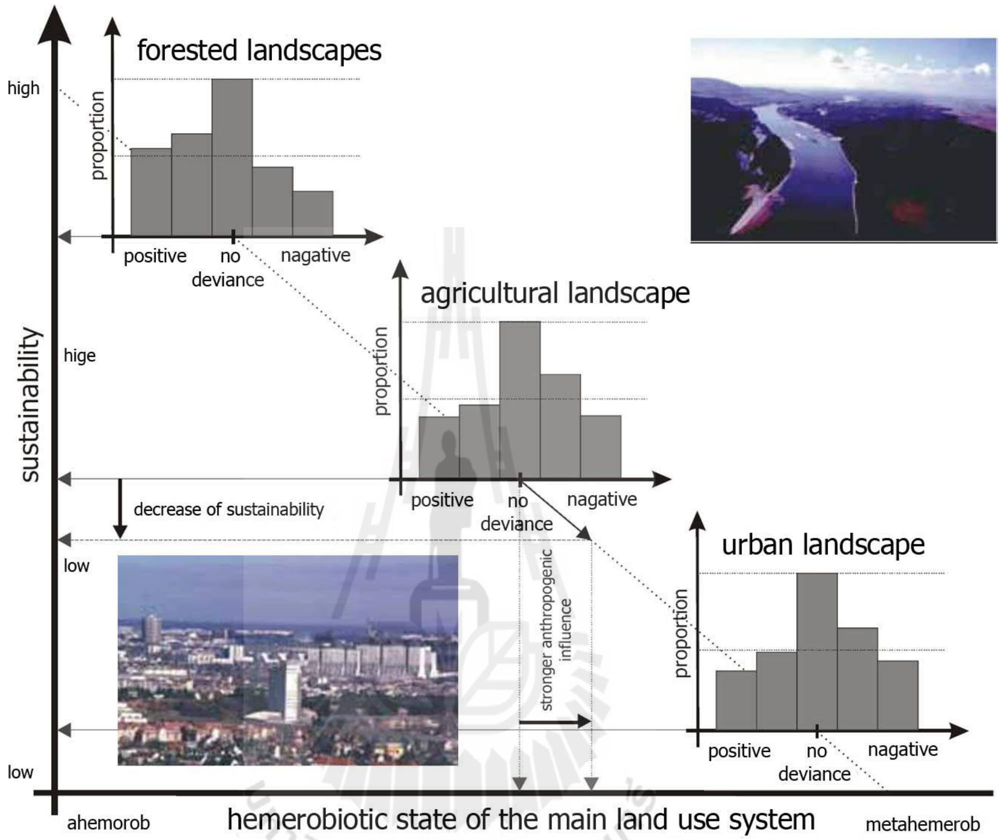


Figure 2.5 Scheme of the Concept of Relative Deviance (Wrbka et al., 2003).

Scheme of the Concept of Relative Deviance which is used for the assessment of land use sustainability of the Austrian cultural landscapes: Changes, e.g. intensification of the land use regime, are reflected by the hemerobiotic state of a specific landscape. These changes of the hemerobiotic state are indicating changes of the sustainability of these landscapes. (Wrbka et al., 2003).

2.7 Hemoroby state

The term of hemeroby come from the greek hemeros (cultivated, tamed, and refined) were born in Europe-in landscape affected (over millennia and over large scales) by human civilization. It was introduced in ecology by botanist Jalas in 1955 and was used to assess level of “naturalness” (native versus alien status) of species. Sukopp (1976) defined hemeroby as the sum of the effects of past and present human activities on ecosystems, whether they are intended or not. The degree of hemeroby is the result of the impact on a particular area and the organisms which inhabit it. It increases with growing human influence.

The degree of hemeroby is measured on the proportion of neophytic and therophytic species, soil characteristics and land use types. (Zepp and Stein, 1991). Six to seven levels of hemeroby which determine the degree of human impacts on a specific landscape and the degree of naturalness. Actually the hemeroby scale depends on the vegetation coverage and the properties of habitats. Natural plant communities are sensitive to changes in the hemeroby scale (intensity of anthropopression).

Data on hemeroby are given on an ordinal scale ranging from level 1 (ahemerob; i.e. no human impact) to level 7 (metahemerob; i.e. sealed soil, where the originally prevalent biocenosis is destroyed). Table 2.1 presents the original hemeroby classification.

Table 2.1 Classification of the human impact on ecosystems and corresponding degrees of hemeroby (Blume and Sukopp, 1976).

Degree of hemeroby	**Degree of naturalness**	**Human impact**
ahemeroby	natural	Non
oligohemeroby	Close to natural	Limited removal of wood, Extensive wood cutting, minor changes in matter circles
Mesohemeroby	Semi-natural	Clearing and occasional ploughing, clear cut, occasional slight fertilizers
β-euhemeroby	Relatively far from natural	Application of fertilizers, lime and pesticides, ditch drainage
α-euhemeroby	Far from natural	Deep ploughing, drainage, application of pesticides and intensive fertilization
polyhemeroby	Strange to natural	Single destruction of the biocenosis and covering of the biotope with external material at the same time
metahemeroby	artificial	Biocenosis destroyed

2.8 Literatures review

Some important literatures depicted LULCC analysis, landscape pattern analysis and landscape sustainability evaluation. These studies in recent years are focused in this review.

2.8.1 Land use and land cover change analysis

Weng (2002) studied on land use change in the Zhujiang Delta of China using of satellite remote sensing, GIS, and stochastic modeling. 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 demonstrates 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.

Reis (2008) analyzed land use and land cover changes by using of Remote Sensing and GIS in Rize, Northeast Turkey. For this purpose (1) land use land covers classification in 1976 and 2000, (2) land use land cover changes by using change detection comparison, and (3) land cover changes analyzed according to the topographic structure (slope and altitude). The results indicate that severe land cover changes have occurred in agricultural (36.2%) (Especially in tea gardens), urban (117%), pasture (-72.8%) and forestry (-12.8%) areas has been experienced in the region between 1976 and 2000. It was seen that the LULC changes were mostly occurred in coastal areas and in areas having low slope values.

Prakasam (2010) studied land use and land cover change in Kodaikanal taluk, Tamil nadu over 40 years period (1969-2008). The land use land cover classification was performed based on the Survey of India Kodaikanal Taluk map and Satellite imageries. GIS software is used to prepare the thematic maps. Ground truth observations were also performed to check the accuracy of the classification. The studied has brought to light that forest area that occupied about 70% of the Taluk's area in 1969 has decreased to 33% in 2008. Agricultural land, Built-up area, Harvested land and Waste land also have experienced change. Built-up lands (Settlement) have increased from 3 to 21% of the total area. Kodaikanal area is identified as one of the biodiversity area in India. Proper land use planning is essential for a sustainable development of Kodaikanal Taluk.

Kasereka, Yansheng, Mbue and Samake (2010) evaluated land use and land cover changes in Wuhan city, China during 1987, 1994 and 2006. Spatial and temporal dynamics of LULCC were quantified using three Landsat TM images (1987, 1994 and 2006). The maximum likelihood supervised classification algorithm and post classification Change detection technique in GIS were also used. The analysis revealed that forest and urban growth over the study period changed by 15.57% and 8.66% respectively, resulting in a significant decrease in the area of cultivated land (16.88%) and water (7.35%). The overall accuracy of the derived LULCC maps ranged from 88% to 92%. The outcomes of this research will benefit society through the creation of reliable land cover information for better decision making.

Wu et al. (2006) monitoring and predicting land use change in Beijing using remote sensing and GIS. The results indicated that there had been a notable and uneven urban growth and a major loss of cropland 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 analyses. 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.

Ratmanee, Bhaktikul and Eamsiri (2007) Developed model of landscape change using remote sensing technique and Markov model for upper Lum Ta Kong basin, Nakorn Ratchasima Province, Thailand. The outcomes of this research work showed that the Remote Sensing Technique and Markov model development can well apply together for the landscape change model construction. Besides the result of predicted landscape with Markov model is appropriately and effectively predicted the proportion landscape change in the upper Lum Takong basin.

Charoenjit (2009) applied Markov-Cellular Automata and Social models for land use prediction in central Petchaburi watershed, Thailand. The studied aims to apply Markov, Cellular Automata, and Social models to identify land use change between the years 2003 and 2008 and predict land use pattern in 2013. The predicted land use in 2013, using CA-Markov model, was identified as the incretion of water bodies since the reservoir was constructed and completed within the study period. Hence, it was affected the analysis. Meanwhile, the predicted land use using CA-Social model was incretion of forest land through alteration from disturbed forest area. The comparison of CA-Markov and CA-Social models showed the substantial agreement (Kappa Index = 0.76) and a similarity index of 85%. In addition, these two models have been accepted for use as land use predict in the study area.

Zhang et al. (2011) analyzed change in wetland trends in arid Yinchuan Plain, China. Three wetland distribution maps were drawn using Two Landsat 5 TM images from 1991 and 1999, and a China–Brazil Earth Resources Satellite (CBERS)-02B image from 2006. The trends of changes in wetland types and the distribution area were predicted using a Markov model. The result of this study showed that the prediction model's relative accuracy was 98.5%. The x^2 test results showed that both the simulated results and the actual wetland distribution area were in good agreement. Therefore, it is feasible to use the wetlands area transfer matrix to establish a transition probability matrix based on the Markov model and to predict the distribution pattern of the wetland in Yinchuan Plain.

Kabba and Li (2011) studied of land use and land cover changes, and their ecological effects in Wuhan, China in 1987-2005. The results showed increased urban and agricultural land uses in 1987-2005. Ecological metrics at landscape level (e.g. number of patches, Shannon and Simpson's diversity indices) showed that fragmentation strengthened in 1987-1994, but weakened in 1994-2005. Socioeconomic factors and ecological metrics indeed explained land use changes and their effects in Wuhan.

2.8.2 Landscape pattern analysis

Gautam, Webb, Shivakoti and Zoedisch (2003) studied land use dynamics and landscape pattern in a mountain watershed in Nepal. This studied analyzed spatial and temporal changes in land use/land cover change from 1976, 1989 and 2000 and investigated changes in the shape of land use patches over the period. The results show the number of forest patches decreased substantially between 1976 and 2000 suggesting merger of patches in the latter periods due to forest regeneration and plantation establishment on lands previously separating two or more forest patches. A shape complexity index (SCI) used to study patchiness of land use indicated improved forest habitat in the watershed but increased mean deviation between actual and optimal SCI of forest polygons indicated higher edge effects at the forest patch level during the latter periods. One of the significant changes within non-forestry land use was increased fragmentation of lowland agricultural areas due to expansion of settlements and infrastructural development in the lowlands.

Kelley and Meyer (2004) studied on agricultural landscape change and stability in northeast Thailand. Pattern metrics calculated at the patch level are assessed as the spatial organization of landscape units that represent: (1) transitional areas of LULC dynamics occurring as peripheral expansion, (2) LULC change from forest to agriculture through deforestation, or (3) agriculture to forest through secondary plant succession, with savanna serving as a transitional matrix. This papered that proposes and tests a method for assessing the temporal persistence of LULC through pattern metrics. The method contributes a technique for analyzing the landscape ecology of sites as a function of their stability/dynamics within a scale-explicit context, and contributes to the growing body of work on relating scale, pattern, and process.

Yang and Liu (2005) quantified landscape pattern and its change in an estuarine watershed using satellite imagery and landscape metrics. The study has several components. First, two land use and land cover maps were produced from satellite imagery. Then, 56 metrics of landscape composition or configuration were computed from the two maps for different spatial observational units. Principal component analysis and Spearman's rank correlation analysis were used to eliminate redundant metrics. These core metrics were finally used to quantify landscape pattern for different spatial observational units at the two different years. Landscape structure has been found to be more fragmented in the Pensacola Bay watershed, around the city centers and along the coastlines, where urbanization and human economic activities are more concentrated. Over time, the landscape mosaics became more heterogeneous while the classes of patches tended to be more fragmented. Results of this study should help coastal managers in the PEDA target those areas in need of conservation and protection.

Abdullah and Nakagoshi (2006) studied on changes in landscape spatial pattern in the highly developing state of Selangor, Peninsular Malaysia. Three land use maps in 1966, 1981 and 1995 were used in this study. These maps were divided into 100 grid squares with each grid square has 10 km×10 km dimension. These grid squares were used as a sampling unit for land use and landscape pattern change analyses. Based on proportion of land use categories, the landscape type of each grid square was determined. Results show that between 1966 and 1981 only one land use category significantly changed ($p < 0.05$) in its proportion compared to five land use categories between 1981 and 1995. This indicates that human land use intensity increased between 1981 and 1995. As response to the intensity of land use change, fragmentation and diversity of the state's landscape increased from 1981 to 1995. Based on the number of grid squares human landscape increased over the period, whereas natural landscape decreased. Between 1981 and 1995, change was mainly occurred in the natural landscape. This study also revealed the potential of landscape type as a reference for land evaluation and complement to landscape metric as measurement for monitoring changes in a landscape.

Olsen, Dale and Foster (2007) studied on landscape pattern as indicators of ecological change at Fort Benning, Georgia, USA. An examination of land-cover class and landscape metrics, computed from the maps, indicated that a suite of metrics adequately describes the changing landscape at Fort Benning, Georgia. The most appropriate metrics were percent cover, total edge (km), number of patches, descriptors of patch area, nearest neighbor distance, the mean perimeter-to-area ratio, shape range, and clumsiness. Identification of such ecological indicators is an important component of building an effective environmental monitoring system.

Langkapisanpong (2008) studied impact of landscape structure from swidden cultivation on forest area in Nong Khao Sub watershed, Mae Hong Son Province. The objective of study change of landscape structure and effects caused from land use in 10 years rotated areas of the Pakakayaw community in Nong Khao sub watershed. As a result, regarding the land use change in Nong Khao sub-watershed during 10 years, from 1997-2006, forest area had increased slightly. The analysis of landscape structure change, found that, Nong Khao sub-watershed has been slightly change. If farmers and the community can still limit areas and pattern of swidden cultivation as the former, the community will be able to exploit the cultivated areas with sustainability, without any impacts on Nong Khao sub-watershed and neighboring areas.

Schindler, Poirazidis, and Wrbka (2008) analyzed the landscape structure of Dadia National Park, Greece. This studied distinguishing nine land cover classes, 119 variables were computed and factor analysis was applied to detect the statistical dimensions of landscape structure and to define a core set of representative metrics. At landscape level, diversity of habitats, fragmentation and patch shape and at class level dominance of mixed forest and the gradient from one pure forest type to another turned out to be the crucial factors across three different scales. Mapping the encountered dimensions and the representative metrics, they detected that the pattern of landscape structure in Dadia National Park was related to dominating habitat types, land use, and level of protection. The evaluated set of metrics are useful in establishing a landscape monitoring program, to detect the local drivers of biodiversity, and to improve management decisions in Dadia NP and similar mosaic-landscapes.

Pôças, Cunha and Pereira (2011) analyzed landscape changes and related driving forces in a mountain rural landscape of Northeast Portugal over three decades. The landscape metrics were obtained from land cover maps derived from Landsat images of 1979, 1989 and 2002. Results indicate a trend for increased landscape fragmentation, decrease of annual crop fields (-43%) and, mainly, increase of meadows (+60%). Results relate with decline and aging of the rural population, and to several measures and policies of subsidies implemented in the region in application of the Common Agriculture Policy, which contributed to the replacement of annual crops by meadows. Results are potentially useful to base appropriate policies for landscape management and conservation planning.

Su, Jiang, Zhang and Zhang (2011) analyzed the spatiotemporal dynamics of agricultural landscape within Hang-Jia-Hu region in China from 1994 to 2003 using set of metrics that closely with sustainability. Spatial regression analysis was carried out to determine the relationships between urbanization indicators and agricultural landscape metrics. The outcomes indicated that, at the whole region scale, agricultural landscapes became lost, fragmented, transformed and isolated as urbanization intensified. Spatial regression models further revealed that changes of agricultural landscapes showed diverging relationships with urbanization indicators for each landscape metric. The character and strength of relationships for each landscape metric were different and changed with scale. While results of agricultural landscape changes consisted with some theoretical predictions in the literature, they also showed different spatiotemporal signatures of urbanization. Resolving these differences will certainly contribute to the ongoing landscape transformation and sustainability debate.

Stupariu, Stupariu, Cuculici and Huzui (2011) applied of the global indicators to landscape change modeling on Prahova Valley, Romania. The aim of the study was to reveal the importance of global landscape metrics for monitoring the diversity, the fragmentation, the complexity and the homogeneity of a region. Based on 1970 maps and on 2009 satellite images, the values of seven global landscape metrics were computed for the mountainous and sub-mountainous region of the Prahova valley (Romania). The values highlighted the tendency of clustering and homogenization correlated with a decrease of shape complexity at landscape level.

The information obtained can be useful both in landscape planning and habitat monitoring, as well as control of human intervention and anthropization.

2.8.3 Landscape sustainability evaluation

Peterseil et al. (2004) evaluated the ecological sustainability of Austrian agricultural landscapes using the SINUS approach. Two different approaches were developed (1) assigning a sustainability value by using expert-rule system based on the concept of fuzzy set theory (FUZSUST), and (2) assigning a sustainability value by using a statistical method based on the deviation from average hemerobiotic state of landscape type (REGSUST). Variables describing the configuration and shape of the land mosaic were derived from a land cover classification based on landform and landscape fragmentation data. Variables describing landscape patterns turned out to be crucial for the model and were a good predictor for land-use intensity estimated by the hemerobiotic state. Despite the methodological differences of the two approaches similarities in the results could be demonstrated. Landscape-structure indicators were shown to be good indicators of ecological sustainability because they are related to ecological characteristics of landscapes such as naturalness and biodiversity.

Fu et al. (2006) studied on change in agricultural landscapes pattern between 1980 and 2000 in the Loess hilly region of Ansai County, China. This studied investigated the changes of the landscape pattern and the changes of the ecological sustainability of the agricultural landscapes using a landscape typology as a spatial reference framework and the concept of hemeroby for the assessment of the ecological aspect of agricultural landscape sustainability. They combined expert judgments with a regression model and a GIS. Fourteen variables describing the landscape structure were chosen as predictors for hemeroby. The research showed the variables describing landscape pattern, Patch size standard deviation (PSSD), Total edge (TE), Mean shape index (MSI), Landscape shape index (LSI), and Shannon's evenness index (SEI) were significant predicators for hemeroby. Although some data limitation, landscape structure turned out to be a good predicator for land use intensity and ecological sustainability of agricultural landscape estimated by hemeroby.

Peng, Wang, Wu, Chang and Ahang (2006) evaluated sustainable land use in mountain areas of Northwestern Yunnan province, China. In this studied a synthetic evaluation index system for sustainable land use was constructed through the application of landscape metrics. A series of quantitative evaluation were conducted in 1996, 1999 and 2001. This researched proved the feasibility of the framework of landscape productivity, landscape threatening and landscape stability in evaluating sustainable land use in mountain areas. The results also showed that, the indexes of population density and land use degree, followed by landscape diversity and cropping index orderly, were the dominant contributing indexes to sustainable land use. The indexes of total production value of industry and agriculture per unit area, yield of cereal crops per unit area, and landscape fragmentation, followed by yield of economic crops per unit area and fertilizer consume per unit area, were the dominant obstacle indexes to sustainable land use.

Tasser, Sternbach and Tappeiner (2008) studied on biodiversity indicators for sustainability monitoring at municipality level an alpine region. The studied was carried out in 2004 for each of the 116 municipalities of South Tyrol, an alpine region in northern Italy. The results showed that the large variance of indicator values mainly arises from anthropogenic activities, and that all indicators are robust to spatial extent, and thus appropriate for multi scale assessment. Further, applying a factor analysis allowed three dimensions to be identified that account for more than 76% of the total variance: (1) naturalness, (2) landscape structure and (3) species diversity. Hence, factor analysis is an objective approach to reduce the number of indicators without losing too much information.

Renetzeder et al. (2010) studied on landscape pattern as a tool for ecological sustainability assessments at the regional (Austrian Cultural Landscapes), national (Austria) and European (European Union + Norway, Switzerland) level with focus on agricultural landscapes. A set of landscape metrics served as a basis to assess naturalness and geometrisation of Austrian and European landscapes as a proxy for their sustainability. To achieve an accurate spatially explicit assessment, they applied a spatial reference framework consisting in units that are homogeneous in biophysical and socio-economic contexts, adapted the regional approach for its application at European level, and developed relative sustainability thresholds for the landscape metrics. The analyses revealed that several landscape metrics, particularly the "Number of Shape Characterizing Points" showed a high correlation with the degree of naturalness. The sustainability map of Austria based on an ordinal regression model revealed well-known problem regions of ecological sustainability. At the European level, the relative deviation from the average pattern showed clearly the simplification processes in the landscapes. However, a better spatial resolution of land cover data would add to the refinement of pattern analysis in regions and therefore the assessment of sustainability.

CHAPTER III

DATA, EQUIPMENT AND METHODOLOGY

3.1 Data and Equipment

Primary data and secondary data of remotely sensed data and readily GIS data had been collected in this study while basic hardware and software are employed for data collection and data analysis. Data and equipments which were used in this study are summarized in Table 3.1.

Table 3.1 Data and equipment.

Data and equipment	Date Production	Path/Row	Scale	Source
1. Primary datasets				
1.1 Landsat-5 TM	1993/12/18	128/50	25X25 m	GISTDA
1.2 Landsat-5 TM	1994/02/27	129/50	25X25 m	GISTDA
1.3 Landsat-7ETM+	2001/02/15	128/50	25X25 m	GISTDA
1.4 Landsat-5 TM	2000/12/12	129/50	25X25 m	GISTDA
1.5 Landsat-5 TM	2009/01/12	128/50	25X25 m	GISTDA
1.6 Landsat-5 TM	2008/12/12	129/50	25X25 m	GISTDA
2. Secondary datasets				
2.1 Color aerial ortho-photographs	2002	-	1:4,000	LDD
2.2 Land use data	2007	-	1:25,000	LDD
2.3 Administrative boundary	2004	-	1: 50,000	NRRU
2.4 Watershed boundary	-	-	1: 50,000	DWR

Note: GISTDA = Geo-Informatics and Space Technology Development Agency (Public Organization), LDD = Land Development department, NRRU = Nakhon Ratchasima Rajabhat University, DWR = Department of water resource, SUT = Suranaree University of Technology

Table 3.1 (Continued).

Data and equipment	Date Production	Path/Row	Scale	Source
3. Equipment				
3.1 Hardware				
- GPS				Personal
- PC computer				Personal
3.2 Software				
- ArcGIS 9.0				Remote Sensing
- Erdas Imagine 8.7				Laboratory, SUT
- IDRISI 15.0				

Note: GISTDA = Geo-Informatics and Space Technology Development Agency (Public Organization), LDD = Land Development department, NRRU = Nakhon Ratchasima Rajabhat University, DWR = Department of water resource, SUT = Suranaree University of Technology

3.2 Methodology

Methodological framework for assessment and prediction of agricultural and forest landscape sustainability in Lamtakhong watershed was schematically displayed in Figure 3.1. Herewith, three main components of research methodology were developed to fulfill all research objectives including:

(1) To classify land use and land cover and their change and predict land use and land cover change;

(2) To measure and evaluate of agricultural and forest landscape pattern;

(3) To evaluate and develop of agricultural and forest landscape sustainability model.

The details of each component of research methodology were separately described in the following sections.

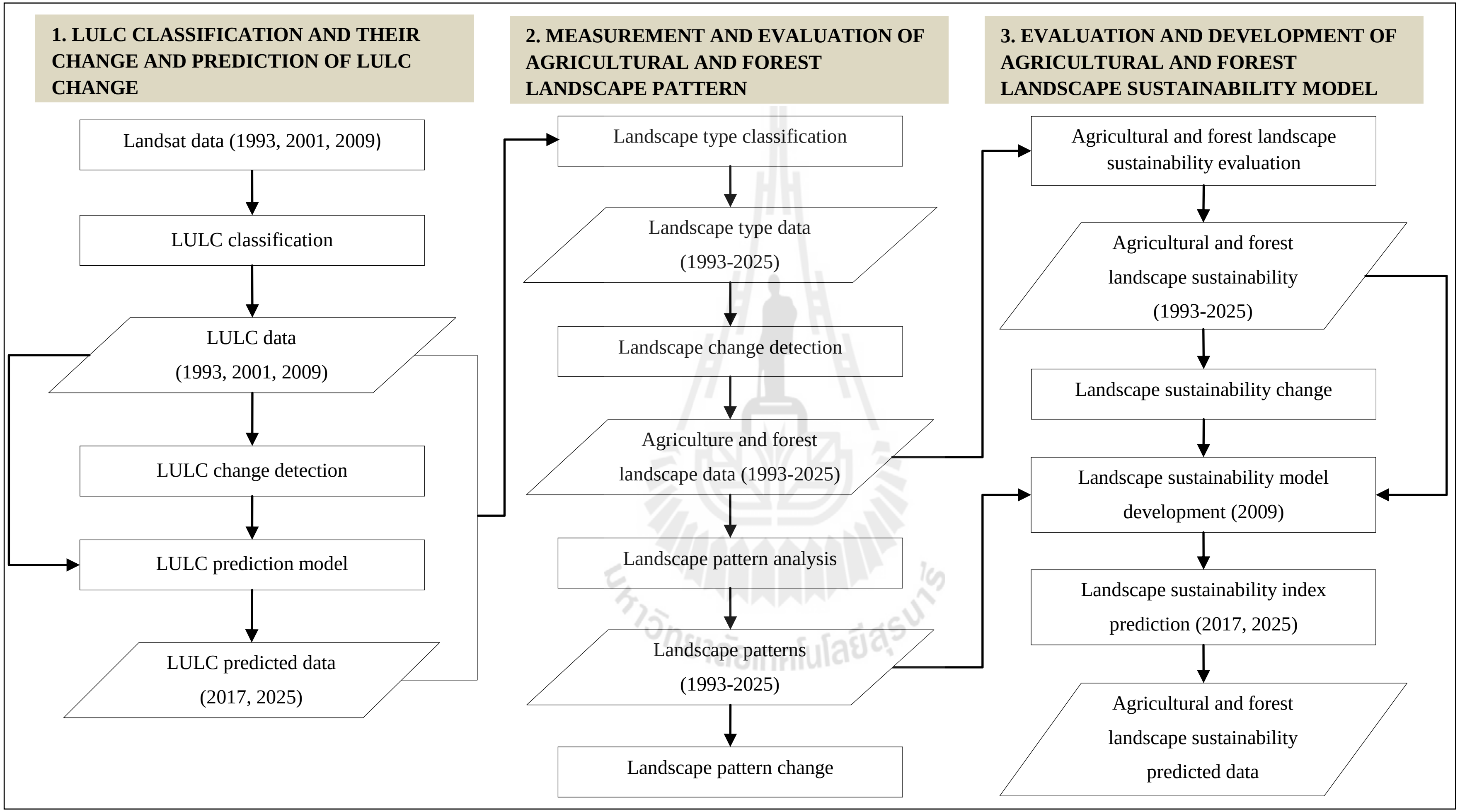


Figure 3.1 The components of research methodology.

3.2.1 Classification of land use and land cover and their change and prediction of land use and land cover change

Major tasks under this component include (1) LULC classification using hybrid algorithm (2) LULCC detection using post-classification comparison, (3) LULCC prediction using CA-Markov model and (4) predictive LULC accuracy assessment (Figure 3.2).

3.2.1.1 Land use and land cover classification

(1) Geometric correction

Landsat-5 TM and Landsat-7 ETM+ imagery in 1993, 2001 and 2009 were geometrically corrected with image to image rectification based on color ortho-photographs image of Ministry of Agriculture and Cooperative taken in 2002. Map projection was universal Transverse Mercator (UTM) Zone 47, World Geodetic System 1984 datum (WGS 84). Herein, polynomial second order transformation for spatial interpolation and nearest neighbor re-sampling for intensity interpolation was here applied with RMS error less than 1 pixel (25 m in real distance).

(2) Image classification

The LULC maps for 1993, 2001 and 2009 were classified by using digital image processing with hybrid classification method. Firstly, unsupervised classification was performed using Iterative Self-organizing Data Analysis Technique (ISODATA) to created the 50 clusters for provide prior knowledge of possible LULC states. Then, supervised classification with Maximum likelihood classifier is applied for LULC classification. Herewith additional training areas from field investigation were included for the optimized LULC type extraction.

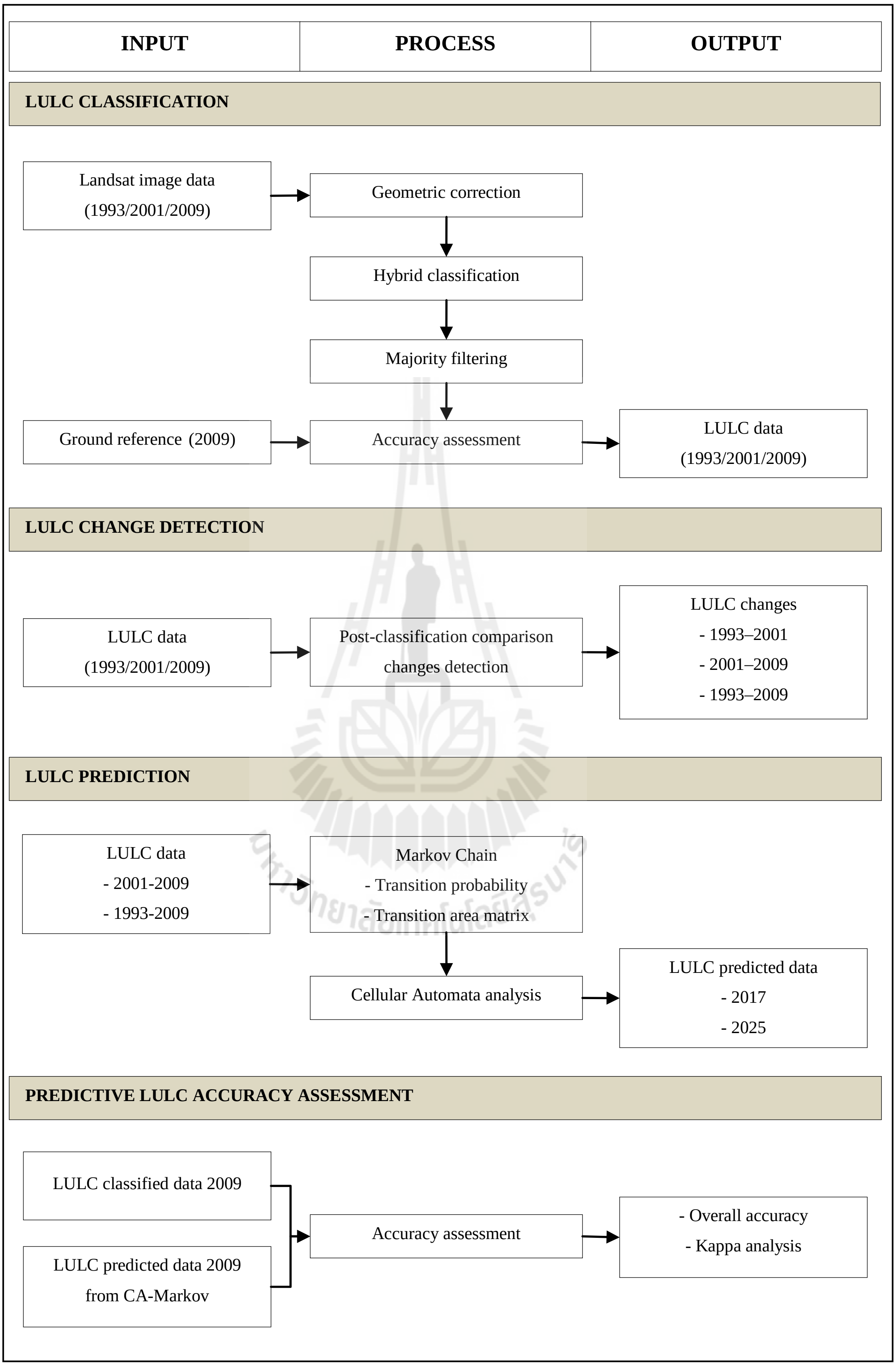


Figure 3.2 Methodology for land use and land cover classification and prediction.

Eight types of LULC were applied to the standard of Land Use Classification System level1 and 2 of LDD included:

1. Urban and built-up area (U): This category includes residential, industrial, commercial, institutional, rural settlement, transportation, communication, and other utilities.

2. Agricultural land (A): This category is further classified comprises of:

(2.1) Paddy field (PF);

(2.2) Field crop (FC);

(2.3) Perennial and orchard (PO);

(2.4) Pasture (PS).

3. Forest land (F): This category includes natural forest and forest plantation.

4. Water body (W): This category comprises of natural water body and man-made water body.

5. Miscellaneous land (M): This category includes marsh and swamp, mine, pit, landfill, and grass land.

(3) Post classification

Post classification was the last step for image classification. The classification results were that eliminate small areas and smoothed with 3 x 3 pixels majority filtering technique.

(4) Accuracy assessment

To access the accuracy of an image classification result, it is common practice to create a confusion matrix or error matrix. In a confusion matrix, a classification result was compared to additional ground truth information. To obtain a confusion matrix, a raster map with ground truth information was required. This map was then crossed with the classification result and displays the cross table.

The accuracy of classification, number of sample sizes was firstly calculated based on statistics and sampling design was then selected for locating and observing points for accuracy assessment. Then classified LULC was compared with ground information as matrix error for accuracy assessment (Jensen, 2005). In this study, number of samples size was derived from a multinomial distribution with desired level of confidence interval of 85% and the precision of 5% according to Congalton and Green (2009) as:

$$N = \frac{BII_i(1-II_i)}{b_i^2} \qquad (3.1)$$

Where

B	is the upper (α/k) x 100^{th} percentile of the chi square χ^2 distribution with one degree of freedom;
II_i (i = 1, 12…k)	is the proportion of the population in the i^{th} category;
b	is the absolute precision of the sample and k is the number of classes.

In practice, stratified random sampling technique was selected for location of the observing points for accuracy assessment. For accuracy assessment, classified LULC in 2009 was compared with ground information in 2009 as matrix error for accuracy assessment with overall accuracy and kappa hat coefficient of agreement. The overall accuracy of the classification map was determined by dividing the total correct pixels by the total number of pixels in the error matrix as computed equation:

$$Overall\ accuracy = \frac{\sum_{i=1}^{k} X_{ii}}{N} \tag{3.2}$$

Where

k is the number of rows in the matrix;

X_{ii} is the number of observations in row i and column i;

N the total number of observations (Congalton and Green, 2009).

Kappa hat coefficient ($\hat{K}$), it was measuring of overall agreement between image data and the reference (ground truth) data. Its coefficient fall typically on a scale between 0 and 1, where the latter indicates complete agreement, and is often multiplied by 100 to give a percentage measure of classification accuracy. Kappa values were characterized into 3 groupings: a value greater than 0.80 (80%) represent strong agreement, a value between 0.40 and 0.80 (40% to 80%) represents moderate agreement, and a value below 0.40 (40%) represents poor agreement (Congalton, 1996). $\hat{K}$ was calculated as:

$$\hat{K} = \frac{N\sum_{i=1}^{k} x_{ii} - \sum_{i=1}^{k}(x_{i+}x_{+1})}{N^2 - \sum_{i=1}^{k}(x_{i+}x_{+1})} \tag{3.3}$$

Where

k the number of rows in the matrix;

x_{ii} is the number of observations in row i and column i and x_{i+} and x_{+i} were the marginal totals for row i and column i respectively;

N is the total number of observations (Congalton and Green, 2009).

3.2.1.2 Land use and land cover change detection

LULCC detection is the process of identifying differences in the state of an object or phenomenon by observing it at different time. Essentially, land cover change detection involves the ability to quantify temporal effects using multi-temporal data sets (Singh, 1989).

The classified LULC in 1993, 2001 and 2009 is used as input image for change detection. The post classification comparison technique is used to quantify a change of LULC from 1993-2001, 2001-2009 and 1993-2009. Post classification comparison change detection is a quantitative change detection method which is widely used to examine LULCC with the major advantage of providing "from-to" change class information (Jensen, 2005).

The rate of LULCC was obtained through determining the proportion of change that occurred in each LULC between the given three time periods. Percentage of change to determine the area of change was calculated by dividing total area as:

$$\%\ of\ change = \frac{Area\ of\ change}{Total\ area} \times 100 \qquad (3.4)$$

To obtain annual rate of change, the area of change was divided by the time interval of the study year.

In addition, the relationship between LULCC during 1993 to 2009 and terrain (elevation and slope) were evaluated to identify the influence of degree of elevation and slope on LULC distribution and transformation. In practice, LULC types in 1993, 2001 and 2009 was firstly overlaid with elevation and slope classes to identify the relationship between LULC type and terrain characteristics. In this study the digital elevation model (DEM) with cell size of 25 x 25 m was used to extract elevation and slope. Standard classification of elevation and slope which was suggested by Land Development Department (2009) was adopted in this study (Table 3.2).

Table 3.2 Classification of elevation and slope.

Elevation Class (m)	Slope Class (%)
1: < 200 m	1: 0-2%
2: 200-250 m	2: 2-5%
3: 250-350 m	3: 5-12%
4: 350-750 m	4: 12-20%
5: 750-800 m	5: 20-35%
6: > 800 m	6: > 35%

Source: LDD, 2009.

3.2.1.3 Land use and land cover change prediction

LULC pattern in 2017 and 2025 were predicted using CA-Markov model of IDRISI 15.0 software. In practice, LULC in 2017 will be firstly predicted using Markov chain model based on LULCC between 2001 and 2009 while LULC in 2025 will be also estimated using Markov chain model based on LULCC between 1993 and 2009. A transition probability matrix, a transition area matrix and a set of conditional probability images between specific periods (2001-2009 and 1993-2009) were identified.

The transition probability matrix is the probability that each land cover category will change to every other category. The transition areas matrix is the number of pixels that was expected to change from each land cover type to each other land cover type over the specified number of time units. The conditional probability images report the probability that each land cover type would be found at each pixel after the specified number of time units (Eastman, 2006).

Then, the transition area and the conditional probability images from Markov chain analysis was used to identify the spatial features of prediction area of each LULC class using CA. The number of iterations was determined by the projection in the future (number of years) and the filter size is a 5 x 5 kernel. The purpose of this filter is to down weighting the suitability of pixels far from existing areas of that class, thus giving preference to contiguous suitable areas (Eastman, 2003). The model uses a contiguity filter to develop a spatially explicit contiguity-weighting factor to change the cells based on its previous state and those of its neighbors. This is a mean filter pool with a Boolean mask filter that will be then multiplied with the suitability map of the class land cover considered (Eastman, 2003).

3.2.1.4 Accuracy assessment of predictive model

The prediction of LULC in 2009 derive CA-Markov based on LULCC between 1993 and 2001 was analyzed and comparing with LULC classified in 2009 using error matrix. The overall accuracy and Kappa hat coefficient of agreement were used to identify acceptable for LULC prediction.

3.2.2 Measurement and evaluation of agricultural and forest landscape pattern

This component involves four main tasks include (1) landscape type classification, (2) Landscape type change detection, (2) landscape pattern evaluation using landscape metrics and (4) landscape pattern change (Figure 3.3).

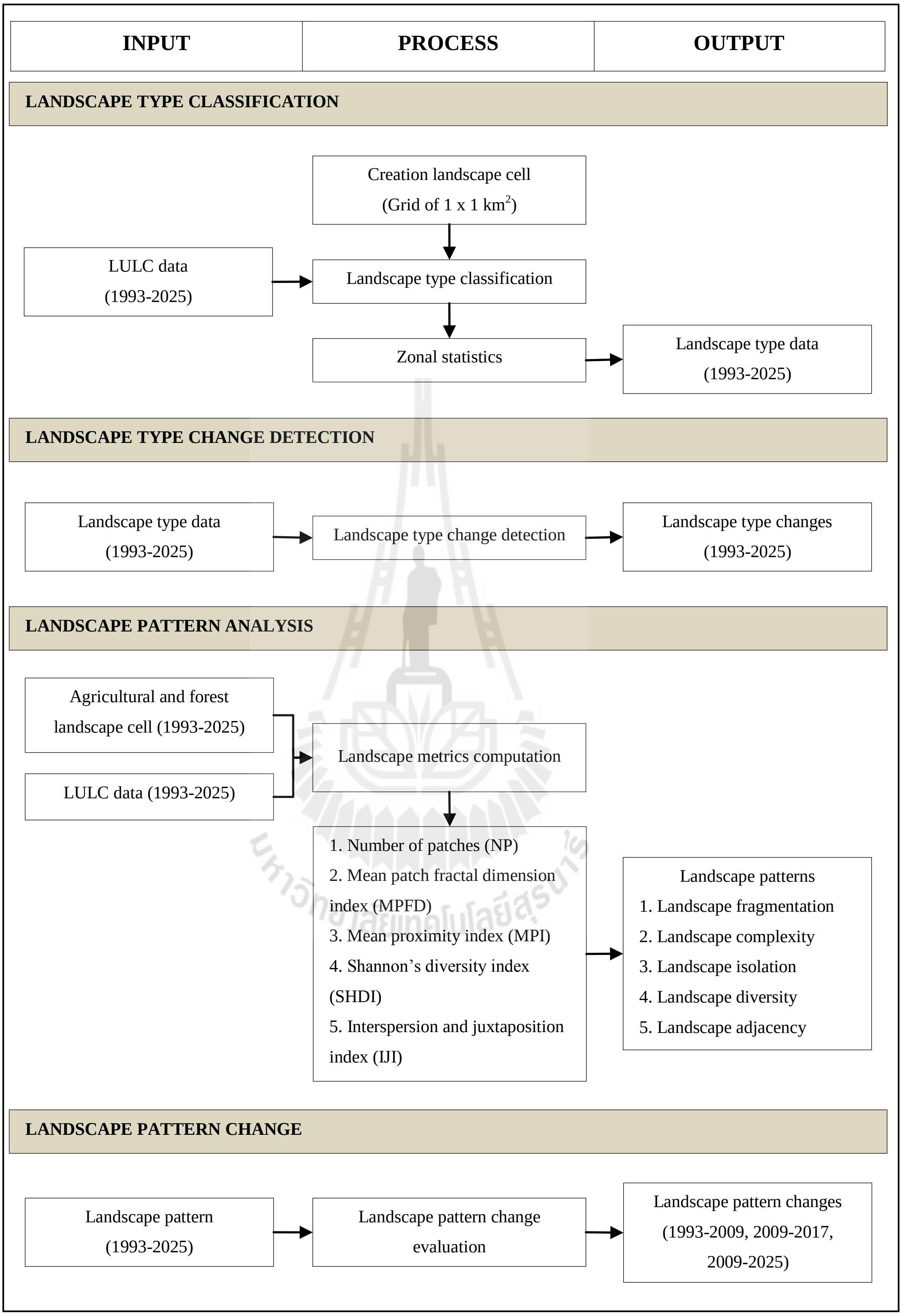


Figure 3.3 Methodology for agricultural and forest landscape pattern evaluation.

3.2.2.1 Landscape type classification and their change

Grid cell with size of 1 x 1 km^2 was the basics unit analysis according to watershed classification in Thailand (Chunkao, 1996), then, it was referred as the ‘landscape cell’. Herewith, regular 1 x 1 km^2 grid was created using create vector grid function of Hawth’s Analysis Tools extension for ArcGIS 9.0.

Based on LULC data in 1993, 2001 2009, 2017 and 2025, four landscape types was classified according to the majority of main LULC type in each landscape cell. In practice, main LULC types in each landscape cell are analyzed using Zonal statistics in ArcGIS 9.0 to assign landscape type as following:

(1) Urban landscape (ULT). This was urban and built-up area;

(2) Agricultural landscape (ALT). This category comprises of paddy field, field crop, pasture, and perennial and orchard of agricultural land;

(3) Forest landscape (FLT). This was forest land;

(4) Miscellaneous landscape (MLT): This category comprises of water body and miscellaneous land. (See example in Figure 3.4).

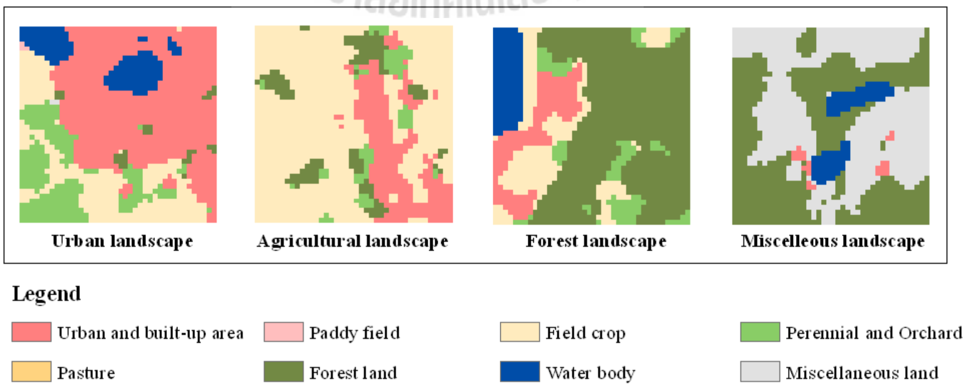


Figure 3.4 Example of landscape type classification for each landscape cell.

Number of grids and percentage of landscape type were here firstly calculated for describing status of landscape. Then, transition matrix was computed to quantify change of landscape types during 1993 to 2025 (1993-2001, 2001-2009, 2009-2017, 2017-2025 and 1993-2025). Herein rate of landscape change in percentage was also calculated as follow:

$$LT_i\ change\ rate = \frac{ALT_{i\ year\ \ 1} - ALT_{i\ year\ \ 2}}{ALT_{i\ year\ \ 1}} \times 100 \quad (3.5)$$

Where

LT_i is change rate of landscape type *i* in percent;

$ALT_{i\ year\ 1}$ is area of landscape type *i* of the first year;

$ALT_{i\ year\ 2}$ is area of landscape type *i* of the second year.

3.2.2.2 Landscape pattern analysis and their change

In this step, landscape metrics were used in the characterization of agricultural and forest landscape pattern and their dynamics. Herein, landscape metrics for agricultural and forest landscape was computed using Patch grid analyst 4.2 extension of ArcGIS 9.0 software. This extension included patch analysis functions was developed by McGarigal and Marks (1995) using Avenue code with interface to the FRACSTAT interface.

In practice, classified LULC maps in 1993, 2001, 2009, 2017 and 2025 were used to retrieve the landscape metrics within the landscape cell (1 x 1 sq. km). For each landscape cell, the landscape metrics was calculated by considering all LULC categories in each landscape cell. For the computation of the landscape metrics, the LULC patches were delineated applying the eight cell neighbor rule to quarantine that linear patches along a direction diagonal to the grid axes were identified as a single patch (Schindler, Poirazidis and Wrbka, 2008). The Mean proximity index was computed using search radian of 1 km.

In the study, five landscape patterns included that landscape fragmentation, landscape complexity, landscape isolation, landscape diversity, and landscape adjacency are analyzed using concerned landscape metrics to characterize pattern of agricultural and forest landscapes.

(1) Landscape fragmentation

Landscape fragmentation is the division of contiguous area or ecosystem into smaller patches (Forman, 1995), the landscape's lack of connectivity (Collinge, 1996). The construction of transport infrastructures, urban development and agriculture was the causes of landscape fragmentation. At the same time, landscape fragmentation is measured of biodiversity and may also be reduced by the fragmentation of landscapes into many isolated patches (Saunders, Hobbs, and Margules, 1991; Wiens, 1985). A fragmented landscape provides less connectivity, greater isolation, and higher percentage of edge area in patches.

An indicator of landscape fragmentation is Number of patches (NP). NP is the total number of patches within landscape (McGarigal and Marks, 1995).

$$\mathrm{NP} = N \tag{3.6}$$

Where

N is total number of patches in the landscape.

The NP has no units and is limitless. Higher NP indicates greater fragmentation and heterogeneity (Figure 3.5).

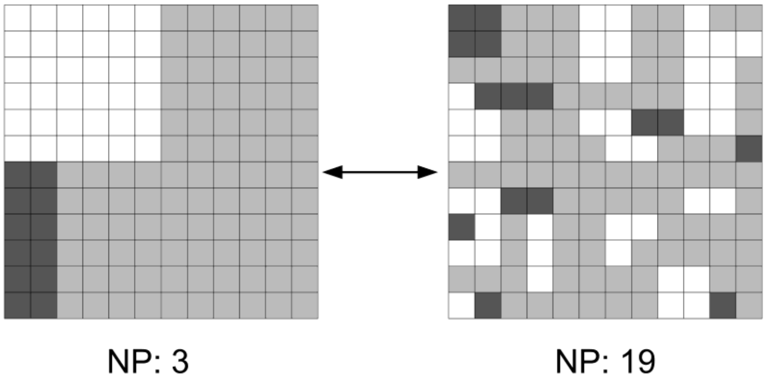


Figure 3.5 Example of Number of patches.

(2) Landscape complexity

Shape complexity relates to the geometry of patches-whether they tend to be simple and compact, or irregular and convoluted. An indicator used in the complexity characterization of the landscape area is Mean patch fractal dimension index (MPFD). MPFD reflects the mean shape complexity across a range of patches.

The MPFD equals the sum of 2 times the logarithm of patch perimeter (m) divided by the logarithm of patch area (m^2) for each patch in the landscape, divided by the number of patches; the raster formula is adjusted to correct for the bias in perimeter (McGarigal and Marks, 1995). The formula for MPFD is:

$$\mathrm{MPFD} = \frac{\sum_{i=j}^{m}\sum_{j=1}^{n}\left(\frac{2\ln\left(0.25p_{ij}\right)}{\ln a_{ij}}\right)}{N} \quad (3.7)$$

Where

p_{ij} is perimeter (m) of patch *ij*;

a_{ij} is area (m^2) of patch *I*;

N is total number of patches in the landscape.

The MPFD value has no units and range between 1 and 2. The value approaches 1 for shapes with very simple perimeters such as squares, and approaches 2 for shapes with highly convoluted perimeters (Figure 3.6).

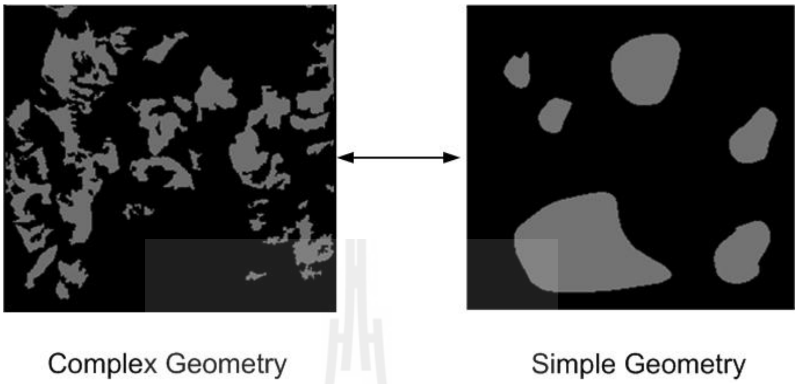


Figure 3.6 Example of geometric complexity or compactness of patch shapes (McGarigal, 2001).

(3) Landscape isolation

Isolation refers to the tendency for patches to be relatively isolated in space (i.e. distant) from other patches of the same or similar ecologically friendly class. An indicator used in the landscape isolation of the landscape area is Mean proximity index (MPI).

MPI equals the sum of patch area (m^2) divided by the squared nearest edge-to-edge distance (m) between the patch and the focal patch of all patches of the corresponding patch type whose edges are within a specified distance (m) of the focal patch, summed across all patches in the landscape and divided by the total number of patches (McGarigal and Marks, 1995).

$$\text{MPI} = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{s=1}^{n} \frac{a_{ijs}}{h_{ijs}^{2}}}{N} \quad (3.8)$$

Where

a_{ijs} is area (m^2) of patch *ijs* within specified neighborhood (m) of patch *ij*;

h_{ijs} is distance (m) between patch $_{ijs}$ [located within specified neighborhood distance (m) of patch *ij*] and patch *ij*, based on edge-to-edge distance;

N is total number of patches in the landscape.

The MPI has no units and greater than or equal to 0. MPI equal 0 if no patch has a neighbor of the same types within the specified search radius. MPI increases as patches become less isolated from patches of the same type and the patch types become less fragmented in distribution (Figure 3.7).

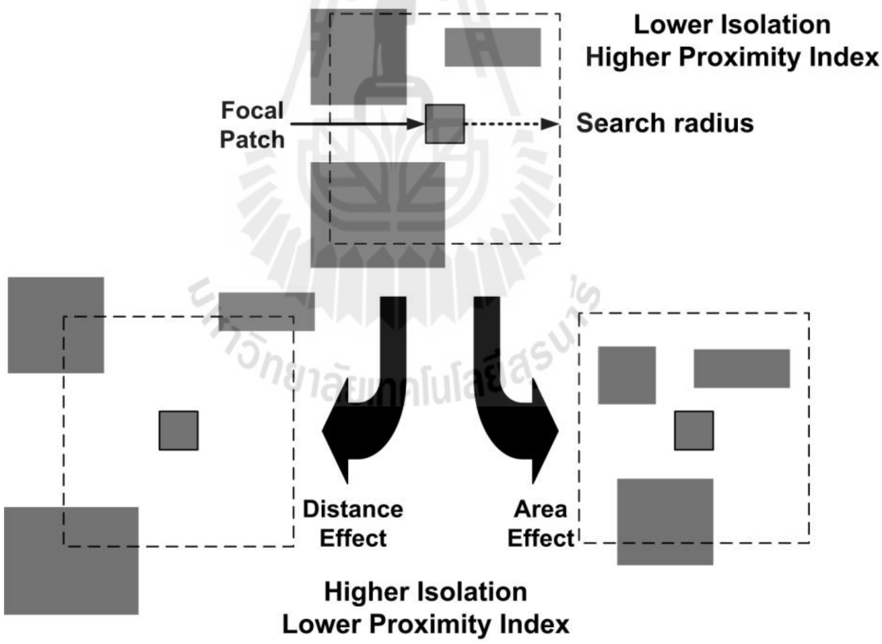


Figure 3.7 Example of Mean proximity index (Gehring, 2011).

(4) Landscape diversity

Landscape diversity is measured the landscape biodiversity or reduction of diversity, heterogeneity that describes landscape composition. Indices related to the number of patches and their distribution throughout the landscape (Graves and Bourne, 2002).

Landscape metric selected to characterize the landscape diversity is Shannon's diversity index (SHDI). It is a popular measure of diversity in community ecology (Mcgarigal and Holmes, 2000). SHDI reflects the patch abundance and heterogeneity in the landscape, which is determined by the distribution of the proportion of different land-use types in a landscape. SHDI quantifies the diversity of the countryside based on two components: the number of different patch types and the proportional area distribution among patch types. Commonly the two components are named richness and evenness. Richness refers to the number of patch types (compositional component) and evenness to the area distribution of classes (structural component). SHDI equals minus the sum, across all patch types, of the proportional abundance of each patch type multiplied by that proportion (McGarigal and Marks, 1995), according to the formula:

$$\text{SHDI} = -\sum_{i=1}^{m}(P_i \circ lnP_i) \qquad (3.9)$$

Where

P_i is proportion of the landscape occupied by patch type (class) i;

m is number of patch types (classes) present in the landscape;

ln is natural logarithm.

The SHDI has no units and greater than or equal to 0.The index will equal zero when there is only one patch in landscape and increase as the number of different patch types increases or proportional distribution of area among patch types become more equitable (Figure 3.8).

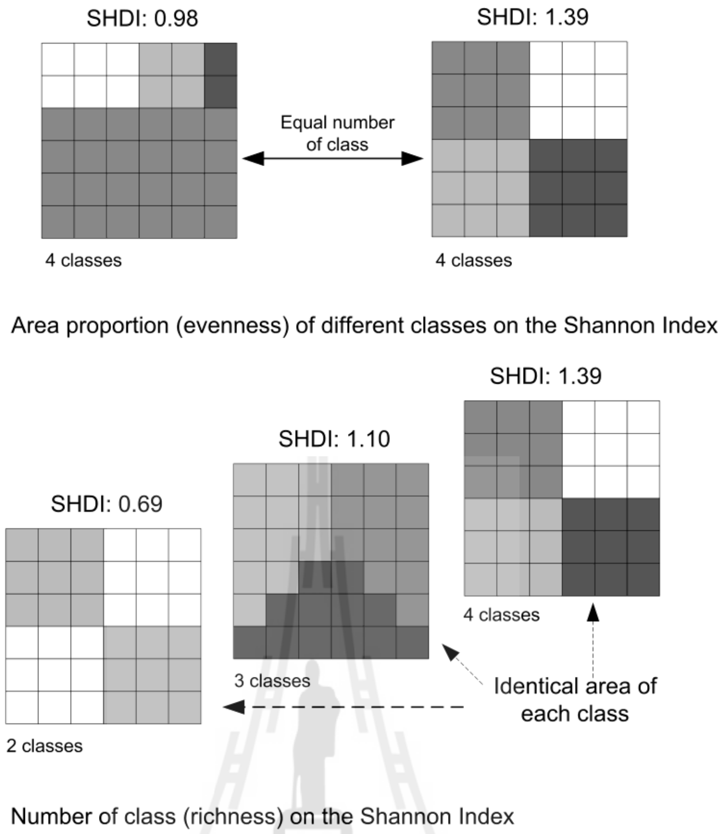


Figure 3.8 Example of Shannon diversity index (Eiden, Kayadjanian and Vidal, 2000).

(5) Landscape adjacency

Landscape adjacency is measure landscape texture by examining the aggregation and intermixing of class patches (Graves and Bourne, 2002). Landscape metric selected in order to characterize the landscape adjacency is Interspersion juxtaposition index (IJI).

IJI measures of relative interspersion and arrangement of adjacent of each class. This index considers the neighborhood relations between patches. Each patch is analyzed for adjacency with all other patch types and measures the extent to which patch types are interspersed i.e. equally bordering other patch types. The IJI equals minus the sum of the length (m) of each unique edge type divided by the total landscape edge (m), multiplied by the logarithm of the same quantity, summed over each unique edge type; divided by the logarithm of the number of patch types times the number of patch types minus 1 divided by 2; multiplied by 100 (to convert to a percentage), according to the formula (McGarigal and Marks, 1995):

$$\text{IJI} = \frac{-\sum_{i=1}^{m'}\sum_{k=i+1}^{m'}\left[\left(\frac{e_{ik}}{E}\circ ln\left(\frac{e_{ik}}{E}\right)\right)\right]}{ln\left(1/2[m'(m'-1)]\right)} \times 100 \qquad (3.10)$$

Where

e_{ik} is total length (m) of edge in landscape between patch types *i* and *k*;

E is total length (m) of edge in landscape;

m' is number of patch types present in the landscape.

The IJI has percent units and range between 0 and 100. Low values characterize landscapes in which patch types are distributed disproportionally or clumped, e.g. classes are bordering only a few other classes. High values result from landscapes in which the patch types are equally adjacent to each other, e.g. each class has a common border with all others (Figure 3.9).

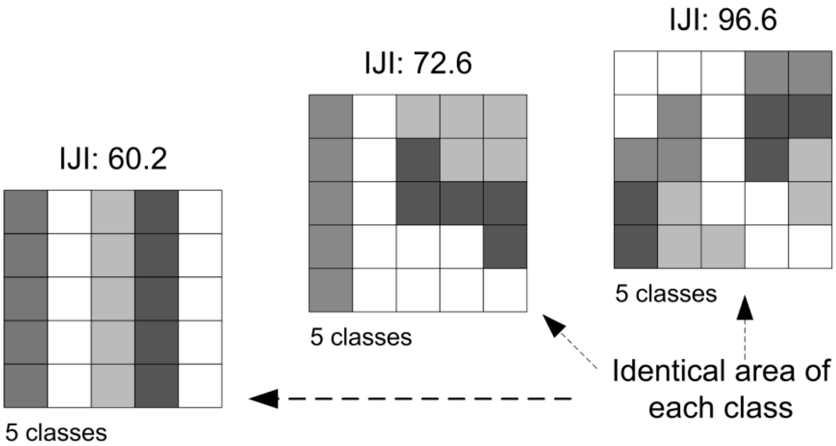


Figure 3.9 Example of Interspersion and juxtaposition index (Eiden, Kayadjanian and Vidal, 2000).

After that, status and change of landscape pattern in agricultural and forest landscape from 1993 to 2025 include fragmentation, complexity, isolation, diversity, and adjacency were evaluated based on normalized landscape metrics. In practice, original landscape metrics were firstly normalized using linear scale transformation as follow:

$$y_i = \frac{x_i - x_{imin}}{x_{imax} - x_{imin}} \quad (3.11)$$

Where

y_i is normalized value of x_i;

x_i is original landscape metric i;

$x_{i\min}$ is minimum value of landscape metric i form 5 year landscape metrics (1993, 2001, 2009, 2017, 2025);

$x_{i\max}$ is maximum value of landscape metric i form 5 year landscape metrics (1993, 2001, 2009, 2017, 2025).

Then the normalize value (0 to 1) of each landscape metric in 1993, 2001, 2009, 2017 and 2025 will be equally divided into 3 levels to explained level of landscape pattern as follows:

(1) 0.00-0.333 Low

(2) 0.333-0.666 Moderate

(3) 0.666-1.000 High

These outputs were then used to explain the status of landscape pattern in 1993, 2001, 2009, 2017 and 2025. Meanwhile, landscape pattern change in three periods: 1993-2009 for past to present, 2009-2017 for short term in the future and 2009-2025 for long term in the future will be conducted using transitional matrix for gain and loss analysis.

3.2.3 Evaluation and development of agricultural and forest landscape sustainability model

Human influence tends to a simplification and geometrization of the landscape' structure (Odum and Turner, 1979; Forman and Godron, 1986). Changes in the configuration of the landscape, e.g. changes in the amount and distribution of small biotopes, are influencing biodiversity. Several studies, also within the Austrian Landscape Research Programme, have shown that the hemerobiotic state, as a measure for land-use intensity, is an important predictor for biodiversity at the landscape level (Moser et al., 2002; Zechmeister and Moser, 2001). The degree of human influence on ecosystems is a highly integrative indicator for the description of the landscape system. Changes in a landscape towards a stronger anthropogenic influence, e.g. the removal of small biotopes or changes in the patch size of land-use parcels to larger units can therefore be seen as an unsustainable development, at least in terms of ecological sustainability.

Under this component, two main tasks include (1) agricultural and forest landscape sustainability evaluation and their change and (2) predictive landscape sustainability model development. The schematic diagram of this component is illustrated in Figure 3.10.

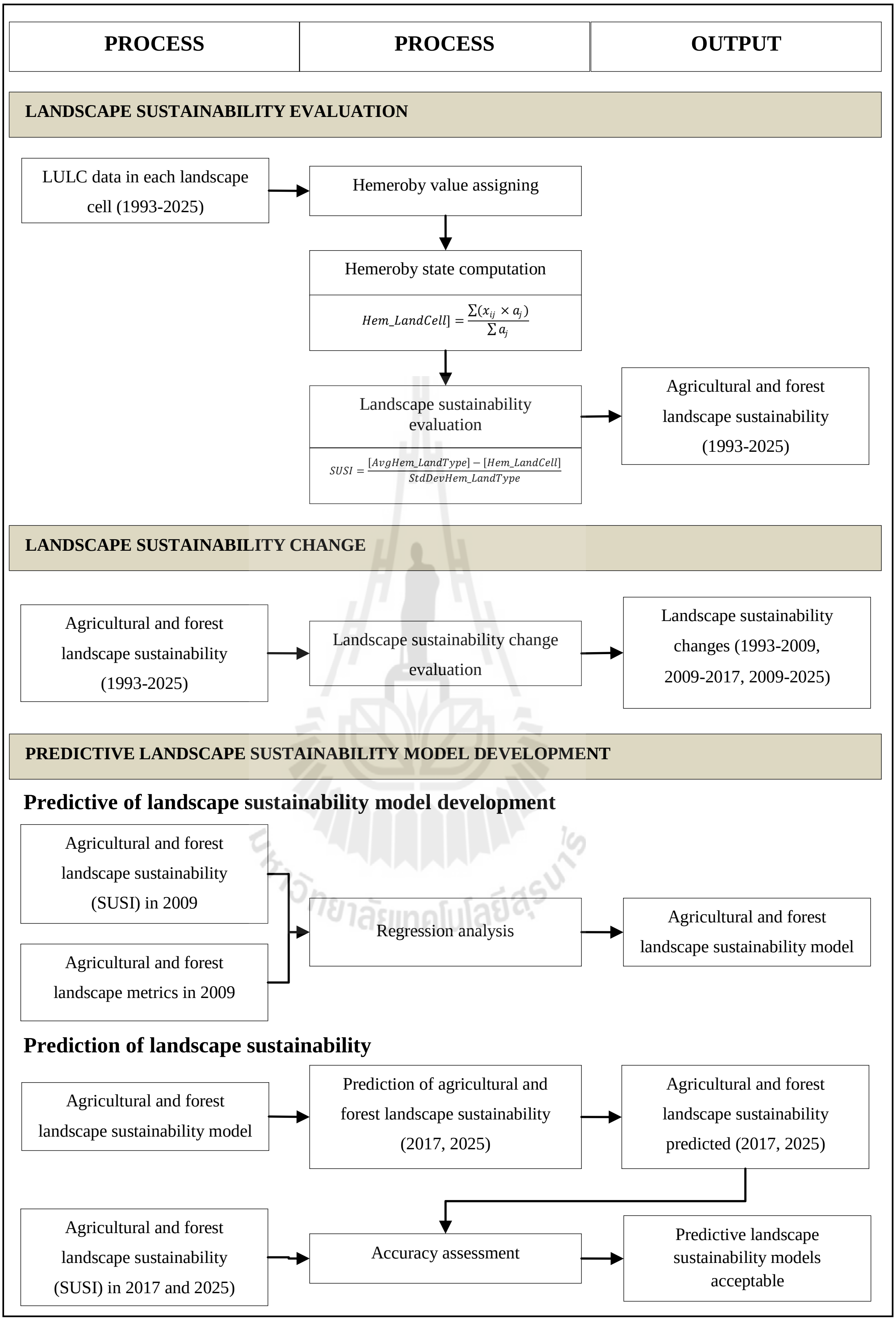


Figure 3.10 Methodology for agricultural and forest landscape sustainability evaluation and predictive landscape sustainability model development.

3.2.3.1 Landscape sustainability evaluation and its change

In practice, the hemeroby value firstly assigned for each LULC type according to the intensity of land use as suggested by Csorbd, Szabó and Sziláed (2009) and Steinhardt, Herzog, Lausch, Müller and Lehmann (1999). In this study, 6 levels of hemeroby value include oligohemeroby, mesohemeroby, β-euhemeroby, α-euhemerobe, polyhemeroby and metahemeroby were applied for each LULC type due to anthropogenic impacts on agricultural and forest landscape as shown in Table 3.3. Then, hemeroby state of each landscape cell was calculated based on hemeroby value of each LULC type and its proportional area in landscape cell using following equation:

$$[Hem\_LandCell] = \frac{\sum(x_{ij} \times a_j)}{\sum a_j} \quad (3.12)$$

Where:

[Hem_LandCell] is the hemeroby state of the *j*th landscape cell within the landscape type;

x_{ij} is the hemeroby value of LULC type *i* in the *j*th landscape cell;

a_{ij} is the proportional area of each LULC type *i* in the *j*th landscape cell.

Table 3.3 Classification of land use and land cover type into hemeroby levels.

Hemeroby level	Hemeroby values	Land use land cover types
Ahemeroby	0	Absent in the study area
Oligohemeroby	1	Forest land
Mesohemeroby	2	Pasture
β-euhemerobe	3	Permanent tree and orchards, water body
α- euhemerobe	4	Paddy field, Field crop,
Polyhemeroby	5	Miscellaneous land
Metahemeroby	6	Urban and built-up land

After that the Sustainability Indicator (SUSI) value of each landscape cell, which represents the deviation of the modeled hemeroby state of a certain landscape cell is compared to the average hemeroby state of the whole landscape type (Peterseil et al., 2004). Herein mean values and standard deviation for each landscape type is calculated and compared to the hemeroby state of each landscape cell within landscape types for sustainability indicator value as:

$$SUSI = \frac{[AvgHem\_LandType] - [Hem\_LandCell]}{StdDevHem\_LandType} \qquad (3.13)$$

Where

SUSI is the sustainability indicator value of a landscape cell

[AvgHem_LandType] is the mean of hemeroby value for a specific landscape type;

[StdDevHem_LandType] is the standard deviation of hemeroby value for a specific landscape type;

[Hem_LandCell] is the hemeroby value of a landscape cell within the landscape type.

Finally, the calculated SUSI values were further classified into five categories as following.

(1) Low sustainability (L), SUSI value less than -2;

(2) Low to moderate sustainability (L-M), SUSI value between -1 to and -2;

(3) Moderate sustainability (M), SUSI value between -1 and +1;

(4) Moderate to high sustainability (M-H), SUSI value between +1 and +2;

(5) High sustainability (H), SUSI value more than +2.

Area and percentage of agricultural and forest landscape sustainability indices were then calculated and distribution of agricultural and forest landscape sustainability indices are also described. In addition, change of agricultural and forest landscape sustainability is analyzed using transition matrix in term loss and gain value. Herein agricultural and forest landscape sustainability change will be divided into three periods: 1993-2009 for past to present, 2009-2017 for short term in the future and 2009-2025 for long term in the future will be conducted and explored in this study.

3.2.3.2 Predictive landscape sustainability model development

Regression analysis is used to study the causal relationship between landscape sustainability as affected by a set of independent variables (landscape metrics: NP, MPFD, MPI, SHDI, IJI). In practice, simple linear regression analysis begins by assuming that a linear relationship exists between the dependent variable (y) and the independent variables (x), proceeds by fitting a straight line to the set of observed data and is then concerned with the interpretation and analysis of the effects of the x variables on y and with the nature of the fit. However, it is most often the case that there is more than one variable that are thought to affect the dependent variable (Rogerson, 2001). Thus, multiple linear regressions might then be applied if it be required. The general form of multiple linear regressions is as follow:

$$Y = b_0 + \sum_{i=1}^{n} b_i \cdot x_i \qquad (3.14)$$

Where

Y is dependent variable (SUSI);

b_0 is the parameters (coefficients);

b_i is the parameters (coefficients);

x_i is the independent variables (landscape metrics).

Finally, output from predictive sustainability landscape model development as regression equation will be then used to predict sustainability of agricultural and forest landscape in 2017 and 2025.

CHAPTER IV

LAND USE AND LAND COVER CLASSIFICATION AND THEIR CHANGE AND PREDICTION OF LULC CHANGE

The content of this chapter was presented the results of the first objectives focusing on classification and change detection of LULC in 1993, 2001 and 2009 and predictive LULC in 2017 and 2025.

4.1 Land use and land cover classification

LULC types of Lamtakhong watershed in 1993, 2001 and 2009 were classified from Landsat imageries based on hybrid classification method. LULC classification which was modified from classification system of LDD consisted of urban and built-up area, paddy field, field crop, perennial and orchard, pasture, forest land, water body and miscellaneous land. Results were described in detail in the following sections.

4.1.1 Land use and land cover in 1993

In 1993, about 1,956.36 sq. km or 59.01% of the Lamtakhong watershed was covered with agricultural land (Figure 4.1 and Table 4.1). These classes consisted of field crop, paddy field, perennial and orchard, and pasture covered an area of 1,400.24 sq. km or 42.24%, 421.11 sq. km or 12.70%, 59.72 sq. km or 1.80%, and 75.30 sq. km or 2.27% of the study area, respectively. The second dominant of LULC type was forest land covering an area of 1,227.75 sq. km or 37.04% of the study area. The third important LULC type was urban and built-up area covered an area of 100.39 sq. km or 3.03% of the study area. Other LULC types included water body and miscellaneous land accounting an area of 30.57 sq. km or 0.92% of the study area.

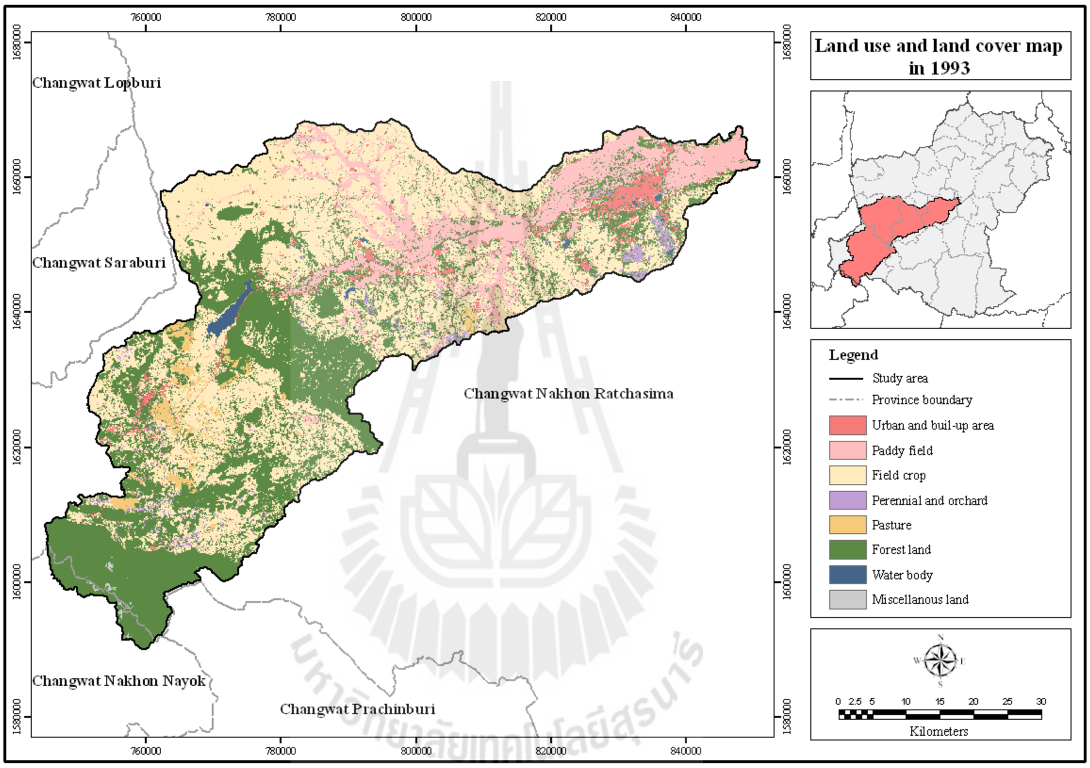


Figure 4.1 Distribution of land use and land cover in 1993.

4.1.2 Land use and land cover in 2001

In this year, the most significant LULC was agriculture land covering an area of 2,046.36 sq. km or 61.73% of the study area (Figure 4.2 and Table 4.1). These areas included field crop, paddy field, perennial and orchard, and pasture covered 1,429.44 sq. km or 43.12%, 434.81 sq. km or 13.12%, 92.26 sq. km or 2.78, and 89.86 sq. km or 2.71% of the study area, respectively. The second dominant

LULC type was forest land covering an area of 1,016.75 sq. km or 30.67% of the study area. The third dominant LULC type was urban and built-up area with area of 181.57 sq. km or 5.48% of the study area. Other LULC types were water body and miscellaneous land accounting area of 70.39 sq. km or 2.12% of the study area.

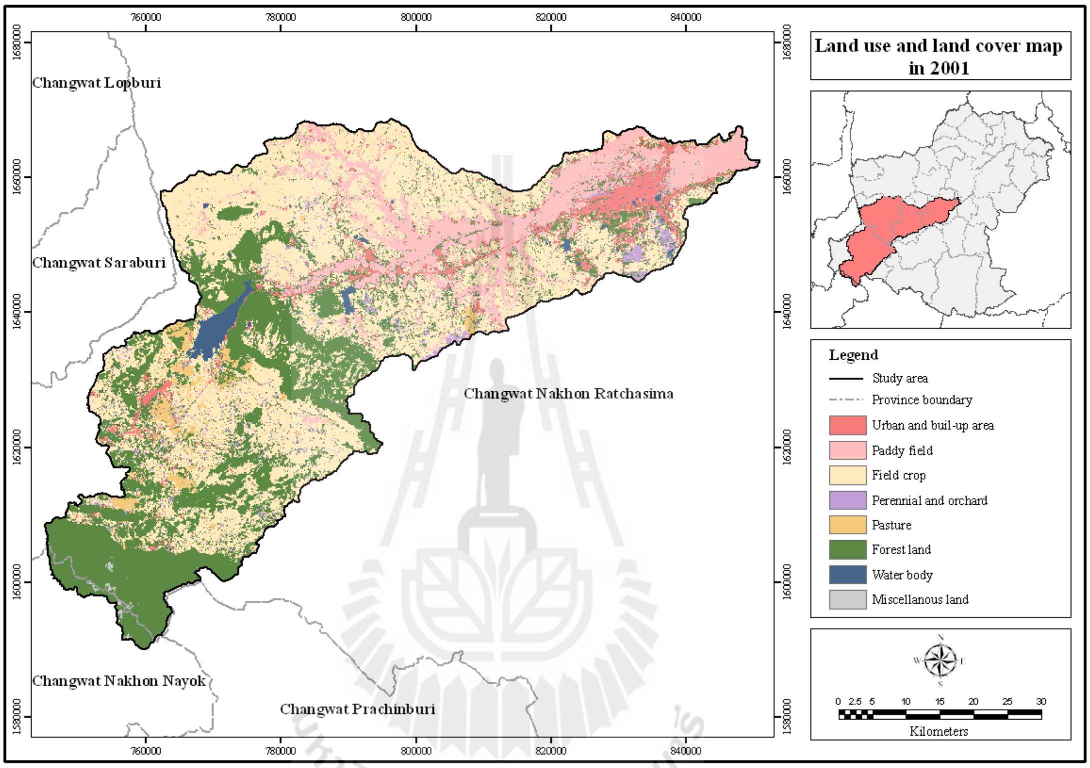


Figure 4.2 Distribution of land use and land cover in 2001.

4.1.3 Land use and land cover in 2009

In general, LULC in 2009 had the same pattern like those in 1993 and 2001. The most significant LULC type was agriculture land covering an area of 2,207.19 sq. km or 66.58% of the study area. These areas included field crop, paddy field, perennial and orchard, and pasture covered area of 1,506.77 sq. km or 45.45%, 420.79 sq. km or 12.69%, 212.65 sq. km or 6.41%, and 66.99 sq. km or 2.02% of the study area, respectively. The second dominant LULC type was forest land covering an area of 770.50 sq. km or 23.24%. The third important LULC type was urban and built-up area covering an area of 251.91 sq. km or 7.60% of the study area. Other LULC types were water body and miscellaneous land accounting area of 85.47 sq. km or 2.58% of the study area (Figure 4.3 and Table 4.1).

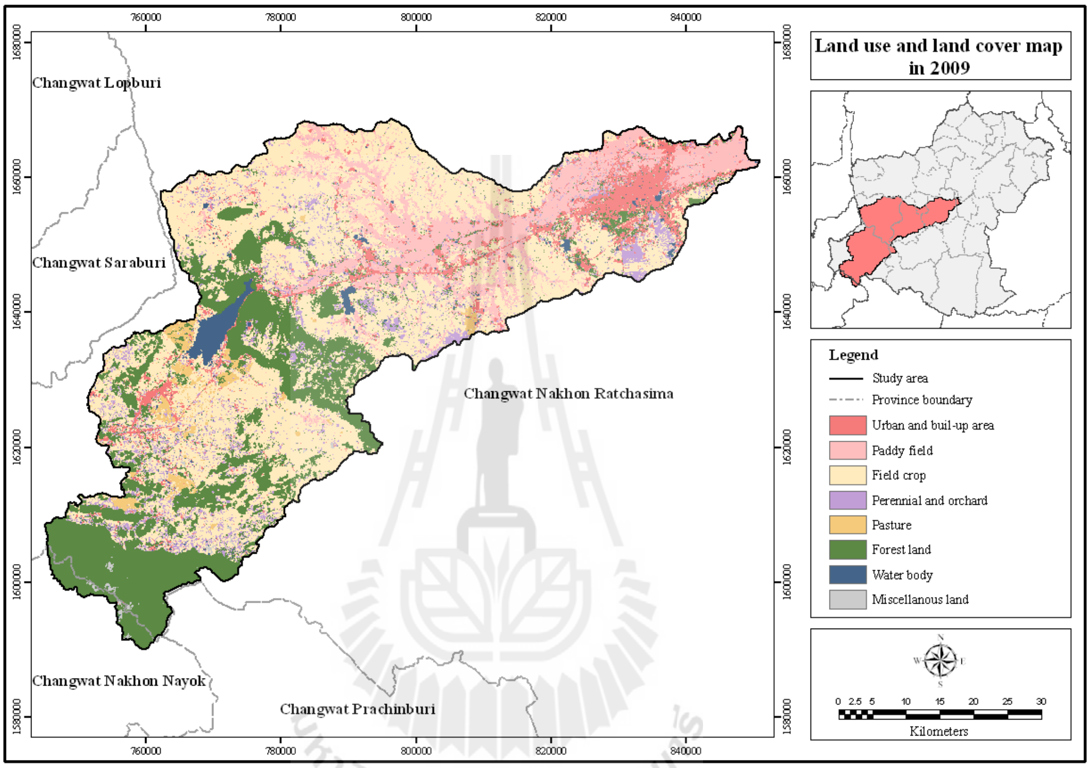


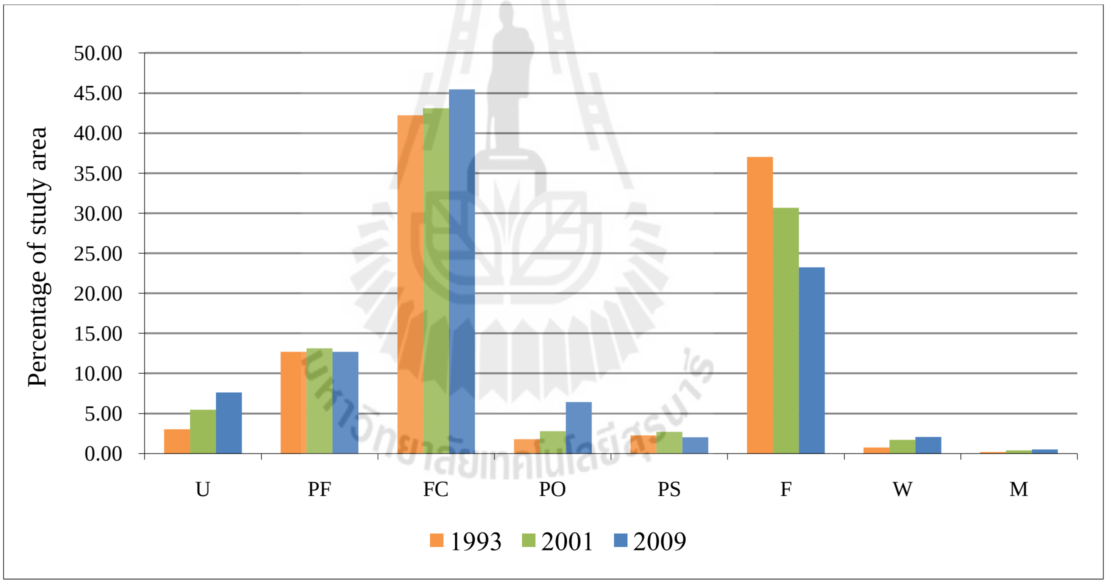
Figure 4.3 Distribution of land use and land cover in 2009.

Table 4.1 Area and percentage for land use and land cover in 1993, 2001 and 2009.

LULC	**1993**		**2001**		**2009**	
	sq. km	**%**	**sq. km**	**%**	**sq. km**	**%**
Urban and built-up area	100.39	3.03	181.57	5.48	251.91	7.60
Paddy field	421.11	12.70	434.81	13.12	420.79	12.69
Field crop	1,400.24	42.24	1,429.44	43.12	1,506.77	45.45
Perennial and orchard	59.72	1.80	92.26	2.78	212.65	6.41
Pasture	75.30	2.27	89.86	2.71	66.99	2.02
Forest land	1,227.75	37.04	1,016.75	30.67	770.50	23.24
Water body	24.18	0.73	57.15	1.72	68.41	2.06
Miscellaneous land	6.39	0.19	13.24	0.40	17.06	0.51
Total	**3,315.07**	**100.00**	**3,315.07**	**100.00**	**3,315.07**	**100.00**

As results shown in Table 4.1, it was found that urban and built-up area, field crop, perennial and orchard, water body, and miscellaneous land were continuously increased while forest land was continuously decreased. However, paddy field and pasture were uneven change (Figure 4.4).

In addition, it can be observed that area of water body was suddenly increased in 2001 because drought phenomena was occurred in Nakhon Ratchasima province in 1993 (Prawphinit and Kobkhuntot, 2011). In fact, in 1993 the reservoir extent of Lamtakhong dam, which situated in the middle part of the study area is very smaller when it was compared with the reservoir extent in 2001 or 2009.



Note: U = Urban and built-up area, PF = Paddy field, FC = Field crop, PO = Perennial and Orchard, PS = Pasture, F = Forest land, W = Water body, M = Miscellaneous land

Figure 4.4 Comparison of land use and land cover types in 1993, 2001 and 2009.

4.1.4 Accuracy Assessment

To access the accuracy of LULC classification result, it is common to create a confusion matrix or error matrix. Classified LULC in 2009 was compared with ground information in 2009 for accuracy assessment using overall accuracy and kappa hat coefficient of agreement. In practice, error matrix between LULC type in 2009 and the reference LULC types from field survey in 2009 is firstly constructed and accuracy assessment is then evaluated. In this study, 570 randomly stratified sampling points based on multinomial distribution theory with desired level of confident 85% and the precision of 5% were used for accuracy assessment.

The accuracy assessment of classified LULC in 2009 was shown as error matrix in Tables 4.2. The overall accuracy was 90.53% and the Kappa hat coefficient of agreement was 0.87. Detail of producer's accuracy and user's accuracy were summarized in Table 4.2.

Table 4.2 Error matrixes and accuracy assessment of land use and land cover in 2009.

LULC classified in 2009	**ground truth data**									
	U	**PF**	**FC**	**PO**	**PS**	**F**	**W**	**M**	**Total**	**User's Accuracy (%)**
U	36	1	3	0	0	0	0	1	41	87.80
PF	1	63	2	0	0	1	0		67	94.03
FC	4	5	242	3	2	3	1	1	261	92.72
PO	2	3	3	28	1	3	0	0	40	70.00
PS	0	0	2	1	9		0	0	12	75.00
F	0	0	4	6	0	126	0	0	136	92.65
W	0	0	0	0	0	0	9	0	9	100.00
M	1	0	0	0	0	0	0	3	4	75.00
Total	**44**	**72**	**256**	**38**	**12**	**133**	**10**	**5**	**570**	
Producer's Accuracy (%)	**81.82**	**87.50**	**94.53**	**73.68**	**75.00**	**94.74**	**90.00**	**60.00**		
Overall Accuracy (%) = 90.53%										
Kappa Coefficient = 0.87%										

Note: U = Urban and built-up area, PF = Paddy field, FC = Field crop, PO = Perennial and Orchard, PS = Pasture, F = Forest land, W = Water body, M = Miscellaneous land

4.2 Land use and land cover change detection

Post-classification comparison change detection algorithm was here applied for LULCC in three periods: 1993-2001 and 2001-2009 and 1993-2009. The results of the study on LULCC are as follows:

4.2.1 Land use and land cover change between 1993 and 2001

In this period, urban and built-up area was increased with area of 81.18 sq. km or 2.45% of the study area. Most of urban and built-up area came from field crop and forest land. At the same time water body, perennial and orchard, field crop, pasture, paddy field, and miscellaneous land also increased with area of 32.97, 32.54, 29.20, 14.56, 13.70 and 6.85 sq. km or 0.99, 0.98, 0.88, 0.44, 0.41 and 0.21% of the study area, respectively.

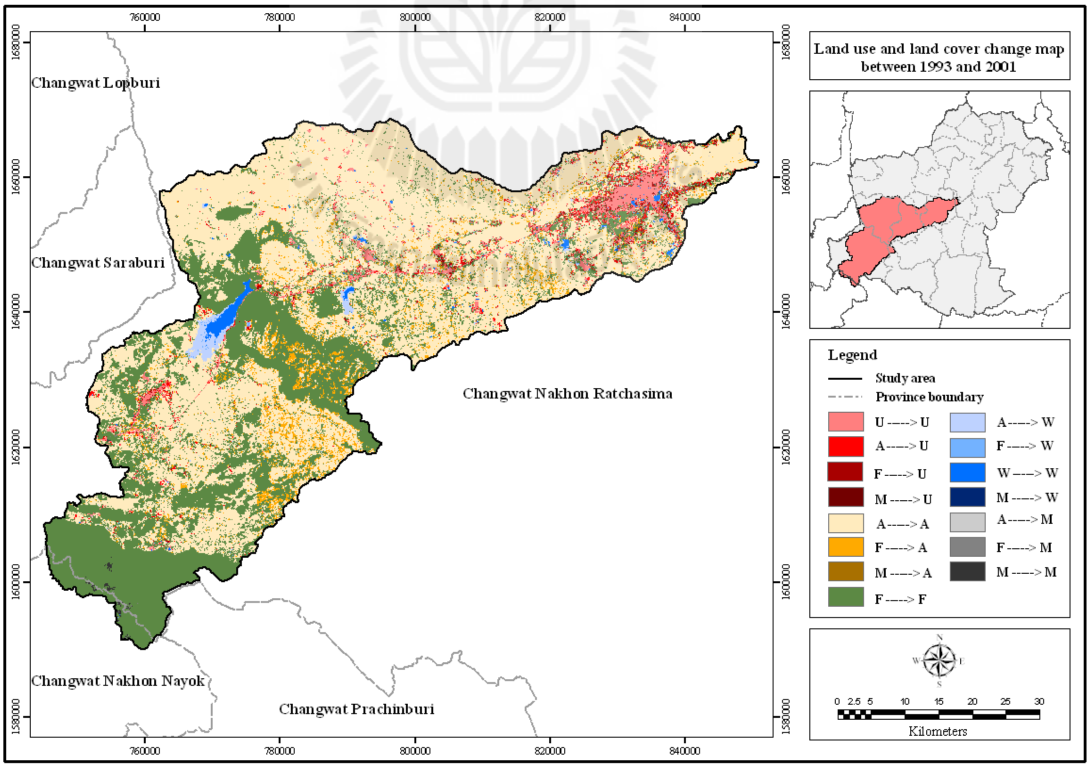
For decreased LULC type, forest land was decreased with area of 211.00 sq. km or 6.36% of the study area. It was changed to urban and build-up area, agricultural land, water body, and miscellaneous land. Details of LULCC between 1993 and 2001 were presented in Table 4.3 and Figure 4.5.

Table 4.3 Change matrix of land use and land cover between 1993 and 2001.

(Unit: sq. km)

LULC in 1993	LULC in 2001 (sq.km)								
	U	**PF**	**FC**	**PO**	**PS**	**F**	**W**	**M**	**Total**
U	100.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.39
PF	8.39	376.88	26.80	1.61	0.52	0.00	2.14	4.77	421.11
FC	36.77	33.63	1,244.64	36.49	22.18	0.00	26.19	0.33	1,400.24
PO	1.32	0.00	23.84	32.78	1.55	0.00	0.19	0.05	59.72
PS	0.30	0.04	13.21	1.01	60.33	0.00	0.40	0.00	75.30
F	34.00	24.24	120.89	20.37	5.27	1,016.75	4.03	2.21	1,227.75
W	0.00	0.00	0.00	0.00	0.00	0.00	24.18	0.00	24.18
M	0.40	0.01	0.06	0.01	0.00	0.00	0.01	5.89	6.39
Total	**181.57**	**434.81**	**1,429.44**	**92.26**	**89.86**	**1,016.75**	**57.15**	**13.24**	**3,315.07**
Area of change (sq. km)	**81.18**	**13.70**	**29.20**	**32.54**	**14.56**	**-211.00**	**32.97**	**6.85**	
Percentage of change (%)	**2.45**	**0.41**	**0.88**	**0.98**	**0.44**	**-6.36**	**0.99**	**0.21**	
Annum rate of change (sq. km)	**10.15**	**1.71**	**3.65**	**4.07**	**1.82**	**-26.37**	**4.12**	**0.86**	

Note: U = Urban and built-up area, PF = Paddy field, FC = Field crop, PO = Perennial and Orchard, PS = Pasture, F = Forest land, W = Water body, M = Miscellaneous land



Note: U = Urban and built-up area, A = Agriculture land, F = Forest land, W = Water body, M = Miscellaneous land

Figure 4.5 Major land use and land cover change between 1993 and 2001.

4.2.2 Land use and land cover change between 2001 and 2009

During this period, the most increased LULC type was perennial and orchard with 120.39 sq. km or 3.63% of the study area. Most of this increased area came from paddy field, field crop, pasture, forest land, and miscellaneous land. At the same time, field crop, urban and built-up area, water body, and miscellaneous land had also increased having area of 77.33, 70.34, 11.26 and 3.82 sq. km or 2.33, 2.12, 0.34 and 0.12% of the study area, respectively.

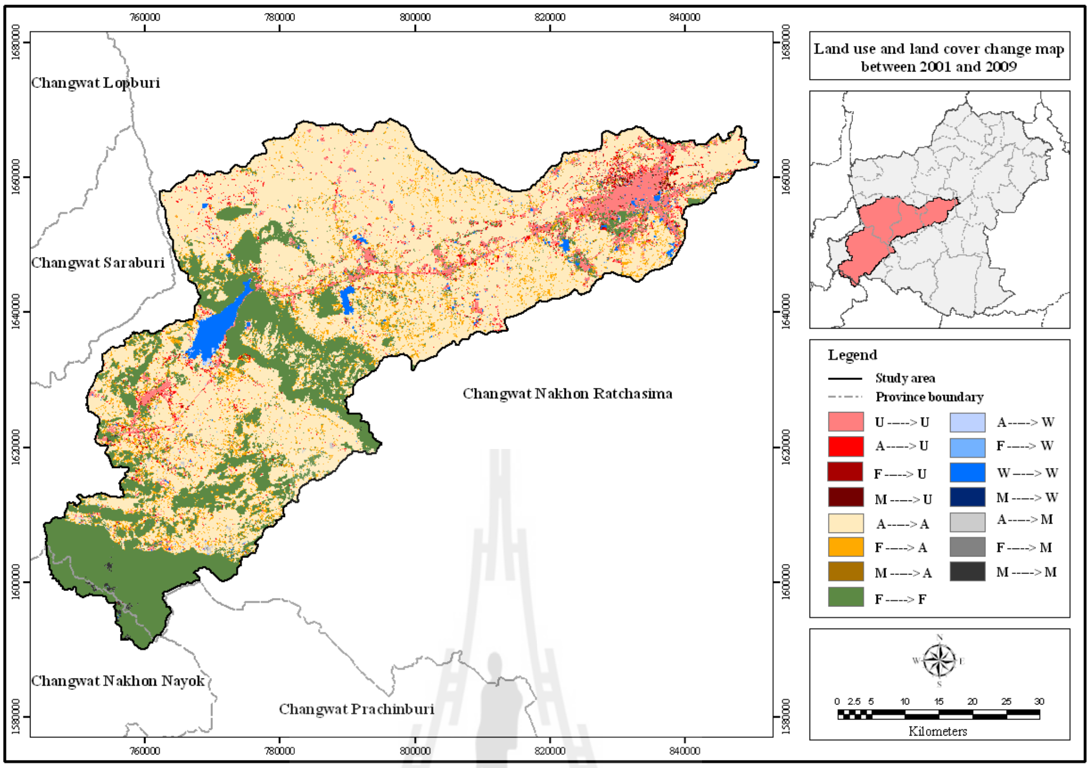
For decreased LULC types, forest land was decreased with area of 246.25 sq. km or 7.43% of the study area. It was changed into urban and built-up area, agriculture land, water body, and miscellaneous land. At the same time pasture and paddy field had also decreased with area of 22.87 and 14.02 sq. km or 0.69 and 0.42% of the study area, respectively. Details of LULCC between 2001 and 2009 were presented in Table 4.4 and Figure 4.6.

Table 4.4 Change matrix of land use and land cover between 2001 and 2009.

(Unit: sq. km)

LULC in 2001	LULC in 2009 (sq.km)								
	U	**PF**	**FC**	**PO**	**PS**	**F**	**W**	**M**	**Total**
U	181.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	181.57
PF	16.68	385.05	19.67	8.26	0.29	0.00	1.08	3.77	434.81
FC	30.33	22.28	1,292.76	68.86	4.97	0.00	7.25	2.99	1,429.44
PO	3.21	0.00	20.90	66.41	1.33	0.00	0.01	0.39	92.26
PS	1.31	0.00	31.82	4.64	51.52	0.00	0.43	0.14	89.86
F	15.69	11.57	141.18	64.10	8.87	770.50	2.41	2.43	1,016.75
W	0.00	0.00	0.00	0.00	0.00	0.00	57.15	0.00	57.15
M	3.11	1.89	0.43	0.37	0.01	0.00	0.08	7.35	13.24
Total	**251.91**	**420.79**	**1,506.77**	**212.65**	**66.99**	**770.50**	**68.41**	**17.06**	**3,315.07**
Area of change (sq. km)	**70.34**	**-14.02**	**77.33**	**120.39**	**-22.87**	**-246.25**	**11.26**	**3.82**	
Percentage of change (%)	**2.12**	**-0.42**	**2.33**	**3.63**	**-0.69**	**-7.43**	**0.34**	**0.12**	
Annum rate of change (sq. km)	**8.79**	**-1.75**	**9.67**	**15.05**	**-2.86**	**-30.78**	**1.41**	**0.48**	

Note: U = Urban and built-up area, PF = Paddy field, FC = Field crop, PO = Perennial and Orchard, PS = Pasture, F = Forest land, W = Water body, M = Miscellaneous land



Note: U = Urban and built-up area, A = Agriculture land, F = Forest land, W = Water body, M = Miscellaneous land

Figure 4.6 Major land use and land cover change between 2001 and 2009.

4.2.3 Land use and land cover change between 1993 and 2009

For long term period (1993-2009), the most increased LULC types was perennial and orchard and urban and built-up area with an area of 152.93 sq. km and 151.52 sq. km or 4.61% and 4.57% of the study area, respectively. Most of these increased areas came from forest land and filed crop. At the same time, field crop, water body, and miscellaneous land increased an area of 106.53, 44.23 and 10.67 sq. km or 3.21, 1.33 and 0.32% of the study area, respectively.

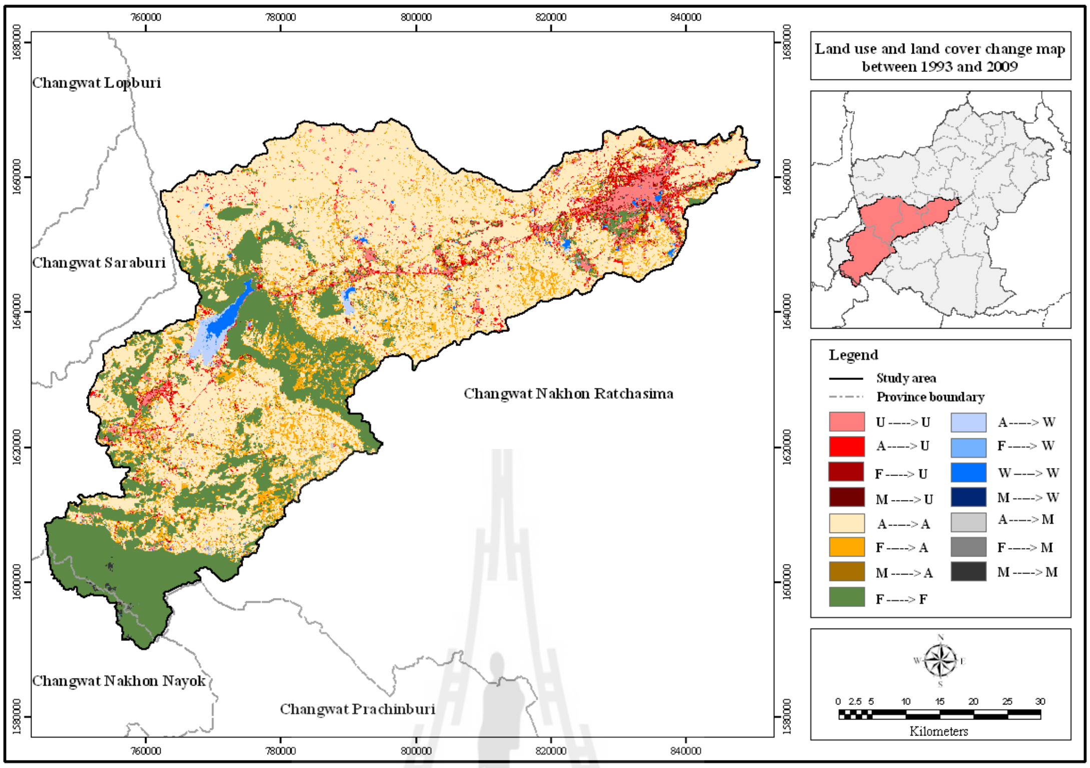
For decreased LULC types, forest land was significantly decreased with area of 457.25 sq. km or 13.79% of the study area. It was changed into urban and built-up area, agricultural land, water body, and miscellaneous land. At the same time pasture and paddy field had also decreased with area of 8.31 and 0.32 sq. km or 0.25 and 0.01% of the study area, respectively. Most pasture and paddy field were changed into field crop. Details of LULCC between 1993 and 2009 were presented in Table 4.5 and Figure 4.7.

Table 4.5 Change matrix of land use and land cover between 1993 and 2009.

(Unit: sq. km)

LULC in 1993	LULC in 2009 (sq. km)								
	U	**PF**	**FC**	**PO**	**PS**	**F**	**W**	**M**	**Total**
U	100.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.39
PF	25.52	349.54	29.74	8.47	0.45	0.00	3.01	4.38	421.11
FC	63.54	37.92	1,178.29	76.03	8.54	0.00	33.06	2.86	1,400.24
PO	2.68	0.02	21.56	34.06	0.90	0.00	0.39	0.11	59.72
PS	1.34	0.01	24.03	3.99	44.99	0.00	0.77	0.16	75.30
F	57.43	33.27	253.03	90.08	12.11	770.50	6.94	4.40	1,227.75
W	0.00	0.00	0.00	0.00	0.00	0.00	24.18	0.00	24.18
M	1.01	0.03	0.12	0.03	0.00	0.00	0.05	5.15	6.39
Total	**251.91**	**420.79**	**1,506.77**	**212.65**	**66.99**	**770.50**	**68.41**	**17.06**	**3,315.07**
Area of change (sq. km)	**151.52**	**-0.32**	**106.53**	**152.93**	**-8.31**	**-457.25**	**44.23**	**10.67**	
Percentage of change (%)	**4.57**	**-0.01**	**3.21**	**4.61**	**-0.25**	**-13.79**	**1.33**	**0.32**	
Annum rate of change (sq. km)	**18.94**	**-0.04**	**13.32**	**19.12**	**-1.04**	**-57.16**	**5.53**	**1.33**	

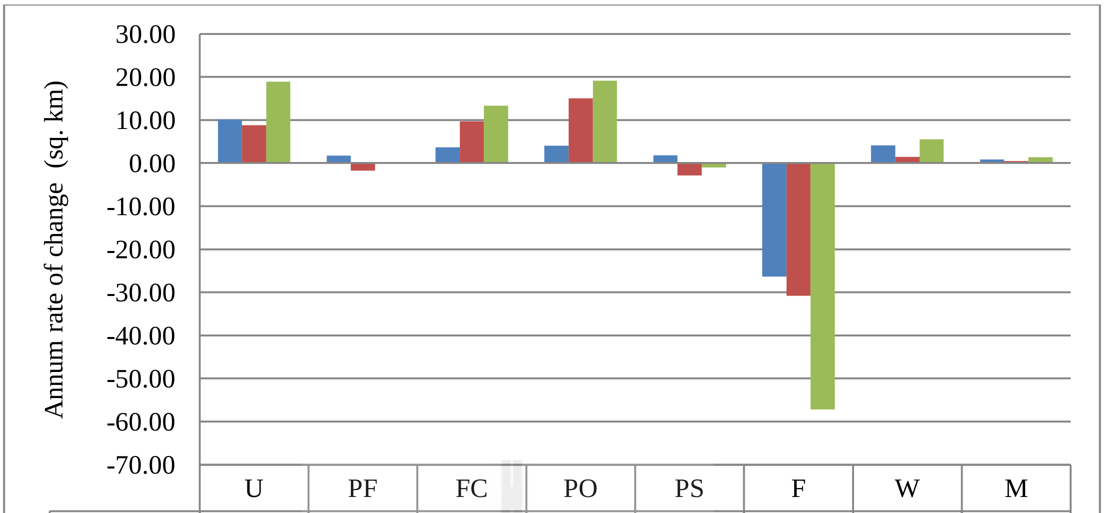
Note: U = Urban and built-up area, PF = Paddy field, FC = Field crop, PO = Perennial and Orchard, PS = Pasture, F = Forest land, W = Water body, M = Miscellaneous land



Note: U = Urban and built-up area, A = Agriculture land, F = Forest land, W = Water body, M = Miscellaneous land

Figure 4.7 Major land use and land cover change between 1993 and 2009.

According to LULC type change in Lamtakhong watershed during 1993-2009, it can be concluded that urban and built-up area, field crop, perennial and orchard, water body and miscellaneous land were continuously increased over study period. In fact, annual increasing rate of field crop and perennial and orchard were continuously increased in two periods (1993-2001 and 2001-2009). While annual increasing rate of urban and built-up area, water body, and miscellaneous land were declined between 1993 and 2001. While, paddy field and pasture were increased between 1993 and 2001 after that they declined between 2001 and 2009. In contrast, area of forest land and annual decreasing rate was steady declined from in two periods (Figure 4.8).



	U	PF	FC	PO	PS	F	W	M
1993-2001	10.15	1.71	3.65	4.07	1.82	-26.37	4.12	0.86
2001-2009	8.79	-1.75	9.67	15.05	-2.86	-30.78	1.41	0.48
1993-2009	18.94	-0.04	13.32	19.12	-1.04	-57.16	5.53	1.33

Note: U = Urban and built-up area, PF = Paddy field, FC = Field crop, PO = Perennial and Orchard, PS = Pasture, F = Forest land, W = Water body, M = Miscellaneous land

Figure 4.8 Annual change rate of land use and land cover in 3 periods (1993-2001, 2001-2009 and 1993-2009).

4.3 Relationship between land use and land cover change and terrain

The LULC in 1993, 2001 and 2009 and terrain (elevation and slope) was here extracted using overlay function in spatial analysis of ArcGIS. Detail of relationship between LULCC with elevation and slope was described in the following section.

4.3.1 Relationship between land use and land cover change and elevation

LULC classes in 1993, 2001 and 2009 were separately overlaid with elevation classes (LDD, 2009) as shown in Table 4.6 and Figure 4.9. Area of LULC class was extracted in each specific elevation class. Distribution of LULC area in each specific class was displayed in Figure 4.10. It was found that urban and built-up area was usually located on less than or equal 250 m and it showed tendency to increase during 1993 and 2009. Field crop was mainly located on 200-750 m. While, forest land was usually located on 350-750 m and it was decreased during 1993 and 2009 in area having elevation less than 750 m.

Table 4.6 Area and percentage of elevation classification.

Elevation (m)	Area (sq. km)	Percentage
< 200	358.66	10.82
200-250	810.44	24.45
250-350	981.88	29.62
350-750	1,044.03	31.49
750-800	48.76	1.47
> 800	71.30	2.15
Total	**3,315.07**	**100.00**

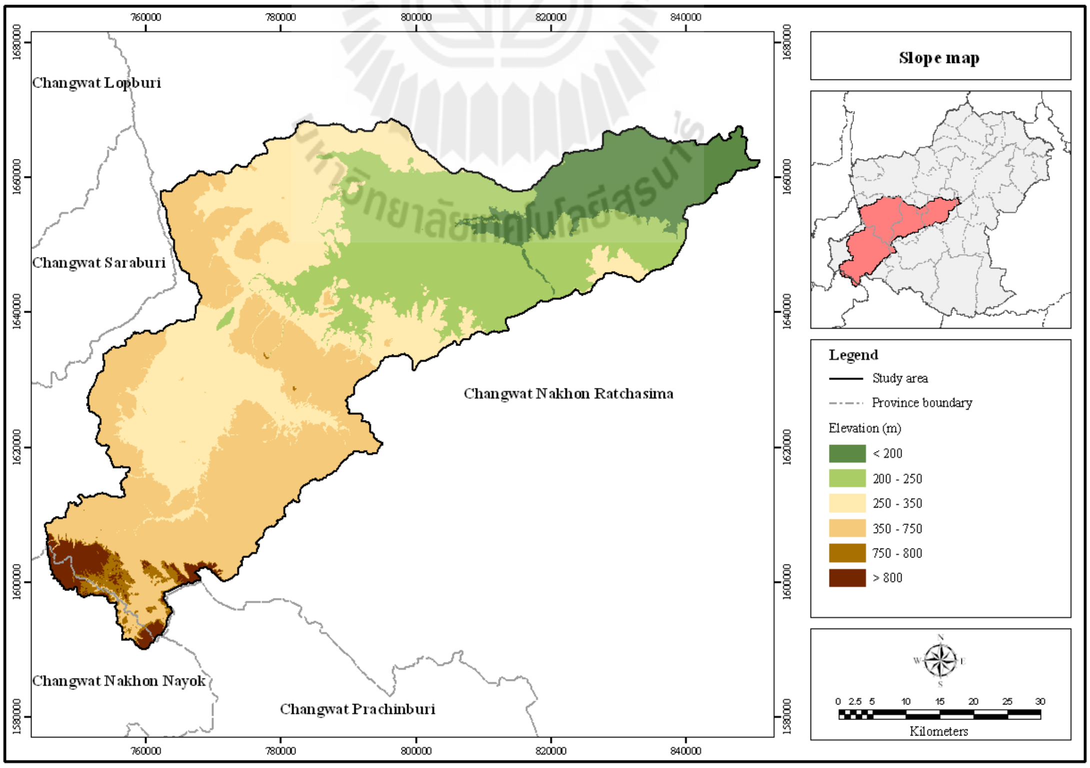


Figure 4.9 Distribution of elevation classification.

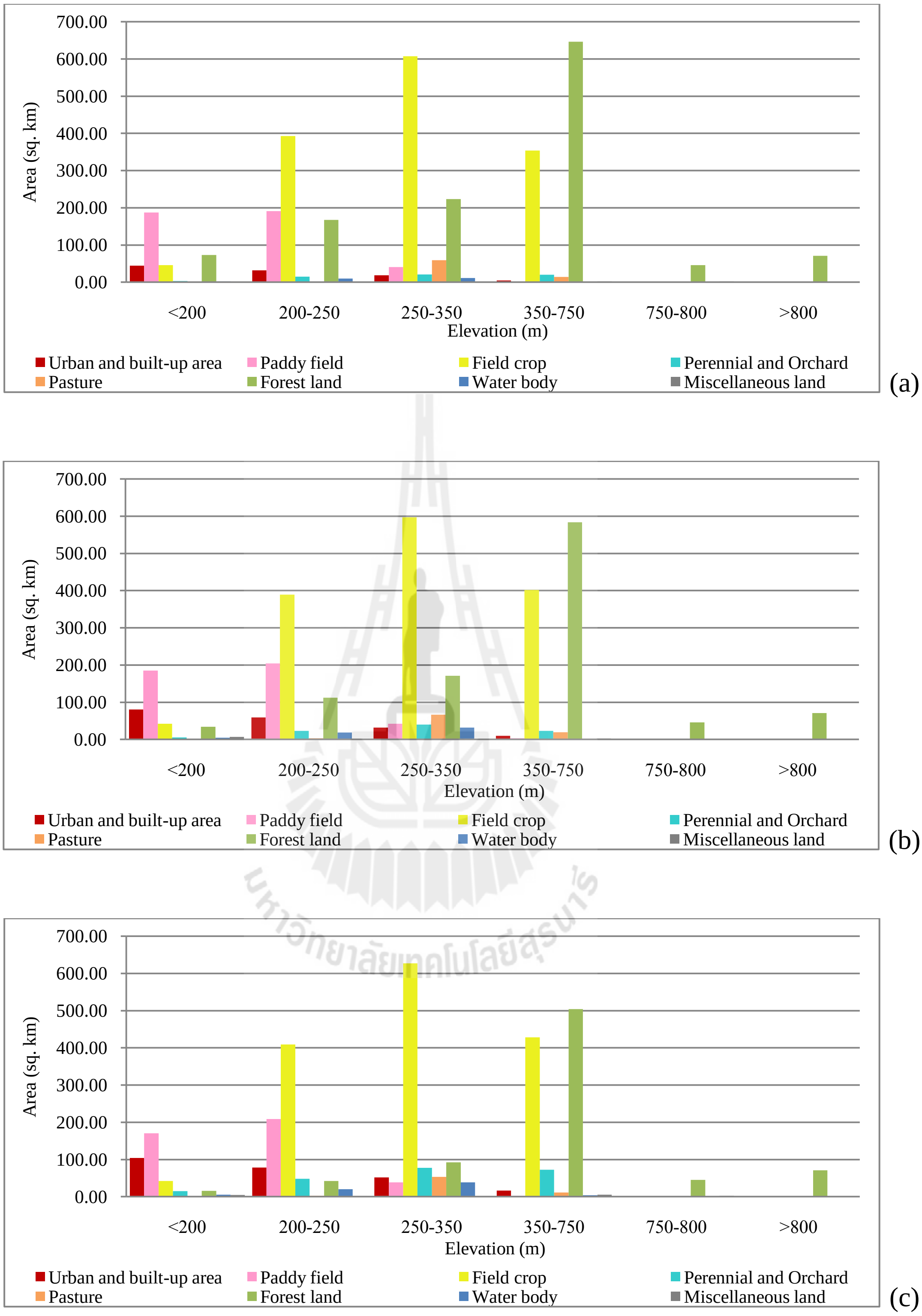


Figure 4.10 Relationship between elevation and land use and land cover classes (a) in 1993 (b) in 2001 and (c) in 2009.

4.3.2 Relationship between land use and land cover change and slope

LULC classes in 1993, 2001 and 2009 were separately overlaid with slope classes (LDD, 2009) as shown in Table 4.7 and Figure 4.11. Area of LULC class was extracted in each specific slope class. Distribution of LULC area in each specific class was displayed in Figure 4.12. It was found that urban and built-up area was usually located on less than or equal 5% slope and it tendency to increase during 1993 and 2009. Moreover, urban and built-up area was expansion to area with 2-5% slope in overtime period. Field crop was mainly located on area having slope between 0 and 12% slope. While, forest land was usually located on 12 to more than 35% slope. During 1993 and 2009, forest land was decreased in area having slope less than 12%.

Table 4.7 Area and percentage of slope.

Slope (%)	Topography	Area (sq. km)	Percentage
0-2	Flat or almost flat	1,573.15	47.45
2-5	Slightly undulating	689.42	20.80
5-12	Undulating	436.71	13.17
12-20	Rolling	201.72	6.08
20-35	Hilly	188.79	5.69
> 35	Steep	225.28	6.80
Total		**3,315.07**	**100.00**

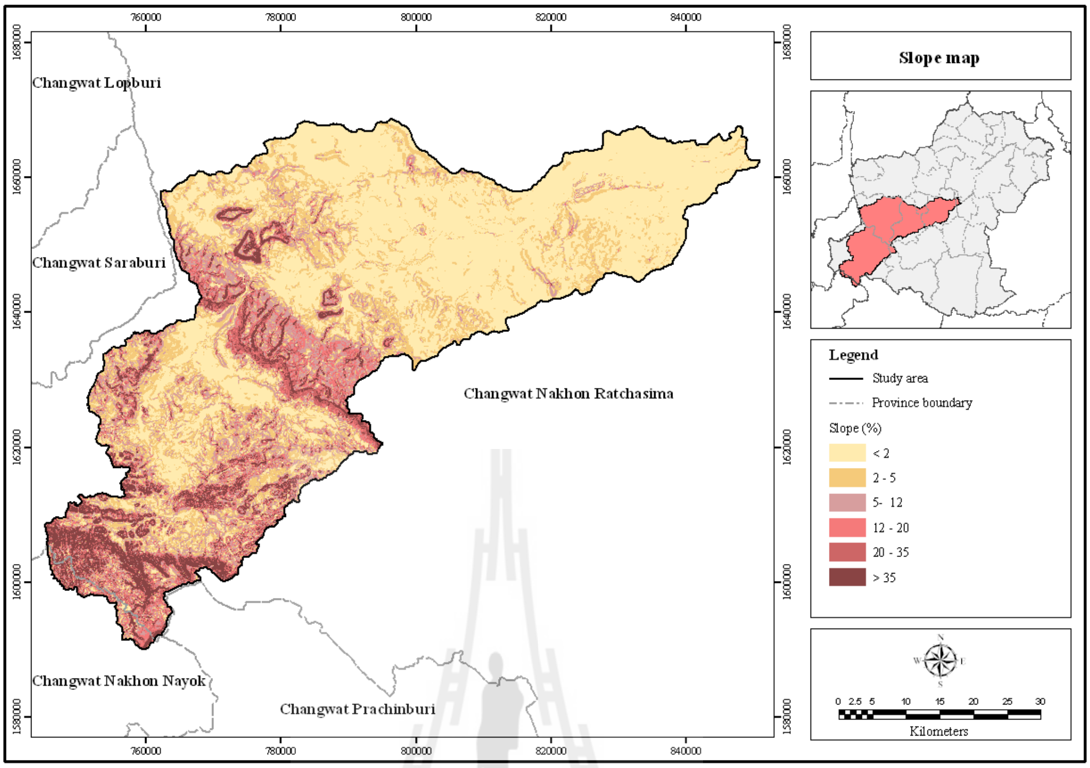
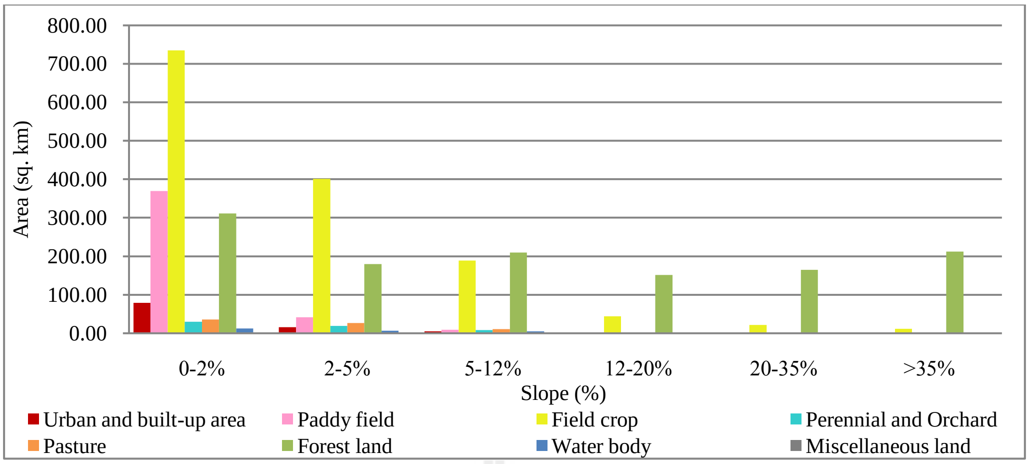
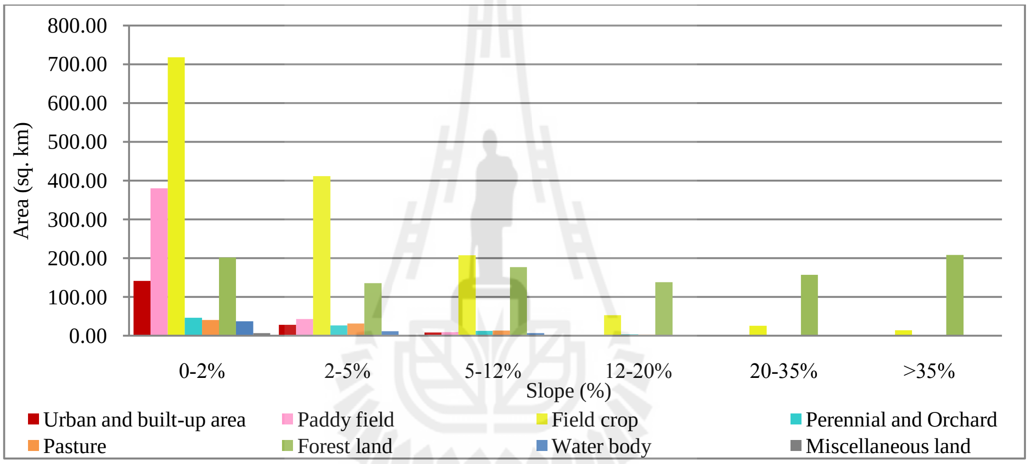


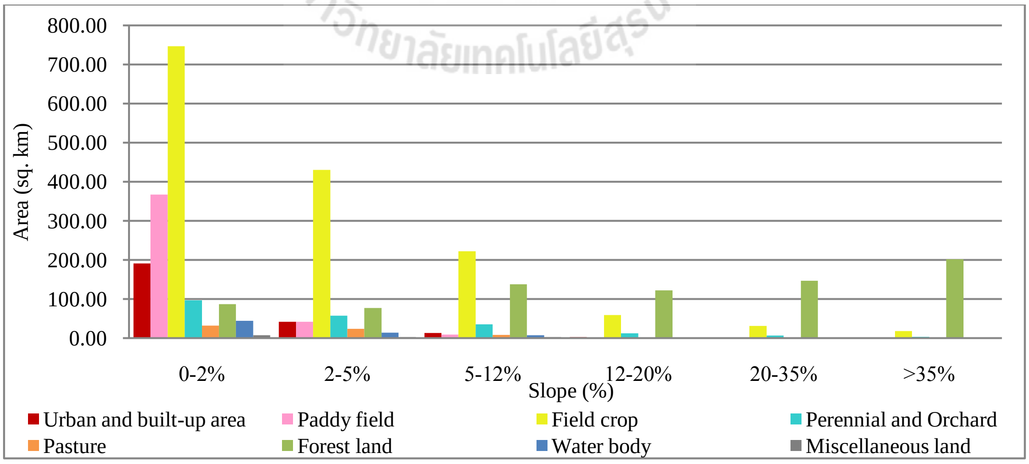
Figure 4.11 Distribution of slope classification.



(a)



(b)



(c)

Figure 4.12 Relationship between slope and land use and land cover classes (a) in 1993 (b) in 2001 and (c) in 2009.

4.4 Land use and land cover prediction

In this study, extracted LULC data in 1993, 2001 and 2009 were used to predict LULC in 2017 and 2025 using CA-Markov model for analysis of LULCC in the future. The results of LULC predicted were described are as following;

4.4.1 Prediction of land use and land cover in 2017

The LULC in 2001 and 2009 that were selected for predictive LULC in 2017 by Markov chain model were employed to generate a transition probability matrix and a transition area matrix as shown in Table 4.8 and Table 4.9, respectively. Such transition probability matrix was used to predict LULC in 2017 with CA model.

Table 4.8 Transition probability matrix of land use and land cover change between 2001 and 2009.

LULC in 2001	**LULC in 2009**							
	U	**PF**	**FC**	**PO**	**PS**	**F**	**W**	**M**
U	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
PF	0.0384	0.8856	0.0452	0.0190	0.0007	0.0000	0.0025	0.0087
FC	0.0212	0.0156	0.9044	0.0482	0.0035	0.0000	0.0051	0.0021
PO	0.0348	0.0000	0.2266	0.7199	0.0144	0.0000	0.0001	0.0042
PS	0.0146	0.0000	0.3541	0.0517	0.5733	0.0000	0.0047	0.0015
F	0.0154	0.0114	0.1389	0.0630	0.0087	0.7578	0.0024	0.0024
W	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
M	0.2350	0.1427	0.0328	0.0280	0.0008	0.0000	0.0060	0.5547

Note: U = Urban and built-up area, PF = Paddy field, FC = Field crop, PNOC = Perennial and Orchard, PT = Pasture, F = Forest land, W = Water body, M = Miscellaneous land

Table 4.9 Transition area matrix of land use and land cover change between 2009 and 2017.

(Unit: sq. km)

LULC in 2009	LULC in 2017								
	U	**PF**	**FC**	**PO**	**PS**	**F**	**W**	**M**	**Total**
U	251.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	251.91
PF	16.14	372.64	19.04	7.99	0.29	0.00	1.04	3.65	420.79
FC	31.98	23.48	1,362.70	72.59	5.24	0.00	7.65	3.15	1,506.77
PO	7.40	0.00	48.18	153.08	3.07	0.00	0.03	0.89	212.65
PS	0.98	0.00	23.72	3.46	38.41	0.00	0.32	0.10	66.99
F	11.89	8.77	106.99	48.57	6.72	583.89	1.83	1.84	770.50
W	0.00	0.00	0.00	0.00	0.00	0.00	68.41	0.00	68.41
M	4.01	2.44	0.56	0.48	0.01	0.00	0.10	9.47	17.06
Total	**324.30**	**407.32**	**1,561.18**	**286.17**	**53.73**	**583.89**	**79.37**	**19.10**	**3,315.07**

Note: U = Urban and built-up area, PF = Paddy field, FC = Field crop, PO = Perennial and Orchard, PS = Pasture, F = Forest land, W = Water body, M = Miscellaneous land

Based on the result of predictive LULC in 2017, the main LULC type was agriculture land covering an area of 2,314.32 sq. km or 69.81% of the study. The second dominant LULC type was forest land covering an area 585.81 sq. km or 17.67% of the study area. The third important LULC type was urban and built-up area covering an area 324.30 sq. km or 9.78% of the study area. Other LULC type were water body and miscellaneous land accounting area of 90.65 sq. km or 2.73% of the study area (Table 4.10 and Figure 4.13).

Table 4.10 Area and percentage of predictive land use and land cover in 2017.

LULC types	Area (sq.km.)	Percentage
Urban and built-up area	324.30	9.78
Paddy field	408.48	12.32
Field crop	1,565.94	47.24
Perennial and Orchard	286.19	8.63
Pasture	53.71	1.62
Forest land	585.81	17.67
Water body	74.25	2.24
Miscellaneous land	16.40	0.49
Total	**3,315.07**	**100.00**

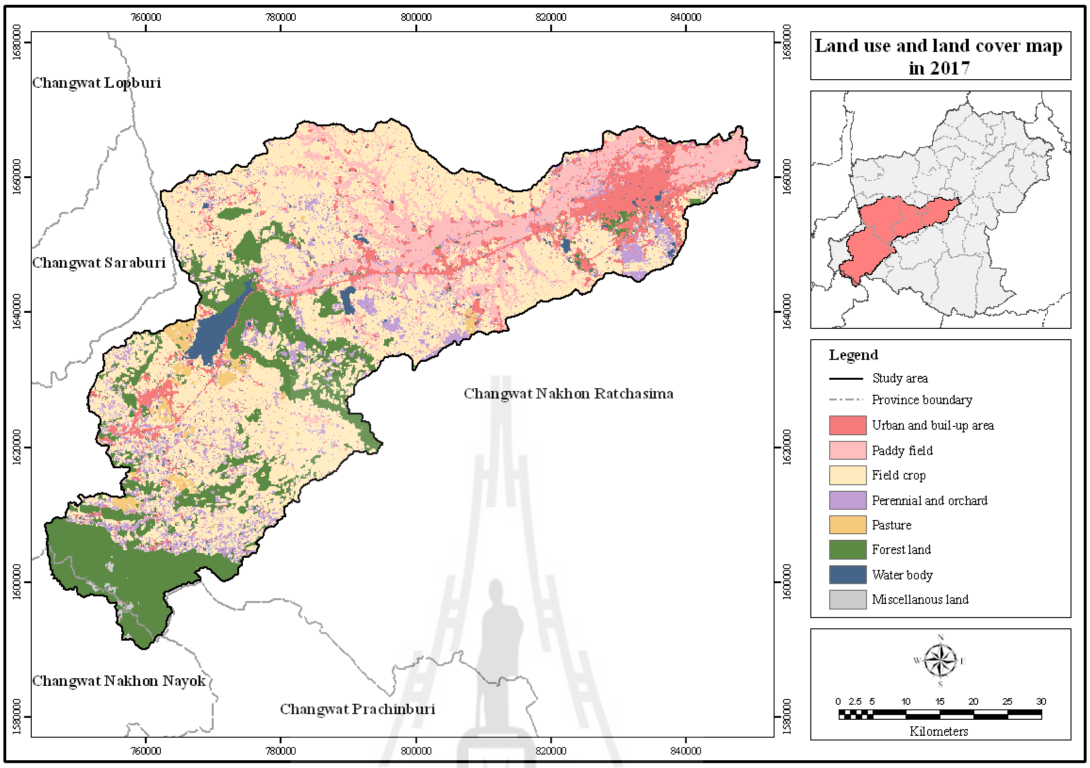


Figure 4.13 Predictive land use and land cover in 2017.

4.4.2 Prediction of land use and land cover in 2025

Predictive LULC in 2025 that was estimated based on LULC between 1993 and 2009 using Markov chain model. Herewith, a transition probability matrix and a transition area matrix and were generated as shown in Table 4.11 and Table 4.12, respectively for predictive LULC in 2025 by CA model as shown in Figures 4.16.

Table 4.11 Transition probability matrix of land use and land cover between 1993 and 2009

LULC in 1993	LULC in 2009							
	U	**PF**	**FC**	**PO**	**PS**	**F**	**W**	**M**
U	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
PF	0.0606	0.8300	0.0706	0.0201	0.0011	0.0000	0.0072	0.0104
FC	0.0454	0.0271	0.8415	0.0543	0.0061	0.0000	0.0236	0.0020
PO	0.0449	0.0003	0.3610	0.5704	0.0151	0.0000	0.0065	0.0019
PS	0.0178	0.0002	0.3192	0.0530	0.5975	0.0000	0.0103	0.0022
F	0.0468	0.0271	0.2061	0.0734	0.0099	0.6276	0.0057	0.0036
W	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
M	0.1576	0.0049	0.0193	0.0045	0.0000	0.0000	0.0075	0.8063

Note: U = Urban and built-up area, PF = Paddy field, FC = Field crop, PO = Perennial and Orchard, PS = Pasture, F = Forest land, W = Water body, M = Miscellaneous land

Table 4.12 Transition area matrix of land use and land cover between 2009 and 2025.

(Unit: sq. km)

LULC in 2009	LULC in 2025								
	U	**PF**	**FC**	**PNOC**	**PT**	**F**	**W**	**M**	**Total**
U	251.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	251.91
PF	25.50	349.28	29.71	8.46	0.45	0.00	3.01	4.38	420.79
FC	68.37	40.81	1267.93	81.81	9.19	0.00	35.58	3.08	1,506.77
PNOC	9.54	0.05	76.76	121.29	3.22	0.00	1.38	0.41	212.65
PT	1.19	0.01	21.38	3.55	40.02	0.00	0.69	0.15	66.99
F	36.04	20.88	158.79	56.53	7.60	483.54	4.36	2.76	770.50
W	0.00	0.00	0.00	0.00	0.00	0.00	68.41	0.00	68.41
M	2.69	0.08	0.33	0.08	0.00	0.00	0.13	13.76	17.06
Total	**324.30**	**407.32**	**1,561.18**	**286.17**	**53.73**	**583.89**	**79.37**	**19.10**	**3,315.07**

Note: U = Urban and built-up area, PF = Paddy field, FC = Field crop, PO = Perennial and Orchard, PS = Pasture, F = Forest land, W = Water body, M = Miscellaneous land

In this period, the most significant LULC type was agriculture land covering an area of 2,301.41 sq. km or 69.42% of the study. The second dominant LULC type was forest land covering an area of 483.79 sq. km or 14.59% of the study area. The third important LULC type was urban and built-up area covering an area 395.24 sq. km or 11.92% of the study area. Other LULC type were water body and miscellaneous land accounting area of 134.64 sq. km or 4.07% of the study area (Table 4.13 and Figure 4.14).

Table 4.13 Area and percentage of predictive land use and land cover in 2025.

Land use and land cover type	Area (sq.km.)	Percentage
Urban and built-up area	395.24	11.92
Paddy field	411.26	12.41
Field crop	1,557.65	46.99
Perennial and Orchard	272.02	8.21
Pasture	60.48	1.82
Forest land	483.79	14.59
Water body	113.56	3.43
Miscellaneous land	21.08	0.64
Total	**3,315.07**	**100.00**

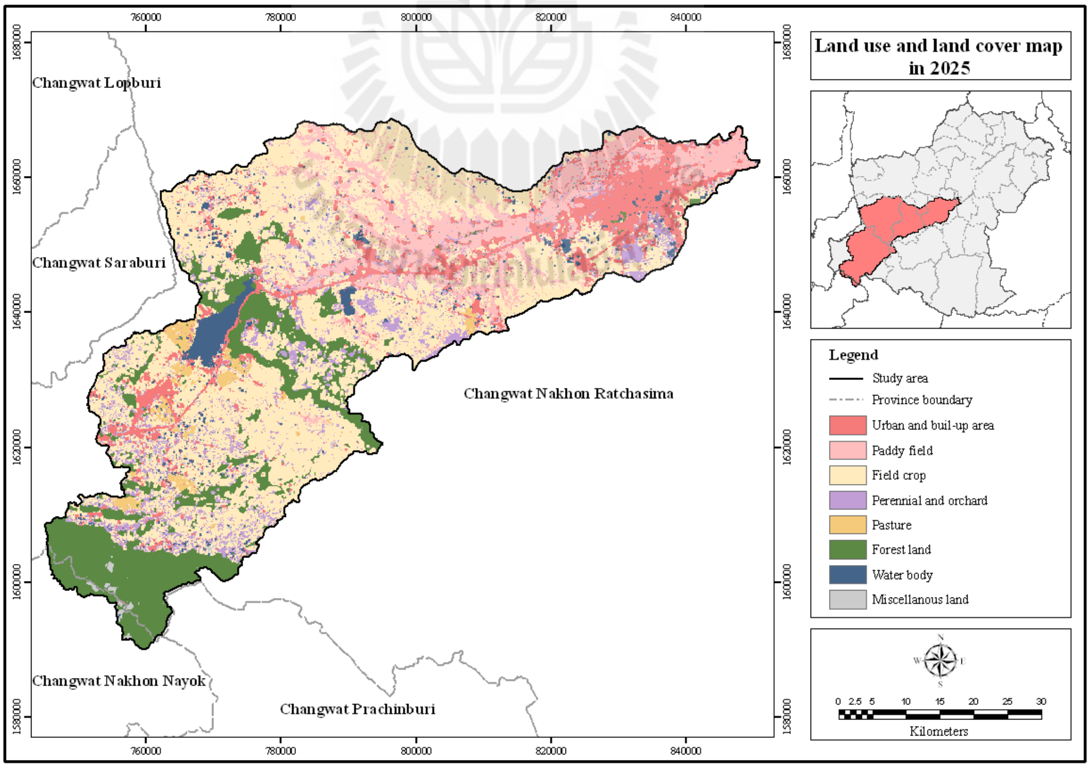


Figure 4.14 Predictive land use and land cover in 2025.

4.5 Status of land use and land cover and annual change rate

Based on the results of LULC classification in 1993, 2001 and 2009 from remote sensed data and LULC prediction in 2017 and 2025 using CA-Markov model, area of LULC between 1993 and 2025 can used to compare and describe about the annual change rate occurring in the past and the future (Figure 4.15 and Table 4.14).

According to area and annual rate change of LULC, urban and built-up area and water body were continuously increased. While, field crop, perennial and orchard were increased during 1993 to 2017 but there decreased in 2025. Paddy field and pasture were increased during 1993 to 2001 but they were increased during 2001 to 2017 and increased during 2017 to 2025. Meanwhile, miscellaneous land was increased during 1993 to 2009 but it was decreased during 2009 to 2017 then it was increased during 2017 to 2025. At the same time forest land was continuously decreased during 1993 to 2025.

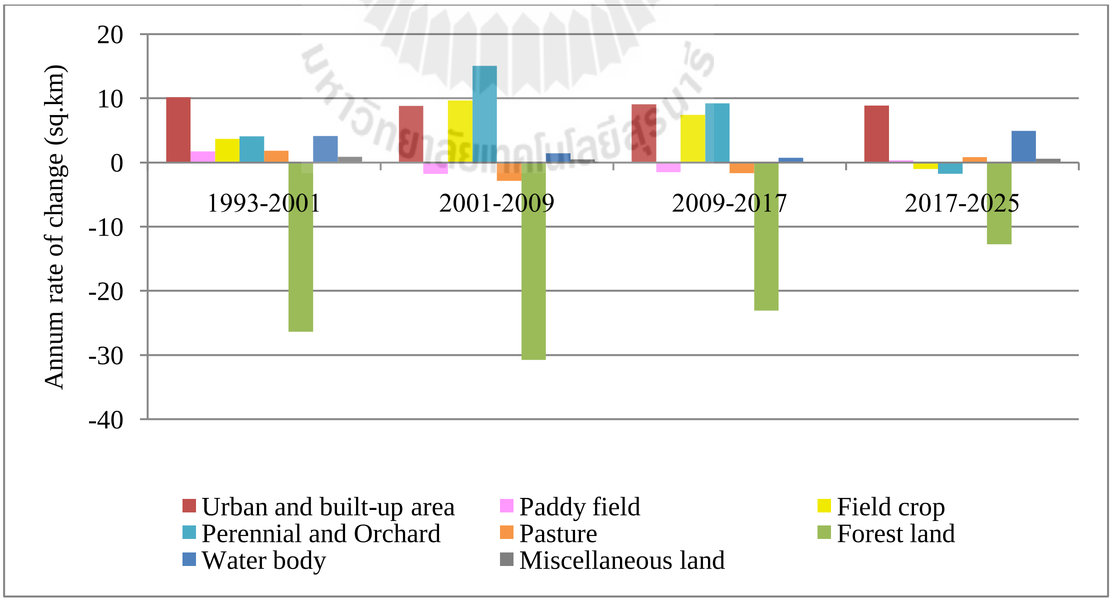


Figure 4.15 Annual change rate of LULC in 4 periods (1993-2001 and 2001-2009, 2009-2017 and 2017-2025).

Table 4.14 Area and rate of change for land use and land cover during 1993 to 2025.

LULC types	Area (sq. km)					Area change rate				Annual change rate			
	1993	**2001**	**2009**	**2017**	**2025**	**1993-2001**	**2001-2009**	**2009-2017**	**2017-2025**	**1993-2001**	**2001-2009**	**2009-2017**	**2017-2025**
U	100.39	181.57	251.91	324.3	395.24	81.18	70.34	72.39	70.94	10.15	8.79	9.05	8.87
PF	421.11	434.81	420.79	408.48	411.26	13.7	-14.02	-12.31	2.78	1.71	-1.75	-1.54	0.35
FC	1,400.24	1,429.44	1,506.77	1,565.94	1,557.65	29.2	77.33	59.17	-8.29	3.65	9.67	7.40	-1.04
PO	59.72	92.26	212.65	286.19	272.02	32.54	120.39	73.54	-14.17	4.07	15.05	9.19	-1.77
PS	75.3	89.86	66.99	53.71	60.48	14.56	-22.87	-13.28	6.77	1.82	-2.86	-1.66	0.85
F	1,227.75	1,016.75	770.5	585.81	483.79	-211	-246.25	-184.69	-102.02	-26.38	-30.78	-23.09	-12.75
W	24.18	57.15	68.41	74.25	113.56	32.97	11.26	5.84	39.31	4.12	1.41	0.73	4.91
M	6.39	13.24	17.06	16.4	21.08	6.85	3.82	-0.66	4.68	0.86	0.48	-0.08	0.59
Total	**3,315.07**	**3,315.07**	**3,315.07**	**3,315.07**	**3,315.07**								

Note: U = Urban and built-up area, PF = Paddy field, FC = Field crop, PO = Perennial and orchard, PS = Pasture, F = Forest land, W = Water body, M = Miscellaneous land

4.6 Accuracy assessment of predictive model

The accuracy of predictive LULC in 2009 was here done by comparison with classified LULC in 2009 from remotely sensed data. It was found that overall accuracy of predictive LULC in 2009 was 84.01% and overall Kappa hat efficient of agreement of was 0.77 as shown in Table 4.15. Thus CA-Markov model could be acceptable for LULC prediction.

As result shown in Table 4.15, it was found that the two significant different LULC area based on classification and prediction were perennial and orchard (104.86 sq. km) and forest land (76.32 sq.km).

Table 4.15 Error matrixes and accuracy assessment for predictive land use and land cover in 2009.

(Unit: sq. km)

Classified LULC in 2009	Predictive LULC in 2009								
	U	**PF**	**FC**	**PO**	**PS**	**F**	**W**	**M**	**Total**
U	199.67	14.24	21.92	2.89	1.58	6.33	1.73	3.54	251.91
PF	4.84	384.23	21.07	0.67	0.05	2.85	1.75	5.33	420.79
FC	28.73	26.70	1,291.22	27.79	39.17	71.77	20.95	0.45	1,506.77
PO	9.09	9.63	77.78	70.36	5.84	37.96	1.47	0.51	212.65
PS	0.17	0.32	5.34	1.02	53.57	6.48	0.10	0.01	66.99
F	15.82	4.54	26.66	4.54	0.86	717.95	0.13	0.00	770.50
W	0.24	0.80	4.32	0.09	0.46	1.66	60.75	0.09	68.41
M	0.60	3.52	2.91	0.43	0.17	1.83	0.22	7.40	17.06
Total	**259.14**	**443.97**	**1,451.23**	**107.79**	**101.70**	**846.82**	**87.09**	**17.32**	**3,315.07**
Overall accuracy (%)	**=**	**84.01%**							
Kappa Coefficient	**=**	**0.77**							

Note: U = Urban and built-up area, PF = Paddy field, FC = Field crop, PO = Perennial and orchard, PS = Pasture, F = Forest land, W = Water body, M = Miscellaneous land

CHAPTER V

LANDSCAPE TYPE CLASSIFICATION AND LANDSCAPE PATTERN ANALYSIS

The content of this chapter was present the results of the second objective focusing on classification of landscape type and agricultural and forest landscape pattern analysis using landscape metrics.

5.1 Landscape type classification and assessment

Landscape type classification was performed using a grid basis or landscape cell. Herewith, landscape cells with 1 km x 1 km grid size were generated covered the study area with 3,548 landscape cells. Based on LULC data in 1993, 2001, 2009, 2017 and 2025, four landscape types were classified. Four landscape types were assigned according to majority of LULC class included urban landscape, agricultural landscape, forest landscape, and miscellaneous landscape.

5.1.1 Assessment of landscape type in 1993

In 1993, agricultural landscape was the most dominant in the study area; it covered an area of 2,344 sq. km or 66.07% of the study area. Forest landscape was the next most abundant landscape type covering an area of 1,123 sq. km or 31.65% of the study area. At the same time, others were urban and miscellaneous landscapes covering an area of 62 and 19 sq. km or 1.75 and 0.54% of the study area, respectively (Figure 5.1 and Table 5.1).

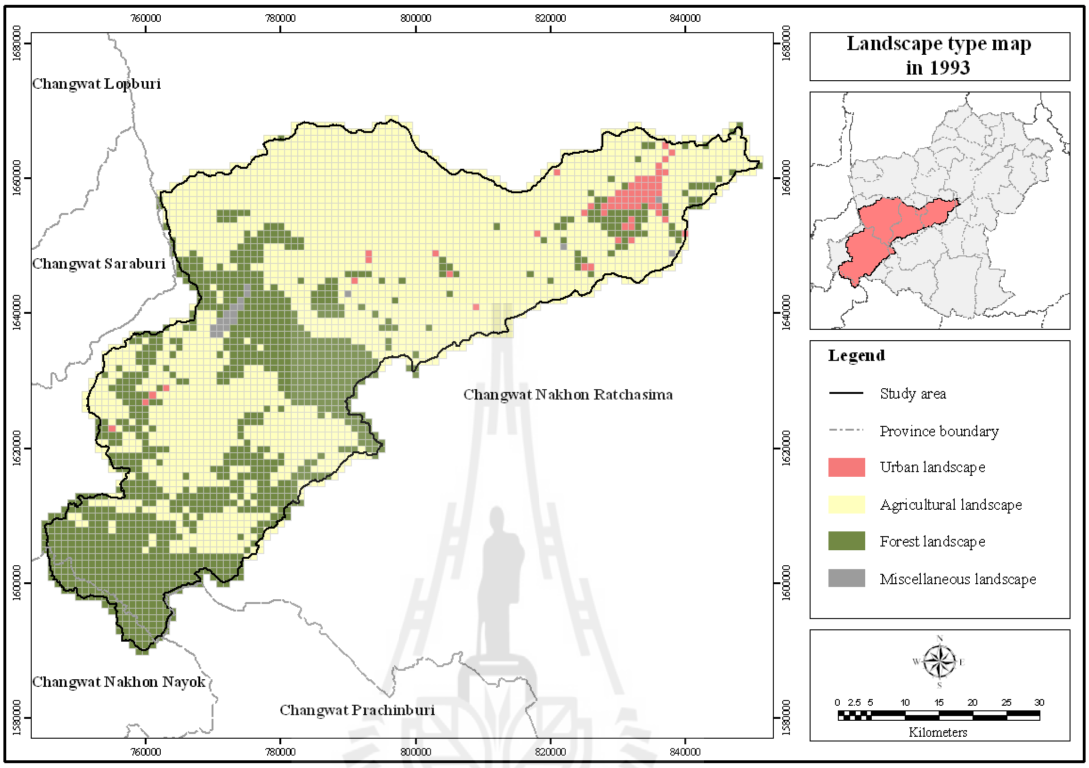


Figure 5.1 Distribution of landscape type of the study area in 1993.

5.1.2 Assessment of landscape type in 2001

In 2001, agricultural landscape was the most dominant in the study area; it covered an area of 2,431 sq. km or 68.52% of the study area. Forest landscape was the next most abundant landscape type covering an area of 941 sq. km or 26.52% of the study area. Urban landscape and miscellaneous landscape were 128 and 48 sq. km or 3.61 and 1.35% of the study area, respectively (Figure 5.2 and Table 5.1).

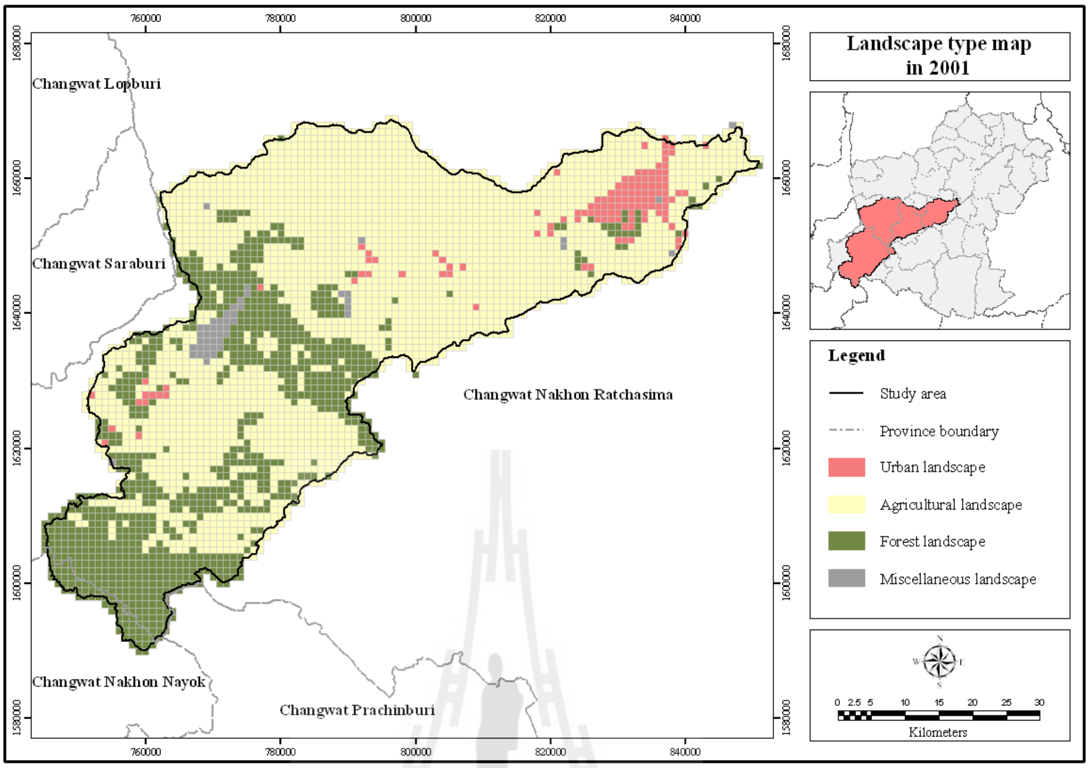


Figure 5.2 Distribution of landscape type of the study area in 2001.

5.1.3 Assessment of landscape type in 2009

In 2009, agricultural landscape was the most dominant in the study area; it covered an area of 2,547 sq. km or 71.79% of the study area. Forest landscape was the next most abundant landscape type covering an area of 781 sq. km or 22.01% of the study area. In the meantime, urban and miscellaneous landscape types were covering an area of 170 and 50 sq. km or 4.79 and 1.41% of the study area, respectively (Figure 5.3 and Table 5.1).

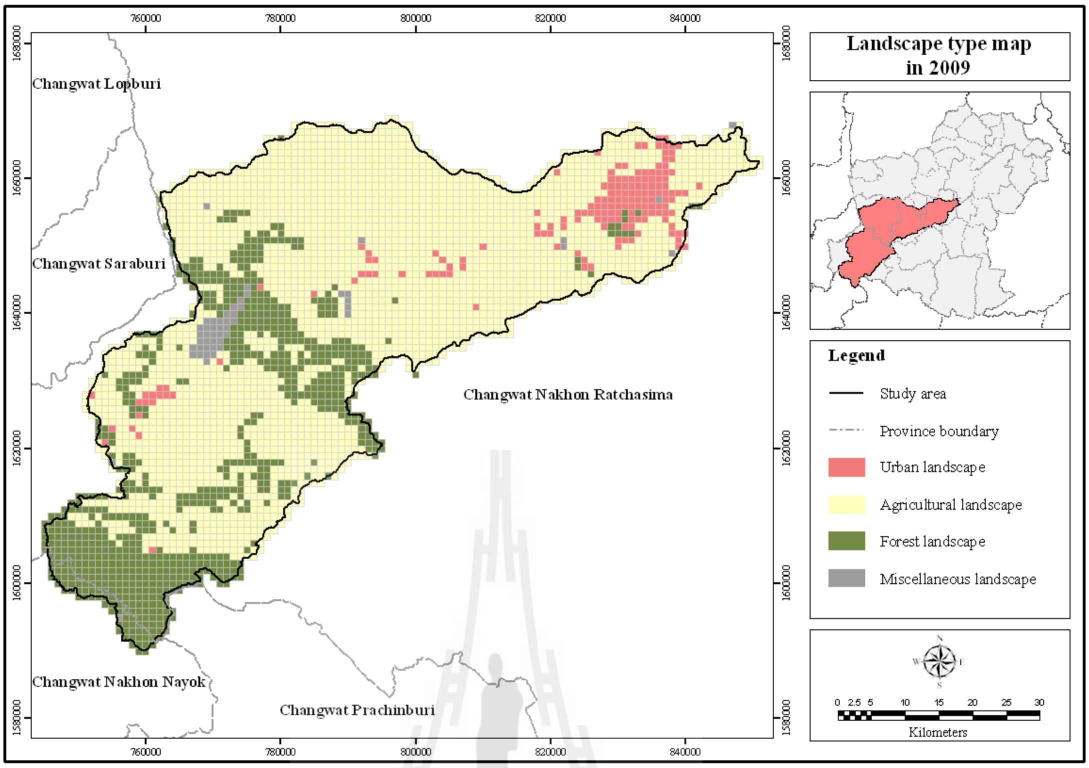


Figure 5.3 Distribution of landscape type of the study area in 2009.

5.1.4 Assessment of landscape type in 2017

Based on predictive LULC in 2017 by CA-Markov model, agricultural landscape will be the most dominant in the study area in 2017; it covering an area of 2,662 sq. km or 75.03% of the study area. Forest landscape will be the next most abundant landscape type covering an area of 602 sq. km or 16.97% of the study area. Urban landscape and miscellaneous landscape will be 224 and 60 sq. km or 6.31 and 1.69% of the study area, respectively (Figure 5.4 and Table 5.1).

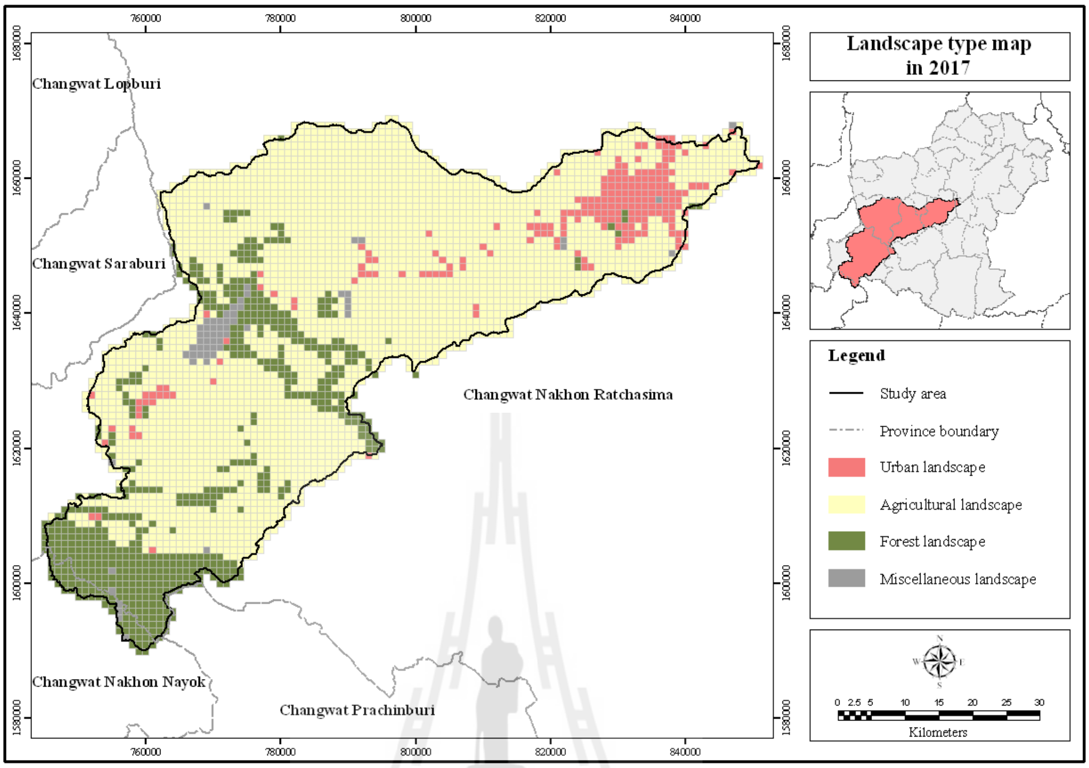


Figure 5.4 Distribution of landscape type of the study area in 2017.

5.1.5 Assessment of landscape type in 2025

Based on predictive LULC in 2025 by CA-Markov model, agricultural landscape will be the most dominant in the study area in 2025; it covering an area of 2,654 sq. km or 74.80% of the study area. Forest landscape will be the next most abundant landscape type covering an area of 519 sq. km or 14.63% of the study area. At the same time, urban and miscellaneous landscapes will be 302 and 73 sq. km or 8.51 and 2.06% of the study area, respectively (Figure 5.5 and Table 5.1).

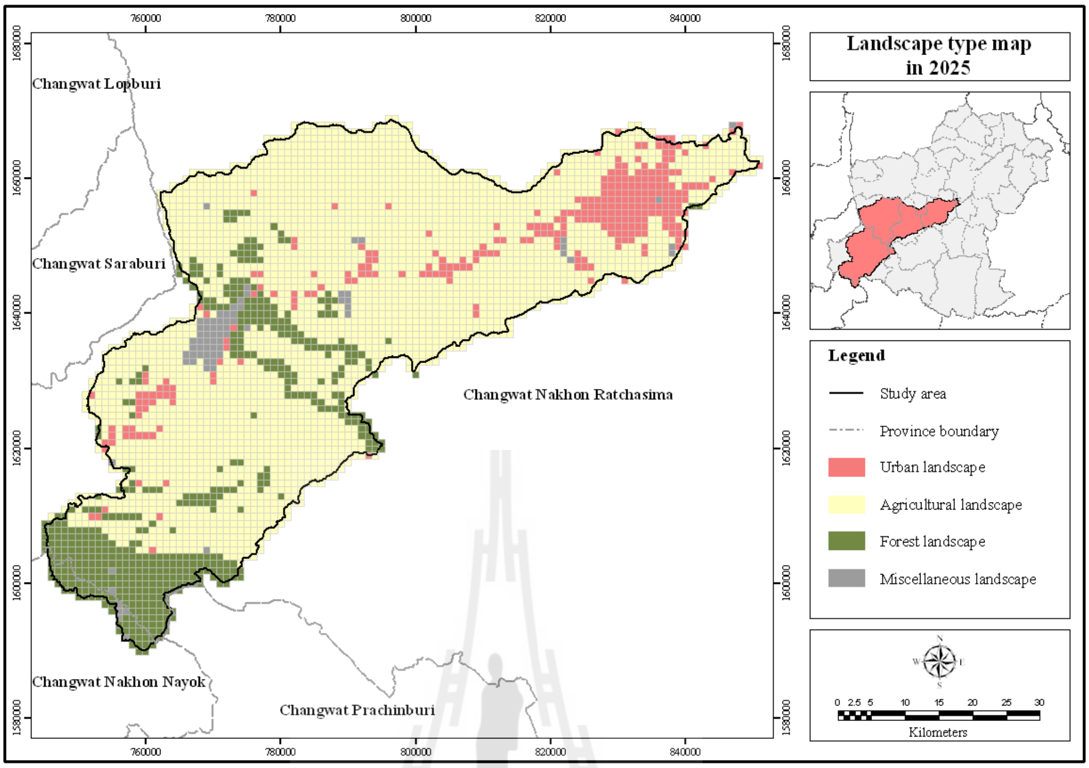


Figure 5.5 Distribution of landscape type of the study area in 2025.

Consequently, it was found that agricultural landscape during 1993 to 2009 was dominant in the study area approximately 60-70% of the study area. Forest landscape was declined because of the increasing of agricultural and urban landscape. While urban and miscellaneous landscapes were continuously increased (Table 5.1).

Table 5.1 Area and percentage of landscape types during 1993 to 2025.

Landscape type	1993		2001		2009		2017		2025	
	Area (sq.km)	%	Area (sq.km)	%	Area (sq.km)	%	Area (sq.km)	%	Area (sq.km)	%
ULT	62	1.75	128	3.61	170	4.79	224	6.31	302	8.51
ALT	2,344	66.07	2,431	68.52	2,547	71.79	2,662	75.03	2,654	74.80
FLT	1,123	31.65	941	26.52	781	22.01	602	16.97	519	14.63
MLT	19	0.54	48	1.35	50	1.41	60	1.69	73	2.06
Total	**3,548**	**100.00**	**3,548**	**100.00**	**3,548**	**100.00**	**3,548**	**100.00**	**3,548**	**100.00**

Note: ULT = Urban landscape, ALT = Agricultural landscape, FLT = Forest landscape, and MLT = Miscellaneous landscape

5.2 Change of landscape type

Quantify change of landscape types in the past and future during 1993 to 2025 were performed using transition matrix were here explained in each specific period (1993-2001, 2001-2009, 2009-2017 and 2017-2025).

5.2.1 Landscape types change between 1993 and 2001

Between 1993 and 2001, urban and miscellaneous landscapes were dramatically increased covering area of 66 and 29 sq. km or 8.25 and 3.63 sq.km per annum. Most of the increased areas were converted from forest landscapes. Herewith urban landscape and miscellaneous landscape change rate were 106.45 and 152.63%, respectively. At the same time, agricultural landscape was also increased with area of 87 sq. km or 10.88 sq. km per annum. However, agricultural landscape change rate was only 3.71%.

For decreased landscape type, forest landscape had the most significant decreased in this period. Decreased areas were 182 sq. km or 22.75 sq. km per annum. Forest landscape change rate was -16.21%. Landscape type change in term of gain and loss between 1993 and 2001 was displayed in Table 5.2 and Figure 5.6.

Table 5.2 Change matrix of landscape types between 1993 and 2001.

(Unit: sq. km)

Landscape type in 1993	Landscape type in 2001				
	ULT	**ALT**	**FLT**	**MLT**	**Total**
Urban landscape (ULT)	62	0	0	0	62
Agricultural landscape (ALT)	32	2,285	0	27	2,344
Forest landscape (FLT)	34	146	941	2	1,123
Miscellaneous landscape (MLT)	0	0	0	19	19
Total	**128**	**2,431**	**941**	**48**	**3,548**
Area of change (sq.km)	**66**	**87**	**-182**	**29**	
Landscape change rate (%)	**106.45**	**3.71**	**-16.21**	**152.63**	
Annual rate of change (sq. km)	**8.25**	**10.88**	**-22.75**	**3.63**	

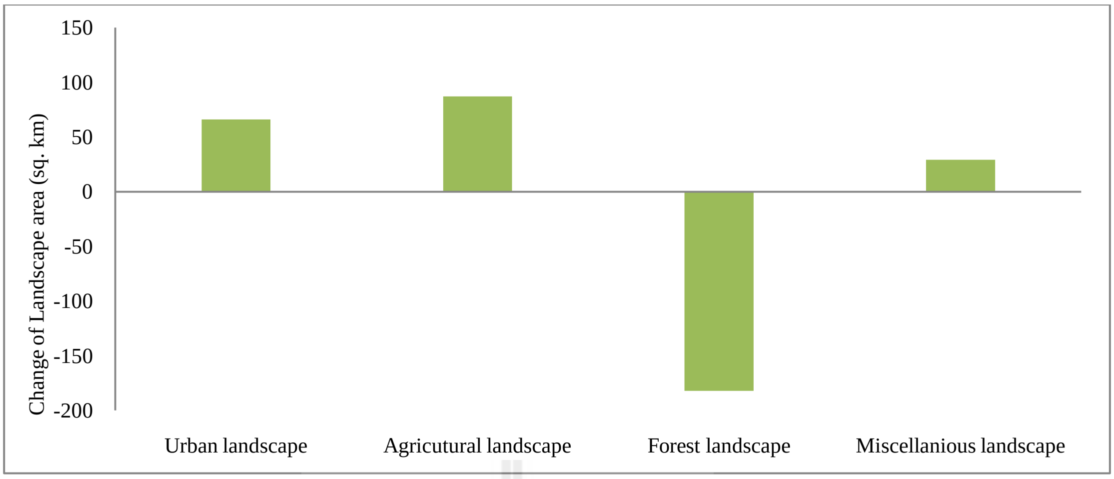


Figure 5.6 Area of landscape type change between 1993 and 2001.

5.2.2 Landscape types change between 2001 and 2009

Between 2001 and 2009, agricultural landscape was dramatically increased covering area of 116 sq. km or 14.50 sq. km per annum. Most of the increased areas were changed from forest landscapes. However, agricultural landscape change rate was only 4.77 %. At the same time, urban landscape type was continuously increased with area of 42 sq. km or 5.25 sq. km per annum. Herein urban landscape change rate was 32.81%. While, miscellaneous landscape was slightly increased with area of 2 sq. km or 0.25 sq. km per annum and miscellaneous landscape change rate was 4.17%.

For decreased landscape type, forest landscape had continuously decreased in this period. Decreased areas were 160 sq. km or 20.00 sq. km per annum. Forest landscape change rate was -17.00%. Landscape type change in term of gain and loss between 2001 and 2009 was displayed in Table 5.3 and Figure 5.7.

Table 5.3 Change matrix of landscape types between 2001and 2009.

(Unit: sq. km)

Landscape type in 2001	**Landscape type in 2009**				
	ULT	**ALT**	**FLT**	**MLT**	**Total**
Urban landscape (ULT)	126	2	0	0	128
Agricultural landscape (ALT)	31	2,399	0	1	2,431
Forest landscape (FLT)	13	146	781	1	941
Miscellaneous landscape (MLT)	0	0	0	48	48
Total	**170**	**2,547**	**781**	**50**	**3,548**
Area of change (sq.km)	**42**	**116**	**-160**	**2**	
Landscape change rate (%)	**32.81**	**4.77**	**-17.00**	**4.17**	
Annual rate of change (sq. km)	**5.25**	**14.50**	**-20.00**	**0.25**	

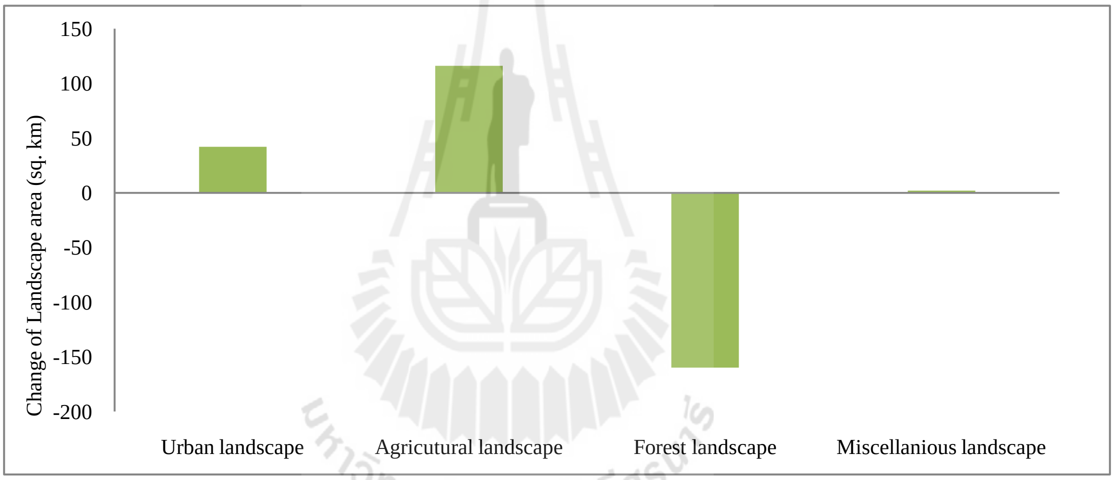


Figure 5.7 Area of landscape type change between 2001 and 2009.

5.2.3 Landscape types change between 2009 and 2017

Landscape type change between 2009 and 2017 will be similar to landscape types change occurring between 2001 and 2009. Agricultural landscape will be still dramatically increased covering area of 115 sq. km or 14.38 sq. km per annum. Most of the increased areas will changed from forest landscapes. Agricultural landscape change rate will be 4.52%. At the same time, urban landscape type will be continuously increased with area of 54 sq. km or 6.75 sq. km per annum. Herein urban landscape change rate will be 31.76%. While, miscellaneous landscape will be slightly increased with area of 10 sq. km or 1.25 sq. km per annum and miscellaneous landscape change rate will be 20.00%.

For decreased landscape type, forest landscape has continuously decreased in this period. Decreased areas will be 179 sq. km or 22.38 sq. km per annum. Forest landscape change rate will be -22.92%. Landscape type change in term of gain and loss between 2009 and 2017 was displayed in Table 5.4 and Figure 5.8.

Table 5.4 Change matrix of landscape types between 2009 and 2017.

(Unit: sq. km)

Landscape type in 2009	Landscape type in 2017				
	ULT	ALT	FLT	MLT	Total
Urban landscape (ULT)	169	1	0	0	170
Agricultural landscape (ALT)	48	2,495	0	4	2,547
Forest landscape (FLT)	7	166	602	6	781
Miscellaneous landscape (MLT)	0	0	0	50	50
Total	**224**	**2,662**	**602**	**60**	**3,548**
Area of change (sq.km)	**54**	**115**	**-179**	**10**	
Landscape change rate (%)	**31.76**	**4.52**	**-22.92**	**20.00**	
Annual rate of change (sq. km)	**6.75**	**14.38**	**-22.38**	**1.25**	

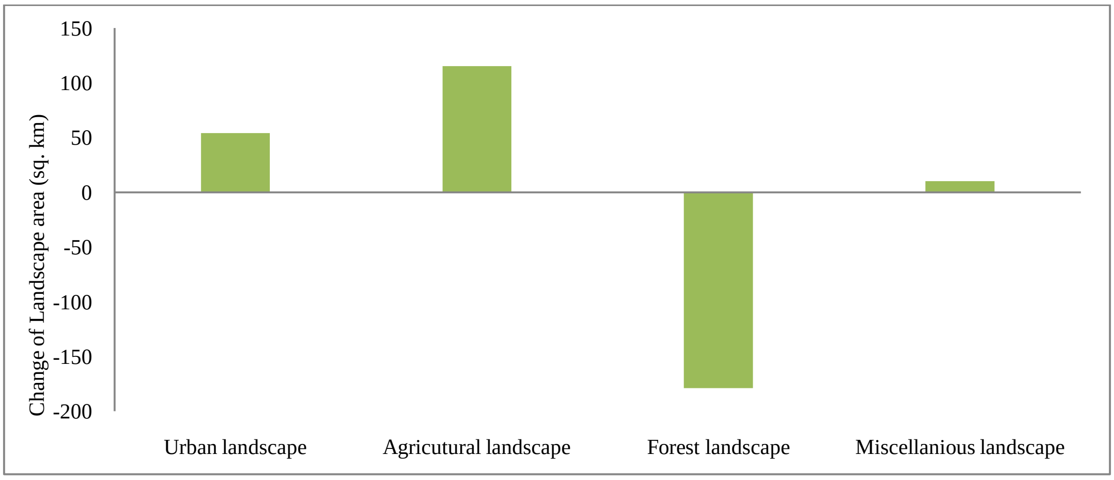


Figure 5.8 Area of landscape type change between 2009 and 2017.

5.2.4 Landscape types change between 2017 and 2025

Between 2017 and 2025, urban and miscellaneous landscapes will be continuously increased covering area of 78 and 13 sq. km or 9.75 and 1.63 sq. km per annum. Most of the increased area will come from forest and agricultural landscapes. Herewith urban landscape and miscellaneous landscape change rate will be 34.82 and 21.67%, respectively.

In contrast, forest landscape has continuously decreased with area of 83 sq. km or 10.38 sq. km per annum. Forest landscape change rate will be -13.79%. At the same time, agricultural landscape will be initially decreased with area of 8 sq. km or 1.00 sq. km per annum. Herewith, agricultural landscape change rate will be only -0.30%. Landscape type change in term of gain and loss between 2017 and 2025 was displayed in Table 5.5 and Figure 5.9.

Table 5.5 Change matrix of landscape types between 2017 and 2025.

(Unit: sq. km)

Landscape type in 2017	Landscape type in 2025				
	ULT	**ALT**	**FLT**	**MLT**	**Total**
Urban landscape (ULT)	224	0	0	0	224
Agricultural landscape (ALT)	64	2,587	0	11	2,662
Forest landscape (FLT)	14	67	519	2	602
Miscellaneous landscape (MLT)	0	0	0	60	60
Total	**302**	**2,654**	**519**	**73**	**3,548**
Area of change (sq.km)	**78**	**-8**	**-83**	**13**	
Landscape change rate (%)	**34.82**	**-0.30**	**-13.79**	**21.67**	
Annual rate of change (sq. km)	**9.75**	**-1.00**	**-10.38**	**1.63**	

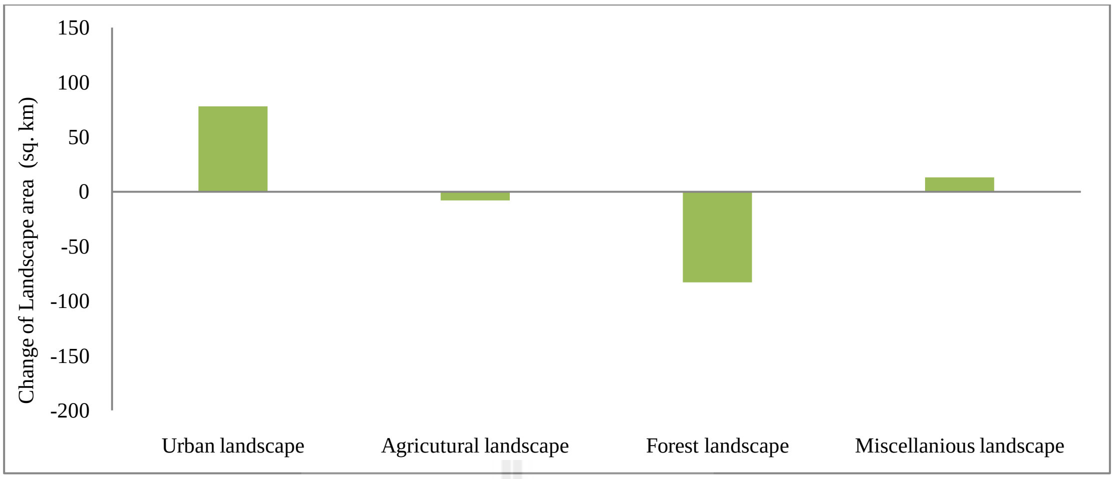


Figure 5.9 Area of landscape type change between 2017 and 2025.

5.3 Landscape pattern analysis

Derived LULC classification and agricultural and forest landscape cell in the past (1993, 2001 and 2009) and in the future (2017 and 2025) with respectively LULC were here used to characterize dynamic landscape pattern using landscape metrics included that landscape fragmentation, landscape complexity, landscape isolation, landscape diversity, and landscape adjacency (see also section 3.2.2.2: Landscape pattern analysis).

Basically, original landscape metrics extracted (minimum and maximum) of agricultural and forest landscape during 1993 to 2025 (Table 5.6 and Table 5.7, respectively) were linearly normalized based on minimum and maximum value of five years metrics. Then normalized metrics of each landscape pattern for agricultural and forest landscape were reclassified using equal interval method into three levels: low, moderate and high. Finally, level of each landscape metric for agricultural and forest landscape pattern were separately used to compare the change of landscape pattern during 1993 to 2025. The change of agricultural and forest landscape pattern separately described in details in the following section.

Table 5.6 Summary statistics for landscape metrics of agricultural landscape.

Landscape metrics	Statistics	1993	2001	2009	2017	2025
Number of patches (NP)	Minimum	1.00	1.00	1.00	1.00	1.00
	Maximum	71.00	77.00	77.00	57.00	52.00
Mean patch fractal	Minimum	1.00	1.00	1.00	1.00	1.00
dimension index (MPFD)	Maximum	1.12	1.10	1.10	1.11	1.09
Mean proximity index	Minimum	0.00	0.00	0.00	0.00	0.00
(MPI)	Maximum	321.67	365.50	446.26	378.53	502.73
Shannon's diversity index	Minimum	0.00	0.00	0.00	0.00	0.00
(SDI)	Maximum	1.59	1.69	1.71	1.69	1.67
Interspersion juxtaposition	Minimum	1.00	1.00	1.00	1.00	1.00
index (IJI)	Maximum	99.38	99.93	99.77	99.96	99.63

Table 5.7 Summary statistics for landscape pattern metrics of forest landscape.

Landscape metrics	Statistics	1993	2001	2009	2017	2025
Number of patches (NP)	Minimum	1.00	1.00	1.00	1.00	1.00
	Maximum	66.00	68.00	57.00	34.00	29.00
Mean patch fractal	Minimum	1.00	1.00	1.00	1.00	1.00
dimension index (MPFD)	Maximum	1.11	1.11	1.12	1.10	1.09
Mean proximity index	Minimum	0.00	0.00	0.00	0.00	0.00
(MPI)	Maximum	517.94	504.52	502.50	222.29	277.63
Shannon's diversity index	Minimum	0.00	0.00	0.00	0.00	0.00
(SDI)	Maximum	1.49	1.59	1.40	1.54	1.38
Interspersion juxtaposition	Minimum	1.00	1.00	1.00	1.00	1.00
index (IJI)	Maximum	99.29	95.88	99.83	99.96	99.68

5.3.1 Agricultural landscape pattern analysis

5.3.1.1 Agricultural landscape fragmentation

It was found that during 1993 to 2025 level of fragmentation of agricultural landscape was mostly low covering an area range from 65 to 92% of the study area (Table 5.8 and Figure 5.10). A low value of fragmentation indicated a relatively homogeneous or larger area. These infer that agricultural pattern in Lamtakhong watershed was cultivation of monocultures with typically contain only a few sown crop types distributed in large uniform fields e.g. crop monocultures of cassava and sugar cane. Transition from traditional agricultural methods with more heterogeneous landscapes contain many different land cover which are distributed in a complex pattern to cultivation of monocultures has been the main reason for the habitat loss of several species and the decline in biodiversity.

Table 5.8 Area and percentage of agricultural landscape fragmentation.

Landscape fragmentation	1993		2001		2009		2017		2025	
	Area (sq.km)	%	Area (sq.km)	%	Area (sq.km)	%	Area (sq.km)	%	Area (sq.km)	%
Low	1,919	81.97	1,585	65.20	1,724	67.69	2,413	90.65	2,467	92.95
Moderate	416	17.77	799	32.87	757	29.72	246	9.24	186	7.01
High	6	0.26	47	1.93	66	2.59	3	0.11	1	0.04
Total	**2,341**	**100.00**	**2,431**	**100.00**	**2,547**	**100.00**	**2,662**	**100.00**	**2,654**	**100.00**

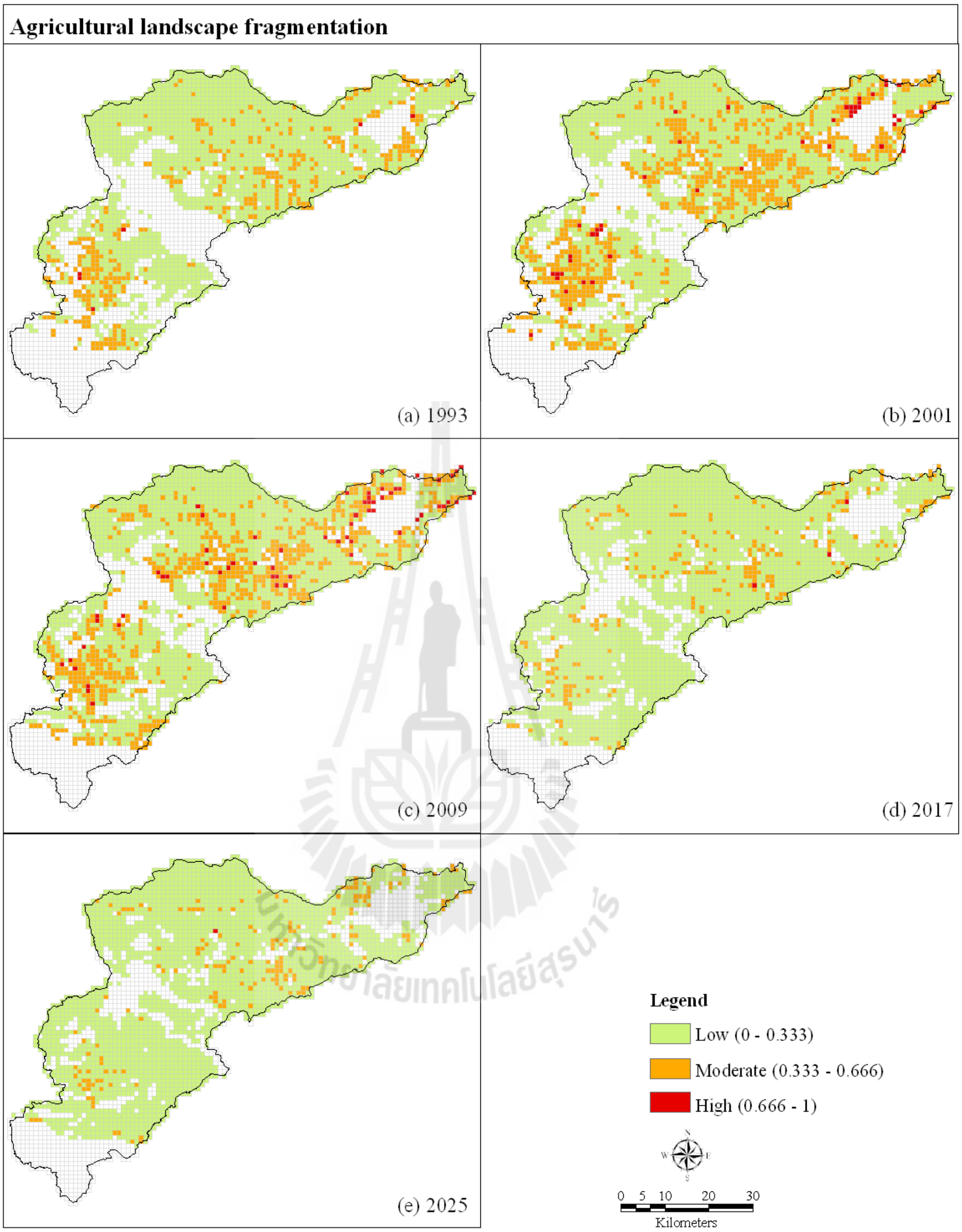


Figure 5.10 Agricultural landscape fragmentations (a) in 1993, (b) in 2001, (c) in 2009, (d) in 2017 and (e) in 2025.

5.3.1.2 Agricultural landscape complexity

For agricultural landscape complexity during 1993-2025, it was found that the most dominant landscape were moderate shape complexity covering an area range from 55 to 74% of the study area (Table 5.9 and Figure 5.11). Low value of landscape complexity was indicated that the shape of land use type tended to be simple and regular. Human activities introduce rectangularity and rectilinearity to landscapes, producing regular shapes with straight borders (O'Nell et al., 1988 and Forman, 1955).

Table 5.9 Area and percentage of agricultural landscape complexity.

Landscape complexity	1993		2001		2009		2017		2025	
	Area (sq.km)	%	Area (sq.km)	%	Area (sq.km)	%	Area (sq.km)	%	Area (sq.km)	%
Low	526	22.47	755	31.06	834	32.74	1,031	38.73	1,167	43.97
Moderate	1,742	74.41	1,654	68.04	1,686	66.20	1,591	59.77	1,455	54.82
High	73	3.12	22	0.90	27	1.06	40	1.50	32	1.21
Total	**2,341**	**100.00**	**2,431**	**100.00**	**2,547**	**100.00**	**2,662**	**100.00**	**2,654**	**100.00**

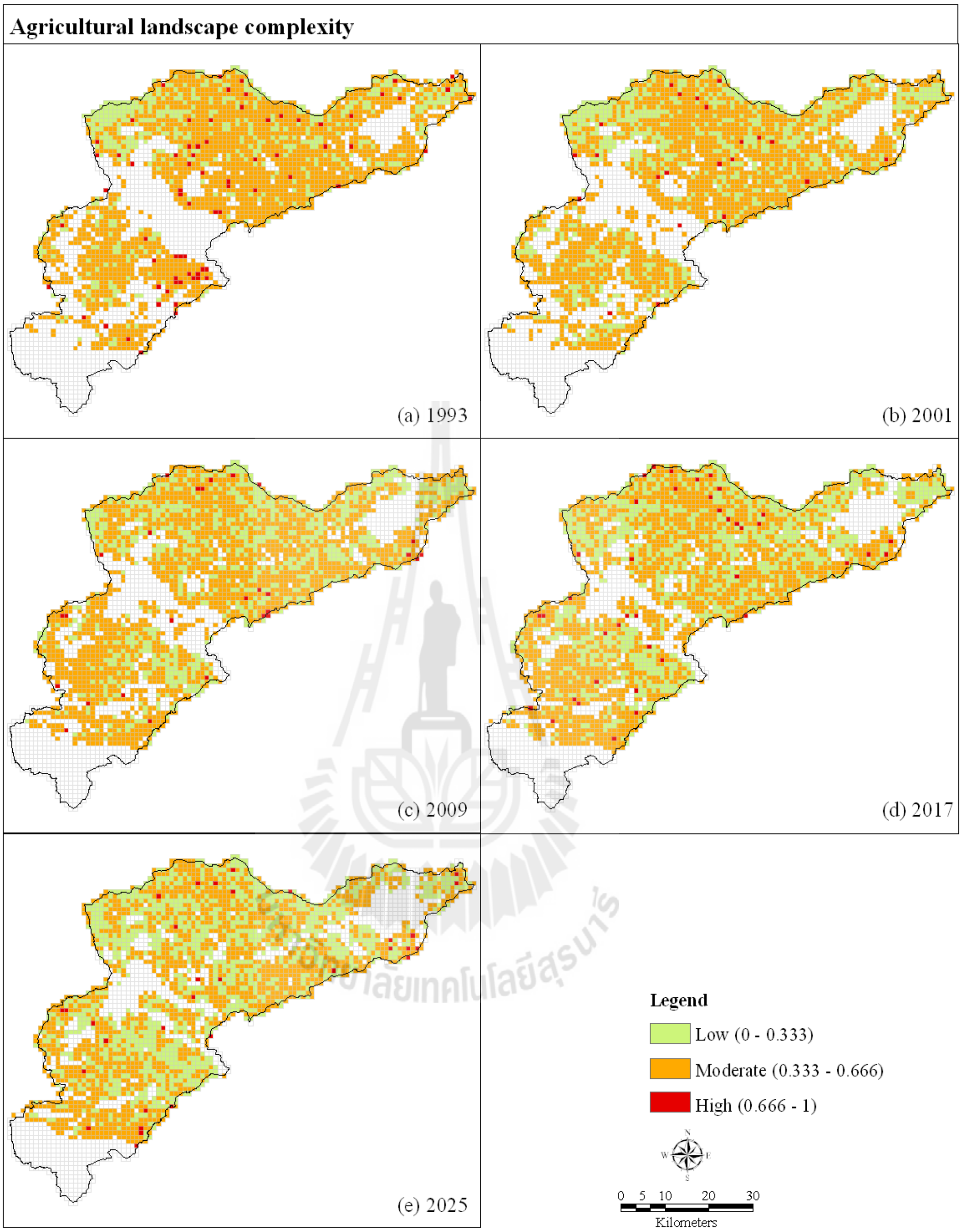


Figure 5.11 Agricultural landscape complexity (a) in 1993, (b) in 2001, (c) in 2009, (d) in 2017 and (e) in 2025.

5.3.1.3 Agricultural landscape isolation

Agricultural landscape isolation during 1993-2025, it was found that the most dominant landscape were high isolation of patch type covering an area about 90% of the study area (Table 5.10 and Figure 5.12) represented agricultural patches was more isolated and not contiguous in distribution while low value represent agricultural patches was aggregated large patches and continuous patches.

Table 5.10 Area and percentage of agricultural landscape isolation.

Landscape isolation	1993		2001		2009		2017		2025	
	Area (sq.km)	%	Area (sq.km)	%	Area (sq.km)	%	Area (sq.km)	%	Area (sq.km)	%
Low	0	0.00	1	0.04	1	0.04	1	0.04	5	0.19
Moderate	63	2.69	23	0.95	28	1.10	24	0.90	25	0.94
High	2,278	97.31	2,407	99.01	2,518	98.86	2,637	99.06	2,624	98.87
Total	**2,341**	**100.00**	**2,431**	**100.00**	**2,547**	**100.00**	**2,662**	**100.00**	**2,654**	**100.00**

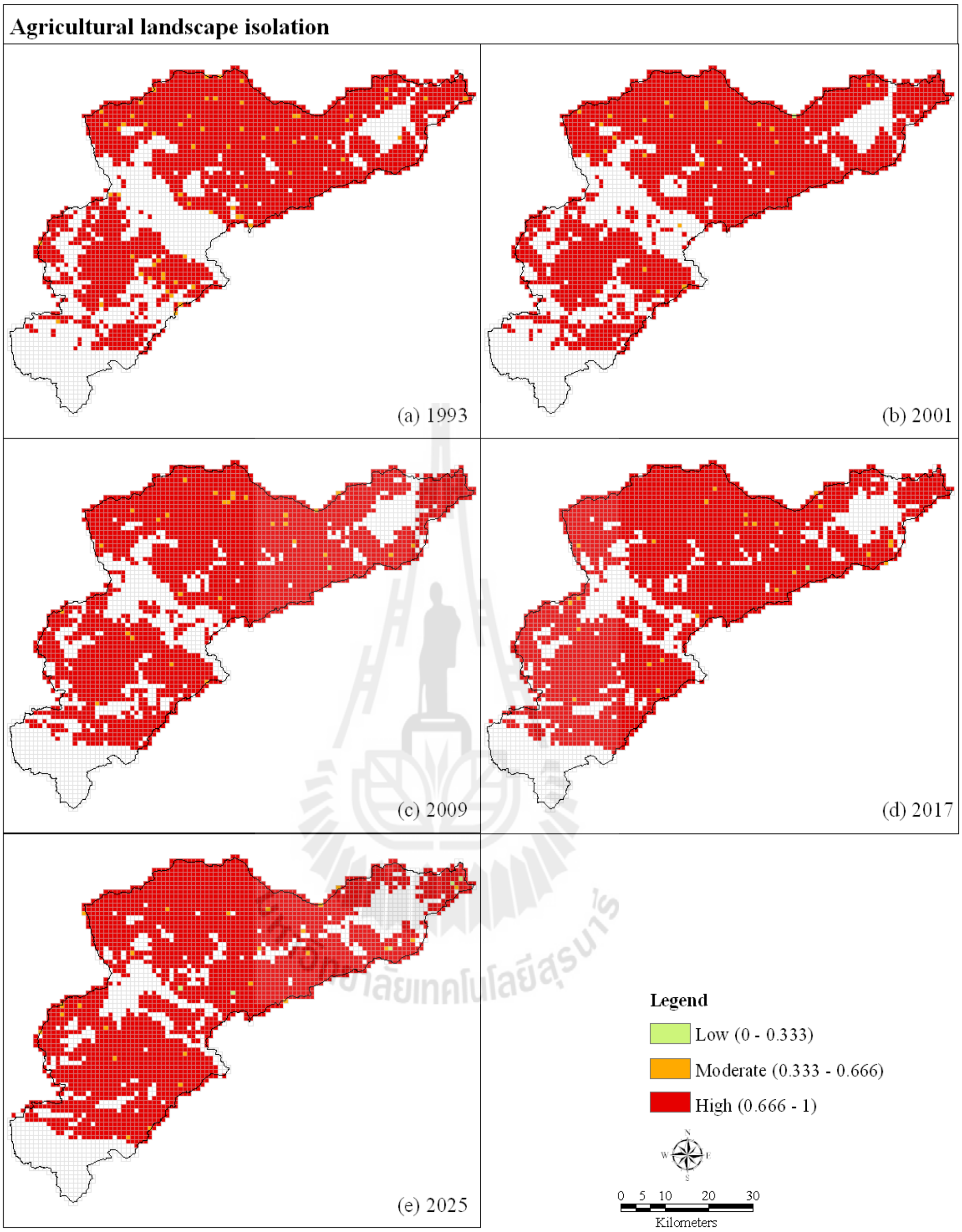


Figure 5.12 Agricultural landscape isolation (a) in 1993, (b) in 2001, (c) in 2009, (d) in 2017 and (e) in 2025.

5.3.1.4 Agricultural landscape diversity

Agricultural landscape diversity during 1993-2025, it was found that the most dominant landscape were moderate diversity covering an area of 49-56% of the study area (Table 5.11 and Figure 5.13). The second dominant landscape was low diversity covering an area 30% of the study. Low value of landscape diversity can be suggesting that the landscape was dominated by large patch of a few land use types. It might be resulted of dominance of field crop. The enlargement of production area effects on biodiversity of farmland ecosystems.

Table 5.11 Area and percentage of agricultural landscape diversity.

Landscape diversity	1993		2001		2009		2017		2025	
	Area (sq.km)	**%**	**Area (sq.km)**	**%**	**Area (sq.km)**	**%**	**Area (sq.km)**	**%**	**Area (sq.km)**	**%**
Low	851	36.35	813	33.44	864	33.92	1,007	37.83	979	36.89
Moderate	1,300	55.53	1,232	50.68	1,255	49.27	1,331	50.00	1,324	49.89
High	190	8.12	386	15.88	428	16.80	324	12.17	351	13.23
Total	**2,341**	**100.00**	**2,431**	**100.00**	**2,547**	**100.00**	**2,662**	**100.00**	**2,654**	**100.00**

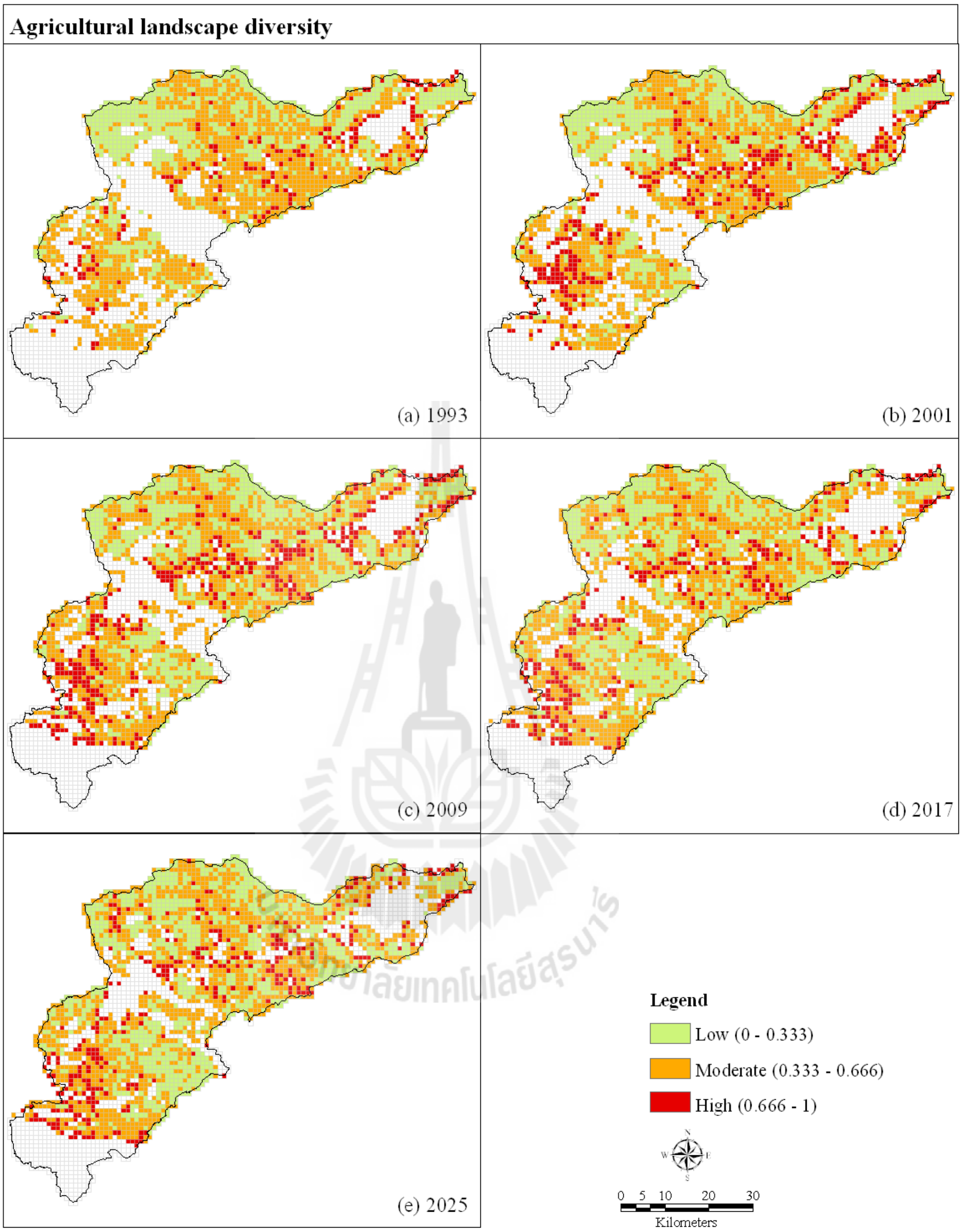


Figure 5.13 Agricultural landscape diversity (a) in 1993, (b) in 2001, (c) in 2009, (d) in 2017 and (e) in 2025.

5.3.1.5 Agricultural landscape adjacency

Agricultural landscape adjacency in during 1993-2025, it was found that the most dominant landscape were moderate adjacency covering an area range from 48-60% of the study area (Table 5.12 and Figure 5.14). Low value of landscape adjacency was indicated the distribution of adjacencies among unique patch types becomes increasingly uneven and high value indicated the patch types was become increasingly interspersed with other patch types.

Table 5.12 Area and percentage of agricultural landscape adjacency.

Landscape adjacency	1993		2001		2009		2017		2025	
	Area (sq.km)	%	Area (sq.km)	%	Area (sq.km)	%	Area (sq.km)	%	Area (sq.km)	%
Low	559	23.88	213	8.76	249	9.78	380	14.27	390	14.64
Moderate	1,124	48.01	1,438	59.15	1,520	59.68	1,548	58.15	1,455	54.62
High	658	28.11	780	32.09	778	30.55	734	27.57	819	30.74
Total	**2,341**	**100.00**	**2,431**	**100.00**	**2,547**	**100.00**	**2,662**	**100.00**	**2,654**	**100.00**

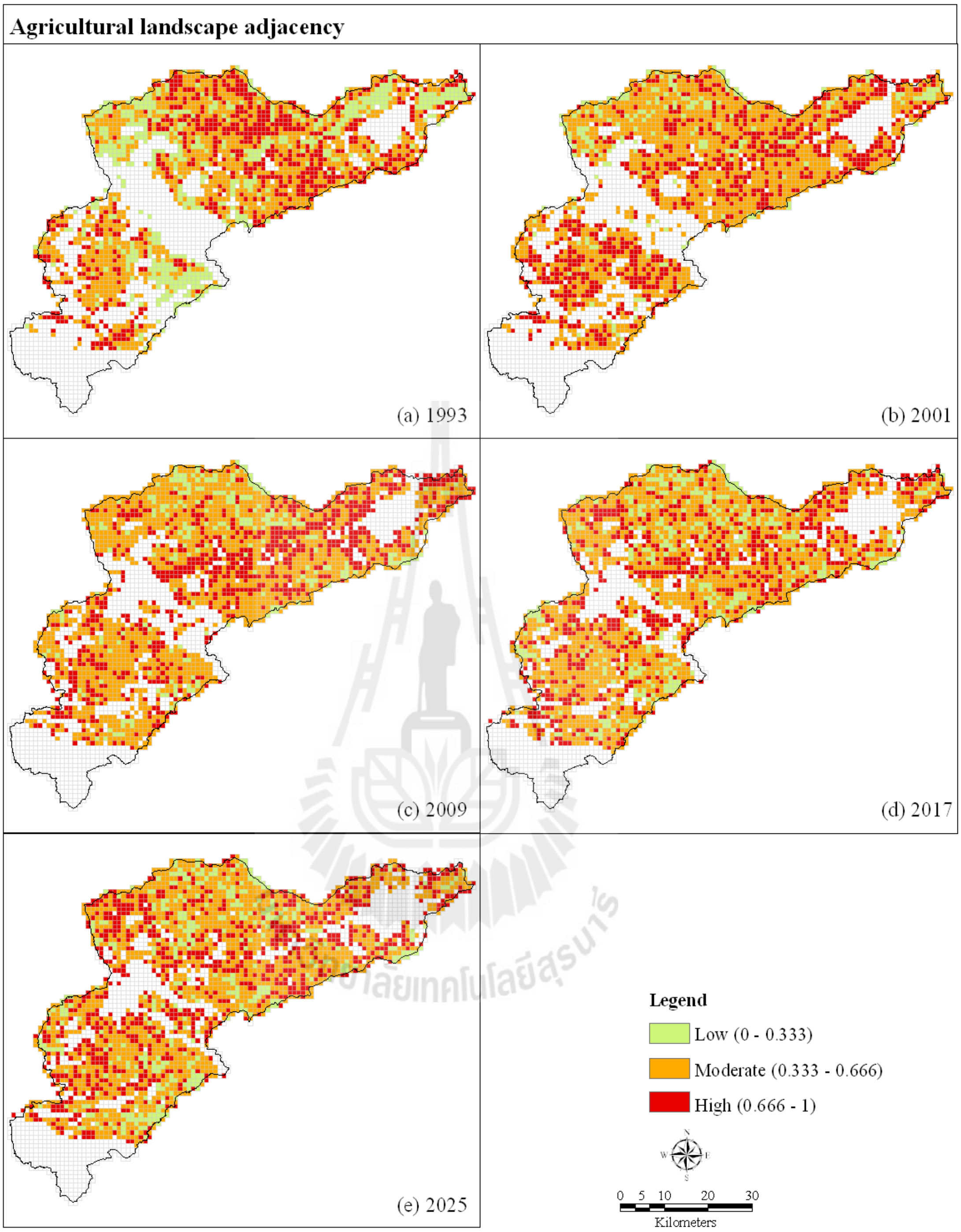


Figure 5.14 Agricultural landscape adjacency (a) in 1993, (b) in 2001, (c) in 2009, (d) in 2017 and (e) in 2025.

According to Tables 5.8 to 5.12 and Figure 5.15, for agricultural landscape pattern evaluation, landscape fragmentation during 1993-2025 was rather low. These imply that agricultural become large. At the same time, landscape complexity, diversity and adjacency were moderate. These infer that agricultural land was mixed with others land cover. While, landscape isolation was high, it indicates that agricultural land was most fragmented.

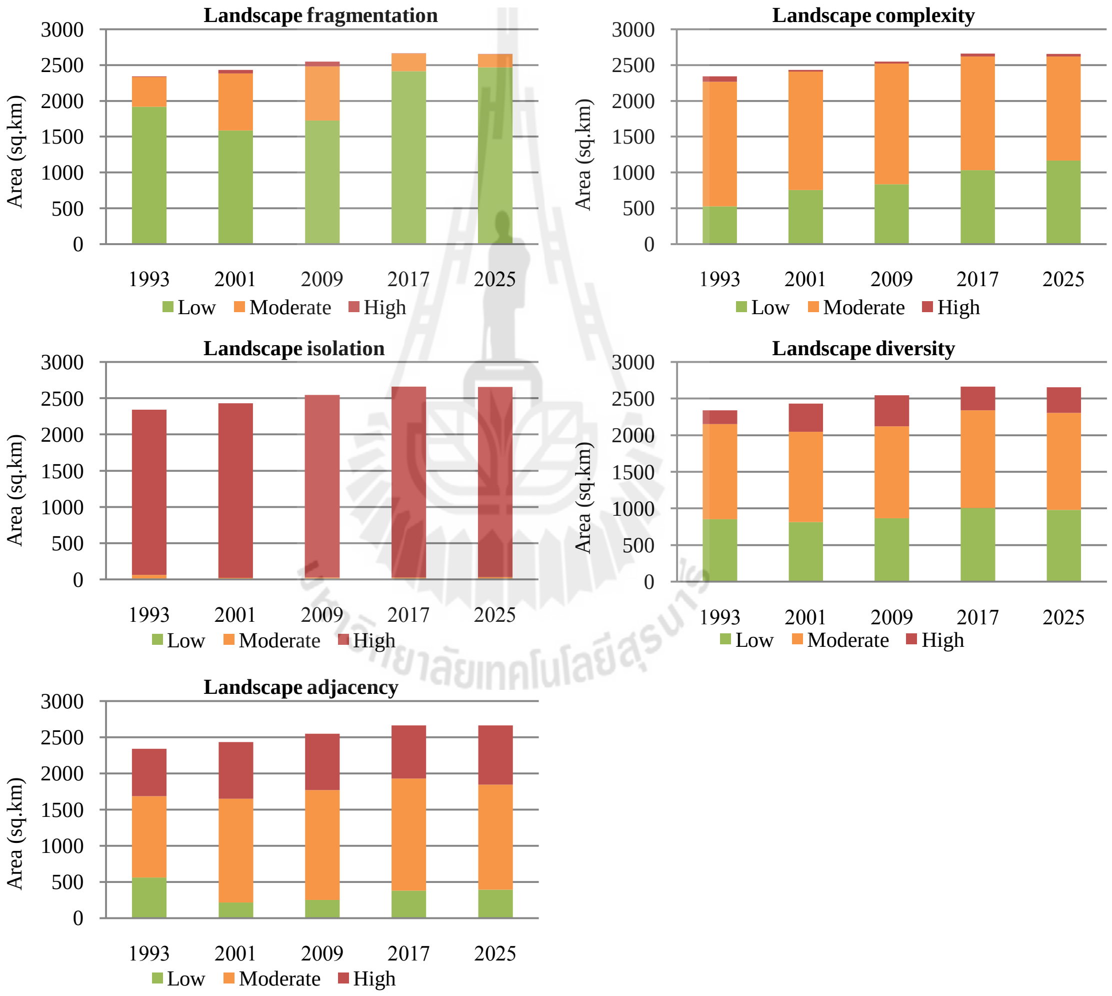


Figure 5.15 Comparison of agricultural landscape pattern during 1993 to 2025.

5.3.2 Forest landscape pattern analysis

5.3.2.1 Forest landscape fragmentation

It was found that most of forest landscape was low fragmented covering an area more than 87 of the study area during 1993 to 2025 (Table 5.13 and Figure 5.16). A low value of fragmentation represented characteristic of landscape dominated by larger forests land. Forest land were less fragmented will be better for those species that require larger areas of undisturbed forest. While, forest fragmented from large or continuous patches became isolated and broke up into small patches having negative impacts on forest biodiversity.

Table 5.13 Area and percentage of forest landscape fragmentation.

Landscape fragmentation	1993		2001		2009		2017		2025	
	Area (sq.km)	%	Area (sq.km)	%	Area (sq.km)	%	Area (sq.km)	%	Area (sq.km)	%
Low	982	87.21	836	88.84	735	94.11	596	99.00	518	99.81
Moderate	136	12.08	92	9.78	44	5.63	6	1.00	1	0.19
High	8	0.71	13	1.38	2	0.26	0	0.00	0	0.00
Total	**1,126**	**100.00**	**941**	**100.00**	**781**	**100.00**	**602**	**100.00**	**519**	**100.00**

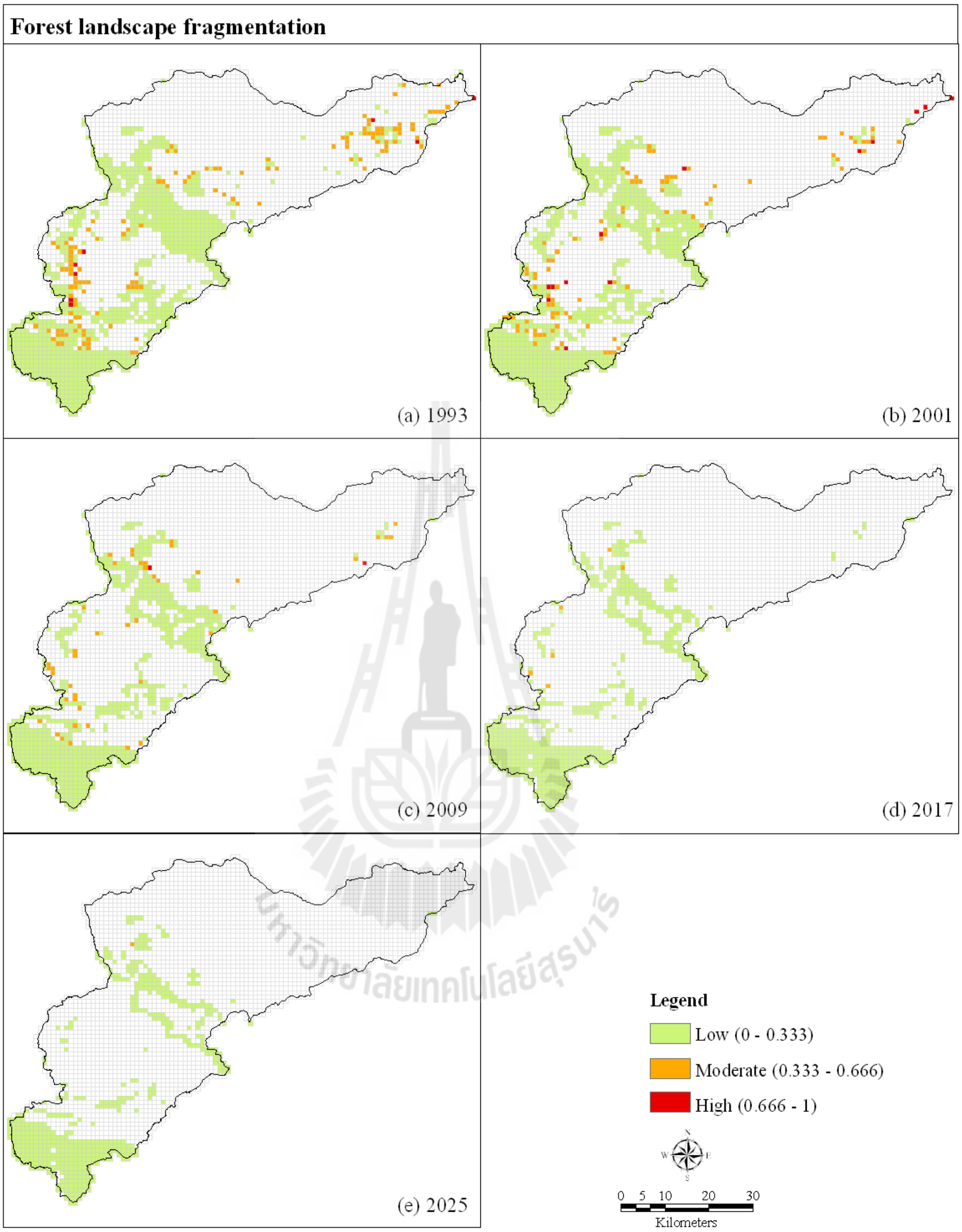


Figure 5.16 Forest landscape fragmentations (a) in 1993, (b) in 2001, (c) in 2009, (d) in 2017 and (e) in 2025.

5.3.2.2 Forest landscape complexity

Forest landscape complexity in 1993, it was found that the most dominant landscape were moderate shape complexity covering an area about 52% of the study area (Table 5.14 and Figure 5.17). These infer that less modification occurs in forest land. However, most forest landscapes in 2001, 2009, 2017 and 2025 have low shape complexity covering an area range from 49 to 76% of the study area. These infer that forest lands the patch shape of forest landscape tends to more regular.

Table 5.14 Area and percentage of forest landscape complexity.

Landscape complexity	1993		2001		2009		2017		2025	
	Area (sq.km)	%	Area (sq.km)	%	Area (sq.km)	%	Area (sq.km)	%	Area (sq.km)	%
Low	494	43.87	458	48.67	392	50.19	431	71.59	395	76.11
Moderate	581	51.60	450	47.82	353	45.20	163	27.08	121	23.31
High	51	4.53	33	3.51	36	4.61	8	1.33	3	0.58
Total	**1,126**	**100.00**	**941**	**100.00**	**781**	**100.00**	**602**	**100.00**	**519**	**100.00**

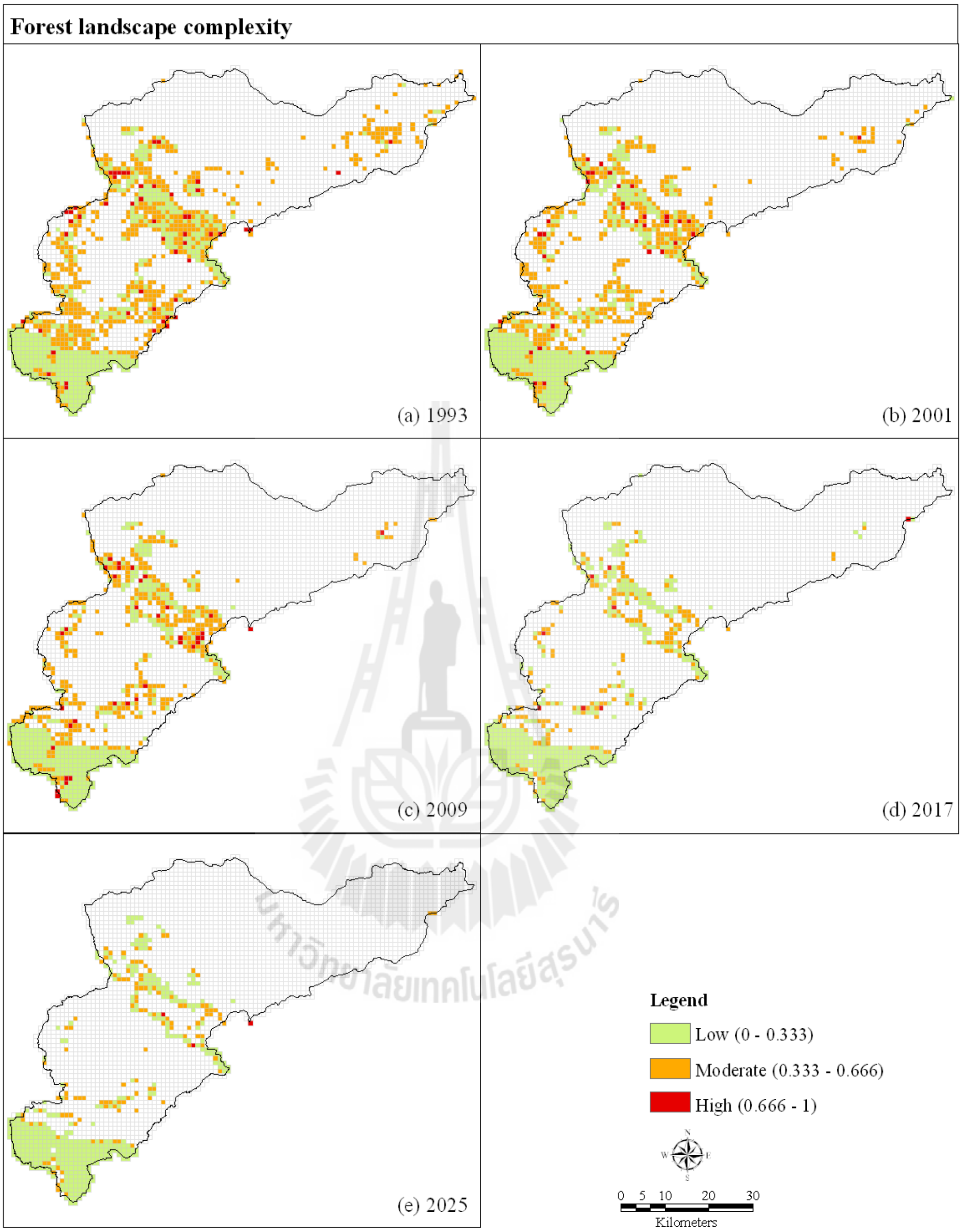


Figure 5.17 Forest landscape complexity (a) in 1993, (b) in 2001, (c) in 2009, (d) in 2017 and (e) in 2025.

5.3.2.3 Forest landscape isolation

Forest landscape isolation during 1993-2025, it was found that the most dominant landscape were high isolation of land use types and covered an area of about 90% of the study area (Table 5.15 and Figure 5.18). These infer that forest patches was consisted of small, isolated patches while high value was represented the landscape consists of large, continuous patches.

Table 5.15 Area and percentage of forest landscape isolation.

Landscape isolation	1993		2001		2009		2017		2025	
	Area (sq.km)	%	Area (sq.km)	%	Area (sq.km)	%	Area (sq.km)	%	Area (sq.km)	%
Low	6	0.53	3	0.32	4	0.51	0	0.00	0	0.00
Moderate	41	3.64	18	1.91	5	0.64	4	0.66	5	0.96
High	1079	95.83	920	97.77	772	98.85	598	99.34	514	99.04
Total	**1,126**	**100.00**	**941**	**100.00**	**781**	**100.00**	**602**	**100.00**	**519**	**100.00**

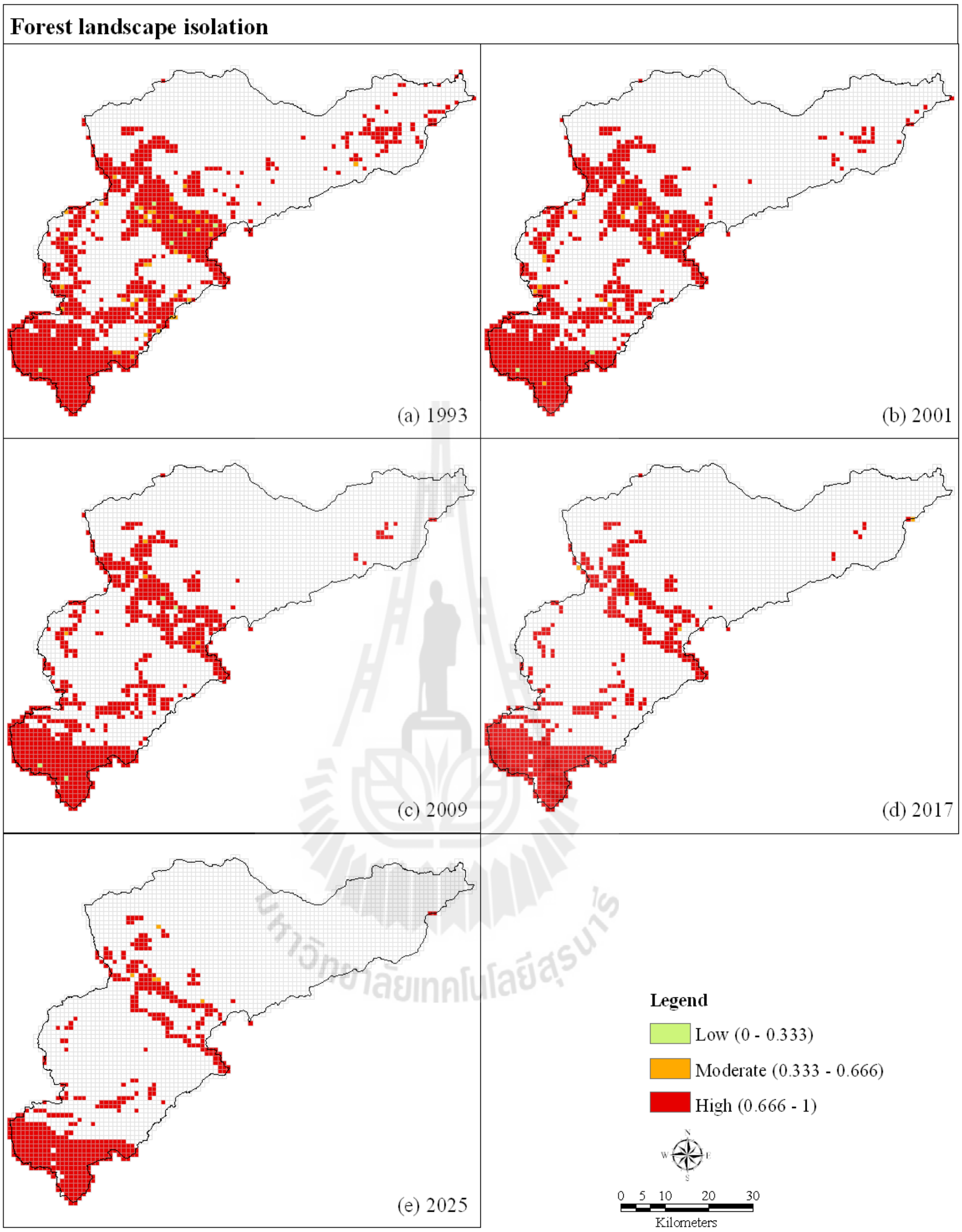


Figure 5.18 Forest landscape isolations (a) in 1993, (b) in 2001, (c) in 2009, (d) in 2017 and (e) in 2025.

5.3.2.4 Forest landscape diversity

Forest landscape diversity during 1993-2025, had the most landscape dominant was low diversity covering an area range from 57-66% of the study area (Table 5.16 and Figure 5.19). Low value of landscape diversity can be drawn a conclusion that the forest landscape was dominated by large patch of a few land use types. It might be resulted of area of Lamtakhong watershed It encompasses some parts of Khao Yai National Park and National Conserved Forest. The enlargement of production area effects on biodiversity of forest ecosystems. High diversity of forest landscape resulted from the increasing human activities influence on forest landscape.

Table 5.16 Area and percentage of forest landscape diversity.

Landscape diversity	1993		2001		2009		2017		2025	
	Area (sq.km)	%	Area (sq.km)	%	Area (sq.km)	%	Area (sq.km)	%	Area (sq.km)	%
Low	640	56.84	529	56.22	452	57.87	377	62.62	341	65.70
Moderate	427	37.92	349	37.09	279	35.72	203	33.72	163	31.41
High	59	5.24	63	6.70	50	6.40	22	3.65	15	2.89
Total	**1,126**	**100.00**	**941**	**100.00**	**781**	**100.00**	**602**	**100.00**	**519**	**100.00**

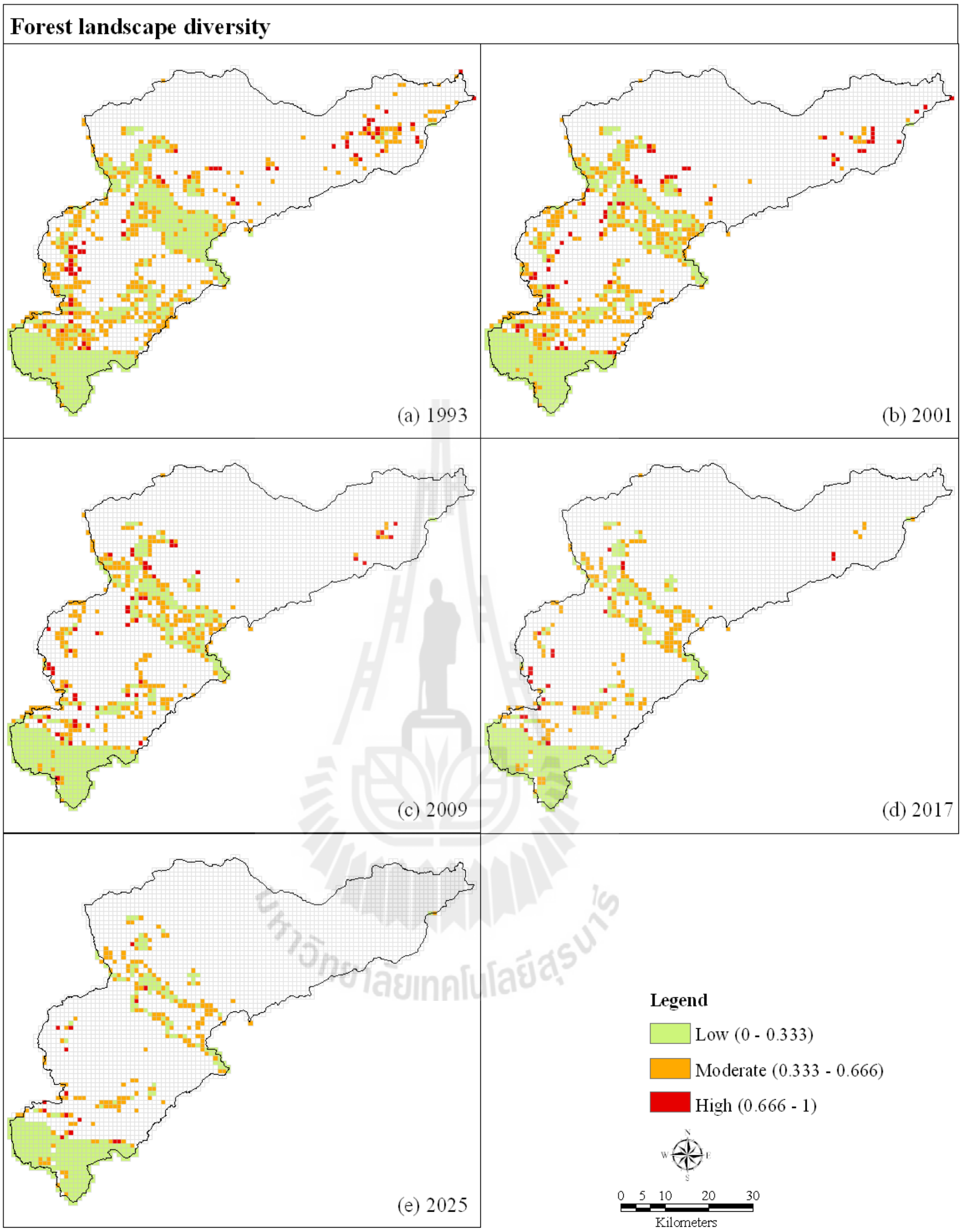


Figure 5.19 Forest landscape diversities (a) in 1993, (b) in 2001, (c) in 2009, (d) in 2017 and (e) in 2025.

5.3.2.5 Forest landscape adjacency

Forest landscape adjacency during 1993-2025, it was found that the most dominant landscape were low adjacency covering an area range from 47-65% of the study area (Table 5.17 and Figure 5.20). Low value of landscape adjacency was indicated the distribution of adjacencies among unique patch types becomes increasingly uneven.

Table 5.17 Area and percentage of forest landscape adjacency.

Landscape adjacency	1993		2001		2009		2017		2025	
	Area (sq.km)	**%**	**Area (sq.km)**	**%**	**Area (sq.km)**	**%**	**Area (sq.km)**	**%**	**Area (sq.km)**	**%**
Low	697	61.90	484	51.43	369	47.25	348	57.81	336	64.74
Moderate	276	24.51	300	31.88	231	29.58	112	18.60	75	14.45
High	153	13.59	157	16.68	181	23.18	142	23.59	108	20.81
Total	**1,126**	**100.00**	**941**	**100.00**	**781**	**100.00**	**602**	**100.00**	**519**	**100.00**

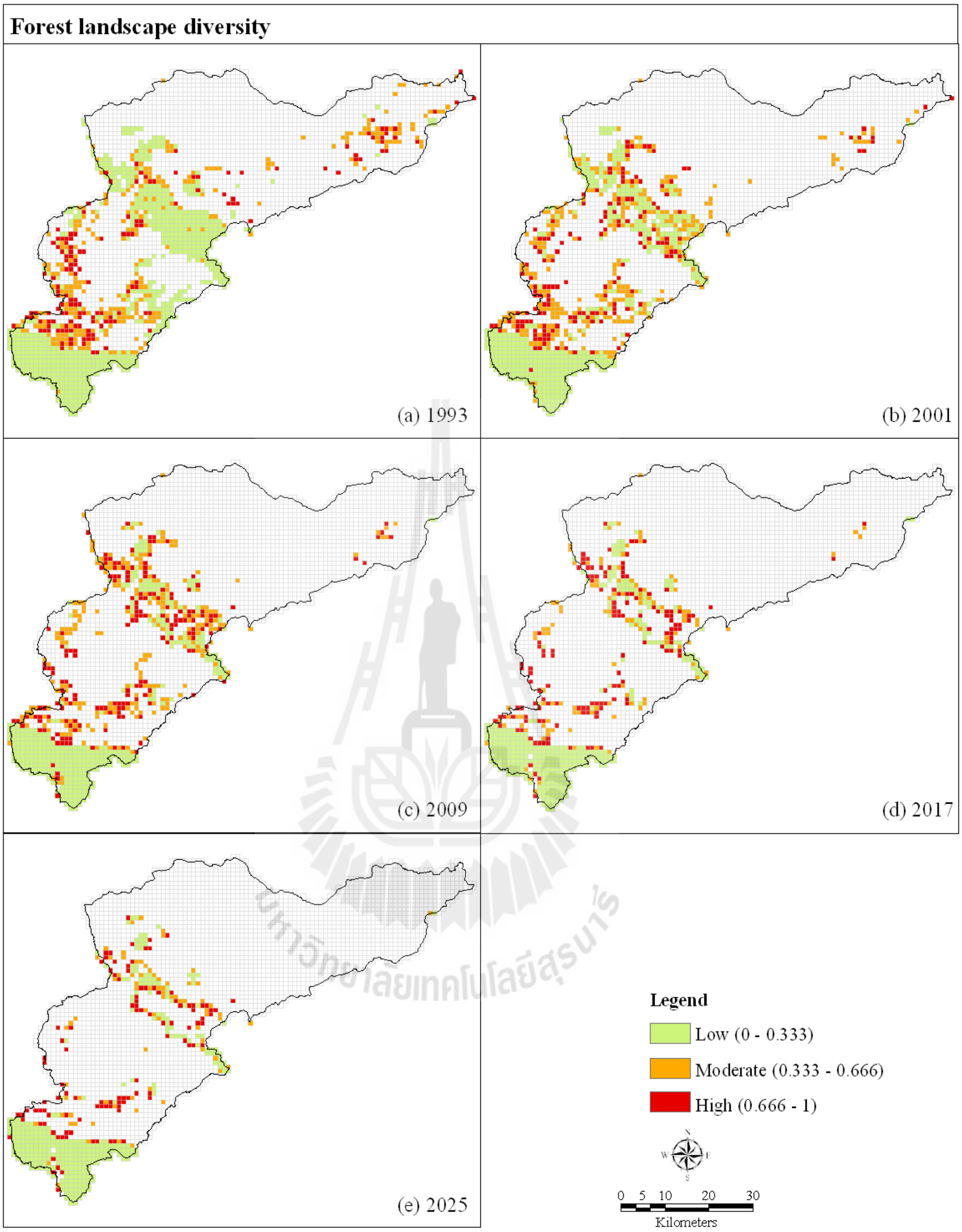


Figure 5.20 Forest landscape adjacencies (a) in 1993, (b) in 2001, (c) in 2009, (d) in 2017 and (e) in 2025.

Refer to Tables 5.13 to 5.17, and Figure 5.21, for forest landscape pattern evaluation, landscape fragmentation, diversity, and adjacency during 1993-2025 were low. These infer that fragmentation in forest landscape is rather low and forest land is large. In addition, landscape complexity in 1993 was moderate while landscape complexity in 2001, 2009, 2017 and 2025 were low. These infer that forest lands the patch shape of forest landscape tends to more regular. While, landscape isolation during 1993-2025 was high, it indicates that forest land was most fragmented.

Figure 5.21 Comparison of forest landscape pattern during 1993 to 2025.

5.4 Landscape pattern changes

In this study, linear scale transformation landscape pattern indices in three periods (1993-2009, 2009-2017 and 2009-2025) were compared by using transitional matrix to explain landscape pattern change in term of gain and loss. When landscape metric levels changes from low to moderate/high or moderate to high, it defines as gain. In contrast, landscape metric level changes from high to moderate/low or moderate to low, it defines as loss. Details of landscape pattern change for agricultural and forest landscape were here separately described in the following section.

5.4.1 Landscape fragmentation change in agricultural landscape

Change of agricultural landscape fragmentation based on transition matrix during 1993-2009, 2009-2017 and 2009-2025 were compared the changes as shown in Table 5.18. It was found that landscape fragmentation with unchanged levels during 1993-2009, 2009-2017 and 2009-2025 covered an area of 1,700, 1,908 and 1,854 sq. km, respectively. In addition, landscape fragmentation with increased levels covered an area of 113, 2 and 2 sq. km, respectively. Landscape fragmentation with decreased levels covered an area of 112, 585 and 570 sq. km, respectively. Distribution of landscape fragmentation changes in agricultural landscape during 1993-2009, 2009-2017 and 2009-2025 were shown in Figure 5.22.

Table 5.18 Comparison fragmentation levels of agricultural landscape during 1993-2009, 2009-2017 and 2009-2025.

(Unit: sq. km)

1993	**2009**			**Total**
	Low	**Moderate**	**High**	
Low	1,453	398	21	1,872
Moderate	108	246	24	378
High	0	4	1	5
Total	**1,561**	**648**	**46**	**2,255**
2009	**2017**			**Total**
	Low	**Moderate**	**High**	
Low	1,714	2	0	1,716
Moderate	539	191	0	730
High	2	44	3	49
Total	**2,255**	**237**	**3**	**2,495**
2009	**2025**			**Total**
	Low	**Moderate**	**High**	
Low	1,705	1	0	1,706
Moderate	530	149	1	680
High	6	34		40
Total	**2,241**	**184**	**1**	**2,426**

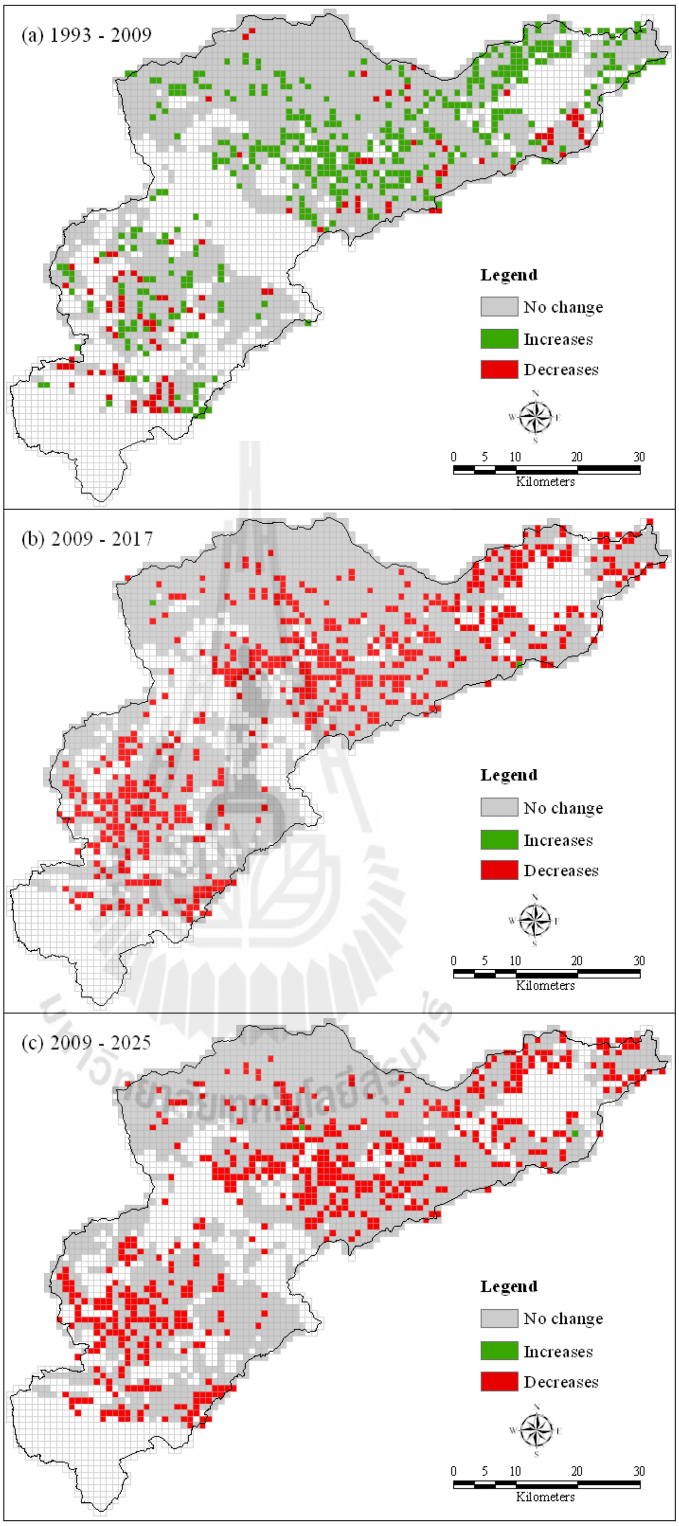


Figure 5.22 Distribution of landscape fragmentation changes in agricultural landscape during (a) 1993-2009, (b) 2009-2017 and (c) 2009-2025.

5.4.2 Landscape complexity change in agricultural landscape

Change of agricultural landscape complexity based on transition matrix during 1993-2009, 2009-2017 and 2009-2025 were compared the changes in Table 5.19. It was found that landscape complexity with unchanged levels during 1993-2009, 2009-2017 and 2009-2025 covered an area of 1,426, 1,931 and 1,748 sq. km, respectively. In addition, landscape complexity with increased levels covered an area of 255, 204 and 199 sq. km, respectively. Landscape complexity as the decreases covered an area of 574, 360 and 479 sq. km, respectively. Distribution of landscape complexity changes in agricultural landscape during 1993-2009, 2009-2017 and 2009-2025 were shown in Figure 5.23.

Table 5.19 Comparison complexity levels of agricultural landscape during 1993-2009, 2009-2017 and 2009-2025.

(Unit: sq. km)

1993	**2009**			**Total**
	Low	**Moderate**	**High**	
Low	276	234	4	514
Moderate	502	1,150	17	1,669
High	26	46	0	72
Total	**804**	**1,430**	**21**	**2,255**
2009	**2017**			**Total**
	Low	**Moderate**	**High**	
Low	649	177	1	827
Moderate	342	1,273	26	1,641
High	1	17	9	27
Total	**992**	**1,467**	**36**	**2,495**
2009	**2025**			**Total**
	Low	**Moderate**	**High**	
Low	637	176	3	816
Moderate	458	1,105	20	1,583
High	0	21	6	27
Total	**1,095**	**1,302**	**29**	**2,426**

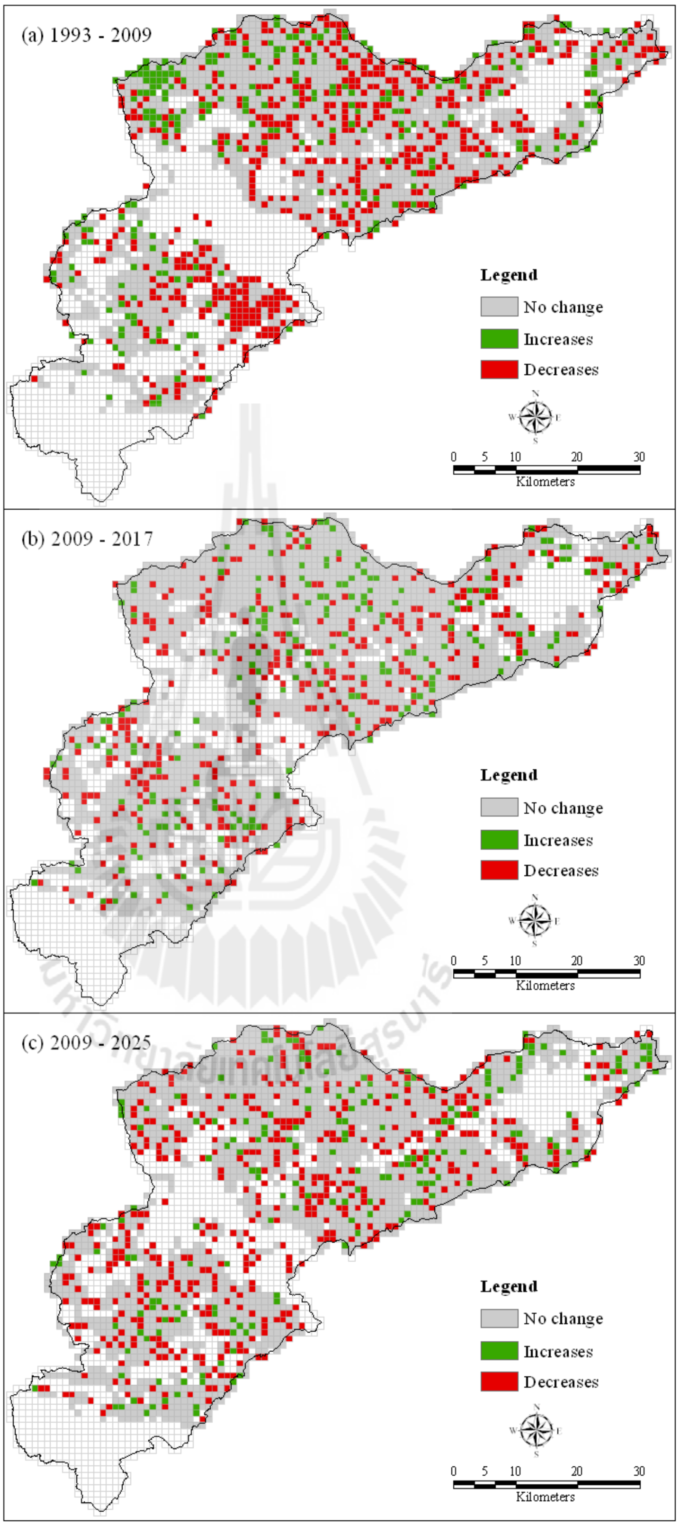


Figure 5.23 Distribution of landscape complexity changes in agricultural landscape during (a) 1993-2009, (b) 2009-2017 and (c) 2009-2025.

5.4.3 Landscape isolation change in agricultural landscape

Change of agricultural landscape isolation based on transition matrix during 1993-2009, 2009-2017 and 2009-2025 were compared the changes as shown in Table 5.20. It was found that landscape isolation with unchanged levels during 1993-2009, 2009-2017 and 2009-2025 covered an area of 2,169, 2,457 and 2,377 sq. km, respectively. In addition, landscape isolation with increased levels covered an area of 60, 22 and 23 sq. km, respectively. Landscape isolation with decreased levels covered an area of 26, 16 and 26 sq. km, respectively. Distribution of landscape isolation changes in agricultural landscape during 1993-2009, 2009-2017 and 2009-2025 were shown in Figure 5.24.

Table 5.20 Comparison isolation levels of agricultural landscape during 1993-2009, 2009-2017 and 2009-2025.

(Unit: sq. km)

1993	**2009**			**Total**
	Low	**Moderate**	**High**	
Low	0	0	0	0
Moderate	0	2	60	62
High	1	25	2,167	2,193
Total	**1**	**27**	**2,227**	**2,255**
2009	**2017**			**Total**
	Low	**Moderate**	**High**	
Low	1	0	0	1
Moderate	0	6	22	28
High	0	16	2,450	2,466
Total	**1**	**22**	**2,472**	**2,495**
2009	**2025**			**Total**
	Low	**Moderate**	**High**	
Low	0	0	1	1
Moderate	2	4	22	28
High	3	21	2,373	2,397
Total	**5**	**25**	**2,396**	**2,426**

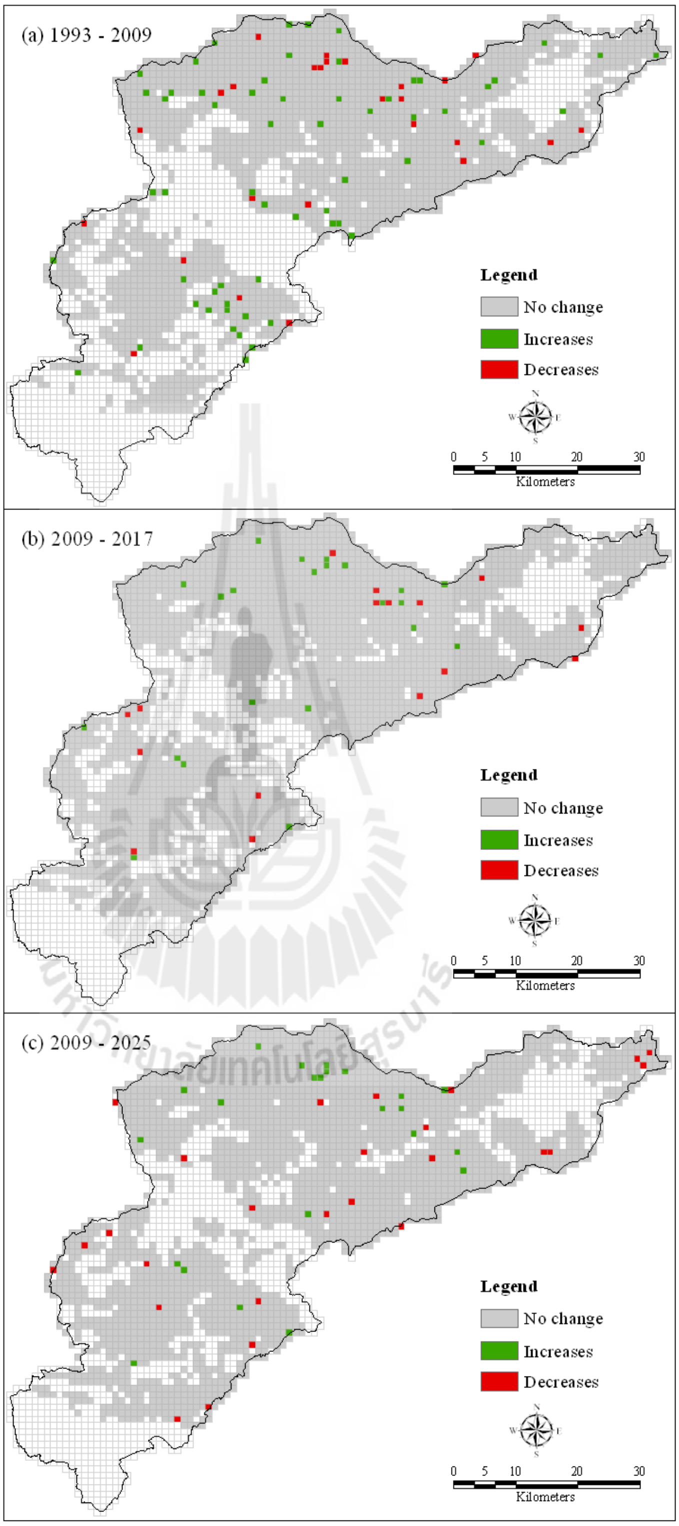


Figure 5.24 Distribution of landscape isolation changes in agricultural landscape during (a) 1993-2009, (b) 2009-2017 and (c) 2009-2025.

5.4.4 Landscape diversity change in agricultural landscape

Change of agricultural landscape diversity based on transition matrix during 1993-2009, 2009-2017 and 2009-2025 were compared the changes as Table 5.21. It was revealed that landscape diversity with unchanged levels during 1993-2009, 2009-2017 and 2009-2025 covered an area of 1,534, 2,188 and 2,006 sq. km, respectively. In addition, landscape diversity with increased levels covered an area of 431, 35 and 139 sq. km, respectively. Landscape diversity with decreased levels covered an area of 290, 272 and 281 sq. km, respectively. Distribution of landscape diversity changes in agricultural landscape during 1993-2009, 2009-2017 and 2009-2025 were shown in Figure 5.25.

Table 5.21 Comparison diversity levels of agricultural landscape during 1993-2009, 2009-2017 and 2009-2025.

(Unit: sq. km)

1993	**2009**			**Total**
	Low	**Moderate**	**High**	
Low	604	229	4	837
Moderate	255	812	198	1,265
High	0	35	118	153
Total	859	1,076	320	2,255
2009	**2017**			**Total**
	Low	**Moderate**	**High**	
Low	845	19	0	864
Moderate	161	1,069	16	1,246
High	0	111	274	385
Total	1,006	1,199	290	2,495
2009	**2025**			**Total**
	Low	**Moderate**	**High**	
Low	781	83	0	781
Moderate	185	980	56	185
High	0	96	245	0
Total	966	1,159	301	966

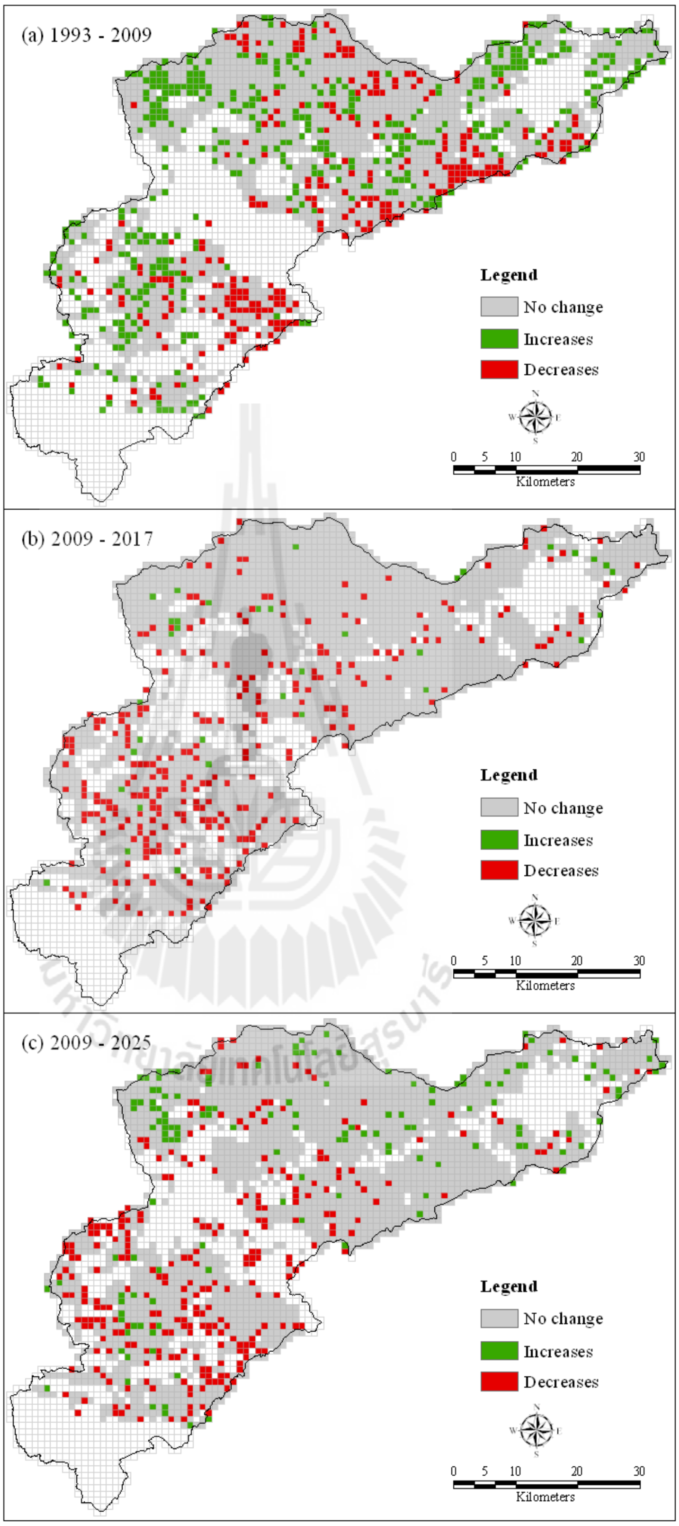


Figure 5.25 Distribution of landscape diversity changes in agricultural landscape during (a) 1993-2009, (b) 2009-2017 and (c) 2009-2025.

5.4.5 Landscape adjacency change in agricultural landscape

Change of agricultural landscape adjacency based on transition matrix during 1993-2009, 2009-2017 and 2009-2025 were compared the changes in Table 5.22. It was found that landscape adjacency with unchanged levels during 1993-2009, 2009-2017 and 2009-2025 covered an area of 925, 1,849 and 1,690 sq. km, respectively. In addition, landscape adjacency with increased levels covered an area of 806, 231 and 319 sq. km, respectively. Landscape adjacency with decreased levels covered an area of 524, 415 and 417 sq. km, respectively. Distribution of landscape adjacency changes in agricultural landscape during 1993-2009, 2009-2017 and 2009-2025 were shown in Figure 5.26.

Table 5.22 Comparison adjacency levels of agricultural landscape during 1993-2009, 2009-2017 and 2009-2025.

(Unit: sq. km)

1993	**2009**			**Total**
	Low	**Moderate**	**High**	
Low	77	352	121	550
Moderate	80	667	333	1,080
High	85	359	181	625
Total	**242**	**1,378**	**635**	**2,255**
2009	**2017**			**Total**
	Low	**Moderate**	**High**	
Low	213	36	-	249
Moderate	137	1,172	195	1,504
High	20	258	464	742
Total	**370**	**1,466**	**659**	**2,495**
2009	**2025**			**Total**
	Low	**Moderate**	**High**	
Low	195	53	1	249
Moderate	146	1,057	265	1,468
High	37	234	438	709
Total	**378**	**1,344**	**704**	**2,426**

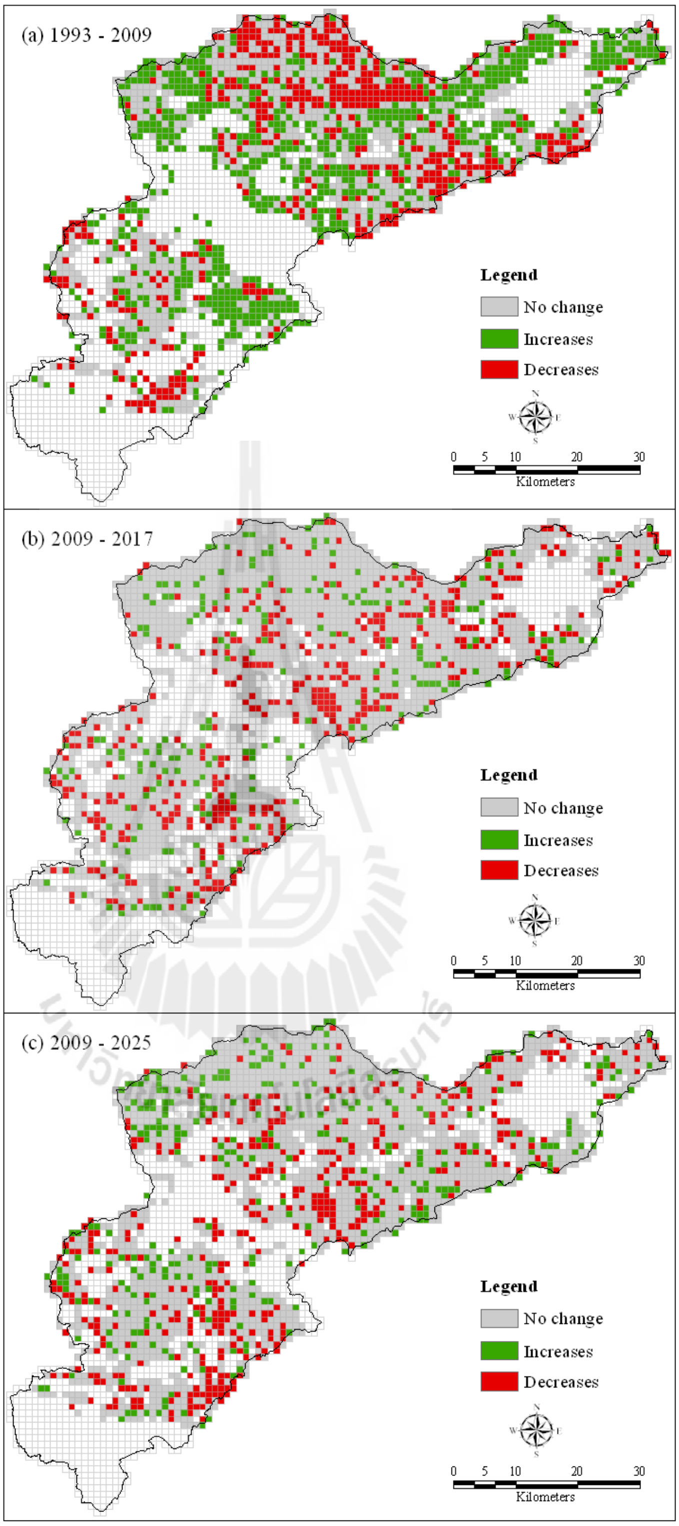


Figure 5.26 Distribution of landscape adjacency changes in agricultural landscape during (a) 1993-2009, (b) 2009-2017 and (c) 2009-2025.

5.4.6 Landscape fragmentation change in forest landscape

Change of forest landscape fragmentation based on transition matrix during 1993-2009, 2009-2017 and 2009-2025 were compared the changes as Table 5.23., It was found that landscape fragmentation with unchanged levels during 1993-2009, 2009-2017 and 2009-2025 covered an area of 741, 596 and 518 sq. km, respectively. In addition, landscape fragmentation with increased levels covered an area of 35, 0 and 0 sq. km, respectively. Landscape fragmentation with decreased levels covered an area of 5, 6 and 1 sq. km, respectively. Distribution of landscape fragmentation changes in forest landscape between during 1993-2009, 2009-2017 and 2009-2025 were shown in Figure 5.27.

Table 5.23 Comparison fragmentation levels of forest landscape during 1993-2009, 2009-2017 and 2009-2025.

(Unit: sq. km)

1993	**2009**			**Total**
	Low	**Moderate**	**High**	
Low	730	33	1	764
Moderate	5	11	1	17
High	0	0	0	0
Total	**735**	**44**	**2**	**781**
2009	**2017**			**Total**
	Low	**Moderate**	**High**	
Low	590	0	0	590
Moderate	6	6	0	12
High	0	0	0	0
Total	**596**	**6**	**0**	**602**
2009	**2025**			**Total**
	Low	**Moderate**	**High**	
Low	517	0	0	517
Moderate	1	1	0	2
High	0	0	0	0
Total	**518**	**1**	**0**	**519**

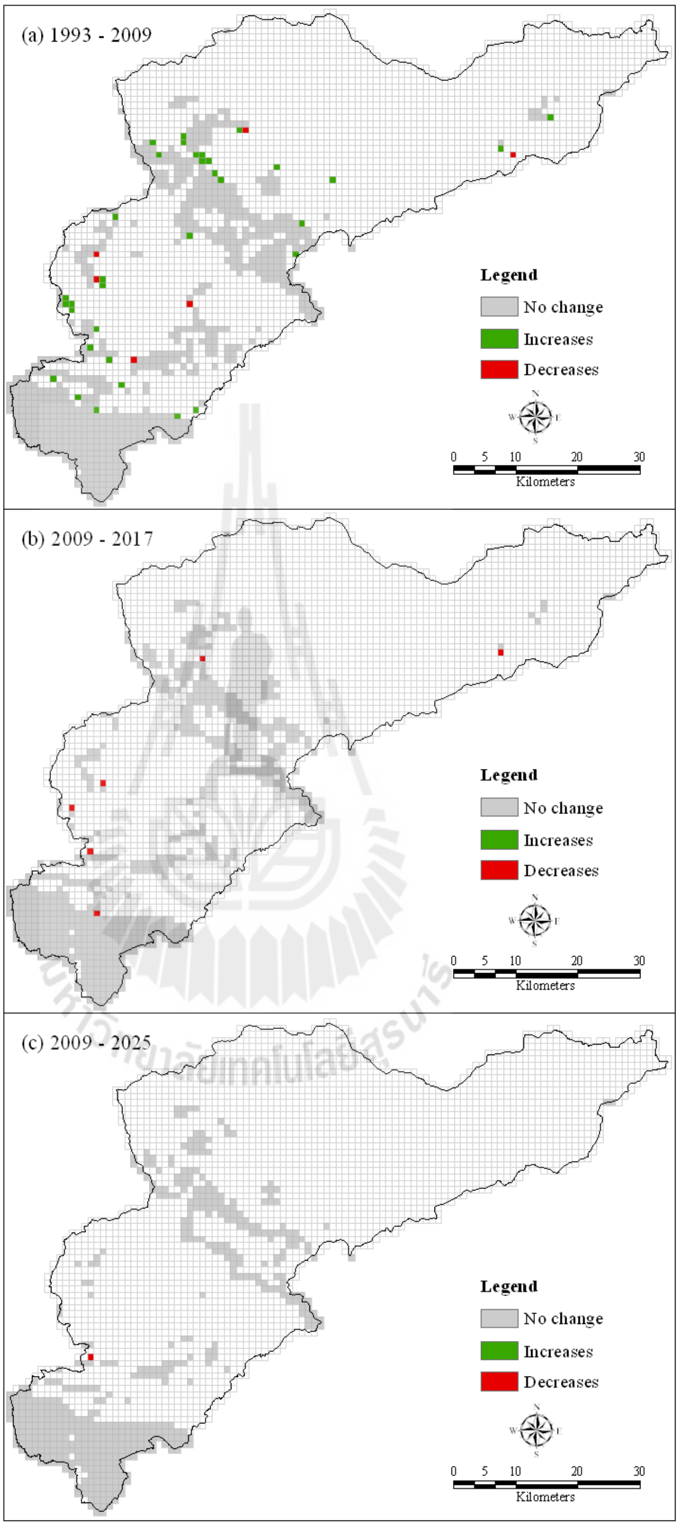


Figure 5.27 Distribution of landscape fragmentation changes in forest landscape during (a) 1993-2009, (b) 2009-2017 and (c) 2009-2025.

5.4.7 Landscape complexity change in forest landscape

Change of forest landscape complexity based on transition matrix during 1993-2009, 2009-2017 and 2009-2025 were compared the changes as Table 5.24. It was found that landscape complexity with unchanged levels during 1993-2009, 2009-2017 and 2009-2025 covered an area of 578, 473 and 407 sq. km, respectively. In addition, landscape complexity with increased levels covered an area of 137, 29 and 35 sq. km, respectively. Landscape complexity with decreased levels covered an area of 66, 100 and 77 sq. km, respectively. Distribution of landscape complexity changes in forest landscape during 1993-2009, 2009-2017 and 2009-2025 were shown in Figure 5.28.

Table 5.24 Comparison complexity levels of forest landscape during 1993-2009, 2009-2017 and 2009-2025.

(Unit: sq. km)

1993	**2009**			**Total**
	Low	**Moderate**	**High**	
Low	347	107	7	461
Moderate	44	225	23	292
High	1	21	6	28
Total	**392**	**353**	**36**	**781**
2009	**2017**			**Total**
	Low	**Moderate**	**High**	
Low	345	25	0	370
Moderate	80	124	4	208
High	6	14	4	24
Total	**431**	**163**	**8**	**602**
2009	**2025**			**Total**
	Low	**Moderate**	**High**	
Low	328	33	0	361
Moderate	62	78	2	142
High	5	10	1	16
Total	**395**	**121**	**3**	**519**

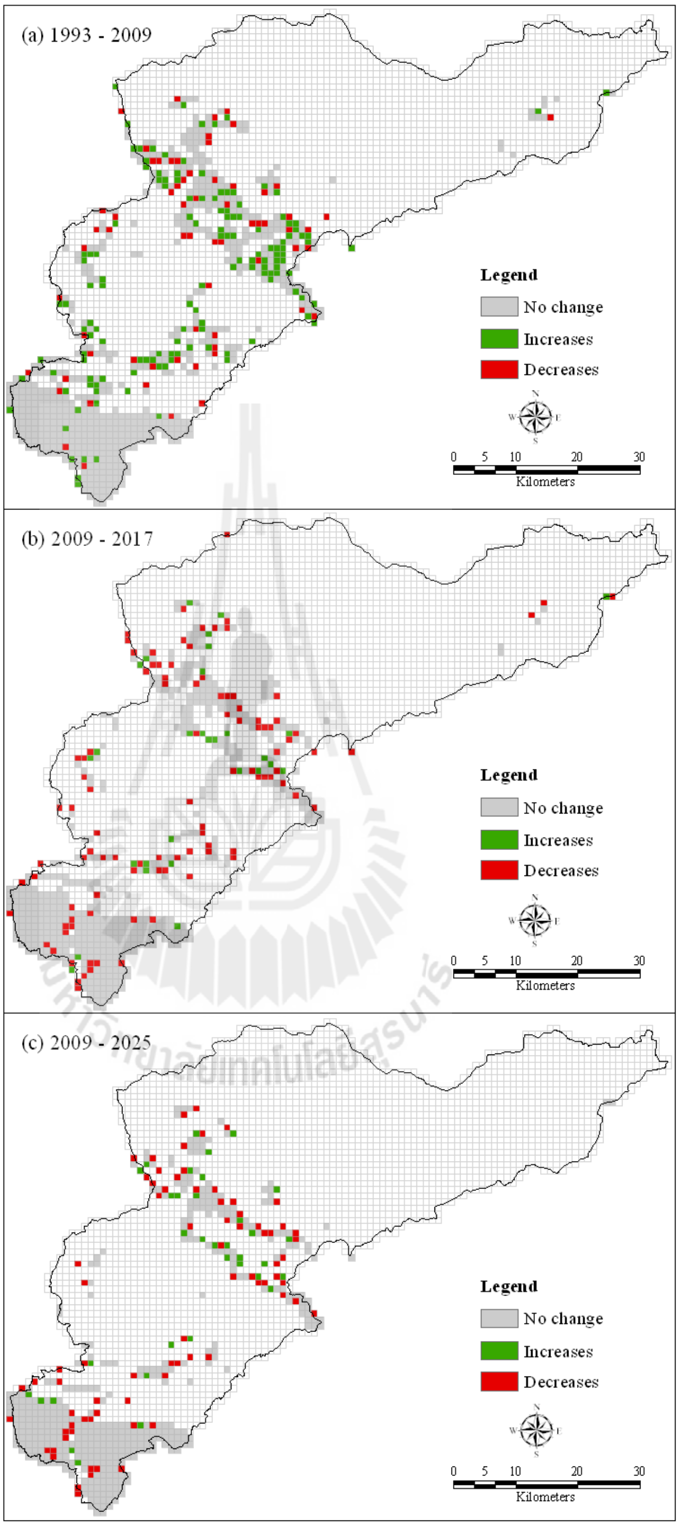


Figure 5.28 Distribution of landscape complexity changes in forest landscape during (a) 1993-2009, (b) 2009-2017 and (c) 2009-2025.

5.4.8 Landscape isolation change in forest landscape

Change of forest landscape isolation based on transition matrix during 1993-2009, 2009-2017 and 2009-2025 were compared the changes (Table 5.25). It was found that landscape isolation with unchanged levels during 1993-2009, 2009-2017 and 2009-2025 covered an area of 750, 589 and 407 sq. km, respectively. In addition, landscape isolation with increased levels covered an area of 24, 9 and 35 sq. km, respectively. Landscape isolation with decreased levels covered an area of 7, 4 and 77 sq. km, respectively. Distribution of landscape isolation changes in forest landscape during 1993-2009, 2009-2017 and 2009-2025 were shown in Figure 5.29.

Table 5.25 Comparison isolation levels of forest landscape during 1993-2009, 2009-2017 and 2009-2025.

(Unit: sq. km)

1993	**2009**			**Total**
	Low	**Moderate**	**High**	
Low	1	0	4	5
Moderate	0	1	20	21
High	3	4	748	755
Total	4	5	772	781
2009	**2017**			**Total**
	Low	**Moderate**	**High**	
Low	0	0	4	4
Moderate	0	0	5	5
High	0	4	589	593
Total	0	4	598	602
2009	**2025**			**Total**
	Low	**Moderate**	**High**	
Low	328	33	0	361
Moderate	62	78	2	142
High	5	10	1	16
Total	395	121	3	519

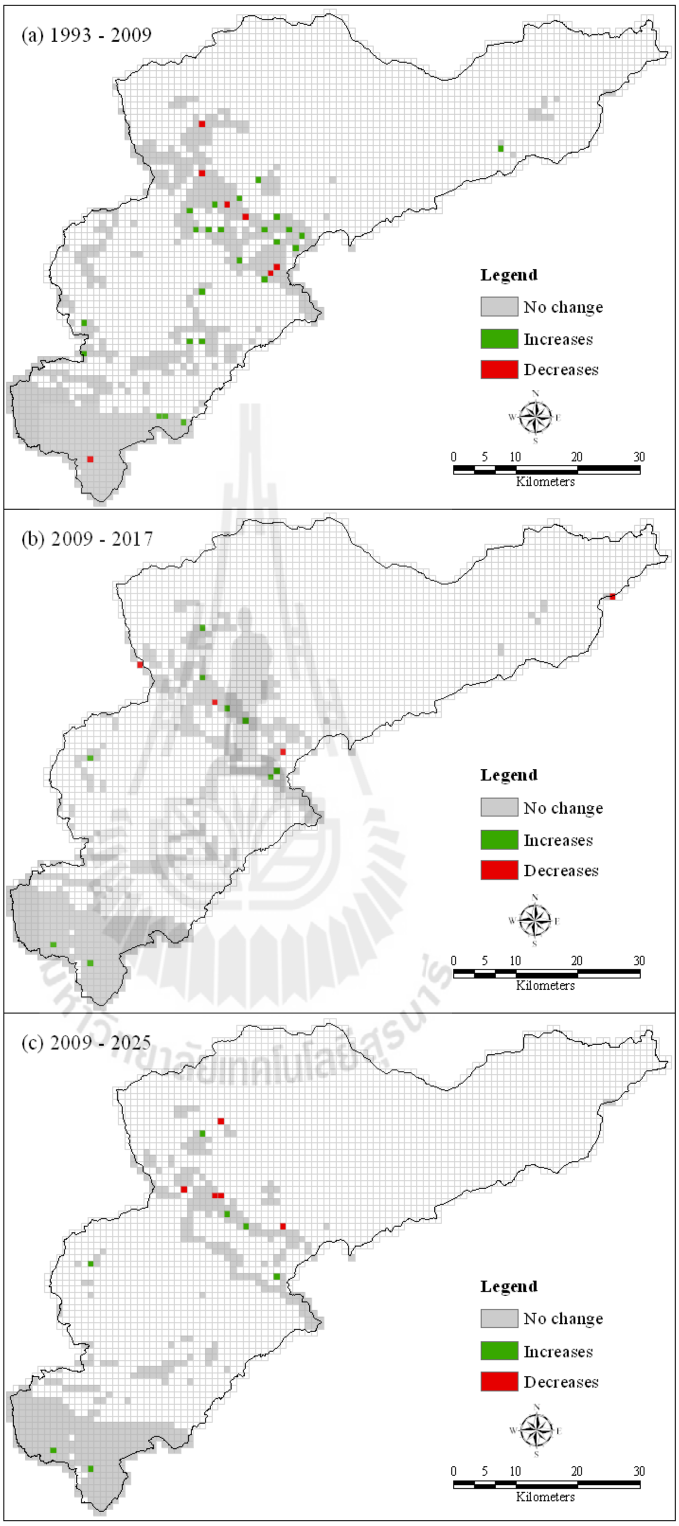


Figure 5.29 Distribution of landscape isolation changes in forest landscape during (a) 1993-2009, (b) 2009-2017 and (c) 2009-2025.

5.4.9 Landscape diversity change in forest landscape

Change of forest landscape diversity based on transition matrix during 1993-2009, 2009-2017 and 2009-2025 were compared the changes (Table 5.26). It was found that landscape diversity with unchanged levels during 1993-2009, 2009-2017 and 2009-2025 covered an area of 578, 516 and 399 sq. km, respectively. In addition, Landscape diversity during 2009-2017 was increased levels covered an area of 203, 86 and 120 sq km, respectively. Landscape diversity with decreased levels covered an area of 0, 0 and 0 sq. km, respectively. Distribution of landscape diversity changes in forest landscape during 1993-2009, 2009-2017 and 2009-2025 were shown in Figure 5.30.

Table 5.26 Comparison diversity levels of forest landscape during 1993-2009, 2009-2017 and 2009-2025.

(Unit: sq. km)

1993	**2009**			**Total**
	Low	**Moderate**	**High**	
Low	452	155	3	610
Moderate	0	124	45	169
High	0	0	2	2
Total	452	279	50	781
2009	**2017**			**Total**
	Low	**Moderate**	**High**	
Low	377	75	0	452
Moderate	0	128	11	139
High	0	0	11	11
Total	377	203	22	602
2009	**2025**			**Total**
	Low	**Moderate**	**High**	
Low	341	106	0	447
Moderate	0	57	14	71
High	0	0	1	1
Total	341	163	15	519

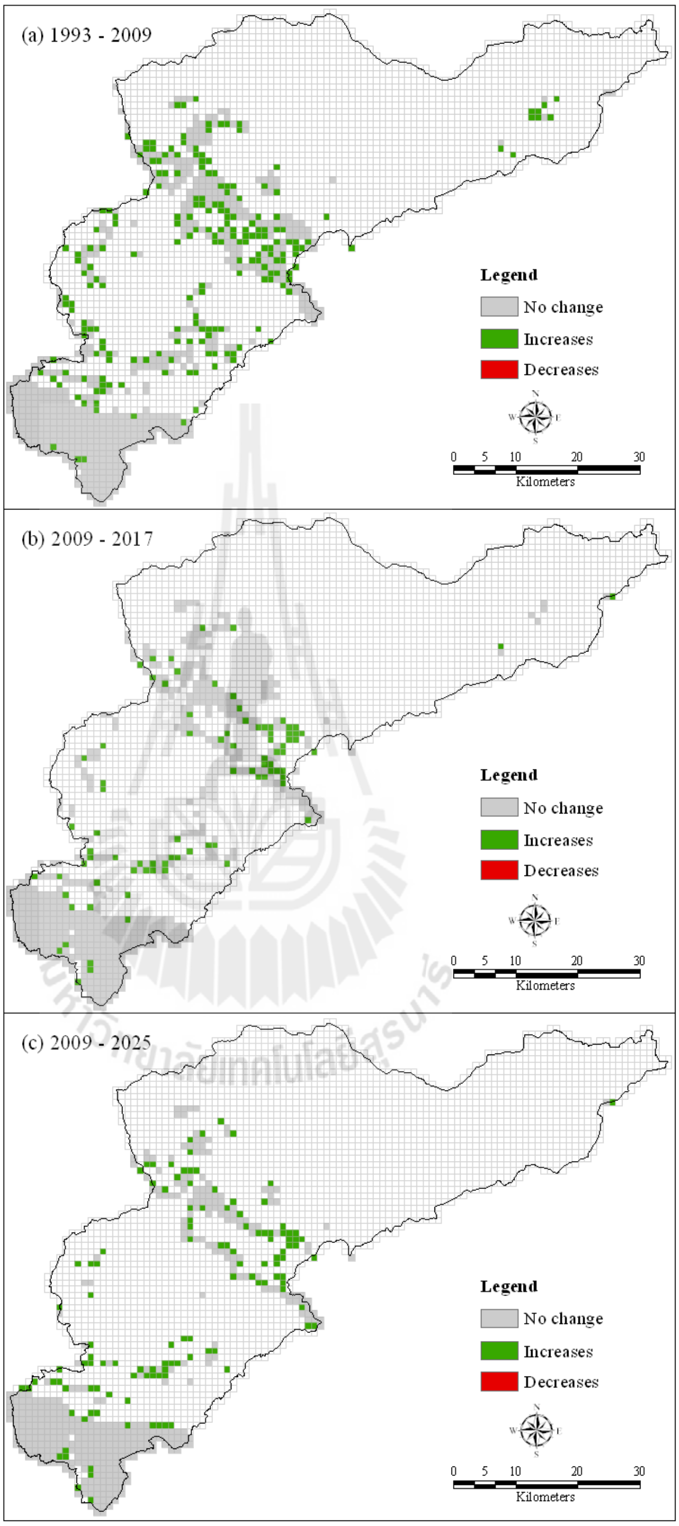


Figure 5.30 Distribution of landscape diversity changes in forest landscape during (a) 1993-2009, (b) 2009-2017 and (c) 2009-2025.

5.4.10 Landscape adjacency change in forest landscape

Change of forest landscape adjacency based on transition matrix during 1993-2009, 2009-2017 and 2009-2025 were compared the changes as Table 5.27. It was found that landscape adjacency with unchanged levels during 1993-2009, 2009-2017 and 2009-2025 covered an area of 466, 550 and 462 sq. km, respectively. In addition, landscape adjacency with increased levels covered an area of 274, 38 and 43 sq. km, respectively. Landscape adjacency with decreased levels covered an area of 41, 14 and 14 sq. km, respectively. Distribution of landscape adjacency changes in forest landscape during 1993-2009, 2009-2017 and 2009-2025 were shown in Figure 5.31.

Table 5.27 Comparison adjacency levels of forest landscape during 1993-2009, 2009-2017 and 2009-2025.

(Unit: sq. km)

1993	**2009**			**Total**
	Low	**Moderate**	**High**	
Low	364	128	91	583
Moderate	4	67	55	126
High	1	36	35	72
Total	369	231	181	781
2009	**2017**			**Total**
	Low	**Moderate**	**High**	
Low	342	10	1	353
Moderate	6	94	27	127
High	0	8	114	122
Total	348	112	142	602
2009	**2025**			**Total**
	Low	**Moderate**	**High**	
Low	330	13	4	347
Moderate	6	54	26	86
High	0	8	78	86
Total	336	75	108	519

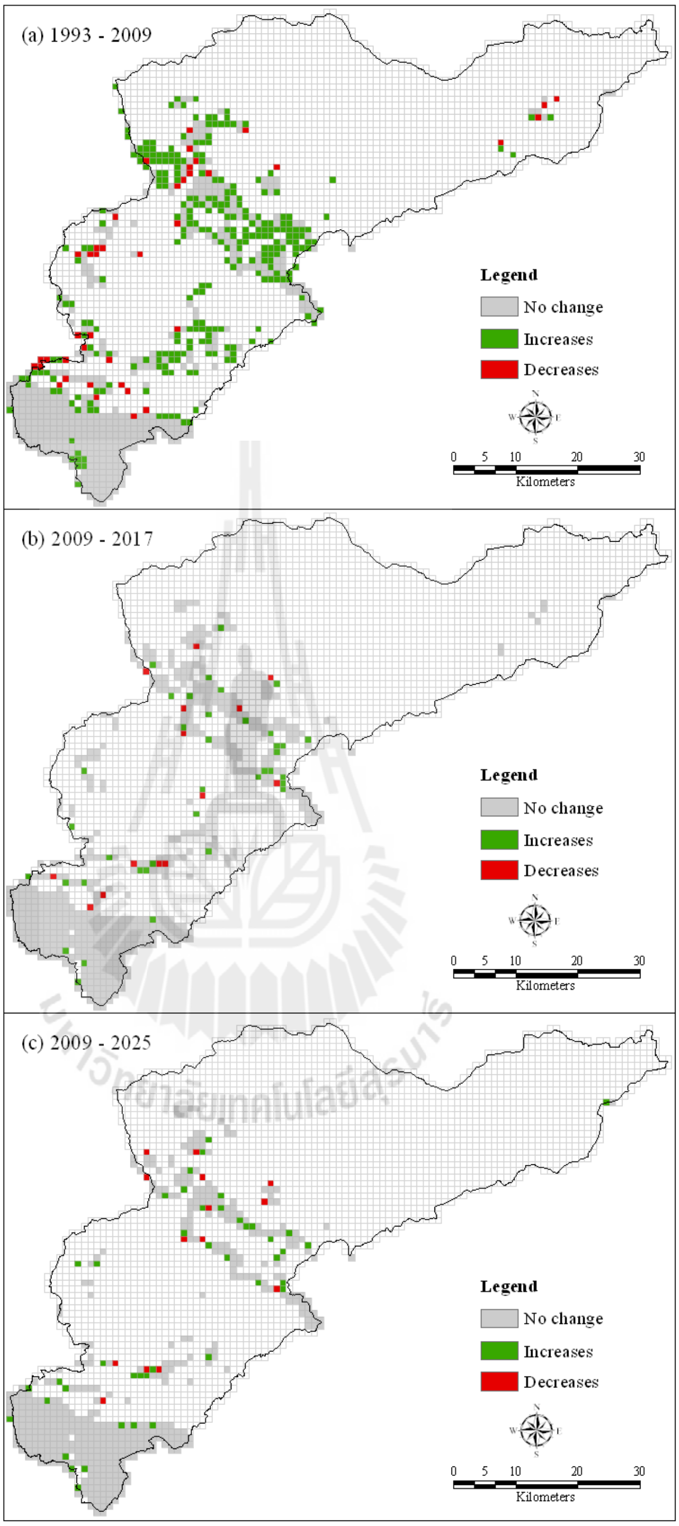


Figure 5.31 Distribution of landscape adjacency changes in forest landscape during (a) 1993-2009, (b) 2009-2017 and (c) 2009-2025.

As results, landscape pattern change of agricultural and forest landscape in term of gain and loss in three periods (1993-2009, 2008-2017 and 2009-2025) can be further synthesized based on landscape metrics as shown in Table 5.28 and Table 5.29, respectively. It was found that agricultural landscape between 1993 and 2009 consisted of heterogeneous types while agricultural landscape between 2009 and 2025 will be composed homogeneous types. Meanwhile, forest landscape between 1993 and 2009 was few disturbed while forest landscape between 2009 and 2025 will be more disturbed

Table 5.28 Summary of agricultural landscape change based landscape metrics during 1993-2009, 2009-2017 and 2009-2025.

(Unit: sq. km)

Landscape pattern		**1993-2009**	**2009-2017**	**2009-2025**	**Meaning**
Fragmentation	Gain	113	2	2	1993-2009: Heterogeneous land
	Loss	112	585	570	2009-2025: Homogeneous land
	Change	Increase	Decrease	Decrease	
Complexity	Gain	255	204	199	1993-2025: Homogeneous land
	Loss	574	360	479	
	Change	Decrease	Decrease	Decrease	
Isolation	Gain	60	22	23	1993-2017: Heterogeneous land
	Loss	26	16	26	2017-2025: Homogeneous land
	Change	Increase	Increase	Decrease	
Diversity	Gain	431	35	139	1993-2009: Heterogeneous land
	Loss	290	272	281	2009-2025: Homogeneous land
	Change	Increase	Decrease	Decrease	
Adjacency	Gain	806	231	319	1993-2009: Heterogeneous land
	Loss	524	415	417	2009-2025: Homogeneous land
	Change	Increase	Decrease	Decrease	

Table 5.29 Summary of forest landscape change based landscape metrics during 1993-2009, 2009-2017 and 2009-2025.

(Unit: sq. km)

Landscape pattern		**1993-2009**	**2009-2017**	**2009-2025**	**Meaning**
Fragmentation	Gain	35	0	0	1993-2009: More forest disturbances
	Loss	5	6	1	2009-2025: Few forest disturbances
	Change	Increase	Decrease	Decrease	
Complexity	Gain	137	29	35	1993-2009: More forest disturbances
	Loss	66	100	77	2009-2025: Few forest disturbances
	Change	Increase	Decrease	Decrease	
Isolation	Gain	24	9	35	1993-2017: More forest disturbances
	Loss	7	4	77	2017-2025: Few forest disturbances
	Change	Increase	Increase	Decrease	
Diversity	Gain	203	86	120	1993-2025: More forest disturbances
	Loss	0	0	0	
	Change	Increase	Increase	Increase	
Adjacency	Gain	274	38	43	1993-2025: More forest disturbances
	Loss	41	14	14	
	Change	Increase	Increase	Increase	

CHAPTER VI

LANDSCAPE SUSTAINABILITY EVALUATION AND MODELING

The content of this chapter will present the results of the third objective focusing on agricultural and forest landscape sustainability evaluation and predictive agricultural and forest landscape sustainability modeling. Two main outputs include evaluation of agricultural and forest landscape sustainability and development of landscape sustainability modeling for prediction of agricultural and forest landscape sustainability in 2017 and 2025.

6.1 Agricultural and forest landscape sustainability evaluation

In practice, the hemeroby value was firstly assigned for each LULC type according to the intensity of land use and average value of hemeroby was then computed by multiplication between proportional areas of each LULC type for each landscape cell with its hemeroby value using Eq. 3.10. After that SUSI of each landscape cell was computed using Eq. 3.11 to generate sustainability indices and then sustainability indices was reclassified into 5 levels for explanation landscape sustainability in different year as follows:

1. Low sustainability (L), SUSI value less than -2;
2. Low to moderate sustainability (L-M), SUSI value between -1 to and -2;
3. Moderate sustainability (M), SUSI value between -1 and +1;
4. Moderate to high sustainability (M-H), SUSI value between +1 and +2;
5. High sustainability (H), SUSI value more than +2.

6.1.1 Status of agricultural landscape sustainability

Area of agricultural landscape sustainability in 1993, 2001, 2009, 2017 and 2025 was summarized as shown in Table 6.1. At the same time, distribution of agricultural landscape sustainability data in 1993, 2001, 2009, 2017 and 2025 were displayed in Figure 6.1 to Figure 6.5, respectively.

Table 6.1 Area and percentage of agricultural landscape sustainability.

Landscape sustainability level	1993		2001		2009		2017		2025	
	Sq. km^2	**%**	**Sq. km**	**%**	**Sq. km**	**%**	**Sq. km**	**%**	**Sq. km**	**%**
L	4	0.17	8	0.33	11	0.43	25	0.94	30	1.13
L-M	378	16.15	134	5.51	169	6.63	231	8.68	238	8.97
M	1,541	65.83	1,893	77.87	1,990	78.10	2,028	76.18	2,048	77.17
M-H	344	14.69	267	10.98	209	8.24	204	7.66	185	6.97
H	74	3.16	129	5.31	168	6.59	174	6.54	153	5.76
Total	**2,341**	**100.00**	**2,431**	**100.00**	**2,547**	**100.00**	**2,662**	**100.00**	**2,654**	**100.00**

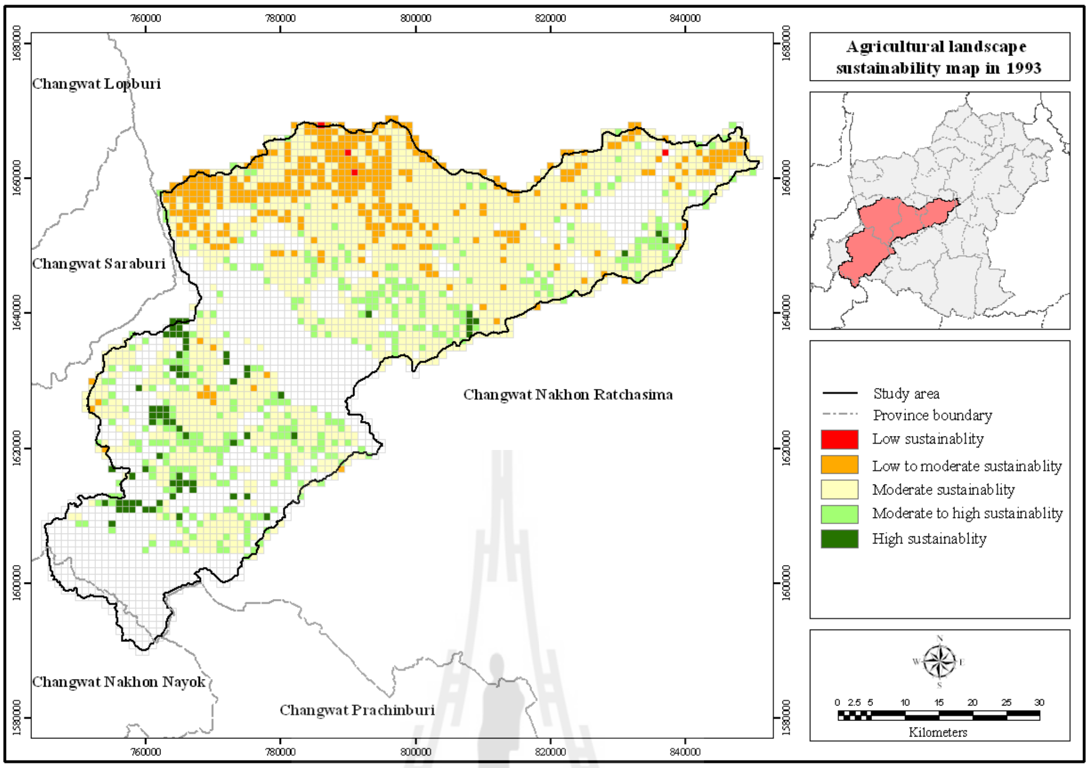


Figure 6.1 Distribution of agricultural landscape sustainability in 1993.

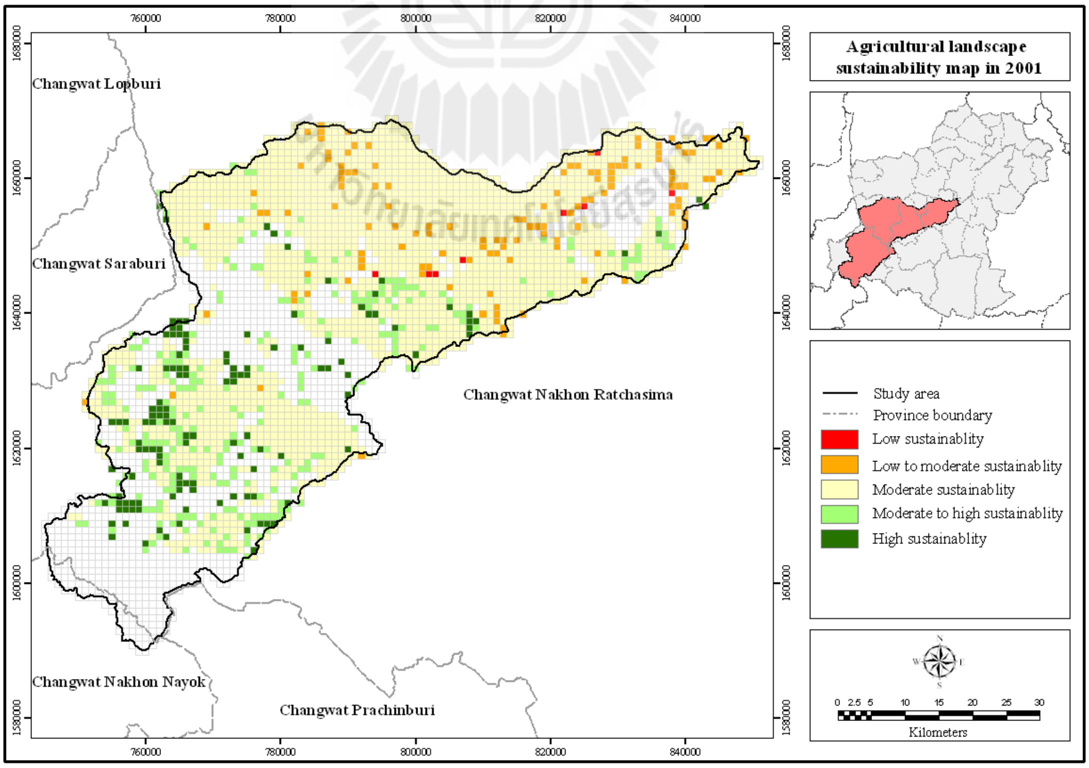


Figure 6.2 Distribution of agricultural landscape sustainability in 2001.

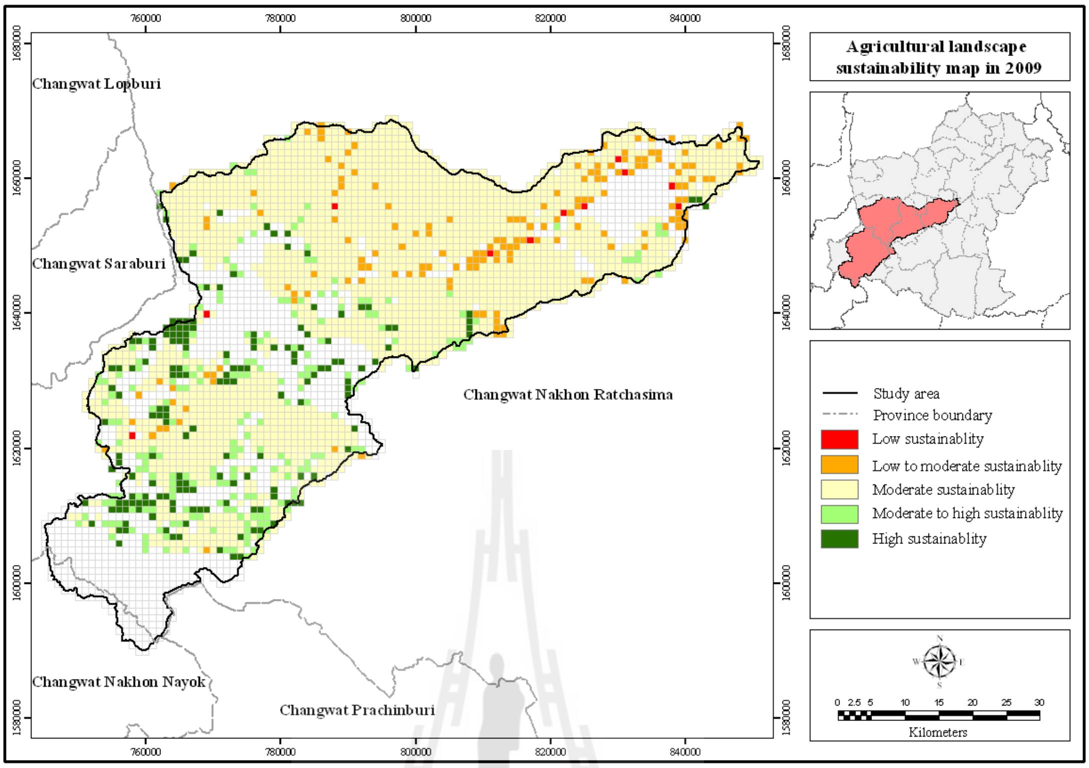


Figure 6.3 Distribution of agricultural landscape sustainability in 2009.

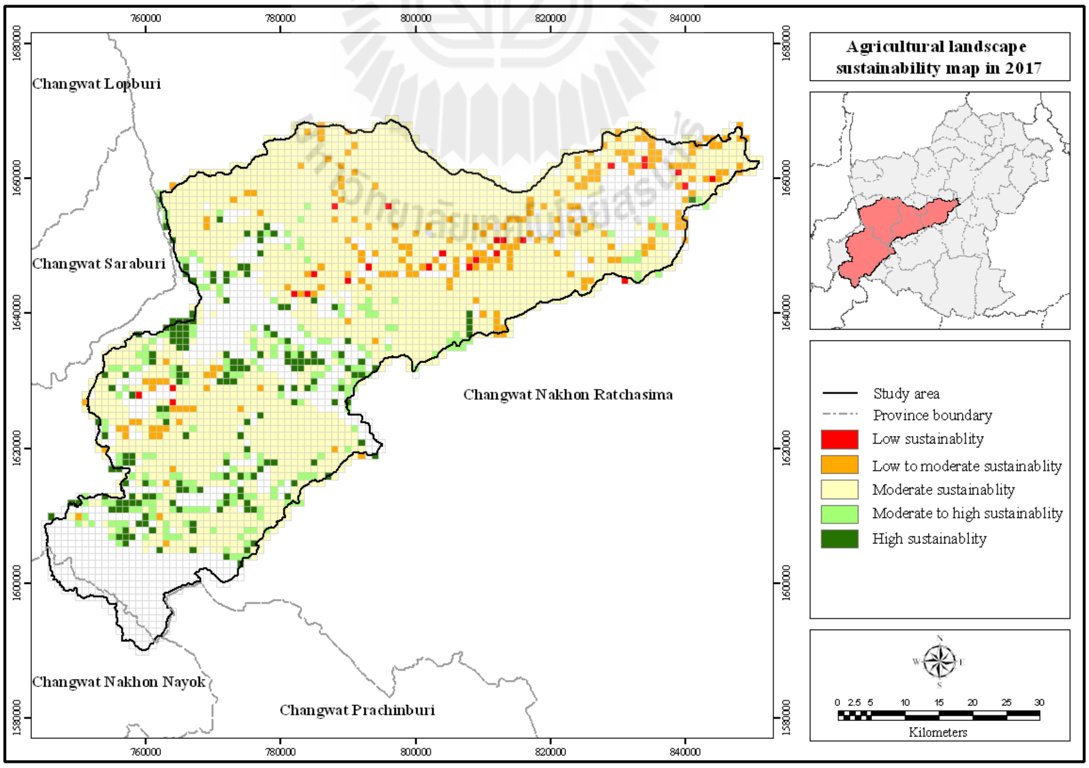


Figure 6.4 Distribution of agricultural landscape sustainability in 2017.

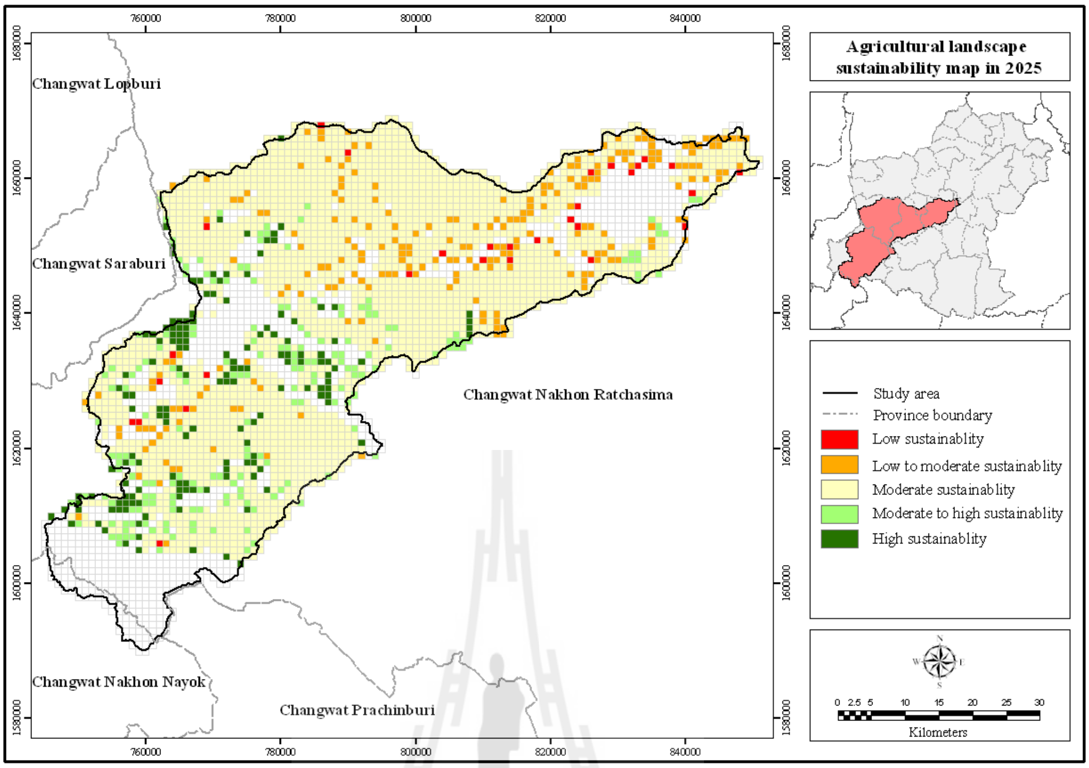


Figure 6.5 Distribution of agricultural landscape sustainability in 2025.

As shown in Table 6.1, dominant level of agricultural landscape sustainability in the past (1993-2009) and in the future (2009-2025) was moderate and area of agricultural landscape sustainability was also continuously increased. However, area of sustainability of agricultural landscape at low level was also continuously increased. While, agricultural landscape sustainability area at high level was increased during 1993-2009 and it was also increased during 2009-2017 but it was decreased during 2017-2025. This resulted infers unpredictability for high sustainability of agricultural landscape.

6.1.2 Status of forest landscape sustainability

Area of forest landscape sustainability in 1993, 2001, 2009, 2017 and 2025 was summarized as shown in Table 6.2. While, distribution of forest landscape sustainability data in 1993, 2001, 2009, 2017 and 2025 were displayed in Figure 6.6 to Figure 6.10, respectively.

Table 6.2 Area and percentage of forest landscape sustainability

Landscape sustainability level	1993		2001		2009		2017		2552	
	Sq. km	%	Sq. km	%	Sq. km	%	Sq. km	%	Sq. km	%
L	38	3.37	46	4.89	28	3.59	19	3.16	17	3.28
L-M	189	16.79	122	12.86	132	16.90	97	16.11	88	16.96
M	899	79.84	773	82.25	621	79.51	486	80.73	414	79.77
Total	**1,126**	**100.00**	**941**	**100.00**	**781**	**100.00**	**602**	**100.00**	**519**	**100.00**

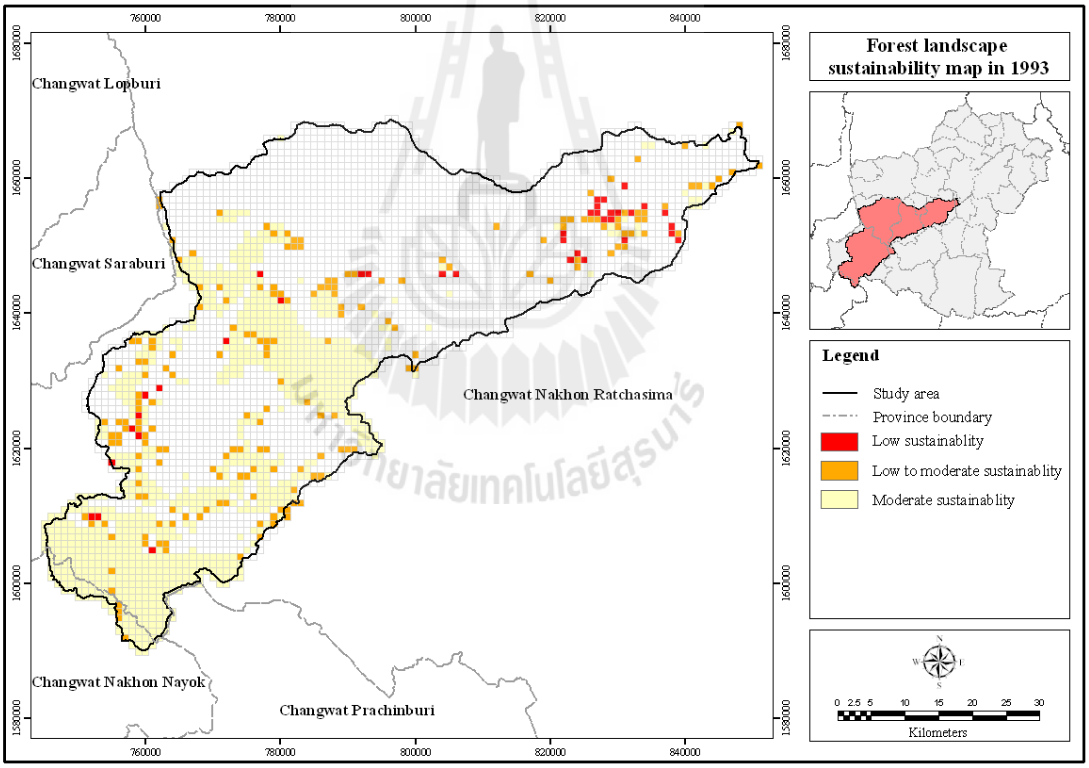


Figure 6.6 Distribution of forest landscape sustainability in 1993.

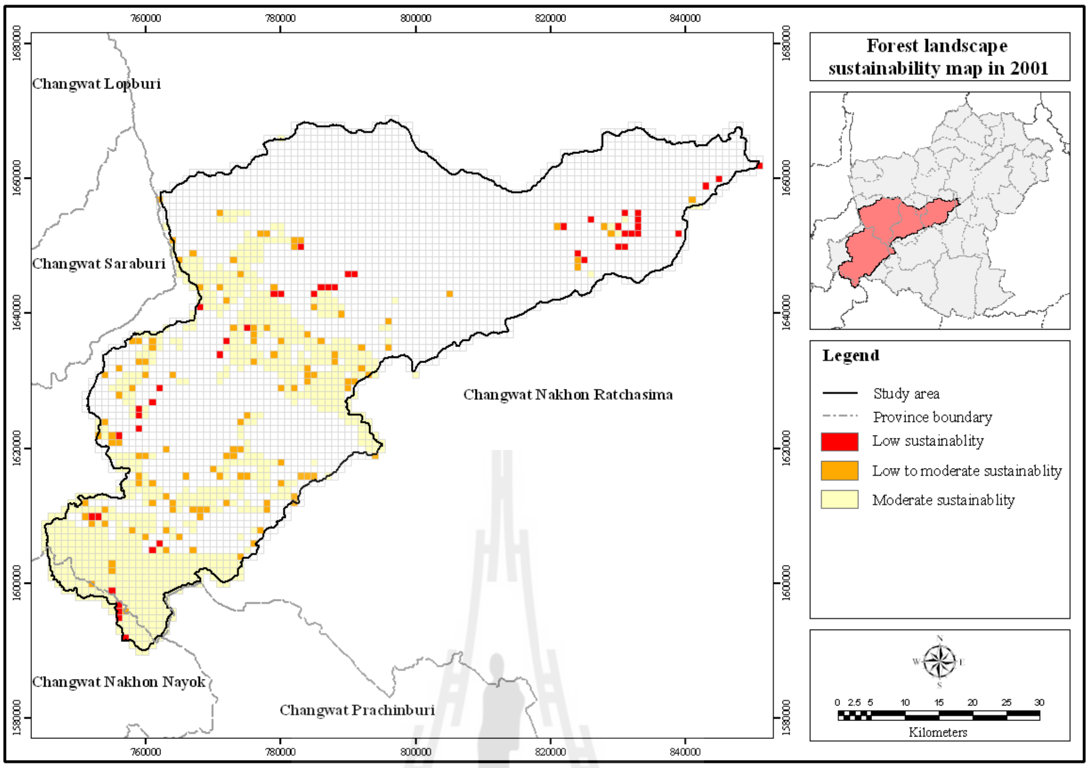


Figure 6.7 Distribution of forest landscape sustainability in 2001.

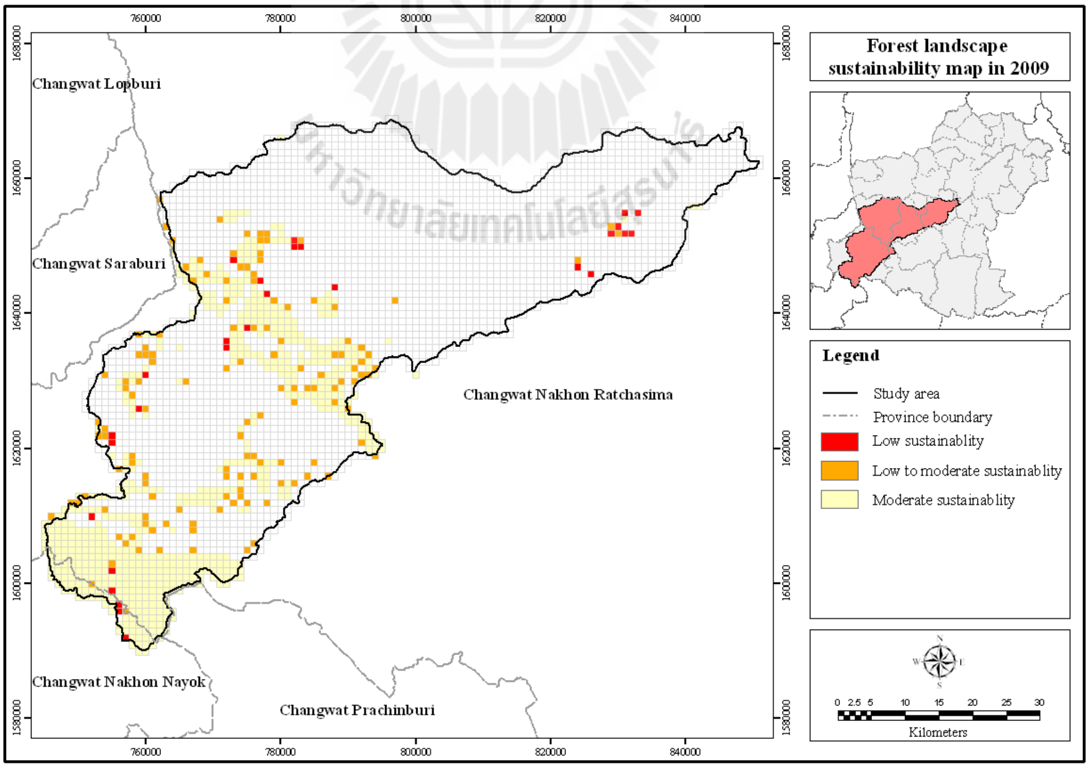


Figure 6.8 Distribution of forest landscape sustainability in 2009.

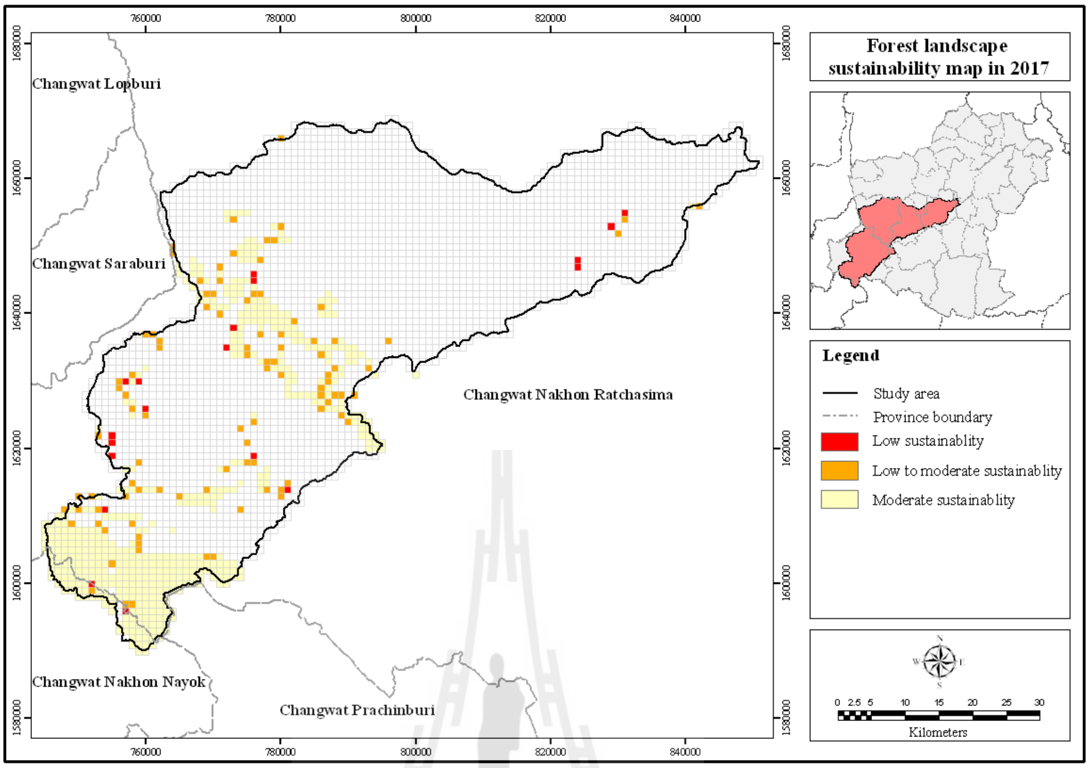


Figure 6.9 Distribution of forest landscape sustainability in 2017.

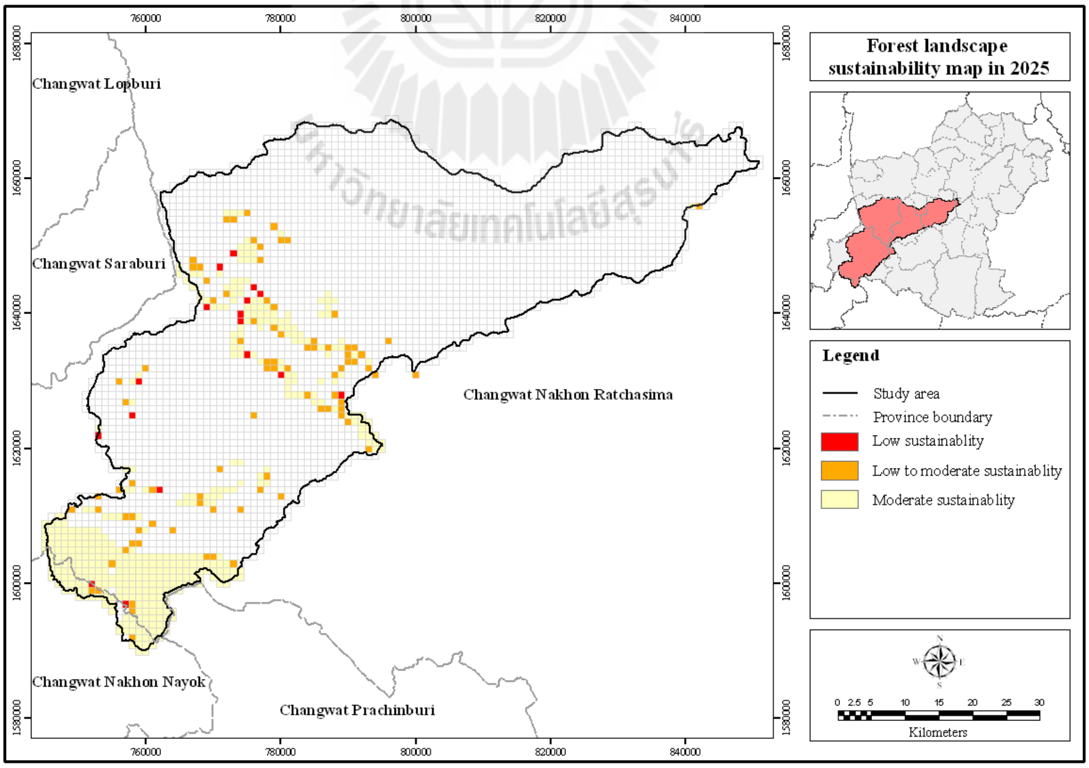


Figure 6.10 Distribution of forest landscape sustainability in 2025.

As shown in Table 6.2, forest landscape sustainability consisted of three levels included low, low to moderate and moderate, the dominant forest landscape sustainability index during 1993 to 2025 was moderate but its area was continuously decreased. At the same time, area of sustainability of forest landscape at low and low to moderate levels was unpredictable. In the past during 1993-2001 forest sustainability at low level was increased but it was decreased during 2001-2009. However in the future (2009-2025) it was decreased. Similarity, in the past (1993-2009) forest sustainability at low to moderate level was decreased but in the future (2009-2025) it was decreased.

6.2 Change of agricultural and forest landscape sustainability

Basically, agricultural and forest landscape sustainability index in the past and in the future were compared using transition matrix to explain sustainability change in term of gain and loss.

6.2.1 Change of agricultural landscape sustainability

Change of agricultural landscape sustainability in the past (1993-2009) and in the future for short term period (2009-2017) and long term period (2009-2025) which were extracted using transition matrix were summarized as shown in Table 6.3 to Table 6.5, respectively.

As shown in Table 6.3, it was found that most of agricultural landscape sustainability index in the past (1993-2009) was moderate. In this period sustainability of agricultural landscape was decreased. Because area of sustainability was gained with area of 356 sq. km and area of sustainability was lost with area of 405 sq. km (Figure 6.11).

For the future agricultural landscape sustainability during 2009-2017 as in short term period (Table 6.4), it was found that most of agricultural landscape sustainability index in 2017 was moderate. At the same period, sustainability of agricultural landscape was also decreased. Because area of sustainability was gained with area of 4 sq. km and area of sustainability was lost with area of 388 sq. km (Figure 6.12).

In addition, for the future agricultural landscape sustainability during 2009-2025 as long term period (Table 6.5), it was found that most of agricultural landscape sustainability index during 2009-2025 will be moderate. However, in this period, sustainability of agricultural landscape was decreased. Because area of sustainability was gained with area of 8 sq. km and area of sustainability was lost with area of 466 sq. km (Figure 6.13).

As results, level of agricultural landscape sustainability in the past (1993-2009) and in the future (2017-2025) were moderate but sustainability of agricultural landscape were continuously declined in the past and the future.

Table 6.3 Agricultural landscape sustainability change between 1993 and 2009.

(Unit: sq. km)

1993	**2009**					**Total**
	L	**M-L**	**M**	**M-H**	**H**	
L	0	3	0	0	0	3
L-M	2	34	330	1	0	367
M	8	121	1,329	14	1	1,473
M-H	1	7	235	88	7	338
H	0	0	9	22	43	74
Total	**11**	**165**	**1,903**	**125**	**51**	**2,255**

Table 6.4 Agricultural landscape sustainability change between 2009 and 2017.

(Unit: sq. km)

2009	2017					Total
	L	**M-L**	**M**	**M-H**	**H**	
L	1	0	0	0	0	1
L-M	24	120	0	0	0	144
M	0	110	1,860	4	0	1,974
M-H	0	0	142	66	0	208
H	0	0	16	96	56	168
Total	**25**	**230**	**2,018**	**166**	**56**	**2,495**

Table 6.5 Agricultural landscape sustainability change between 2009 and 2025.

(Unit: sq. km)

2009	2025					Total
	L	**M-L**	**M**	**M-H**	**H**	
L	0	0	0	0	0	0
L-M	24	80	1	0	0	105
M	6	153	1,781	6	0	1,946
M-H	0	1	165	40	1	207
H	0	0	61	56	51	168
Total	**30**	**234**	**2,008**	**102**	**52**	**2,426**

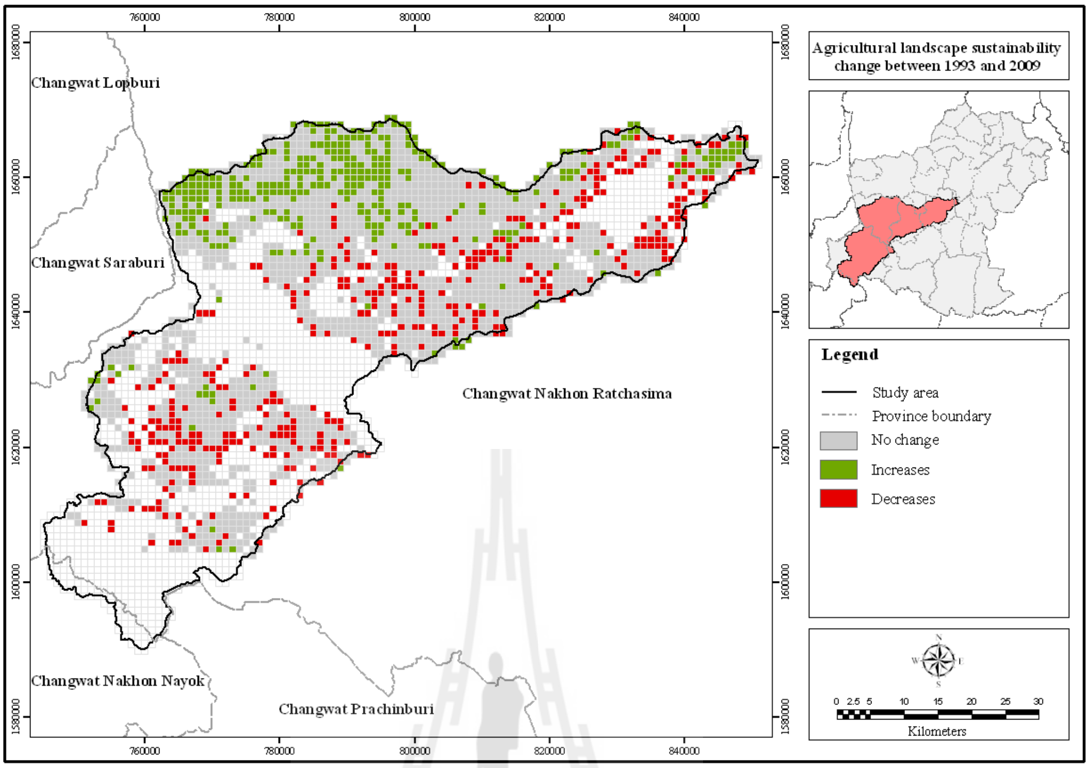


Figure 6.11 Agricultural landscape sustainability change between 1993 and 2009.

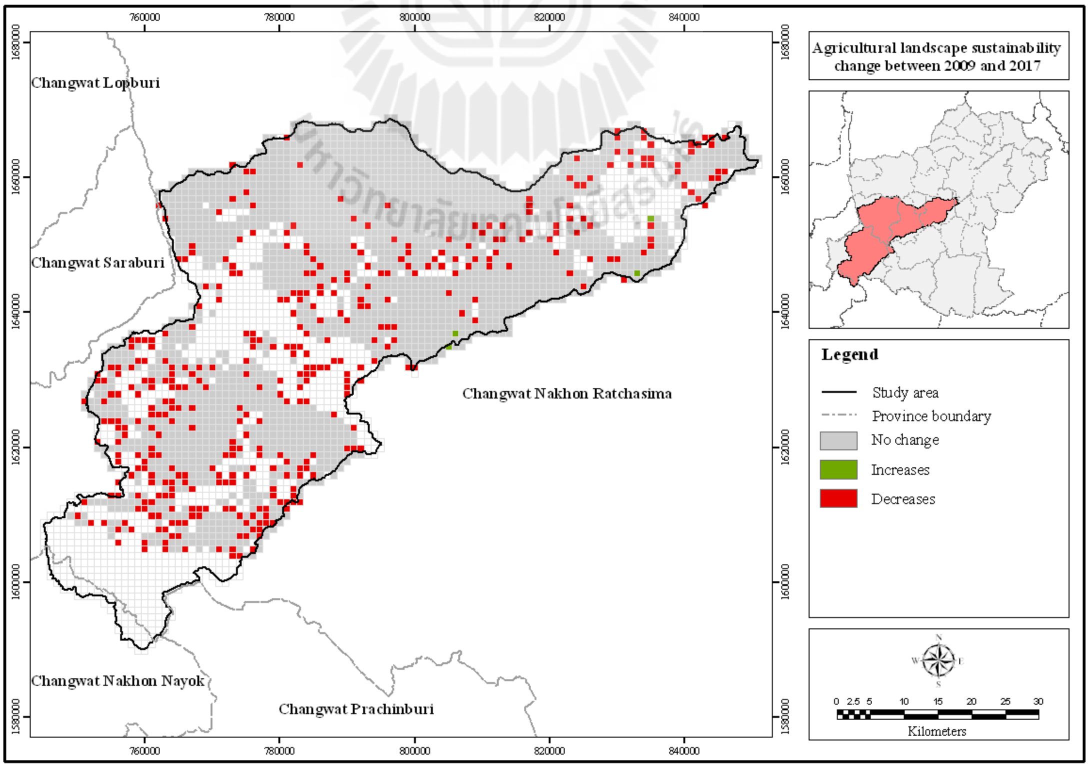


Figure 6.12 Agricultural landscape sustainability change between 2009 and 2017.

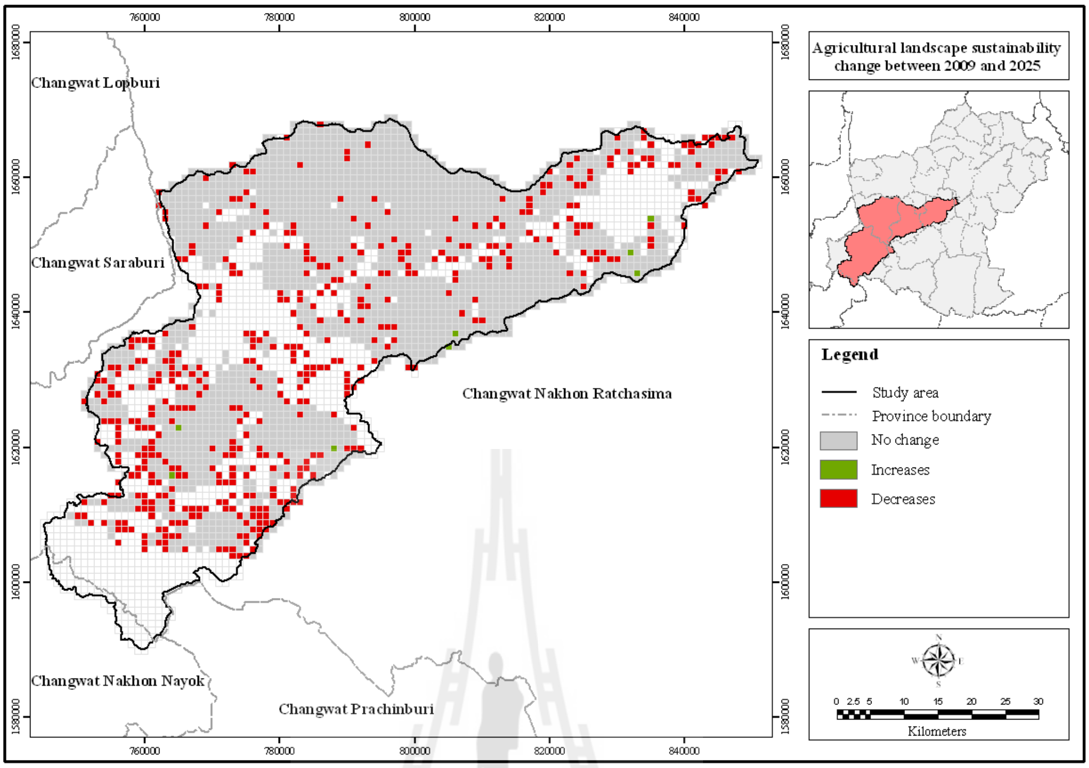


Figure 6.13 Agricultural landscape sustainability change between 2009 and 2025.

6.2.2 Change of forest landscape sustainability

Change of forest landscape sustainability in the past (1993-2009) and in the future for short term period (2009-2017) and long term period (2009-2025) which were extracted using transition matrix were summarized as shown in Table 6.6 to Table 6.8, respectively.

Refer to the result of forest landscape sustainability change, it was found that most of forest landscape sustainability index the past (1993-2009) was moderate (Table 6.6). In this period sustainability of forest landscape was decreased with no gain and loss value of 151 sq. km (Figure 6.14).

For the future forest landscape sustainability in short term period (2009-2017), it was found that most of forest landscape sustainability index in 2017 will be moderate (Table 6.7). At the same period, sustainability of forest landscape will be decreased with no gain and loss value of 103 sq. km (Figure 6.15).

In addition, for the future forest landscape sustainability in long term period (2009-2025), it was found that most of forest landscape sustainability index in 2025 will be moderate (Table 6.8). In this period, sustainability of forest landscape will be also decreased with no gain and loss value of 103 sq. km (Figure 6.16).

As results, level of forest landscape sustainability in the past (1993-2009) and in the future (2017-2025) were moderate but sustainability of forest landscape were continuously declined without gain in the past and the future.

Table 6.6 Forest landscape sustainability change between 1993 and 2009.

(Unit: sq. km)

1993	2009			Total
	L	**L-M**	**M**	
L	2	0	0	2
M-L	19	7	0	26
M	7	125	621	753
Total	**28**	**132**	**621**	**781**

Table 6.7 Forest landscape sustainability change between 2009 and 2017.

(Unit: sq. km)

2009	2017			Total
	L	**M-L**	**M**	
L	5	0	0	5
M-L	12	8	0	20
M	2	89	486	577
Total	**19**	**97**	**486**	**602**

Table 6.8 Forest landscape sustainability change between 2009 and 2025.

(Unit: sq. km)

2009	2025			Total
	L	M-L	M	
L	0	0	0	0
M-L	4	2	0	6
M	13	86	414	513
Total	**17**	**88**	**414**	**519**

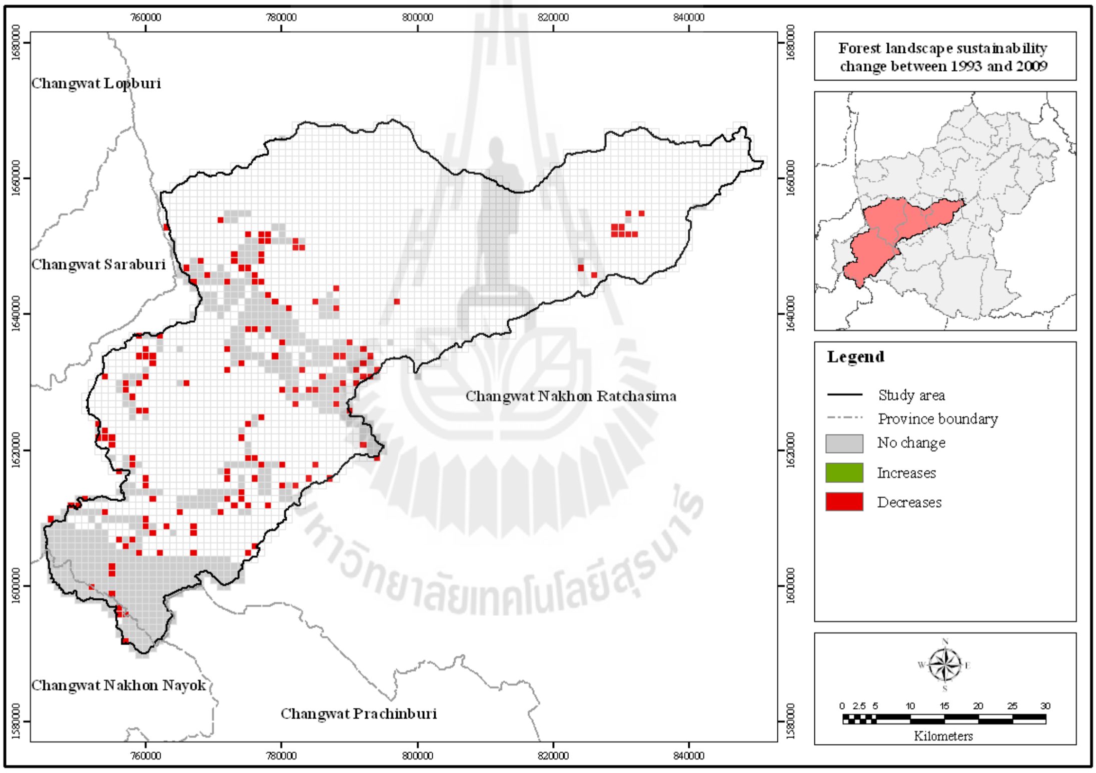


Figure 6.14 Forest landscape sustainability change between 1993 and 2009.

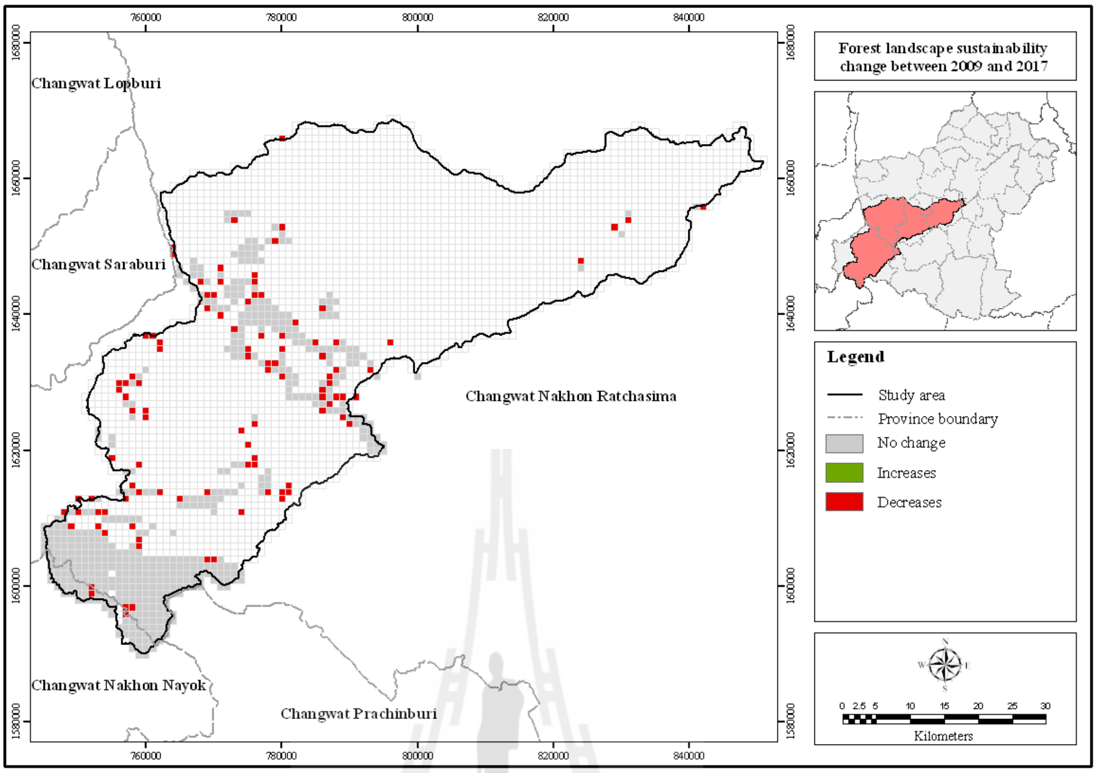


Figure 6.15 Forest landscape sustainability change between 2009 and 2017.

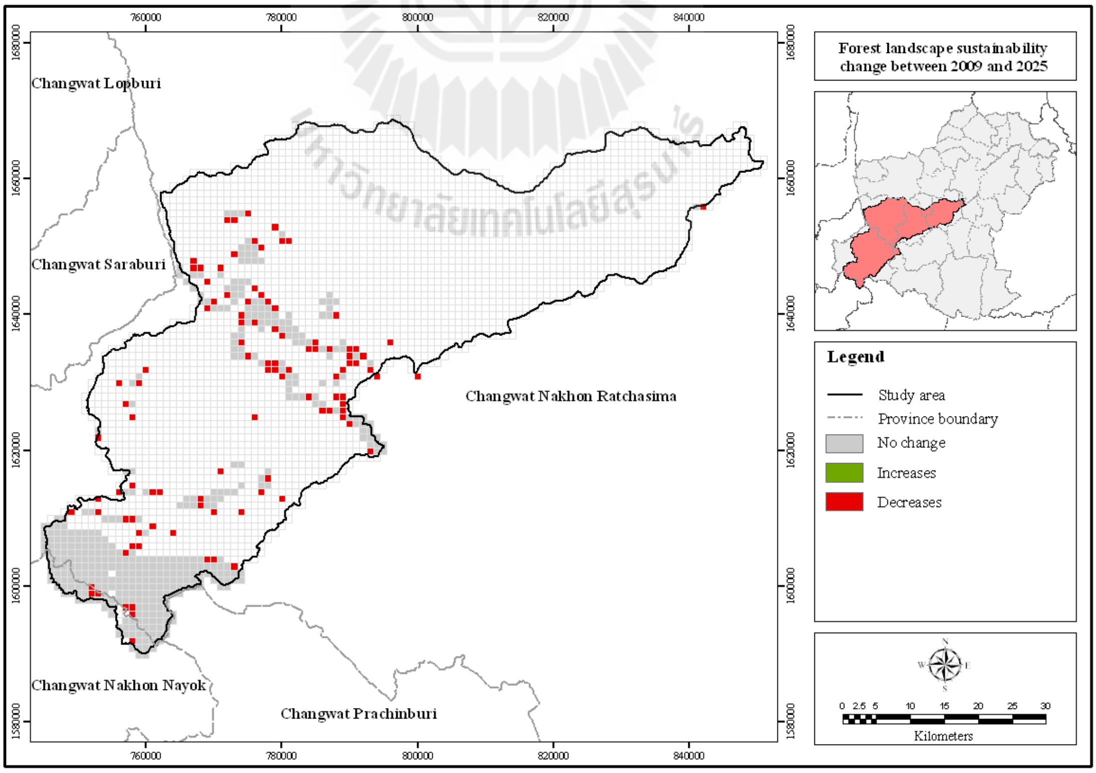


Figure 6.16 Forest landscape sustainability change between 2009 and 2025.

6.3 Agricultural and forest landscape sustainability modeling

In this study, simple and multiple linear regression were employed for explanation the relationship between agricultural and forest landscape sustainability in 2009 as explained in Section 6.1 and theirs landscape metrics which include that Number of patches (NP), Mean patch fractal dimension index (MPFD), Mean proximity index (MPI), Shannon's diversity index (SHDI), and Interspersion juxtaposition index (IJI) as explained in Section 5.3 Then extracted simple or multiple linear regression equation was selected to predict agricultural and forest landscape sustainability in 2017 and 2025 using coefficient of determination (R^2).

6.3.1 Predictive agricultural landscape sustainability model

The result of the predictive agricultural landscape sustainability model using simple linear regression analysis based on Sustainability Index (SUSI) and its landscape metric in 2009 was summarized as equation from in Table 6.9. Detail of simple linear regression analysis was presented in Appendix A. As a result it was found that the best simple linear regression model for agricultural landscape sustainability prediction according to coefficient of determination (R^2) was simple linear regression model of Mean patch fractal dimension index (MPFD) as:

$$ALSI = 0.7781 + 0.8309 \times MPFD \qquad (6.1)$$

Where

ALSI is agricultural landscape sustainability index;

MPFD is mean patch fractal dimension index.

This equation provides coefficient (R) about 0.89 and coefficient of determination (R^2) about 0.78

Table 6.9 Summary of simple linear regression model for agricultural landscape sustainability prediction.

Landscape metrics	**Model**	**Coefficient (R)**	**Coefficient of determination (R^2)**
NP	ALSI = 5.1568 + 0.7951 x NP	0.70	0.49
MPFD	ALSI = 0.7781 + 0.8309 x MPFD	0.89	0.78
MPI	ALSI = 8.9378 + 1.6667 x MPI	0.53	0.28
SDI	ALSI = 3.2891 + 0.6245 x SDI	0.80	0.65
IJI	ALSI = 1.6876 + 0.5512 x IJI	0.85	0.71

At the same time, the result of the predictive agricultural landscape sustainability model using multiple linear regression analysis based on SUSI and 5 landscape metrics in 2009 was shown in following equation:

$$ALSI = 0.5917 - 0.4595 \times NP + 0.5203 \times MPFD - 0.0005 \times MPI + 0.3007 \times SHDI + 0.2263 \times IJI \quad (6.2)$$

Where

ALSI is agricultural landscape sustainability index;

NP is Number of patches;

MPFD is mean patch fractal dimension index;

MPI is Mean proximity index;

SHDI is Shannon's diversity index;

IJI is Interspersion and juxtaposition index.

This equation provides coefficient (R) about 0.90 and coefficient of determination (R^2) about 0.81.

As a result it was found that an optimum predictive agricultural landscape sustainability model should be multiple linear regression model because it provides R and R^2 higher than simple linear regression. Thus, multiple linear regression model was used to predict agricultural landscape sustainability in 2017 and 2025.

Distribution of predictive agricultural landscape sustainability using multiple linear regression model was displayed in Figure 6.17. It was found that level of predictive agricultural sustainability in 2009 consists of 5 levels. Area and percentage of sustainability level for agricultural landscape in 2009 were summarized as Table 6.10.

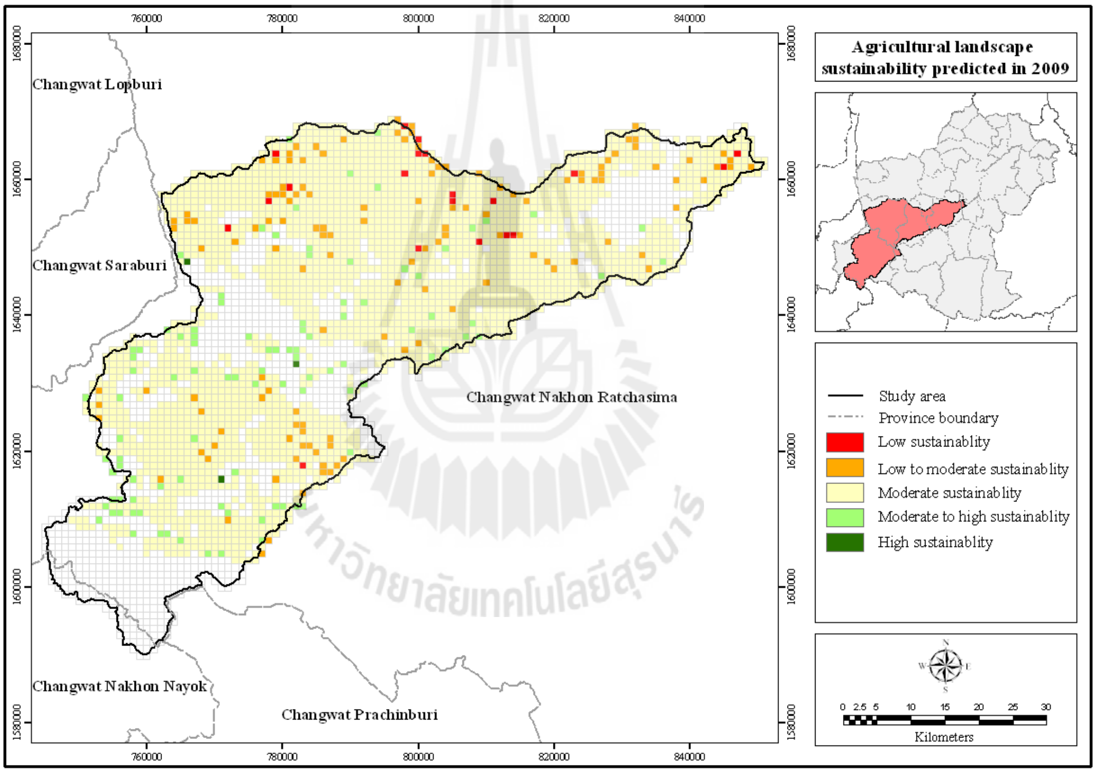


Figure 6.17 Distribution of predictive agricultural landscape sustainability in 2009 using multiple linear regression model.

Table 6.10 Area and percentage of prediction agricultural landscape sustainability in 2009.

Sustainability level	Area (sq. km)	Percentage
Low sustainability	20	0.79
Low to moderate sustainability	134	5.26
Moderate sustainability	2,291	89.95
Moderate to high sustainability	99	3.89
High sustainability	3	0.12
Total	**2,547**	**100.00**

In addition, actual agricultural landscape sustainability in 2009 using SUSI as reference data (Figure 6.3) and predictive agricultural landscape sustainability in 2009 using multiple linear regression model (Figure 6.17) was here compared using overall accuracy and Kappa analysis. It was found that the consistency of both sustainability indices based on overall accuracy was 83.59%. However the consistency of both sustainability indices based on Kappa hat coefficient of agreement was 31.56% (Table 6.11). This resulted was represent poor agreement between both sustainability indices. This affected might result from the different method for sustainability calculation. Multiple linear regression model was derived from predictors and it can used to explain sustainability only 81%. In contrast, SUSI relies on intensity of land use in each landscape cell.

Table 6.11 Comparison of agricultural landscape sustainability index in 2009 using Sustainability Indicator and multiple linear regression model.

(Unit: sq. km)

ALSI2009	**SUSI2009**					**Total**
	L	**L-M**	**M**	**M-H**	**H**	
L	0	0	2	0	0	2
L-M	0	3	10	0	0	13
M	1	12	202	9	6	230
M-H	0	0	1	8	1	10
H	0	0	0	0	1	1
Total	**1**	**15**	**215**	**17**	**8**	**256**
Overall Accuracy (%)	**=**	**83.59%**				
Kappa Coefficient	**=**	**31.51%**				

Note: SUSI = Sustainability Indicator and ALSI = agricultural landscape sustainability index**.**

6.3.2 Prediction of agricultural landscape sustainability

Multiple linear regression equation (Eq. 6.2) was here used to predict agricultural landscape sustainability in 2017 and 2025 based on theirs predictive landscape metrics using Map Algebra Module of ArcGIS software. Distribution of predictive agricultural landscape sustainability in 2017 and 2025 were presented in Figure 6.18 and Figure 6.19, respectively. Area and percentage of sustainability level for agricultural landscape in 2017 and 2025 were summarized as Table 6.12 and Table 6.13, respectively.

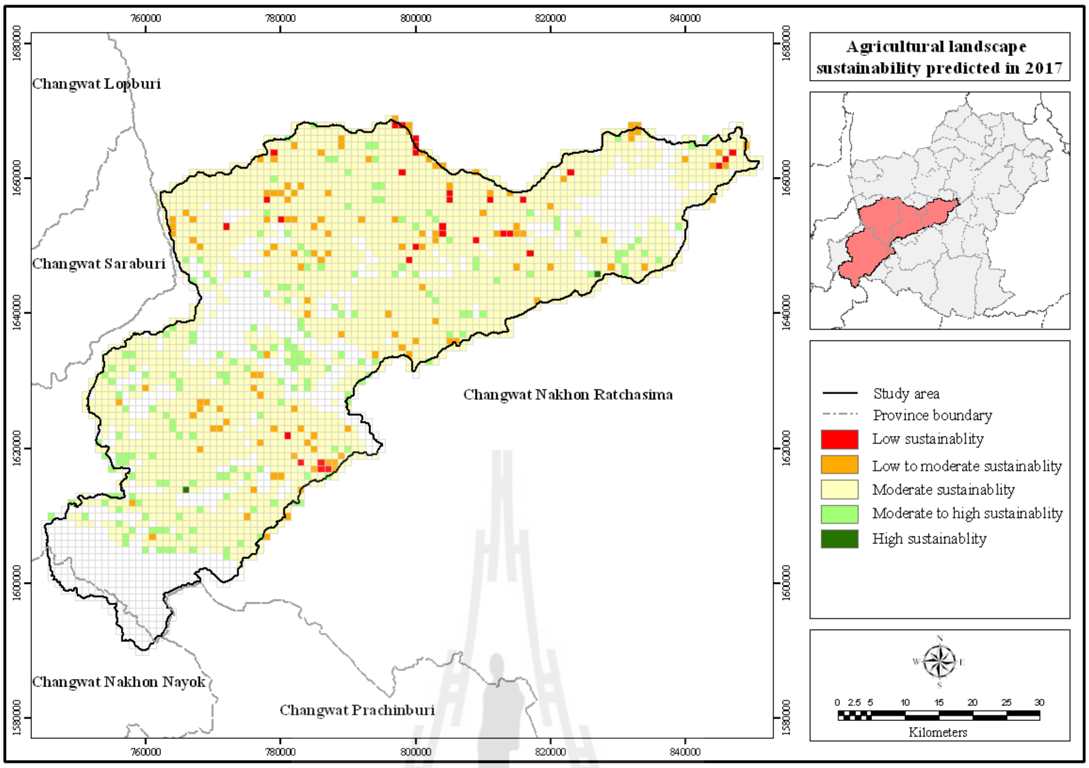


Figure 6.18 Prediction of agricultural landscape sustainability in 2017.

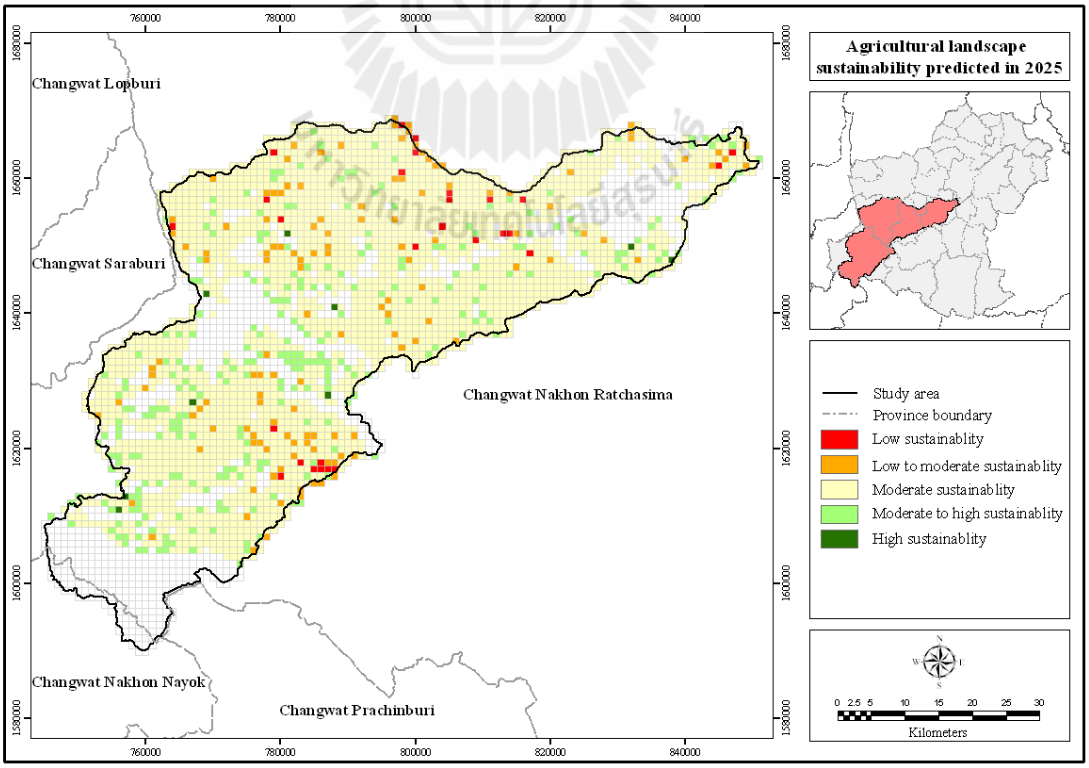


Figure 6.19 Prediction of agricultural landscape sustainability in 2025.

Table 6.12 Area and percentage of prediction agricultural landscape sustainability in 2017.

Sustainability level	Area (sq. km)	Percentage
Low sustainability	31	1.16
Low to moderate sustainability	129	4.85
Moderate sustainability	2,308	86.70
Moderate to high sustainability	192	7.21
High sustainability	2	0.08
Total	**2,654**	**100.00**

Table 6.13 Area and percentage of prediction agricultural landscape sustainability in 2025.

Sustainability level	Area (sq. km)	Percentage
Low sustainability	28	1.06
Low to moderate sustainability	132	4.97
Moderate sustainability	2,203	83.01
Moderate to high sustainability	282	10.63
High sustainability	9	0.34
Total	**2,654**	**100.00**

Results shown in Table 6.12 and 6.13, it was found that level of predictive agricultural sustainability in 2017 and 2025 has completely 5 levels. The dominant sustainability level was moderate.

In addition, actual agricultural landscape sustainability index in 2017 based on SUSI as reference data (Figure 6.4) and predictive agricultural landscape sustainability in 2017 using multiple linear regression model (Figure 6.18) was also compared using overall accuracy and Kappa Analysis. It was found that the consistency of both sustainability indices based on overall accuracy was 81.64%. In the meantime, Kappa hat coefficient of agreement was 33.55% (Table 6.14). This resulted was represent poor agreement between actual sustainability index in 2017 using SUSI and predictive sustainability index in 2017 using multiple linear regression model.

Similarly, actual agricultural landscape sustainability index in 2025 based on SUSI as reference data (Figure 6.5) and predictive agricultural landscape sustainability in 2025 using multiple linear regression model (Figure 6.19) was also compared using overall accuracy and Kappa Analysis. It was found that the consistency of both sustainability indices based on overall accuracy was 80.08%. In the meantime, Kappa hat coefficient of agreement was 38.58% (Table 6.15). This resulted was also represent poor agreement between actual sustainability index in 2025 using SUSI and predictive sustainability index in 2025 using multiple linear regression model.

Table 6.14 Comparison of agricultural landscape sustainability index in 2017 using Sustainability Indicator and multiple linear regression model.

(Unit: sq. km)

ALSI2017	SUSI2017					Total
	L	**L-M**	**M**	**M-H**	**H**	
L	0	0	3	0	0	3
L-M	0	1	11	0	0	12
M	1	14	194	9	4	222
M-H	0	0	3	13	2	18
H	0	0	0	0	1	1
Total	1	15	211	22	7	256

Overall Accuracy (%) = **81.64%**

Kappa Coefficient = **33.55%**

Note: **SUSI =** Sustainability Indicator, ALSI = agricultural landscape sustainability index

Table 6.15 Comparison of agricultural landscape sustainability index in 2025 using Sustainability Indicator and multiple linear regression model.

(Unit: sq. km)

ALSI2025	**SUSI2025**					**Total**
	L	**L-M**	**M**	**M-H**	**H**	
L	0	0	3	0	0	3
L-M	0	1	12	0	0	13
M	1	12	186	6	7	212
M-H	0	1	4	17	5	27
H	0	0	0	0	1	1
Total	1	14	205	23	13	256
Overall Accuracy (%) = **80.08%**						
Kappa Coefficient = **38.58%**						

Note: SUSI = Sustainability Indicator, ALSI = agricultural landscape sustainability index

6.3.3 Predictive forest landscape sustainability model

The result of the predictive forest landscape sustainability model using simple linear regression analysis based on SUSI and its landscape metric in 2009 was summarized as equation from as shown in Table 6.16. Detail of simple linear regression analysis was presented in Appendix B. As a result, it was found that the best simple linear regression model for forest landscape sustainability prediction according to coefficient of determination (R^2) was simple linear regression model of mean patch fractal dimension index (MPFD) as:

$$FLSI = 4.1312 + 1.3359 \times MPFD \quad (6.3)$$

Where

FLSI is Forest Landscape Sustainability Index;

MPFD is mean patch fractal dimension index.

This equation provides coefficient (R) about 0.62 and coefficient of determination (R^2) about 0.39.

Table 6.16 Summary of simple linear regression model for forest landscape sustainability prediction.

Landscape metrics	Model	Coefficient (R)	Coefficient of determination (R^2)
NP	FLSI = 5.9255 + 2.1168 x NP	0.43	0.19
MPFD	FLSI = 4.1312 + 1.3359 x MPFD	0.62	0.39
MPI	FLSI = 7.2953 + 2.4658 x MPI	0.29	0.09
SDI	FLSI = 5.2226 + 1.1149 x SDI	0.50	0.25
IJI	FLSI = 4.9228 + 0.9288 x IJI	0.56	0.31

At the same time, the result of the predictive forest landscape sustainability model using multiple linear regression analysis based on SUSI and 5 landscape metrics in 2009 was shown in following equation.

$$FLSI = 4.1329 + 0.3520 \times NP + 1.8191 \times MPFD - 0.2353 \times MPI - 1.0398 \times SDI + 0.2911 \times IJI \quad (6.4)$$

Where

FLSI is Forest landscape sustainability index;

NP is Number of patches;

MPFD is Mean patch fractal dimension index;

MPI is Mean proximity index;

SHDI is Shannon's diversity index;

IJI is Interspersion and juxtaposition index.

This equation provides coefficient (R) about 0.64 and coefficient of determination (R^2) about 0.41.

As a result it was found that an optimum forest landscape sustainability prediction model should be multiple linear regression model because it provides R and R^2 higher than simple linear regression. Therefore multiple linear regression model was used to predict forest landscape sustainability in 2017 and 2025.

Distribution of predictive forest landscape sustainability using multiple linear regression model was displayed in Figure 6.20. It was found that level of predictive forest sustainability in 2009 has 5 levels. Area and percentage of sustainability level for agricultural landscape in 2009 were summarized as Table 6.17.

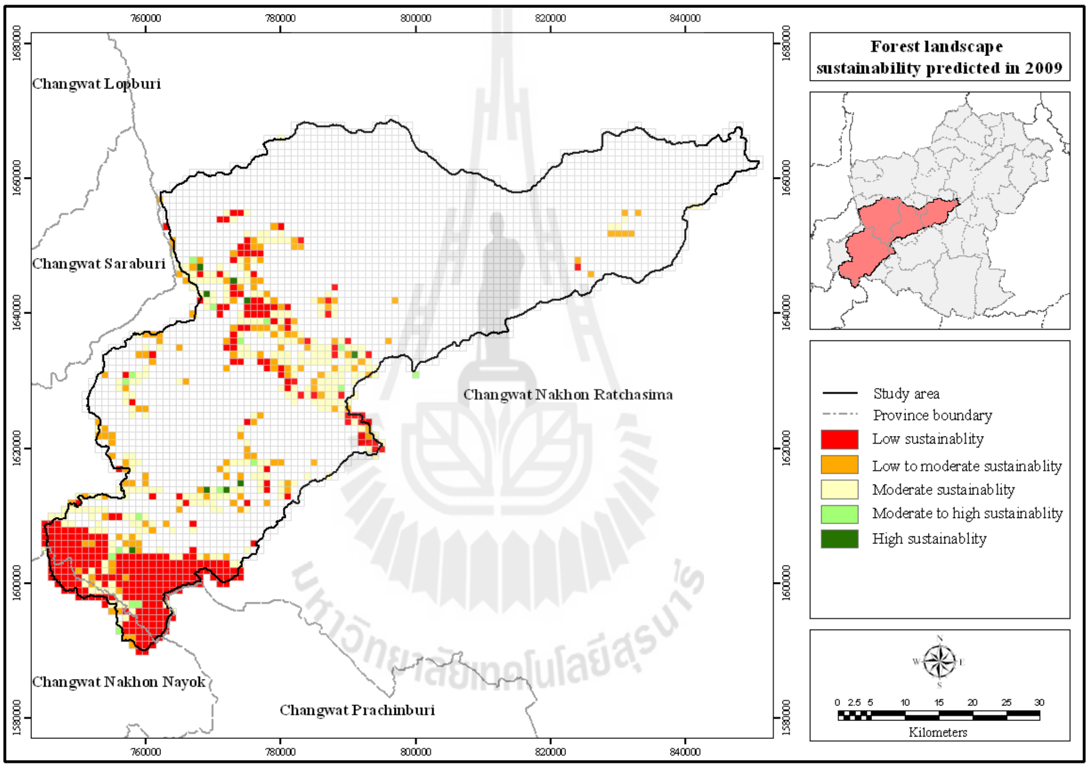


Figure 6.20 Distribution predictive forest landscape sustainability in 2009 using multiple linear regression model.

Table 6.17 Area and percentage of prediction forest landscape sustainability in 2009.

Sustainability level	Area (sq. km)	Percentage
Low sustainability	316	40.46
Low to moderate sustainability	153	19.59
Moderate sustainability	286	36.62
Moderate to high sustainability	17	2.18
High sustainability	9	1.15
Total	**781**	**100.00**

In addition, actual forest landscape sustainability in 2009 using Sustainability Indicator (SUSI) as reference data (Figure 6.8) and predictive forest landscape sustainability in 2009 using multiple linear regression model (Figure 6.20) was here compared using overall accuracy and Kappa Analysis. It was found that the consistency of both sustainability indices based on overall accuracy was 46.88%. However the consistency of both sustainability indices based on Kappa hat coefficient of agreement was 20.01% (Table 6.18). This resulted was represent poor agreement between both sustainability indices. This affected might be come from the different method for sustainability calculation. Multiple linear regression model was derived from predictors and it can used to explain sustainability only 41%. In contrast, SUSI relies on intensity of land use in each landscape cell.

Table 6.18 Comparison of forest landscape sustainability index in 2009 using Sustainability Indicator and multiple linear regression model .

(Unit: sq. km)

FLSI2009	SUSI2009					Total
	L	L-M	M	M-H	H	
L	4	8	92	0	0	104
L-M	5	32	13	0	0	50
M	1	9	84	0	0	94
M-H	0	0	6	0	0	6
H	0	0	2	0	0	2
Total	**10**	**49**	**197**	**0**	**0**	**256**

Overall Accuracy (%) = **46.88%**

Kappa Coefficient = **20.01%**

Note: SUSI = Sustainability Indicator, FLSI = Forest landscape sustainability index

6.3.4 Prediction of forest landscape sustainability

Multiple linear regression equation (Eq. 6.4) was here used to predict forest landscape sustainability in 2017 and 2025 based on theirs predictive landscape metrics using Map Algebra Module of ArcGIS software. Distribution of predictive forest landscape sustainability in 2017 and 2025 were presented in Figure 6.21 and Figure 6.22, respectively. Area and percentage of sustainability level for forest landscape in 2017 and 2025 were summarized as Table 6.19 and Table 6.20, respectively.

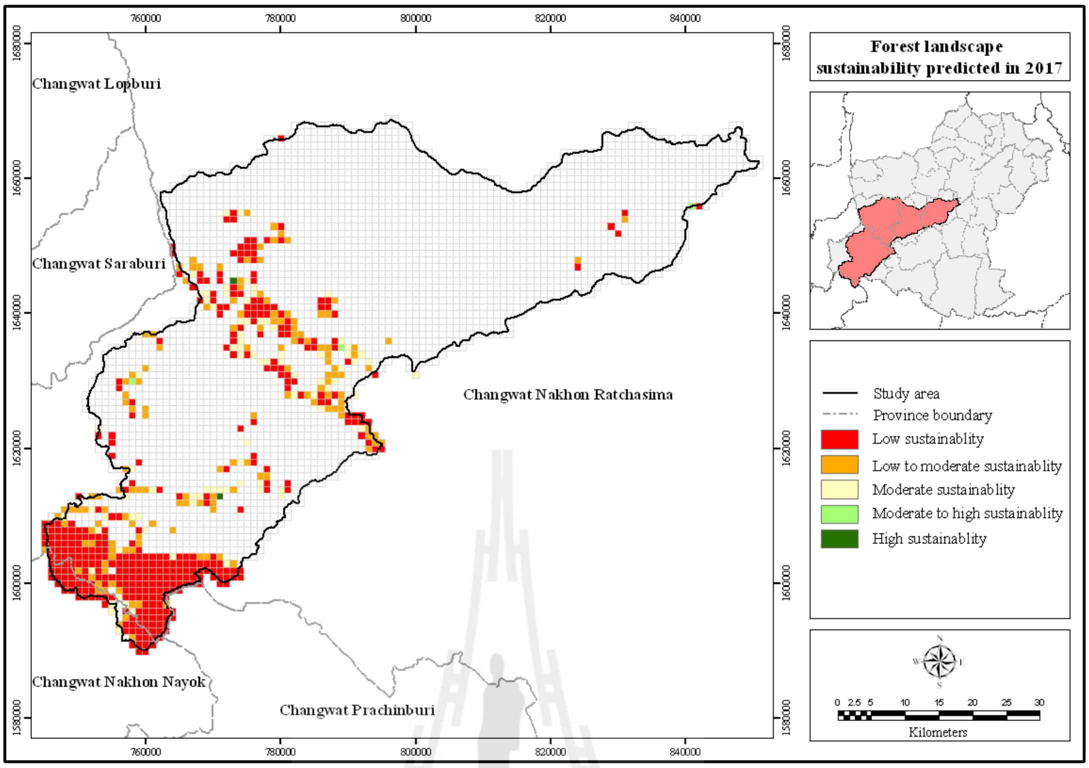


Figure 6.21 Prediction of forest landscape sustainability in 2017.

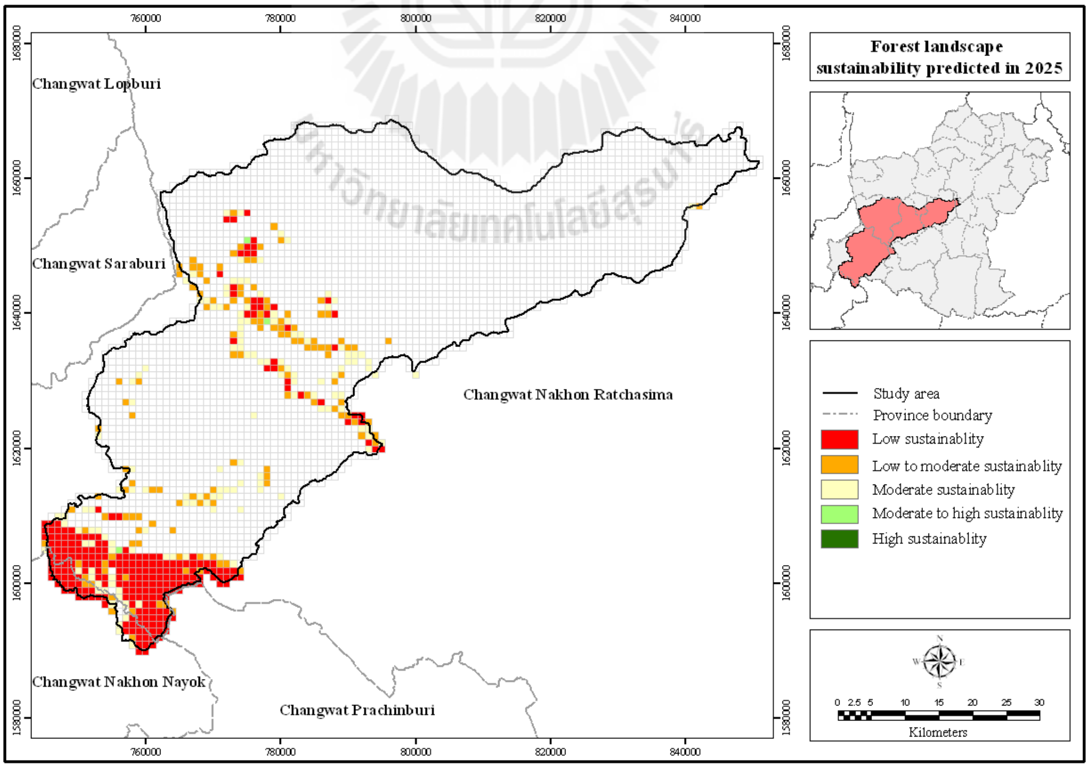


Figure 6.22 Prediction of forest landscape sustainability in 2025.

Table 6.19 Area and percentage of prediction forest landscape sustainability in 2017.

Sustainability level	Area (sq. km)	Percentage
Low sustainability	368	61.13
Low to moderate sustainability	146	24.25
Moderate sustainability	83	13.79
Moderate to high sustainability	3	0.50
High sustainability	2	0.33
Total	**602**	**100.00**

Table 6.20 Area and percentage of prediction forest landscape sustainability in 2025.

Sustainability level	Area (sq. km)	Percentage
Low sustainability	247	47.59
Low to moderate sustainability	130	25.05
Moderate sustainability	139	26.78
Moderate to high sustainability	3	0.58
Total	**519**	**100.00**

As a result in Table 6.19, it was found that level of predictive forest sustainability in 2017 has 5 levels. The dominant sustainability level was low. In the meanwhile, it was found that level of predictive forest sustainability in 2025 has 4 levels. The dominant sustainability level was low (Table 6.20).

In addition, actual forest landscape sustainability index in 2017 based on SUSI as reference data (Figure 6.9) and predictive forest landscape sustainability in 2017 using multiple linear regression model (Figure 6.21) was also compared using overall accuracy and Kappa Analysis. It was found that the consistency of both sustainability indices based on overall accuracy was 32.81%. In the meantime, Kappa hat coefficient of agreement was 18.56% (Table 6.21). This resulted was represent poor agreement between actual sustainability index in 2017 using SUSI and predictive sustainability index in 2017 using multiple linear regression model.

Similarly, actual forest landscape sustainability index in 2025 based on SUSI as reference data (Figure 6.10) and predictive forest landscape sustainability in 2025 using multiple linear regression model (Figure 6.22) was also compared using overall accuracy and Kappa Analysis. It was found that the consistency of both sustainability indices based on overall accuracy was 35.16%. In the meantime, Kappa hat coefficient of agreement was 10.95% (Table 6.22). This resulted was also represent poor agreement between actual sustainability index in 2025 using SUSI and predictive sustainability index in 2025 using multiple linear regression model.

Table 6.21 Comparison of forest landscape sustainability index in 2017 using Sustainability Indicator and multiple linear regression model.

(Unit: sq. km)

FLSI2017	**SUSI2017**					**Total**
	L	**L-M**	**M**	**M-H**	**H**	
L	7	9	140	0	0	156
L-M	1	44	18	0	0	63
M	0	2	33	0	0	35
M-H	0	0	1	0	0	1
H	0	0	1	0	0	1
Total	**8**	**55**	**193**	**0**	**0**	**256**

Overall Accuracy (%) = 32.81%

Kappa Coefficient = 18.56%

Note: SUSI = Sustainability Indicator, FLSI = Forest landscape sustainability index

Table 6.22 Comparison of forest landscape sustainability index in 2025 using Sustainability Indicator and multiple linear regression model.

(Unit: sq. km)

FLSI2025	**SUSI2025**				**Total**
	L	**L-M**	**M**	**M-H**	
L	0	6	116	0	122
L-M	4	37	23	0	64
M	4	12	53	0	69
M-H	0	0	1	0	1
Total	**8**	**55**	**193**	**0**	**256**
Overall Accuracy (%)	**=**	**35.16%**			
Kappa Coefficient	**=**	**10.95%**			

Note: SUSI = Sustainability Indicator, FLSI = Forest landscape sustainability index

CHAPTER VII

CONCLUSIONS AND RECOMMENDATION

There are three main results which are reported in these studies including: (1) LULC classify and their change and prediction (Chapter IV), (2) landscape type classification and landscape pattern analysis (Chapter V), (3) landscape sustainability evaluation and develop landscape sustainability model (Chapter VI). For this chapter main results from the last three chapters which consist of (1) LULC assessment, (2) LULCC detection, (3) LULC prediction, (4) landscape type classification and assessment, (5) change of landscape type (6) landscape pattern analysis, (7) landscape pattern changes, (8) agricultural and forest landscape sustainability evaluation, (9) change of agricultural and forest landscape sustainability and (10) agricultural and forest landscape sustainability modeling and discussed with some recommendations.

7.1 Conclusions

7.1.1 Land use and land cover assessment

Basically, assessment of LULC and its change of Lamtakhong watershed, Nakhon Ratchasima province between 1993, 2001 and 2009 were analyzed by using remotely sensed data with hybrid algorithm. They consisted of urban and built-up area, paddy field, field crop, perennial and orchard, pasture, forest land, water body and miscellaneous land. The development of LULC use between 1993, 2001 and 2009 shown that urban and built-up area, field crop, perennial and orchard, water body and miscellaneous land had continued to increase, while forest land had successively decreased.

7.1.2 Land use and land cover change detection

For LULCC during 1993-2001 and 2001-2009, urban and built-up area, field crop, perennial and orchard, water body and miscellaneous land had continued to increase with annual growth rate of 10.15 and 8.79, 3.65 and 9.67, 4.07 and 15.05, 4.12 and 1.14 and 0.86 and 0.48 sq. km, respectively. At the same periods, paddy field, pasture and forest land continuously decreased with annual declining rate of 1.71 and 1.75, 1.82 and 2.86 and 26.37 and 30.78, respectively.

In addition, most of increasing urban and built-up area and water body had been developed from agriculture land, forest land, and miscellaneous land between 1993 and 2001. At the same time, most of increasing field crop had succeeded from forest land and most of perennial and orchard came from field crop and forest land. In opposite, forest land was changed to urban and build-up area, agricultural land, water body, and miscellaneous land.

Similarity, it was found that most of increasing built-up area between 2001 and 2009 had been developed from agriculture land, forest land, and miscellaneous land while most of increasing field crop had succeeded from forest land. At the same time, most of perennial and orchard came from field crop and forest land. On the contrary, forest land was changed to urban and built-up area, agricultural land, water body, and miscellaneous land.

For the relationship between LULCC and terrain (elevation and slope) by overlay analysis, it was found that most of increased urban and built-up areas between 1993 and 2009 occurred in region having elevation less than or equal 250 m while field crop and perennial and orchard occurred in area having elevation between 250 and 750 m. At the same period, decreased forest land occurred in area having elevation less than 750 m. In the meantime, most of increased urban and built-up areas between 1993 and 2009 occurred in region having slope less than or equal 5% and field crop and perennial and orchard occurred in area having slope between 0 and 12%. At the same time, decreased forest land occurred in area having slope less than 20%.

7.1.3 Land use and land cover prediction

Basically, LULC in 2017 and 2025 were predicted by CA-Markov based on LULC in 1993 and 2009 and LULC in 2001 and 2009, respectively. It was found that in 2017 and 2025 urban and built-up area, field crop, pasture, water body and miscellaneous land were continued to increase while forest land is continued to decrease. Meanwhile, paddy field will decrease in 2017 and will increase in 2025 while perennial and orchard will increase in 2017 and will decrease in 2025.

7.1.4 Landscape type classification and assessment

Classification of landscape type in 1993, 2001, 2009, 2017 and 2025 were performed on landscape cell basis (1 x 1 km^2). Based on LULC data, four landscape types including urban, agricultural, forest and miscellaneous were classified using Zonal statistics according to the majority of LULC type in each landscape cell. The characteristic of landscape pattern and their dynamics were focused on agricultural and forest landscape. As results, during 1993 to 2025 the most dominant landscape was agricultural landscape while forest landscape was the next most abundant landscape type. The development of landscape types during 1993 to 2025 showed that urban, agricultural and miscellaneous landscapes had continued to increase but forest landscape had successively decreased.

7.1.5 Change of landscape type

Quantitative changes of landscape types in the past and future during 1993 to 2025 were computed using transitional matrix and change of agricultural and forest landscape pattern were evaluated in term of gain and loss. In the past (1993-2001 and 2001-2009) it was found that urban, agricultural and miscellaneous landscapes had increased with the annual growth rate at 8.25 and 5.52, 10.88 and 14.50, 3.63 and 0.25 sq.km, respectively. In contrast, forest landscape had decreased with the annual declining rate at 22.75 and 20.00 sq. km. Meanwhile, it was found that urban and miscellaneous landscapes had increased with the annual growth rate at 6.75 and 9.75 and 1.25 and 1.63 sq. km during 2009-2017 and 2017-2025, respectively. For agricultural landscape, it had increased with the annual growth rate at 14.38 sq. km during 2009-2017 while it had decreased with the annual declining rate at 1.00 sq. km during 2017-2025. In contrast, forest landscape had annually decreased in both periods with the annual declining rate at 22.38 and 10.38 sq. km during 2009-2017 and 2017-2025, respectively.

7.1.6 Landscape pattern analysis

Landscape metrics included fragmentation, complexity, isolation, diversity, and adjacency were used to analyze landscape pattern of agricultural and forest landscape in 1993, 2001, 2009, 2017 and 2025. It was revealed that landscape fragmentation of agricultural landscape during 1993-2025 were rather low. These imply that practically agricultural field in the study area was quite large. At the same time, landscape complexity, diversity and adjacency were moderate. These infer that agricultural field was mixed with others land cover. While, landscape isolation during 1993-2025 was high, it indicates that agricultural land was most fragmented. Meanwhile, landscape fragmentation, diversity and adjacency indices of forest landscape during 1993-2025 were low. These infer that fragmentation in forest landscape was rather low and forest land is large. In addition, landscape complexity of forest landscape in 1993 and 2001 were moderate. These infer that a forest land was mixed with others land cover. However, landscape complexity of forest landscape in 2009, 2017 and 2025 were low. These infer that forest lands the patch shape of forest landscape tents to more regular. While, landscape isolation during 1993-2025 was high, it indicates that forest land was most fragmented.

7.1.7 Landscape pattern changes

Landscape pattern indices in three periods during 1993-2009 for the past to present, during 2009-2017 for short term in the future and during 2009-2025 for long term in the future were here concluded in term of gain and loss by transitional matrix.

Consequently, it was found that agricultural during 1993-2009 consisted of heterogeneous types while agricultural landscape during 2009-2017 and during 2009-2025 will be composed homogeneous types. Meanwhile, forest landscape between 1993 and 2009 was a few disturbed while forest landscape during 2009-2017 and 2009-2025 will be more disturbed.

7.1.8 Agricultural and forest landscape sustainability evaluation

Basically, agricultural and forest landscape sustainability were evaluated using Sustainability Index (SUSI) relative to intensity of land use. As results, it was found that level of agricultural landscape sustainability in the past (1993-2009) and in the future (2009-2025) was moderate and theirs areas had continued to increase. However, at the same time area of sustainability of agricultural landscape at low level had continuously increased. While, agricultural landscape sustainability area at high level increased during 1993-2009 and 2009-2017 and it decreased during 2017-2025. In similarity, level of forest landscape sustainability in the past (1993-2009) and in the future (2017-2025) was moderate but its area had continued to decrease. In addition, forest sustainability at low level increased during 1993-2001 and it decreased between 2001 and 2025. Similarity, forest sustainability at low to moderate level decreased between 1993 and 2001 but it increased during 2001-2009. However, it will decrease between 2009 and 2025. These results infer that area of sustainability of forest landscape at low and low to moderate levels were unpredictable.

7.1.9 Change of agricultural and forest landscape sustainability

Change of agricultural and forest landscape sustainability in the past (1993-2009) and in the future for short term period (2009-2017) and long term period (2009-2025) were here extracted using transitional matrix and it was evaluated in term of gain and loss. In consequence, it was found that agricultural landscape sustainability in three periods had continued to decrease. In fact, ratio between gain and loss of sustainability was 356 to 405 sq. km in the past (1993-2009). Also, ratio between gain and loss of sustainability for short and long term period in the future were 4 to 388 and 8 to 466 sq. km, respectively. Similarity, it was found that forest landscape sustainability in three periods had continued to decrease and without gain. In fact, sustainability loss of forest landscape in three periods (1993-2009, 2009-2017 and 2009-2025) covered area of 151, 103 and 103 sq. km, respectively. With these results, it concluded that sustainability of agricultural and forest landscape in Lamtakhong watershed will be decreased in near the future.

7.1.10 Agricultural and forest landscape sustainability modeling

Simple and multiple linear regression models were employed for explanation the relationship between agricultural and forest landscape sustainability index in 2009 and theirs landscape metrics which include that Number of patches (NP), Mean patch fractal dimension index (MPFD), Mean patch proximity (MPI), Shannon's diversity index (SHDI), and Interspersion juxtaposition index (IJI). An optimum modeled was then used to predict agricultural and forest landscape sustainability in 2017 and 2025.

Consequently, it was found that an optimum model for agricultural and forest landscape sustainability index was multiple linear regression model. The model of agricultural landscape sustainability index (ALSI) and forest landscape sustainability index (FLSI) were obtained as follows:

$$\text{ALSI} = 0.5917 - 0.4595 \times \text{NP} + 0.5203 \times \text{MPFD} - 0.0005 \times \text{MPI} + 0.3007 \times \text{SHDI} + 0.2263 \times \text{IJI} \quad (9.1)$$

$$\text{FLSI} = 4.1329 + 0.3520 \times \text{NP} + 1.8191 \times \text{MPFD} - 0.2353 \times \text{MPI} - 1.0398 \times \text{SDI} + 0.2911 \times \text{IJI} \quad (9.2)$$

The coefficient (R) and coefficient of determination (R^2) of ALSI and FLSI were 0.90 and 0.81% and 0.64 and 0.41%, respectively. These results imply that 5 selected landscape metrics can be used to explained agricultural and forest landscape sustainability indices about 80 and 50 percentage, respectively.

In addition, agricultural and forest sustainability index in 2009, 2017 and 2025 based on SUSI and multiple linear regression model had been compared using overall accuracy and Kappa hat coefficient of agreement. As results it was found that overall accuracy and Kappa coefficient of predictive agricultural sustainability index in 2009, 2017 and 2025 of multiple linear regression models were 83.59, 81.64 and 80.08 percentage and 0.32, 0.34 and 0.39 respectively. Meanwhile, it was found that overall accuracy and Kappa coefficient of predictive forest sustainability index in 2009, 2017 and 2025 of multiple linear regression models were 46.88, 32.81 and 35.16 percentage and 0.20, 0.19 and 0.11, respectively. Results of overall accuracy were comparable with R^2 of ALSI and FLSI. However, Kappa coefficient shows poor agreement between SUSI and multiple linear regression models.

Finally, it may be agricultural and forest landscape sustainability can be measured as a degree of land use intensity using SUSI model.

7.2 Recommendations

Many objectives were taken into account dealing with assessment of LULC and prediction, landscape type assessment and landscape pattern analysis, landscape sustainability evaluation and modelling in Lamtakhong watershed. The possibly expected recommendations could be made for further studies as follows:

1. LULC prediction under CA-Markov should be applied the second order of Markov chain model for more precise result.

2. Finer resolution of spatio-temporal remotely sensed data and field survey should be applied to improve and enhance the capacity for landscape pattern analysis and landscape sustainability evaluation.

3. Size of landscape cell should be explored with optimum size for efficiencies landscape pattern analysis.

4. The evaluation of landscape sustainability in the future should be integrated an environmental, economic and social dimensions in the analysis.

5. Relevant landscape metrics to sustainability should be more investigated and applied for landscape sustainability modeling.

6. Landscape sustainability indicator value (SUSI) model should be tested in another area or region for verification and validation of the model. The output of SUSI will be useful for biodiversity conservation.

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APPENDICES

APPENDIX A

STATISTICCAL DATA FROM THE SIMPLE LINEAR REGRESSION ANALYSIS OF AGRICULTURAL LANDSCAPE SUSTAINABILITY

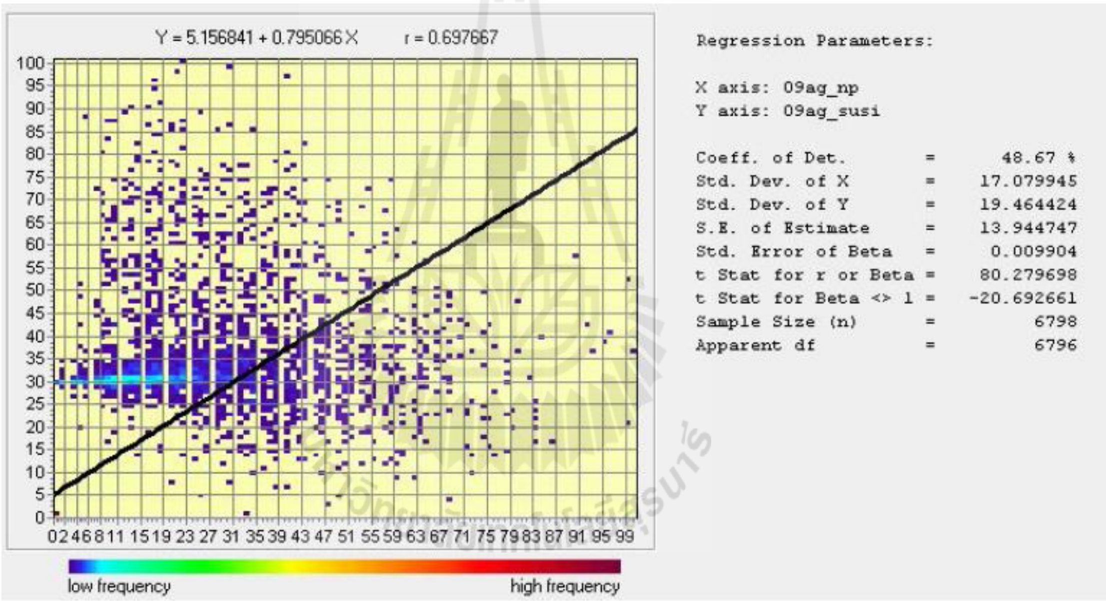

Figure A-1 Coefficient of simple linear regression analysis from number of patches and agricultural landscape sustainability.

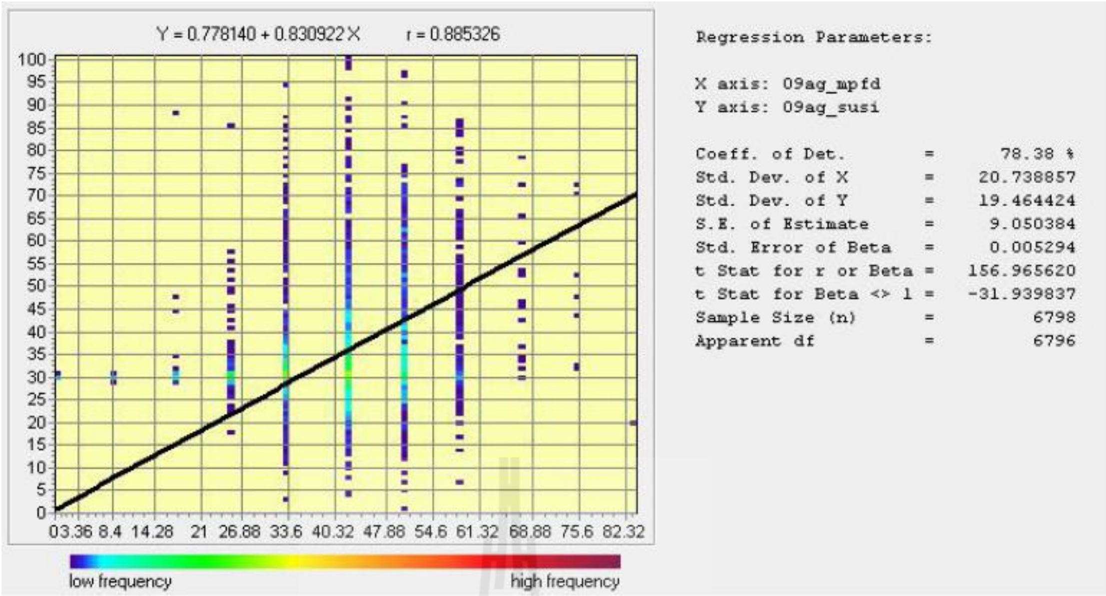

Figure A-2 Coefficient of simple linear regression analysis from mean patch fractal dimension index and agricultural landscape sustainability.

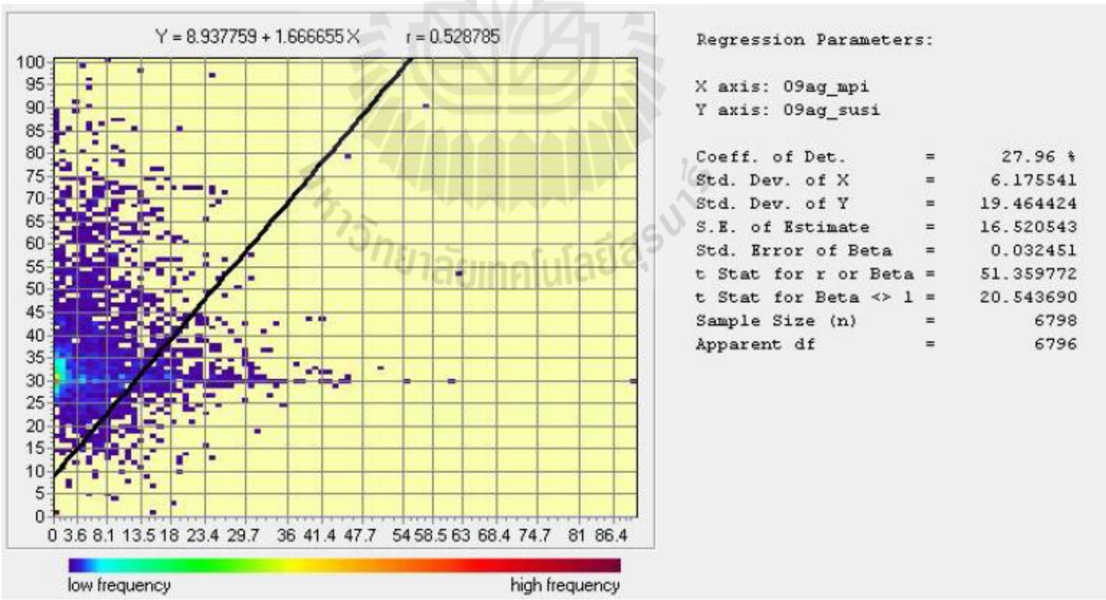

Figure A-3 Coefficient of simple linear regression analysis from mean proximity index and agricultural landscape sustainability.

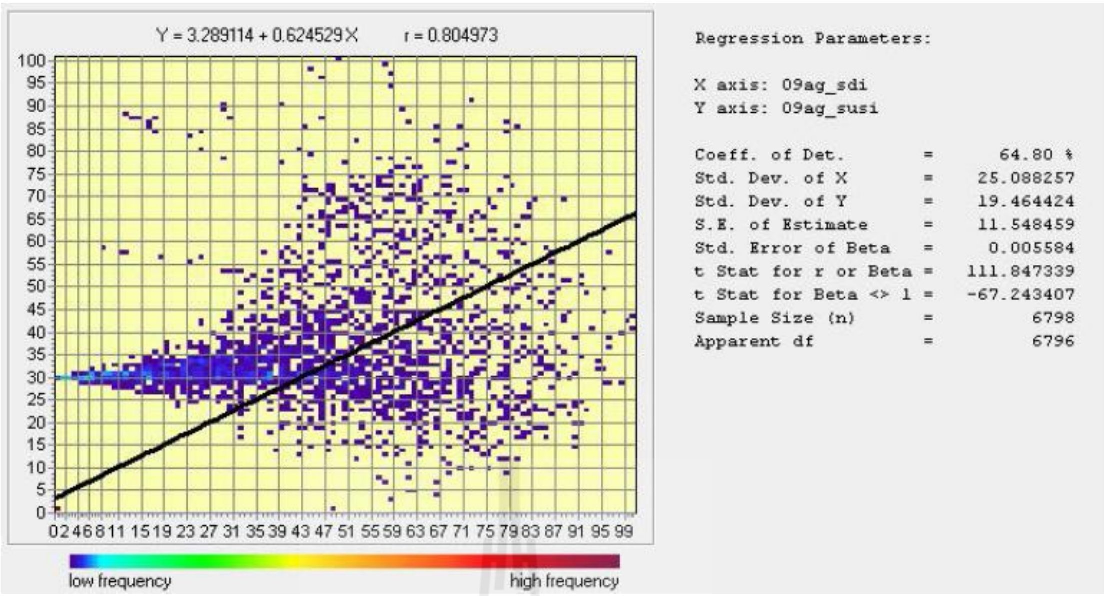

Figure A-4 Coefficient of simple linear regression analysis from Shannon's diversity index and agricultural landscape sustainability.

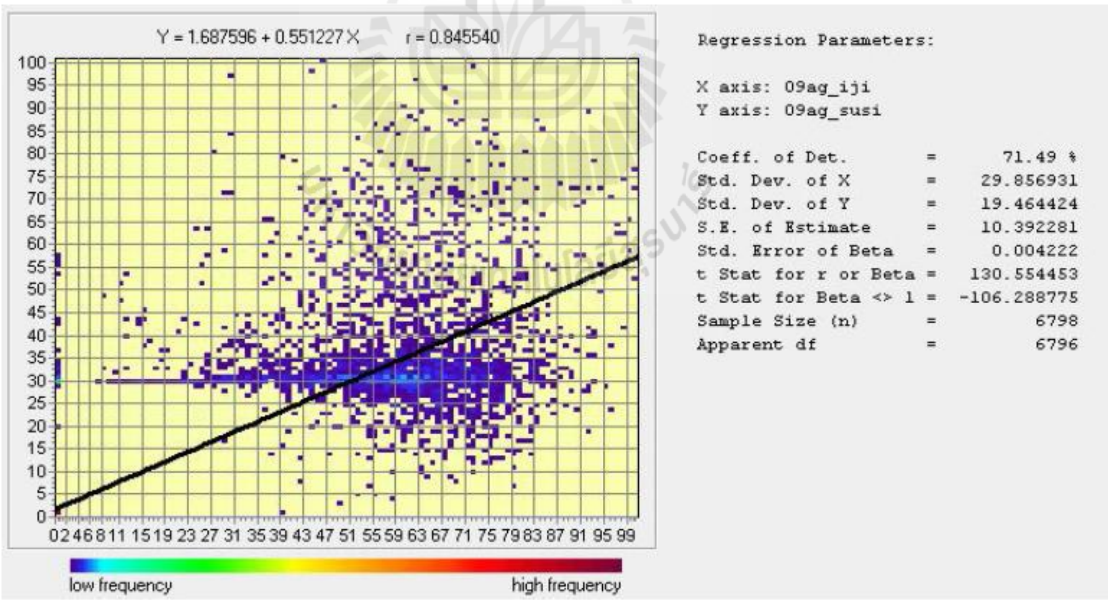

Figure A-5 Coefficient of simple linear regression analysis from Interspersion and juxtaposition index and agricultural landscape sustainability.

APPENDIX B

STATISTICCAL DATA FROM THE SIMPLE LINEAR REGRESSION ANALYSIS OF AGRICULTURAL LANDSCAPE PREDICTION

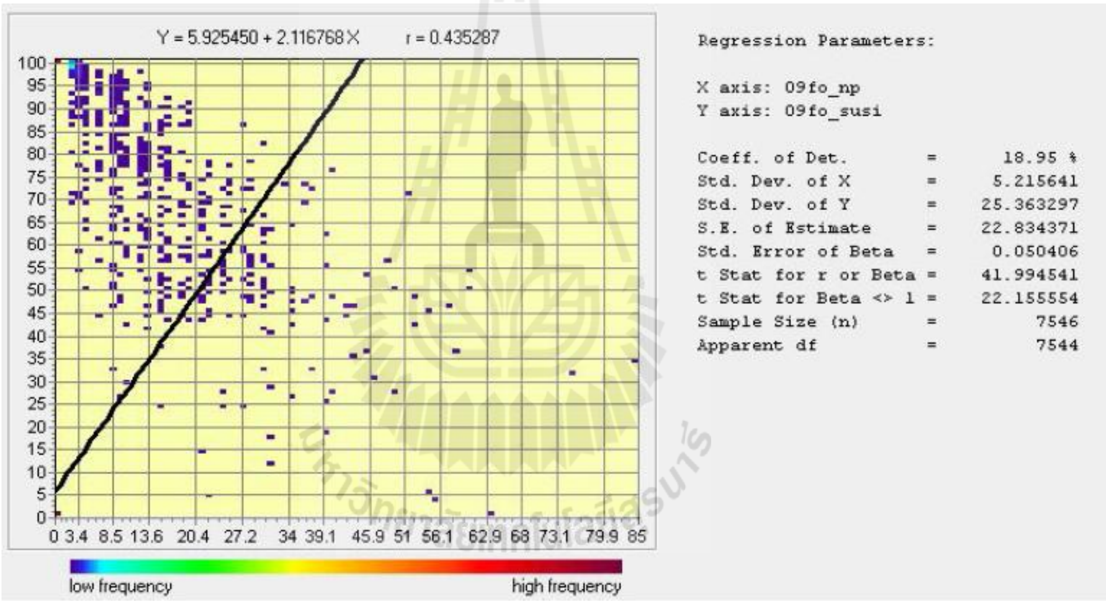

Figure B-1 Coefficient of simple linear regression analysis from number of patches and forest landscape sustainability.

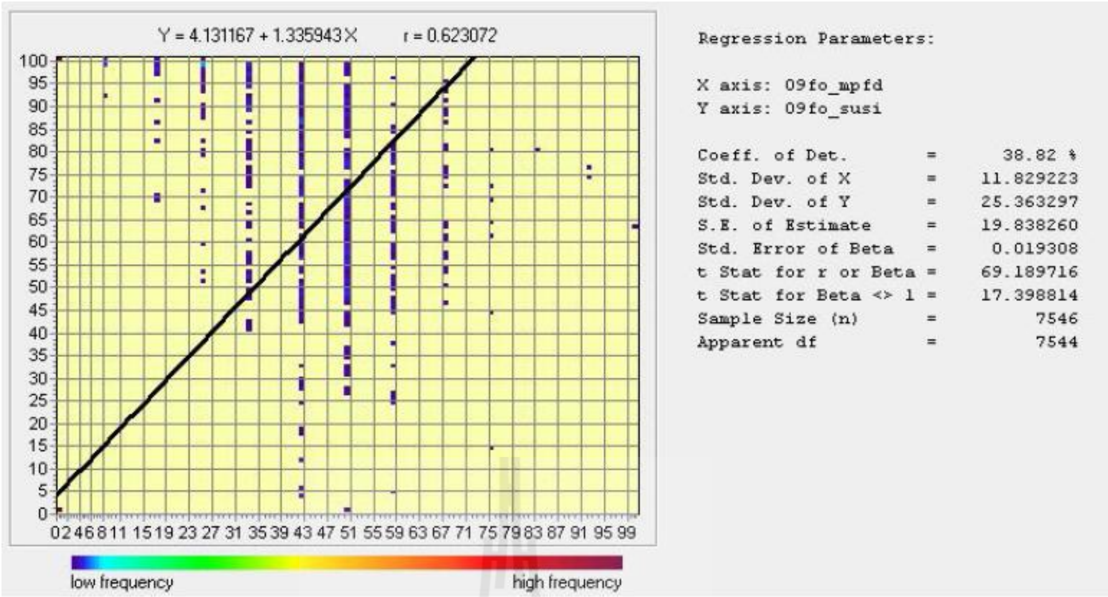

Figure B-2 Coefficient of simple linear regression analysis from mean patch fractal dimension index and forest landscape sustainability.

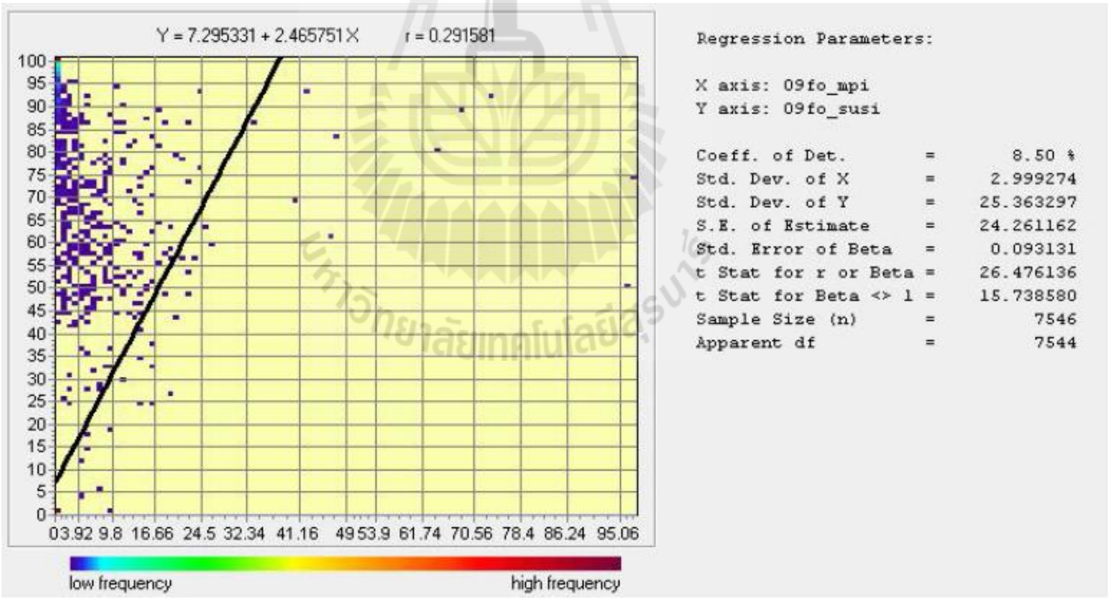

Figure B-3 Coefficient of simple linear regression analysis from mean proximity index and forest landscape sustainability.

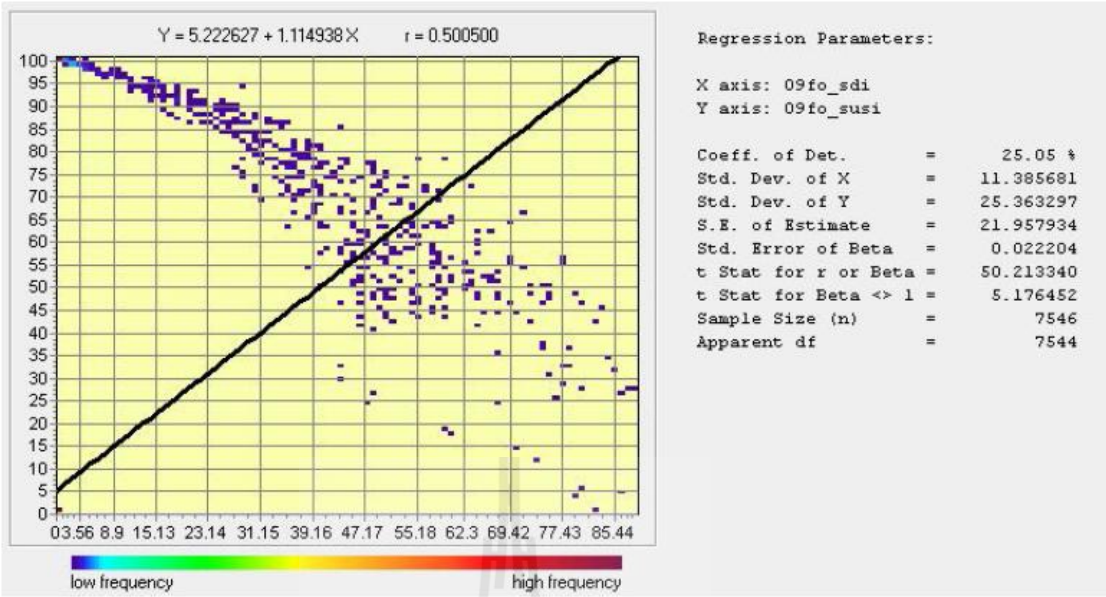

Figure B-4 Coefficient of simple linear regression analysis from Shannon's diversity index and forest landscape sustainability.

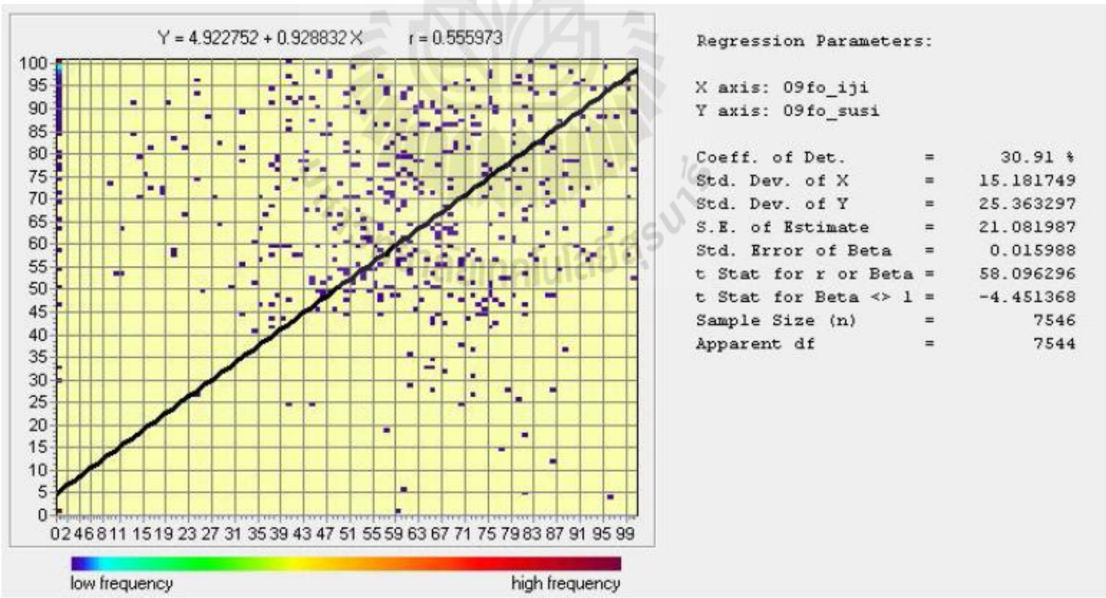

Figure B-5 Coefficient of simple linear regression analysis from Interspersion and juxtaposition index and forest landscape sustainability.

CURRICULUM VITAE

Name Siriwan Ruamkaew

Birthday 7 September 1978

Birth Place 35 Moo 4, Arunprasert Road, Pho Sai sub-district, Pa Tio district, Yasothon, Thailand

Education

- 1994 Bachelor of Science (Agricultural Management): Faculty of Agricultural Technology, King Mongkut's Institute of Technology Ladkrabang, Thailand
- 2005 Master of Science (Agricultural Resources and Environmental Management): Faculty of Agricultural Production, Mae Jo University, Thailand

Grants and Fellowships

- The potential student scholarships with Suranaree University of Technology
- The TRF/BIOTEC Special Program for Biodiversity Research and Training program (BRT)