ปัจจัยและความสัมพันธ์ที่มีผลต่อการเปลี่ยนแปลงการใช้ประโยชน์ที่ดินระหว่างปี พ.ศ. 2531-2550 และการคาดคะเนการใช้ประโยชน์ที่ดินในอนาคตโดยใช้แบบจำลอง คลู-เอส บริเวณลุ่มน้ำห้วยทับเสลา จังหวัดอุทัยธานี

นายคธาวุฒิ ไวยสุศรี

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชาโลกศาสตร์ ภาควิชาธรณีวิทยา
คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2554

FACTORS AND THEIR RELATIONSHIPS AFFECTING LAND USE CHANGE DURING 1988-2007 AND PREDICTING FUTURE LAND USE BY CLUE-s MODEL IN HUAI THAP SALAO WATERSHED, CHANGWAT UTHAITHANI

Mr. Katawut Waiyasusri

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Earth Sciences
Department of Geology
Faculty of Science
Chulalongkorn University
Academic Year 2011

Thesis Title	FACTORS AND THEIR RELATIONSHIPS AFFECTING LAND USE CHANGE DURING 1988-2007 AND PREDICTING FUTURE LAND USE BY CLUE-s MODEL IN HUAI THAP SALAO WATERSHED, CHANGWAT UTHAI THANI
By	Mr. Katawut Waiyasusri
Field of Study	Earth Sciences
Thesis Advisor	Assistant Professor Sombat Yumuang, Ph.D.

Accepted by the Faculty of Science, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master's Degree

……………………………………………….. Dean of the Faculty of Science

(Professor Supot Hannongbua, Dr.rer.nat)

THESIS COMMITTEE

……………………………………………….. Chairman

(Professor Thanawat Jarupongsakul, Ph.D.)

……………………………………………….. Thesis Advisor

(Assistant Professor Sombat Yumuang, Ph.D.)

……………………………………………….. Examiner

(Srilert Chotpantarat, Ph.D.)

……………………………………………….. External Examiner

(Assistant Professor Sunya Sarapirom, Ph.D.)

คธาวุฒิ ไวยสุศรี: ปัจจัยและความสัมพันธ์ที่มีผลต่อการเปลี่ยนแปลงการใช้ประโยชน์ที่ดินระหว่างปี พ.ศ. 2531-2550 และการคาดคะเนการใช้ประโยชน์ที่ดินในอนาคตโดยใช้แบบจำลอง คลู-เอส บริเวณลุ่มน้ำห้วยทับเสลา จังหวัดอุทัยธานี. (FACTORS AND THEIR RELATIONSHIPS AFFECTING LAND USE CHANGE DURING 1988-2007 AND PREDICTING FUTURE LAND USE BY CLUE-s MODEL IN HUAI THAP SALAO WATERSHED, CHANGWAT UTHAI THANI) อ.ที่ปรึกษาวิทยานิพนธ์หลัก : ผศ.ดร. สมบัติ อยู่เมือง, 206 หน้า.

การศึกษาปัจจัยและความสัมพันธ์ที่มีผลต่อการเปลี่ยนแปลงการใช้ประโยชน์ที่ดินระหว่างปี พ.ศ. 2531-2550 ในบริเวณลุ่มน้ำห้วยทับเสลา จังหวัดอุทัยธานี ได้ทำการศึกษาโดยใช้ข้อมูล 3 ประเภทประกอบด้วย ข้อมูลที่จัดทำด้วยระบบสารสนเทศภูมิศาสตร์และข้อมูลจากการสำรวจระยะไกล ข้อมูลจากการสำรวจภาคสนาม และข้อมูลจากการวิเคราะห์ในห้องปฏิบัติการ นอกจากนี้การศึกษาวิจัยยังได้คาดคะเนลักษณะการใช้ประโยชน์ที่ดินในอนาคตโดยใช้แบบจำลองคลู-เอส เพื่อจำลองรูปแบบการใช้ประโยชน์ที่ดินที่อาจจะเกิดขึ้น และสังเคราะห์คาดคะเนการใช้ประโยชน์ที่ดินในพื้นที่ดังกล่าวแต่ละช่วงเวลาตามลำดับ

การวิเคราะห์รูปแบบการใช้ประโยชน์ที่ดินในลุ่มน้ำห้วยทับเสลาระหว่างปี พ.ศ. 2531-2550 ได้จากการแปลความหมายโดยกระบวนการโทรสัมผัสและการออกภาคสนาม จากนั้นนำผลที่ได้มาจัดทำและแสดงผลเป็นแผนที่ ผลการวิเคราะห์พบว่าพื้นที่ป่ามีการเปลี่ยนแปลงมากที่สุด ส่วนใหญ่เกิดการเปลี่ยนแปลงบริเวณตอนกลางของลุ่มน้ำห้วยทับเสลา (ห้วยระบำ) และบริเวณตะวันออกของลุ่มน้ำห้วยทับเสลาซึ่งเป็นพื้นที่ราบลุ่มแม่น้ำ (ห้วยทับเสลา และห้วยรัง)

การวิเคราะห์ปัจจัยและความสัมพันธ์ที่มีผลต่อการเปลี่ยนแปลงการใช้ประโยชน์ที่ดิน ได้ใช้ข้อมูลเชิงพื้นที่ที่เกี่ยวข้อง ได้แก่ ระดับความสูงของภูมิประเทศ ความลาดชัน ปริมาณน้ำฝนโดยเฉลี่ย ระยะห่างจากลำน้ำ ระยะห่างจากถนน ระยะห่างจากหมู่บ้าน และลักษณะเนื้อดิน มาทำการวิเคราะห์การถดถอยโลจิสติก ผลการวิเคราะห์พบว่า พื้นที่ดังกล่าวได้เปลี่ยนแปลงจากพื้นที่ป่าไม้เป็นพื้นที่เกษตรกรรม เนื่องจากปัจจัยระยะห่างจากถนนและปัจจัยระยะห่างจากชุมชนเป็นตัวเร่งให้เกิดการเปลี่ยนแปลง

การคาดคะเนลักษณะการใช้ประโยชน์ที่ดินในอนาคตโดยใช้แบบจำลองคลู-เอส ได้จำลอง 2 ภาพเหตุการณ์ที่แตกต่างกัน ในปี พ.ศ.2570 คือ การเปลี่ยนแปลงรูปแบบการใช้ประโยชน์ที่ดินในอดีตโดยไม่มีการกำหนดขอบเขตอนุรักษ์ และการเปลี่ยนแปลงรูปแบบการใช้ประโยชน์ที่ดินในอดีตโดยมีการกำหนดขอบเขตอนุรักษ์ ผลการวิเคราะห์พบว่า ภาพเหตุการณ์ที่ 1 พบว่าพื้นที่ป่าไม้ได้ลดจำนวนลงเป็นอย่างมากเหลือเพียงร้อยละ 63 ของพื้นที่ทั้งหมด (จากร้อยละ 68 ในปี 2550) พบการเปลี่ยนแปลงบริเวณตอนกลางของลุ่มน้ำทับเสลา ขณะที่ภาพเหตุการณ์ที่ 2 พบการเพิ่มขึ้นของรูปแบบการใช้ประโยชน์ที่ดินชุมชนและสิ่งปลูกสร้างบริเวณรอบๆ ตัวอำเภอเมืองลานสัก และบริเวณตะวันออกของลุ่มน้ำห้วยทับเสลา ข้อมูลและผลวิเคราะห์ที่ได้จากการศึกษาในครั้งนี้ สามารถนำข้อมูลเชิงพื้นที่ไปใช้สำหรับสนับสนุนการตัดสินใจในการกำกับ ติดตามและควบคุมการเปลี่ยนแปลงรูปแบบการใช้ประโยชน์ที่ดินในพื้นที่ลุ่มน้ำห้วยทับเสลามีประสิทธิภาพอย่างเป็นรูปธรรมที่มีเป้าหมายในเชิงพื้นที่ที่ชัดเจนในการดำเนินการที่ดีขึ้นในอนาคต

ภาควิชา ธรณีวิทยา ลายมือชื่อนิสิต
สาขาวิชา โลกศาสตร์ ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก
ปีการศึกษา 2554

5272238523 : MAJOR EARTH SCIENCES

KEYWORDS : GIS AND REMOTE SENSING / LAND USE CHANGE / CLUE-s MODEL / THAP SALAO WATERSHED

KATAWUT WAIYASUSRI : FACTORS AND THEIR RELATIONSHIPS AFFECTING LAND USE CHANGE DURING 1988-2007 AND PREDICTING FUTURE LAND USE BY CLUE-s MODEL IN HUAI THAP SALAO WATERSHED, CHANGWAT UTHAI THANI. ADVISOR : ASST. PROF. SOMBAT YUMUANG, Ph.D., 206 pp.

GIS and remote sensing data interpretation, field investigation, and laboratory analysis were carried out to investigate dynamic spatial patterns of land use changes and to identify driving factors that caused land use changes during 1988-2007 in Huai Thap Salao watershed, Changwat Uthai Thani. Besides, the purpose of study was to simulate model of land use changes using CLUE-s model to predict the future land use change in current.

Dynamic spatial patterns of land use changes in Huai Thap Salao watershed during 1988-2007 were detected from remote sensing interpretation and field surveys that were complied into a GIS database. Various maps were constructed from those relevant parameters derived from the database. Deforestation which the major change was mostly found in the central part (Huai Rabam stream) and the eastern part (Huai Thap Salao and Huai Rang stream) of Huai Thap Salao watershed.

The affecting parameters, namely elevation, slope, mean annual precipitation, distance to streams, distance to roads, distance to villages and soil textures were analyzed by logistic regression analysis. The result revealed that the forest land had been changed to agriculture land and were related to the distance to villages and the distance to roads in Huai Thap Salao watershed during 1988-2007.

The CLUE-s model was simulated from two scenarios, namely, scenario without restriction area and scenario with reserved area in 2027. Without restriction area, the result revealed that the highest rate of deforestation would be 63% (from previously 68% in 2007) and mostly in the central part of Huai Thap Salao watershed whereas with reserved area, it revealed that the mostly increased land use category would be urban and built-up land surrounding Amphoe Lan Sak in the eastern part of Huai Thap Salao watershed. The final results from this research can be used as a spatial data for decision making in handling, monitoring, and controlling the land use and forest management in order to enhance the land use and forest management efficiency.

Department : Geology	Student's Signature ....
Field of Study : Earth Sciences	Advisor's Signature ....
Academic Year : 2011	

ACKNOWLEDGEMENTS

The Graduate School of Chulalongkorn University and Geo-Informatics and Space Technology Development Agency (Public Organization) provided a partial funding and data for study.

I sincerely thank my Advisor, Assistant Professor Dr. Sombat Yumuang, Department of Geology, Faculty of Science, Chulalongkorn University for their supports, encouragements, critically advises and reviews of thesis.

I would like to thank Miss Boossarasiri Thana, Department of Geology, Faculty of Sciences, Chulalongkorn University ,Mr. Komsan Kiriwongwattana and Mr. Phraepan Hammawan Department of Geography, Faculty of Arts, Silapakorn University especially for their valuable suggestion and support. Furthermore, I would like to thank Miss Wilaiwan Chanpuang, Coordinator, Prachakom Muang Uthai for his useful suggestions.

I sincerely gratify the Geo-Informatics and Space Technology Development Agency (Public Organization) (GISTDA), and Royal Thai Survey Department, for their permission to use essential data for this research.

I thank to Mr. Nawat Chiangsai, Miss Wilairat Khositchaisri, Mr. Sorasit Thanomponkrang, Mr. Morakot Worachairungreung, Mr. Chakarat Buaket, Mr.Puttinun Sukumonjan, Miss Chanita Duangyiwa, Miss Wichuratree Klubsaeng, and all of my friends for their support throughout my thesis with their valuable suggestions.

Finally, I would like to thank my parents for their support and encouragement throughout my study at the university.

CONTENTS

Page

Page

Page

Page

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

Figure | Page

Figure Page

Figure Page

Figure Page

CHAPTER I

INTRODUCTION

Deforestation in Thailand is mainly caused by human activities and is a major reason of the degradation of the forest resources in the last 50 years. In 1961, Thailand issued the economic and social development plan of the nations for the first time. It impacted the large expansion of settlements, industries, and agriculture areas causing the invasion of the upstream forests. In the year 1961, forests in Thailand covered an area of about 273,600 km^2 and they were left only 129,600 km^2 in the year 1998 (the Office of Surveying and Map, Department of Forestry, 2002) It meant that throughout 37 years the forest areas were decreased as an area of about 144,000 km^2 and the average decreased forest areas were 3,840 km^2 per year. The impacts from these decreased forest areas have caused both direct and indirect effects on other resources (soil, water, air, etc.) in both of quantity and quality terms which will consequently effect on human life in the country as well.

1.1 Rationale

Huai Thap Salao watershed also faced with problem of deforestation for agriculture areas, especially in Khao Hin Lek Fai village, Tambon Rabam, Amphoe Lan Sak, Changwat Uthaithani where people migrated to the area and built settlements since 1978 (Sutee Sadee, 2007). The first waves of settlements in the area were compacted as clusters in limited areas. The main economic activities in the area were depended on agricultures and forests but there was the problem of inappropriate land use planning in this basin area which was caused the degradation of natural resources (Prachumporn Niratsayakul, 1999). Besides, the problem of soil erosion was also caused from the rainfall and surface runoff in the slope areas too. Moreover, in the dry season there was the problem of water shortage for agriculture activities (Office of Natural Calamity and Agricultural Risk Prevention, 2007). So the understanding of patterns and affecting factors for land use changes are necessary for the sustainable management of land use planning of Huai Thap Salao watershed. These required information have not been studied by a systematic approach with the application of remote sensing technology in conjunction with Geographic Information Systems (GIS) for sustainable development in Huai Thap Salao watershed yet.

In general, land use changes was originated by evidence from empirical case studies that identified both proximate causes and underlying forces of tropical deforestation suggested that no universal link between cause and effect existed (Geist and Lambin, 2002). Rather than providing support for dominant theories of global deforestation (neoclassical, impoverishment, political ecology), analysis of these studies showed that tropical forest decline was determined by different combinations of various proximate causes and underlying driving forces in varying geographical and historical contexts. Besides, the study land cover and land use change process and its implication for environmental condition and ecosystem functioning was conducted by Gonzales (2009), it was essential to identify and recognized the services provided by the ecosystem. Remotely sensed data together with GIS increase the capability to analyze the human impact on the environment in quantitative, qualitative and spatial form (Jensen and Kiefer, 2007). The main goal of this study was to generate the land cover and land use multi-temporal information. Land use planning was the primary discipline to approach sustainable way of management. The Conversion of Land Use and its Effects at Small regional extent modeling framework (CLUE-s) was developed to simulate land use change using empirically quantified relations between land use and its affecting factors in combination with dynamic modeling of competition between land use categories (Verburg and Veldkamp, 2004). Every year of simulation a land use prediction map was created. It was an important tool in studying land use in the future, or track land use changes for various agencies to solve problems and making a plan for land use management. The results of some scenarios based on main relevant settings were applied to conclude the main outputs, source of information and tools for decision makers for sustainable environmental management and land use planning was conducted by Orékan (2005).

This thesis addresses to study the spatial patterns of land use changes in Huai Thap Salao watershed, Changwat Uthaithani during 1988-2007, to identify affecting factors that caused land use changes and to simulate models of land use changes as well as extrapolate to predict the CLUE-s model of the future change in Huai Thap Salao watershed, Changwat Uthaithani.

1.2 Objectives

The purposes of this study are

- To investigate dynamic spatial patterns of land use changes during 1988-2007 in Huai Thap Salao watershed.
- To analyze and identify affecting factors that caused land use changes in Huai Thap Salao watershed.
- Simulating and extrapolating land use changes by the CLUE-s model for predicting of the future scenarios in Huai Thap Salao watershed under different scenarios.

1.3 Scope and limitation

In this research Landsat 7ETM+ satellite images data was not available to use to analyze of land use patterns during 1988-2007 in Huai Thap Salao watershed because of the Scan Line Corrector (SLC) in the ETM+ instrument failed on May 31, 2003, that caused some areas to be imaged twice and others that were not imaged at all. So the analysis of land use changes in this research was especially conducted from Landsat 5TM of resolution 30 meters to study land use patterns during 1988-2007 in the study area.

Beside, the CLUE-s model was only simulated from two scenarios, namely, scenario without restriction area and scenario with reserved area in Huai Thap Salao watershed. Whereas the third scenario of the CLUE-s model that was used economic factors were not addressed in this research because the economic data was not available and too complex to be simulated and extrapolated.

1.4 Location of the study area

The study area is conducted in the Huai Thap Salao watershed, situated in Changwat Uthaithani that is in the west of Central Thailand (Figure 1-1). The extents of the coordinates of the study area are approximately defined as 520000 E, 1450000 N in the northwestern edge and 580000 E, 1690000 N in the southeastern edge in Universal Transverse Mercator projection with 47 North zone in WGS 1984 ellipsoid (Figure 1-2). The total study area is about 766.85 km^2, covering path 130 row 49 of LANDSAT-5 TM. Its elevation ranges from 50 to 1600 meters above average mean sea level. The geographical features of the study area consist of high mountainous and narrow flood plain areas.

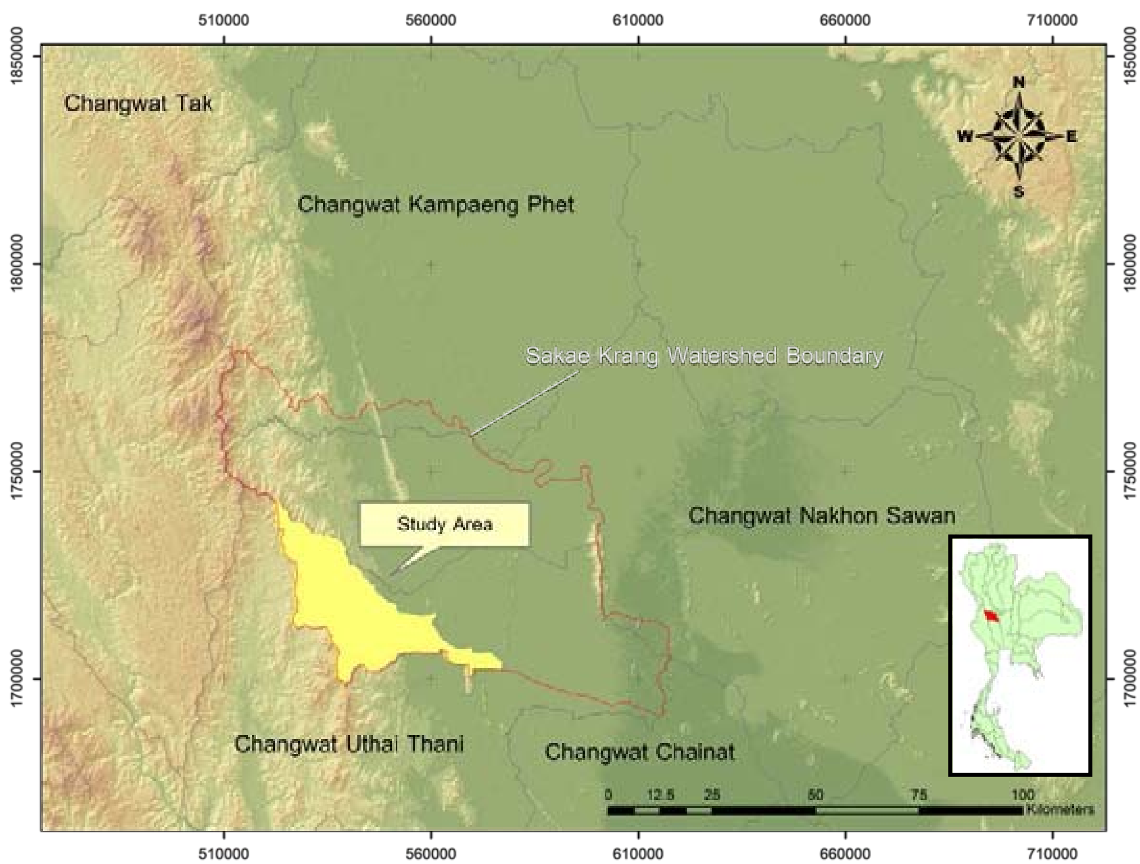
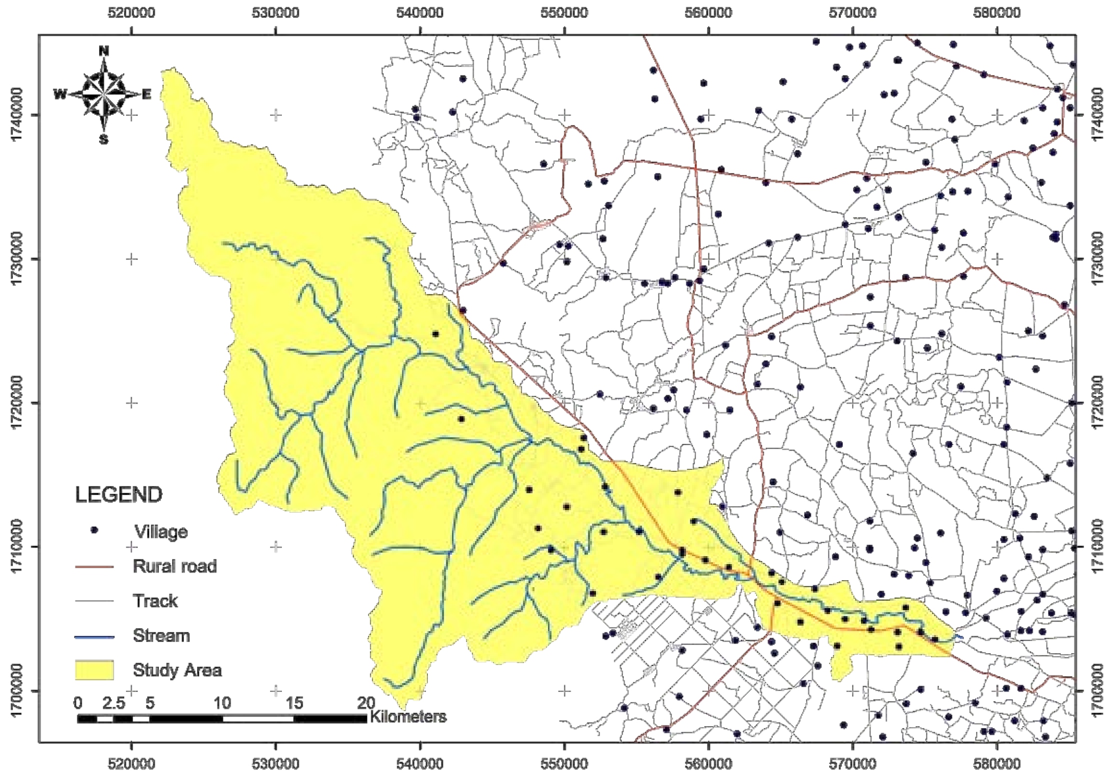
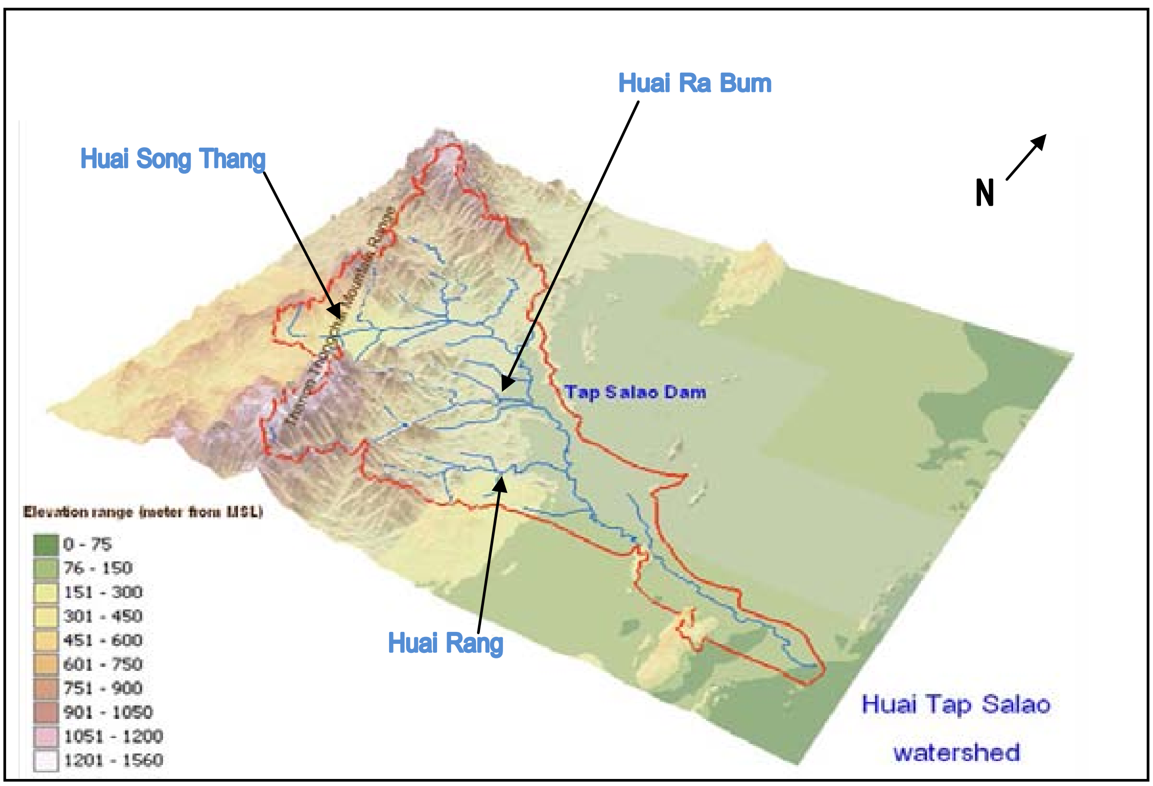


Figure 1-1Geographic setting of the study area.



a)



b)

Figure 1-2 a) Location of the study area with important reference locations, and

b) 3D Digital Terrain Model of Huai Thap Salao watershed.

1.5 Expected outputs

The expected outputs of this thesis consist of:

- Land use and land use change maps during 1988-2007 in Huai Thap Salao watershed.
- Relationships between affecting factors that caused land use changes in Huai Thap Salao watershed.
- Spatial allocation maps of the future scenarios simulated and predicted from land use changes during 1988-2007 by the CLUE-s model in Huai Thap Salao watershed.

These results should supply planners and decision-makers with adequate and understandable information for a more effective planning with appropriate strategies for reducing and mitigating land use changes and related phenomena in a long term risk that may be repeatedly occurred in the study area as well as in other areas of similar geographical conditions. Therefore, the land use changes were investigated to study the possibly potential changes in land use with a view to identifying more sustainable systems of natural resources management. Meanwhile, to reduce the impact on the over-exploitation of resources is also a key issue for the better quality of people life in Huai Thap Salao watershed.

1.6 Research methodology

To accomplish the aims of this thesis, the research involves four sequential steps are designed. Each of which is described as follows:

1.6.1 Preparation

This step includes:

- Literature review of the related researches in the study area, western Thailand, and other countries.

- Acquisition and study of the previous basic data acquisition, i.e. satellite images of medium resolution (Landsat 5TM), topographic map, land use map, and soil map to understand the topography, land use, and agronomy of the study area as general background information.
- Intensive comprehension on the conceptual framework of land use changes, deforestations and CLUE-s model especially the criteria to evaluate land use changes occurrence.

1.6.2 Field investigation

The field investigation and direct observation were carried out as follows:

- Reconnaissance to understand and recognize the limitation in the study area for preparing the data and related plan that would be used in further steps of the field investigation.
- Intermediate field investigation to conduct ground-truth to inspect the correctness of the analyzed results from the remote sensing image analysis and interpretation.

1.6.3 Laboratorial studies

The laboratorial analysis is conducted as follows:

- Thematic (GIS and remote sensing) data preparation. These inventory data consist of topography (slope, elevation), land use and land cover. Software of geographic information system (GIS) and remote sensing (ArcGIS 9.2 and ERDAS IMAGINE 8.7) are applied in developing, manipulating, and analyzing the digital data.
- Interpretation of medium resolution satellite images (Landsat 5TM) that were acquired during 1988-2007. This sub-step was conducted to develop the new data (e.g. deforestation). These inventory data were also checked from ground-

truth information from brief field traverses to inspect the accuracy in the intermediate field investigation.

- Land use changes analysis in Huai Thap Salao watershed is conducted. This is preliminary land use changes by logistic regression analysis to present the spatial relationship between what types of land use changes are taking place and explores the relevant factors that drive land use changes (as theoretically mentioned) in Huai Thap Salao watershed. The CLUE-s model was used to predict the future scenarios under different scenarios.

1.6.4 Synthesis, discussion and conclusions

This step includes:

- Synthesizing, discussing and concluding deforestation occurrence in Huai Thap Salao watershed.

In order to accomplish the objectives of this research, the schematic diagram illustrating the present methodology system was designed as shown in Figure 1-3.

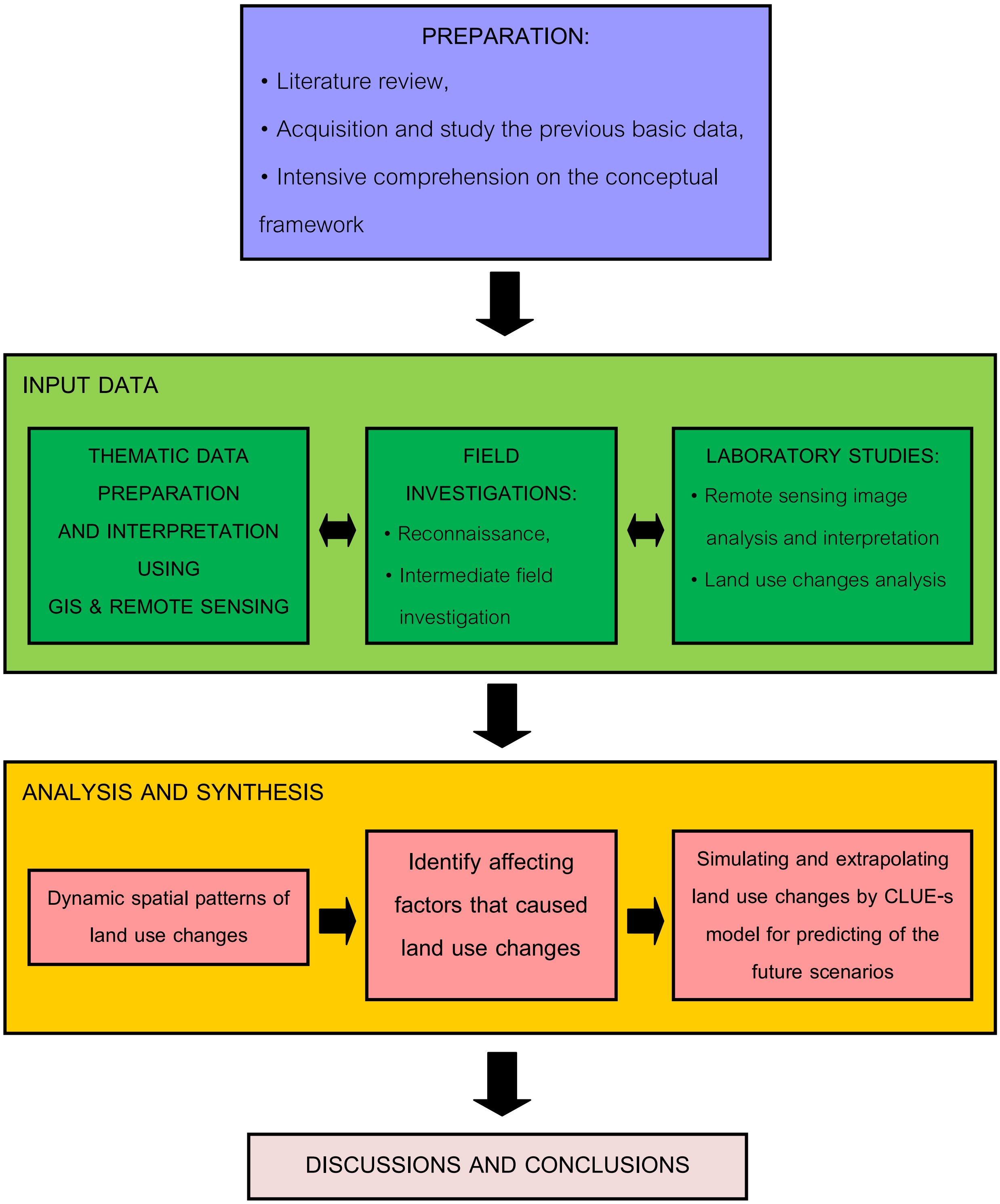


Figure 1-3 Schematic diagrams illustrating the research methodology system.

1.7 Components of the thesis

This thesis comprises five chapters including this introductory Chapter 1. Chapter 2 is initiated with the definition and terminology of deforestation and driving factors of land use changes research. The applications of the remote sensing, geographic information system (GIS) and Global positioning system (GPS) in land use changes are briefly reviewed. The previous investigations from the related technical literatures are also presented.

Since the possibilities and limitations of the proposed methodology can only be evaluated critically when field data are available. Data preparation and interpretation in terms of types of input data and data production stage is given in Chapter 3. In this chapter, data input from thematic data pre-processed with the application of geographic information system (GIS) and remote sensing techniques are produced and interpreted.

Following the data preparation and interpretation stages, land use change analysis of Huai Thap Salao watershed by the statistic approach is proposed in Chapter 4. Identify affecting factors that caused land use changes by logistic regression analysis to present the spatial relationship between what types of land use changes and the relevant causes. Besides, the affecting factors of land use changes are then indicated. The approach of CLUE-s model was simulated from two scenarios, namely, scenario without restriction area and scenario with reserved area in 2027 are also proposed in this chapter.

In Chapter 5 the attention is firstly focused on discussing of dynamic spatial patterns of land use changes describing the results of deforestation processes. Secondly, affecting factors were caused land use changes in Huai Thap Salao watershed are discussed. Thirdly, the predicting future land use conditions to forecast possible land use patterns based on the affecting factor in the past and in the current situation are also discussed. Finally, conclusions and recommendations in this research were discussed.

CHAPTER II

LITERATURE REVIEW

In this chapter, the definition and terminology of deforestation and affecting factors of land use change researches and the applications of the remote sensing, geographic information system (GIS) and Global positioning system (GPS) in land use changes are briefly reviewed. Besides, the CLUE-s model structure and the previous investigations from the related technical literatures are also presented.

2.1 Definition and terminology

There are many definitions about deforestation. For example, the Food and Agriculture Organization-FAO in the documentation for the Convention to Combat Desertification (2001) defined as “The conversion of forest to another land use or the long-term reduction of the tree canopy cover below the minimum 10 percent threshold”. While the United Nations Framework Convention on Climate Change - UNFCCC (2003) defined as “the direct human-induced conversion of forested land to non-forested land”. Lambin et al. (2004) defined the meaning of the deforestation as “The term can thus be viewed as a process of destroying forests (the removal of trees) by human beings and their replacement by agricultural systems”. The United Nations Environment Programme-UNEP (2002) defined the meaning of the deforestation as “specifically excludes areas where the trees have been removed as a result of harvesting or logging, and where the forest is expected to regenerate naturally or with the aid of silvicultural measures”.

It comes out from the above definitions that land use and land cover are not the same although they may overlap. It can be stated that the term "land cover" refers to the biophysical state of the earth’s surface and immediate subsurface. It includes biota, surface water, ground water, soil, topography and human-made structures (Braimoh and Vlek, 2004), whereas land use refers to the intended employment and management underlying human exploitation of a land cover. It is characterized by the arrangements, activities and input people undertake in a certain land cover type to produce, change or maintain it (Di Gregorio, 2005).

2.2 Affecting factors of land use changes

Affecting factors can be simply defined as causes or factors responsible for land use and land cover changes - LUCC (Braimoh and Vlek, 2004). A precise meaning of the "drivers" or "determinants" or "affecting factors" of land use change is not always clear (Briassoulis, 2000). Therefore, two principal distinctions are made regarding the origins of the drivers of land use and land cover change on one hand, and the factors and processes that contribute to land use change and, through certain human actions, cause land cover and environmental change on the other hand.

Concerning the first distinction, two main categories are almost distinguished: biophysical and socio-economic affecting factors cited by Orékan (2007). The "bio-physical affecting factors" include characteristics and processes of the natural environment (weather and climate variations, landform, topography, and geomorphologic processes, volcanic eruptions, plant succession, soil types and processes, drainage patterns, availability of natural resources) while "socio-economic affecting factors" comprise demographic, social, economic, political and institutional factors and processes (population and population change, industrial structure and change, technology and technological change, the family, the market, various public sector bodies and the related policies and rules, values, community organization and norms, property regime).

On the other hand, Lambin (2004), took into account a variability that exists in the land cover types, the physical environments, the socio-economic activities and the cultural contexts associated with land use change to distinguish four categories of affecting forces of land use changes. These are factors that:

- Affect the demands that will be placed on the land, i.e. population and affluence.

- Control the intensity of exploitation of the land: through technology.
- Are related to access to or control over land resources: the political economy, and
- Create the incentives that motivate individual decision-makers: the political structure, attitudes and values.

Therefore, the author suggested for identifying the causes of land use change to first understanding how these different factors interact in specific environmental, historical and social contexts to produce different uses of the land.

The next subsections focus specifically on the forces that drive respectively land use and land cover changes (LUCC) and deforestation in Tropical regions as one of the main component of global environment.

2.3 Affecting factors of land use changes in Tropical regions

The development of land use change models to generate projections requires, first, a good understanding of the major causes of these changes in different geographical and historical contexts (Lambin and Geist, 2002). Numerous factors of change have been identified from selective land use changes studies that focus on the tropical regions. The most cited drivers in selected case studies corresponding to six different tropical countries (included regions) can be summarized as follow in Table 2-1 (Orékan, 2007). The six case studies were selected based on geographical location to which are referred the numbers 1 to 6 as a follow:

1) Serneels and Lambin (2001)	Kenya
2) Mertens and Lambin et al. (1997)	Cameroun
3) Gobin et al. (2002)	Nigeria
4) Braimoh (2004)	Ghana
5) Verburg and Veldkamp (2001)	China
6) Verburg and Veldkamp (2004)	Philippines

Table 2-1 Affecting factors of land use change extracted from selected case studies in tropical regions (Orékan, 2007).

Affecting factors	Case study references					
	1	2	3	4	5	6
Demography						
Population density	X			X	X	X
Urban population					X	
Labor force density					X	
Agricultural labor force density					X	
Climate						
Range in precipitation				X		
Total precipitation				X		
Average temperature (temperature)					X	
Agro-climatic zone	X					
Economy and infrastructure						
Distance to city (or towns)	X	X			X	
Distance to river (or river)			X		X	
Distance to stream			X			
Distance to road (or road)	X	X	X	X		
Distance to water	X			X		
Distance to forest/non forest		X				X
Market accessibility (or distance to market)			X	X		
Distance to settlements			X			
Illiteracy					X	
Income					X	
Geomorphology						
Mean altitude (or altitude/elevation)	X			X	X	X
Mean slope (or slope)				X	X	X
Aspect				X		
Soil						
Land tenure (or land status)	X			X		X
Suitability for agriculture (aptitude)	X	X		X		

The table shows that demography and accessibility are the most dominant affecting factors which 66% and 50% of the case studies cited these affecting factors as explanatory factors of land use changes in their respective study areas. This observation is confirmed by Lambin and Geist (2002) who stressed that the relevant drivers are: population growth, change in population structure and migration; intensification of agriculture, seeking an increased productivity; improvement of accessibility; changes in life styles and rural-urban interactions; demands for energy, products and amenities (consumption patterns, tourism); extreme events and variability in biophysical conditions; macro-economic drivers; national policy measures and directives, opening to external economy and economic integration; external drivers (globalization, trade regimes, international agreements), etc.

In conclusion, these interrelations can be summarized with some interconnections between various drivers and land use change through the following equation:

Land use = f (pressures, opportunities, policies, vulnerability, and social organization) with

Pressures = f (population or resource users, labor availability, quantity of resources, and sensitivity of resources)

Opportunities = f (market prices, production costs, transportation costs, and technology)

Policies = f (subsidies, taxes, property rights, infrastructure, and governance)

Vulnerability = f (exposure to external perturbations, sensitivity, and coping capacity), and

Social organization = f (resource access, income distribution, household features, and urban-rural interactions)

With the functions f having forms that account for strong interactions between causes of land use change.

Besides, understanding these interactions could result in improving modeling of the changes in land cover in tropical regions.

2.4 Components of deforestation assessment

2.4.1 Causes and factors

It is important at the outset to carefully distinguish between the “underlying causes” of deforestation and forest degradation, about which there might be divergent views, and the “actual factors”, which could be part of the area of objective observation. For instance, in dealing with deforestation in developing tropical countries, the expansion, by means of clearing, of the different forms of subsistence agriculture, of cash cropping, or of ranching are all evident factors. The underlying causes are the triggering mechanisms for these factors. In the case of the first factor, we might say that the farmers' poverty obliges them to clear more land in order to enable them to buy the inputs that would allow them to produce more on less land, and that their poverty is itself engendered by their difficulty to sell what they produce, as a result of the insufficient farm price supports, due to the low priority given to the farming sector. We can go back a long way in this manner to find the underlying causes, with the increasing risk however of uncertainty, subjectivity and ideological posing. We will therefore limit ourselves to studying the factors (Lanly, 2003).

Knowing what to measure and account for at the level of a forested hectare is an important starting point. However, what will really matter in the context of emission reductions will be the overall carbon flows coming from forests and the means to account for these at the national level. Globally, deforestation occurs in most countries (for example, removal of forest cover for urban uses), but considerable area also returns to forests, whether naturally, from seeding or through planting. Generally, this is land that had been in agriculture or pasture that is no longer cultivated. Thus the global net change in forest cover is the sum of all positive and negative changes in forest area in terms of increasing and decreasing as shown in Figure 2-1 (FAO, 2006; Martin, 2008).

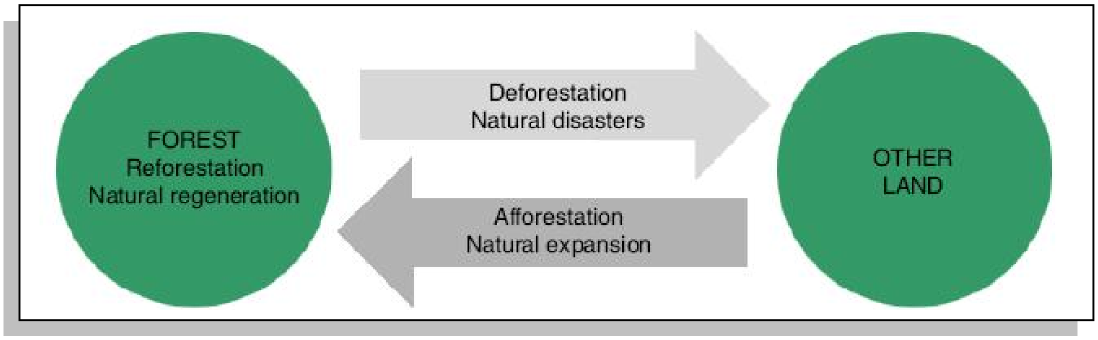


Figure 2-1 Forest change dynamics (FAO, 2006; Martin, 2008).

2.4.2 Affecting factors of tropical deforestation

As considered in above sections, a number of drivers of land use changes can be distinguished. Lambin (2004) showed that deforestation results from slash-and-burn cultivation, either by landless migrants or traditional shifting cultivators, government-sponsored resettlement schemes, fuel wood gathering and charcoal production, conversion of forested areas for cattle ranching, inefficient commercial logging operations, provision of infrastructure, and large-scale, uncontrolled forest fires of an exceptional nature.

By classifying the causes of deforestation, Geist and Lambin (2001) distinguished three categories of drivers namely: proximate, underlying and other causes.

"Proximate causes" are defined as human activities (land uses) that directly affect the environment and thus constitute proximate sources of changes. They are seen to operate at the local level (i.e. test sites). Proximate causes are grouped into three broad classes: agricultural expansion (e.g.: expansion of cropped land and pasture), wood extraction (e.g. fuelwood extraction, charcoal production) and expansion of infrastructure (e.g. settlements, transport, public services). Proximate causes of deforestation are generally thought to be driven by a combination of underlying affecting forces such as population growth, poverty, land hunger, shifting cultivation in large tracts of forest (Geist and Lambin, 2001), inequitable social conditions, property-rights regimes, inappropriate technology, international trade relations, economic pressures, etc.

"Underlying affecting forces" (or social processes) are seen as complex of social, political, economic, technological, and cultural variables that constitute initial conditions in the human environmental relations that are structural (or systemic) in nature. Explanations collected from literature result in five classes of drivers:

- Demographic factors (human population dynamics or population pressure).
- Economic factors (commercialization, development, economic growth or change).
- Technological factors (technological change or progress).
- Policy and institutional factors (change or impact of political-economic institutions, institutional change), and
- Complex of socio-political or cultural factors (values, public attitudes, beliefs, household behavior).

"Other causes" category is composed of pre-disposing environmental factors (land characteristics such as soil quality, topography, features of the biophysical environment), biophysical drivers and social trigger events.

In regard to the above development, it comes out that there are some relations depicted between different drivers. The relative importance of each cause varies widely in space and time.

Figure 2-2 Forest cleared for rice production, Indonesia (FAO, 2006).

Figure 2-3 Tropical forest removed for plantation of rubber or oil palm, Malaysia. (FAO , 2006).

2.4.3 Deforestation processes and spatial patterns

Specific sequences of events leading to deforestation are commonly assumed to leave unmistakable footprints. Processes such as agricultural expansion by subsistence farmers, cattle ranchers, agro-enterprises, etc., wood extraction by local users, outside logging companies, etc., or infrastructure expansion in the form of roadside clearing, river-bound colonization, etc., are associated with spatial patterns of the forest-nonforest interface. Across the tropical belt, a few characteristic spatial deforestation patterns were recognized and categorized in terms of geometric, corridor, fishbone, diffuse, patchy and island patterns as shown in Figure 2-4 (Geist and Lambin, 2001)

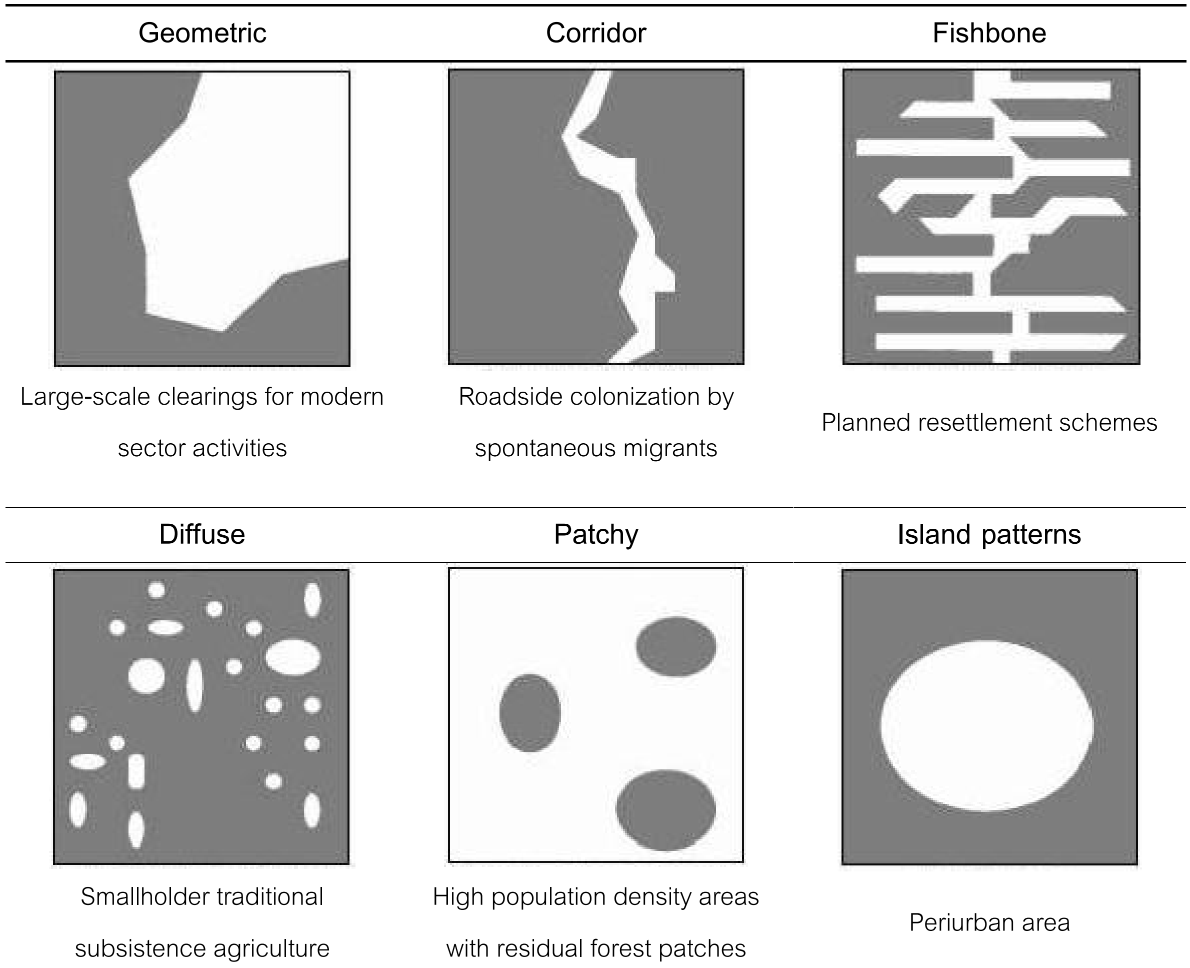


Figure 2-4 Typologies of the Forest-Nonforest spatial patterns and deforestation processes (Geist and Lambin, 2001).

- **Geometric pattern of deforestation**

The geometric pattern of deforestation, commonly associated with large-scale clearings for modern sector activities, is related here to activities such as large-scale commercial (plantation) agriculture, large-scale pasture creation for cattle ranching, estate settlement agriculture, and industrial forestry plantation settlements as shown in Figure 2-5 (Mertens and Lambin, 1997). A case has been found Southeast Asia (Malaysia, Indonesia) and a mainland South America (Brazilian Amazon, Mexico and the Napo Region of Ecuador, Peru and Columbia).

Figure 2-5 Geometric pattern of deforestation in Brazilian Amazon (NASA, 2010).

- **Corridor pattern of deforestation**

The corridor pattern of deforestation, commonly associated with roadside colonization by spontaneous migrants, is related here to cases in which spontaneous colonization coincides with roadside deforestation as shown in Figure 2-6 (Mertens and Lambin, 1997). Corridor cases were found to be regionally widespread in Latin America (Amazon lowlands of Brazil, Bolivia and Ecuador, coastal sites of both the Dominican Republic and Honduras, various frontier regions in Costa Rica), Asia (North and East Thailand, Indonesian Kalimantan, and various sites in upland Vietnam), and in Africa (East Cameroon, Southern Malawi).

Figure 2-6 Illegally logged to clear land for soya plantation, Amazon, Brazil (NASA, 2010).

- **Fishbone pattern of deforestation**

The fishbone pattern of deforestation, commonly associated with planned resettlement schemes, is related here to cases of colonization, transmigration and (re)settlement as shown in Figure 2-7 (Mertens and Lambin, 1997). A case has been found Amazon lowlands of Brazil: Para State (Xingu River Basin, Tailandia and Altamira towns and surrounding areas), Rondinia State (Theobroma area, central parts), and Acre State (Pedro Peixoto area).

Figure 2-7 Fish bone pattern of deforestation, shown here in Brazil, has been surpassed by large, block clearings typical of industrial forest clearing (NASA, 2010).

- **Diffuse pattern of deforestation**

The diffuse pattern of deforestation, commonly associated with smallholder traditional subsistence agriculture, is related here to cases of traditional shifting cultivation and permanent cultivation by smallholder for predominantly subsistence needs (i.e. no slash-and-burn-agriculture practiced by colonizing settlers). Diffuse cases were found to be regionally widespread among all continents, originating from Latin American countries (Honduras, Ecuador and especially Mexico and Peru), from Asian countries (Nepal, China, Indonesia, Malaysia, Samoa Islands, and Philippines), and from Africa (Madagascar, Cameroon), with next to all of them under humid climates (Mertens and Lambin, 1997).

Figure 2-8 Palm oil plantations in the remote tropical nation of Papua New Guinea.

- **Patchy pattern of deforestation**

The patchy pattern of deforestation, commonly related to high population density areas with residual forest patches, is associated here to case of exceptionally high population density, which is different from island or corridor cases (Mertens and Lambin, 1997). Cases show wide distribution among the continents in Asia (Thailand, India, Nepal, Philippines) in Latin America (Guatemala, Dominican Republic, Honduras, Brazil and Columbia) and Africa (Southern Malawi, Upland Kenya and Southern Congo-Zaire). All patchy cases are located in midland, highland and foothill zones under varying climates and types of forest (dry, humid, transitional).

- **Island patterns pattern of deforestation**

The island pattern of deforestation, commonly associated with periurban areas, has been related here to cases of deforestation occurring around (semi)urban settlements and not associated with other spatial patterns (also including peri-urban situations) as shown in Figure 2-9 (Mertens and Lambin, 1997). Cases show wide distribution among the continents in Africa (Northern Nigeria, Southern Malawi, Southern Madagascar), in Asia (Indonesian Java, Cebu island of the Philippines, Sarawak of Malaysian Borneo), and Latin America (Central Costa Rica, Southern Mexico, Tucuma and Paragominas town areas in Para State of Brazilian Amazon).

Figure 2-9 Tierras Bajas deforestation, Bolivia (NASA, 2010).

2.5 Geo-Informatics

The geo-informatics is included remote sensing (RS), geographic information system (GIS), and global positioning system (GPS). They are defined as multi-disciplinary science of geo-informatics to measure, record, process, analyze, represent, and visualize geo-spatial data.

2.5.1 Remote sensing

2.5.1.1 Definition

Remote Sensing can be defined as the instrumentation, techniques and methods to observe the Earth's surface at a distance and to interpret the images or numerical values obtained in order to acquire meaningful information of particular objects on earth. Three definitions of remote sensing are given below:

Remote Sensing is defined as “instrument-based techniques employed in the acquisition and measurement of spatially organized (for the Earth, most commonly geographically distributed) data/information on some properties (spectral; spatial; physical) of an array of target points (pixels) within the sensed scene that correspond to features, objects, and materials, doing this by applying one or more recording devices not in physical, intimate contact with the item(s) under surveillance; techniques involve amassing knowledge pertinent to the sensed scene (target) by utilizing electromagnetic radiation, force fields, or acoustic energy sensed by recording cameras, radiometers and scanners, lasers, radio frequency receivers, radar systems, sonar, thermal devices, sound detectors, seismographs, magnetometers, gravimeters, scintillometers, and other instruments" (NASA, 2010)

Remote sensing is the science and art of obtaining information about an object, area, or phenomenon under investigation (Lillesand et. al., 2008).

Remote sensing is a tool or technique similar to mathematics. Using sensors to measure the amount of electromagnetic radiation (EMR) exiting an object or geographic area from a distance and then extracting valuable information from the data using mathematically and statistically based algorithms is a scientific activity". It functions in harmony with other spatial data-collection techniques or tools of the mapping sciences, including cartography and geographic information systems (GIS) (Clarke, 2001; Jensen et. al., 2007).

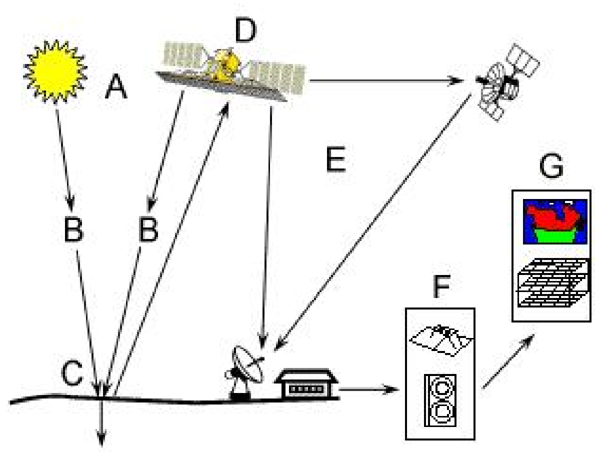


Figure 2-10 Process of Remote Sensing (Canada Centre for Remote Sensing, 2008).

Note: A) Energy source to illuminate the target; B) Interaction of the radiation with the earth's atmosphere; C) Radiation-target interactions; D) Data reception; E) Data transmision; F) Data processing; G) Data application

2.5.1.2 Remote sensing Techniques

Basic concept of remote sensing focus on the facts that everything on the Earth above 0 Kelvin generates electromagnetic energy. An object reflects, absorbs sunlight or emits its own internal energy according to its atomic and molecular vibration. Human eyes are restricted to see only visible reflected light (wavelength between 0.4-0.7 μm). Remote sensing uses sophisticated equipment to record invisible light such as infrared, thermal infrared and microwave radiation.

Remote sensing system may be classified into two systems, passive remote sensing and active remote sensing. (Jensen and Kiefer, 2007)

Passive remote sensing is sensors detect natural radiation that is emitted or reflected by the object or surrounding area being observed. Reflected sunlight is the most common source of radiation measured by passive sensors. Examples of passive remote sensors include film photography, infrared, charge-coupled devices, and radiometers.

Active remote sensing is emits energy in order to scan objects and areas whereupon a sensor then detects and measures the radiation that is reflected or backscattered from the target. RADAR is an example of active remote sensing where the time delay between emission and return is measured, establishing the location, height, speeds and direction of an object.

Generally, remote sensing works on the principle of the inverse problem. While the object or phenomenon of interest (the state) may not be directly measured, there exists some other variable that can be detected and measured (the observation), which may be related to the object of interest through the use of a data-derived computer model. The common analogy given to describe this is trying to determine the type of animal from its footprints. For example, while it is impossible to directly measure temperatures in the upper atmosphere, it is possible to measure the spectral emissions from a known chemical species (such as carbon dioxide) in that region. The frequency of the emission may then be related to the temperature in that region via various thermodynamic relations (Lillesand et. al., 2008).

The quality of remote sensing data consists of its spatial, spectral, radiometric and temporal resolutions as shown in Table 2-3 (Jensen and Kiefer, 2007).

- **Spatial resolution**

The size of a pixel that is recorded in a raster image – typically pixels may correspond to square areas ranging in size length from 1 to 1,000 meters (3.3 to 3,300 ft).

- **Spectral resolution**

The wavelength width of the different frequency bands recorded – usually, this is related to the number of frequency bands recorded by the platform. Current Landsat collection is that of eight bands (Table 2-2), including several in the infra-red spectrum, ranging from a spectral resolution of 0.07 to 2.1 μm. The Hyperion sensor on Earth Observing-1 resolves 220 bands from 0.4 to 2.5 μm, with a spectral resolution of 0.10 to 0.11 μm per band.

- **Radiometric resolution**

The number of different intensities of radiation the sensor is able to distinguish. Typically, this ranges from 8 to 14 bits, corresponding to 256 levels of the gray scale and up to 16,384 intensities or "shades" of color, in each band. It also depends on the instrument noise (Figure 2-11).

- **Temporal resolution**

The frequency of flyovers by the satellite or plane, and is only relevant in time-series studies or those requiring an averaged or mosaic image as in deforesting monitoring. This was first used by the intelligence community where repeated coverage revealed changes in infrastructure, the deployment of units or the modification/introduction of equipment. Cloud cover over a given area or object makes it necessary to repeat the collection of said location.

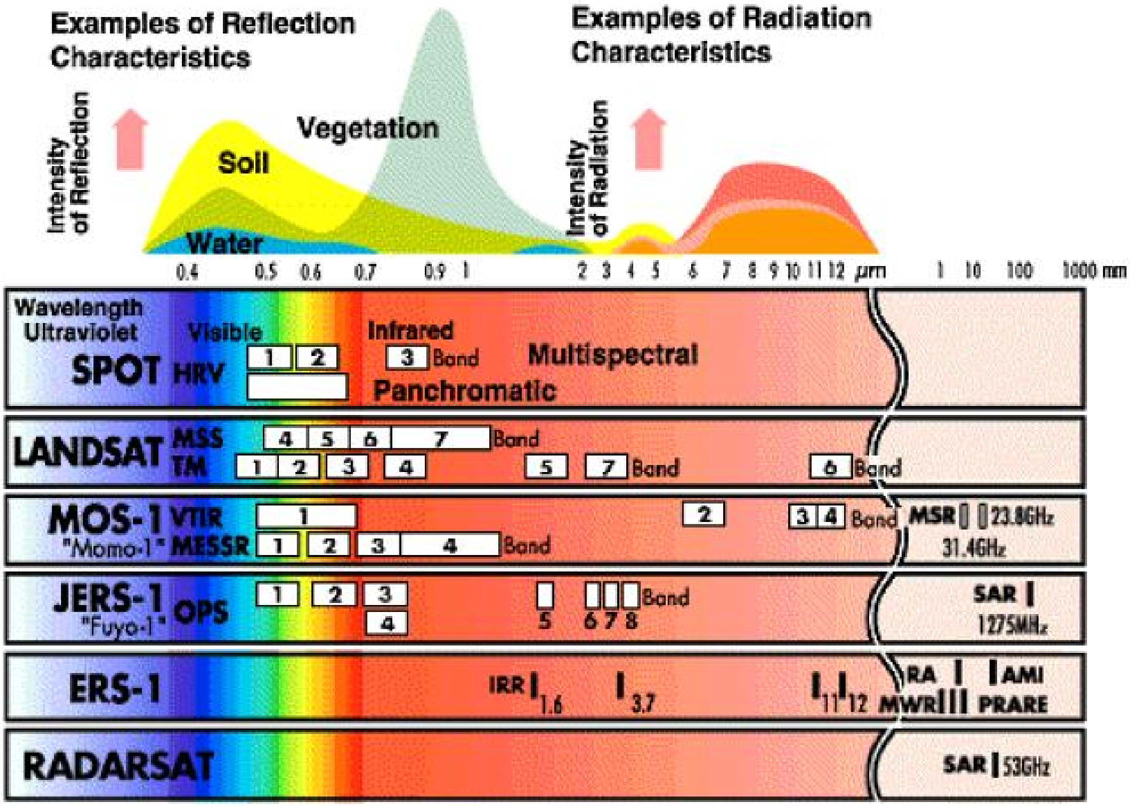


Figure 2-11 Radiometric resolution of Satellites characteristics.

Table 2-2 Spectral resolution of Landsat 7ETM+ and 5TM sensors (Geoscience Australia, 2009).

Band Number	Spectral Range (in Microns)	EM Region	Generalised Application Details
1	0.45 - 0.52	Visible Blue	Coastal water mapping, differentiation of vegetation from soils
2	0.52 - 0.60	Visible Green	Assessment of vegetation vigour
3	0.63 - 0.69	Visible Red	Chlorophyll absorption for vegetation differentiation
4	0.76 - 0.90	Near Infrared	Biomass surveys and delineation of water bodies
5	1.55 - 1.75	Middle Infrared	Vegetation and soil moisture measurements; differentiation between snow and cloud
6	10.40- 12.50	Thermal Infrared	Thermal mapping, soil moisture studies and plant heat stress measurement
7	2.08 - 2.35	Middle Infrared	Hydrothermal mapping
8	0.52 - 0.90 (panchromatic)	Green, Visible Red, Near Infrared	Large area mapping, urban change studies

Table 2-3 The quality of remote sensing data (Geoscience Australia, 2009).

Satellite	Sensors	Subsensors	Swath width	Bands	Spatial Resolution	Altitude	Orbit	Repeat
Landsat 5	Multispectral scanner, (MSS)		185 Km	1-5&7 +6	30 - 129 m	705 Km	Sun Synchronous	16 days or 233 orbits.
	Thermatic Mapper, TM							
Landsat 7	Enhance Thermatic Mapper Plus, (ETM+)		185 Km	1-5&7+6+8	15 - 60 m	705 Km	Sun Synchronous	16 days or 233 orbits.
Terra, EOS-AM1	Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)	Visible and Near Infrared(VNIR)	60 Km	1 to 3	15 Km	705 Km	Sun Synchronous	16 days
		Shortwave Infrared (SWIR)	60 Km	4 to 9	30 Km			
		Thermal Infrared (TIR)	60 Km	10 to 14	90 Km			
	Moderate Resolution Imaging Spectroradiometer (MODIS)		2330 Km	1 to 36	250 -1000 m			
Aqua, EOS-PM1	Moderate Resolution Imaging Spectroradiometer (MODIS)		2330 Km	1 to 36	250 -1000 m	705 Km	Sun Synchronous	16 days.
ALOS, Advanced Land Observing Satellite	Panchromatic Remote Sensing Instrument for Steromapping (PRISM)		35-70 Km		2.5 m	692 Km	Sun synchronous	46 days
	Advanced Visable and Near Infrared Radiometer type 2 (AVNIR-2)		70 Km	1 to 4	10 m			
	Phased Array type L-band Synthetic aperture radar (PALSAR)		30 - 70 Km	Radar	10 - 100 m			
NOAA	Advanced Very High Resolution Radiometer (AVHRR)		2399 Km	1 to 5		833 Km	Sun synchronous	9 days
Radarsat-1	Synthetic Aperture Radar (SAR)			Radar				24 days
Resourcesat-1	Linear Imaging and Self Scanning sensor (LISS-III)		141Km	2 to 4	23.5 m	817 Km		24 days
	Advanced Wide Field Sensor (AWiFS)		740km		56 m			5 days

2.5.2 Geographic information system

2.5.2.1 Definition

Geographic information system (GIS), a new technology, is becoming essential tools for analyzing and graphically transferring knowledge about the world. There are many definitions about geographic information system. For example, the United States Geological Survey-USGS (2007) defined as “a computer system capable of capturing, storing, analyzing, and displaying geographically referenced information; that is, data identified according to location. Practitioners also define a GIS as including the procedures, operating personnel, and spatial data that go into the system”. While Briggs (2010) noted that geographic information system can be defined as “a software systems with capability for input, storage, manipulation/analysis and output/display of geographic (spatial) information”. Skrdla (2005), however; defines the meaning of the geographic information system as “management of information with a geographic component primarily stored in vector form with associated attributes.”

2.5.2.2 Geographic information system Techniques

GIS uses spatial-temporal (space-time) location as the key index variable for all other information. Just as a relational database containing text or numbers can relate many different tables using common key index variables, GIS can relate otherwise unrelated information by using location as the key index variable. The key is the location and/or extent in space-time.

Any variable that can be located spatially, and increasingly also temporally, can be referenced using a GIS. Locations or extents in Earth space-time may be recorded as dates/times of occurrence, and x, y, and z coordinates representing, longitude, latitude, and elevation, respectively. These GIS coordinates may represent other quantified systems of temporal-spatial reference (for example, film frame number, stream gage station, highway mile marker, surveyor benchmark, building address, street intersection, entrance gate, water depth sounding, POS or CAD drawing origin/units). Units applied to recorded temporal-spatial data can vary widely (even when using exactly the same data, see map projections), but all Earth-based spatial-temporal location and extent references should, ideally, be relatable to one another and ultimately to a "real" physical location or extent in space-time (Bettinger and Wing, 2004).

Related by accurate spatial information, an incredible variety of real-world and projected past or future data can be analyzed, interpreted and represented to facilitate education and decision making. This key characteristic of GIS has begun to open new avenues of scientific inquiry into behaviors and patterns of previously considered unrelated real-world information.

2.5.2.3 Components of GIS Database

Traditionally, there are two broad methods used to store data in a GIS for both kinds of abstractions mapping references: Spatial data and Attribute data (Clarke, 2001). Sutton et al. (2009) explains that spatial data is usually represented on maps as one of two type of spatial primitive: raster data and vector data

Raster data are stored as a grid of values, or pixel or fixed size cells having digital values, covering a certain area, provided by satellite images, scanned maps and digital terrain modeling. Raster data display information that is continuous across an area.

Vector data is stored as a series of x,y coordinate pairs inside the computer's memory. Vector data is used to represent points features represent spatial data existing at a single location, lines represent linear features and polygon features represent enclosed homogeneous areas or regions. A polygon is a series of line segments connected to form an enclosed area.

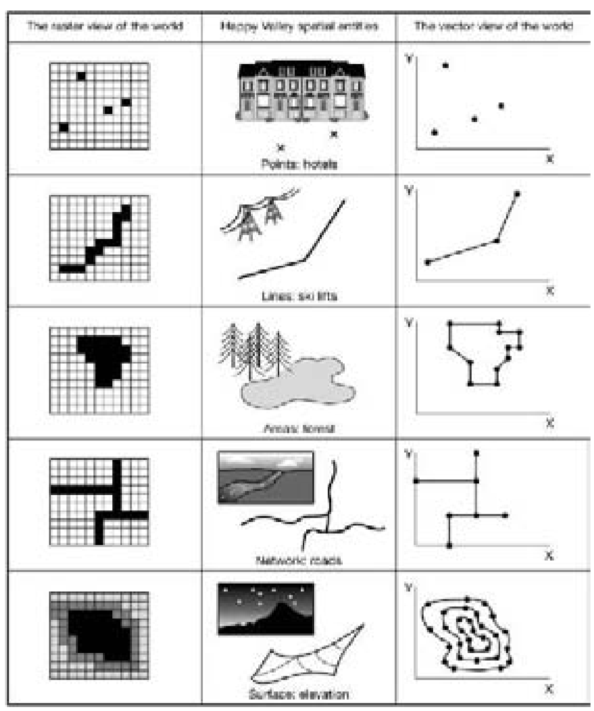


Figure 2-12 Spatial Data in GIS Database (Indiana University, 2005).

Attribute data is an object's description which may be graphical, such as a symbol, point, line or polygon, or it could be test describing specific nature of an object, i.e. number of inhabitants, production volume, and population density. The attribute data is stored in a relational database, with the spatial data kept in a standard hierarchical database (Clarke, 2001).

2.5.3 Global positioning system

Global positioning system (GPS) has permitted convenient, inexpensive, and accurate measurement of absolute location. GPS has greatly enhances the usefulness of remote sensing data. These instruments now are inexpensive, easy to use, and can be employed in almost any area on the earth's surface.

A Global positioning system receiver consists of a portable receiving unit sensitive to signals transmitted by a network of earth-orbiting satellites. These satellites are positioned in orbits such that each point on the earth's surface will be in view of at least four, and perhaps as many as twelve, satellites at any given time. A system of 24 satellites is positioned at an altitude of about 13,500 miles, to circle the earth at intervals of 12 hours, spaced to provide complete coverage of the earth's surface (Earth Science Australia, 2010).

These satellites continuously broadcast signals at two carrier frequencies within the L-band region of the microwave spectrum. Although at ground level these signals are very weak, they are designed so that they can be detected even under adverse condition (e.g. severe weather or interference from other signals). The frequency of each of these carrier signals is modulated in a manner that both identify the satellite that broadcasts the signal and gives the exact time that the signal was broadcast. A receiver therefore can calculate the time delay for the signal to travel from a specific satellite, and then accurately estimate the distance from the receiver to specific satellite (Bettinger and Wing, 2004).

One reason that it is possible to employ such a weak signal is that the time and identification information each satellite transmits is very simple, and the receiver can listen for long periods to acquire it accurately. Because a receiver is always within range of multiple satellites, it is possible to combine positional information from three or more satellites to accurately estimate geographic positional on the earth's surface. A network of ground stations periodically recomputed and uploads new positional data to the GPS satellites (Earth Science Australia, 2010).

2.5.4 Use of Geo-Informatics in land use changes assessment

The geo-informatics is powerful tools to derive accurate and timely information on the spatial distribution of land use changes over medium to large. A past and present study conducted by organizations and institutions around the world, mostly, has concentrated on the application of land use changes.

Remote Sensing Technology involves the use of a sensor that is not in physical contact with its subject of interest. These electromagnetic reflectances are recorded by the sensors in terms of their wavelength of energy, as described by the electromagnetic spectrum (Lillesand et al., 2008). The electromagnetic wave lengths are then converted to a digital format and transmitted back to a computer for processing and interpolation. Satellites such as the Landsat Thematic Mapper (TM) series can capture wide swaths of the Earth's surface (185 km, or 115 mi) and, thus, have the potential to record vast amounts of information over a short time period (Geoscience Australia, 2009). The advantages provided by the much finer spatial resolution of the second generation satellites (e.g. Landsat TM, SPOT) are now well recognized. In favorable circumstances, thematic maps can be prepared at a scale of 1:50000 and revised at a scale of 1:25000 or possibly larger (Howard, 1991). In addition, the finer resolution data of these second generation satellites provides a record of the surface texture of forests, which in classification of the images can be combined with their spectral characteristics. Further, the spectral inclusion of the mid-infrared in Landsat TM sensing is helping to improve the classification of land use and land cover (Adams and and Gillespie, 2006).

GIS provides a flexible environment for collecting, storing, displaying and analyzing digital data necessary for change detection. Remote sensing imagery is the most important data resources of GIS. Satellite imagery is used for recognition of synoptic data of earth's surface. Landsat Multispectral Scanner (MSS), Thematic Mapper (TM) and Enhanced

Thematic Mapper Plus (ETM+) data have been broadly employed in studies towards the determination of land use changes, the starting year of Landsat program, mainly in forest and agricultural areas. The rich archive and spectral resolution of satellite images are the most important reasons for their use. And GPS has permitted convenient, inexpensive, and accurate measurement of absolute location. And GPS has greatly enhances the usefulness of remote sensing data. These instruments now are inexpensive, easy to use, and can be employed in almost any area on the earth's surface. The frequency of each of these carrier signals is modulated in a manner that both identify the satellite that broadcasts the signal and gives the exact time that the signal was broadcast. A receiver therefore can calculate the time delay for the signal to travel from a specific satellite, and then accurately estimate the distance from the receiver to specific satellite. The results of this analysis from the geo-informatics technology in the study area. This information is essential for a feasible and sustainable land use plan (Wang et al., 2010).

2.6 Models in land use planning

To preserve or create a healthy living environment careful land use planning is more and more important. Models of land use change can be important tools to help land use planning. With the use of models in land use planning it is possible to make more informed land use decisions. This decision support function is only one of the functions that a land use model can fulfill. In total five different uses for models in land use planning are defined (Briassoulis, 2000):

2.6.1 Decision support

First, general use of models in the land use planning is to provide decision support. Models can be used to give more insight into the problems in land use planning. The models situations can be evaluated to help land use planners making better decisions.

With the use of models for decision support in land use planning a more scientific based choice can be made. This output of the models can give support next to the planning theories.

In general two different types of land use change models can be distinguished, descriptive models and prescriptive models that contribute to decision making in land use planning.

- Descriptive models simulate realistic changes in land use under specified conditions defined in a scenario. These models are able to make a yearly prediction up to 20 to 30 years into the future. The CLUE-S model is such a descriptive model. Land use planners can use the results of the simulations for assessment of consequences of proposed policy or autonomous development.
- Prescriptive models are used in situations where the objectives of a policy are known in advance. These models simulate, on basis of the given objectives, land use configurations that best match these objectives. These models are also known as optimization models.

The results of both models can be used to inform land use planners. Comparing the outcomes of these two model types it is possible to find out if policies for which the effect on land use is simulated in the descriptive model matches with the simulated land use configuration in the prescriptive model. In most cases deviation between the results will occur. The locations, where are deviation between the two results are found, can be analyzed. With this analysis new policy can be developed for the study area. A new run of the models, that contain this new policy, can be used to test if the new policy will lead to the desired land use configuration. This iterative process can continue until policies designed fit the objectives of land use planning.

Another advantage of using both types of models is the possibility to assess to what extent actual land use matches with the desired, optimal land use configuration. Out of this analysis new policies can be developed to reach the desired land use configuration.

2.6.2 Explanation

Models can be used for the explanation of relationships between affecting factors and land use change. The models can give insight in which drivers are important for a certain land use planning problem. With this use of a model its possible to simplify the complex social and natural system and make scientifically based decisions on planned changes in land use.

2.6.3 Prediction

Another type of model use is prediction of land use changes. These descriptive models simulate realistic changes in land use under a set of conditions specified in a scenario. Most of the descriptive models are able to make a yearly prediction up to 20 or 30 years into the future.

The models are capable to identify areas that have high probabilities for future changes in land use, so called ‘hot-spots’ of land use change. The identification of ‘hot-spots’ is important because research can focus in more detail on these locations to determine the processes giving rise to the changes and assess the impact. Land use planners can decide if the locations and the rate of change of these ‘hot-spots’ are desirable. If not, alternative policies can be proposed that reduce the forecasted changes in these ‘hot-spots’.

With the descriptive models different scenarios can be calculated. Defining the dynamics of the affecting factors or including a new driving factor creates these scenarios. For each scenario the configuration of the future land use is calculated.

Decision-makers can use this method to evaluate the different probable scenarios.

2.6.4 Impact assessment

Models can play an important role in impact assessment of past or future land use changes. There are two different ways in which models can be used for impact assessment.

On the one hand it’s possible to evaluate the impact of a planned land use change. A scenario of a future change is simulated by a model with the objective to find the impact on the land use configuration. On the other hand, it’s possible to assess the impact of a land use change on the environment and the social and economical system, for example land degradation, desertification or unemployment.

2.6.5 Prescribe optimum

Prescriptive models are also known as normative, operations research or optimization models. These models operate on basis of known objectives. These prescriptive models simulate the land use configuration that matches best with the selected objectives.

With prescriptive models the requirements of different sectors are balanced. Due to this method it's necessary to indicate the relative importance of every formulated objective. A difference in importance of the objectives will lead to different outcome of the prediction of the land use configuration. This can be made more explicitly by presenting the spatial claims of the different sectors.

The results of the analysis can be used by land use planners to decide about the desired land use planning. These results show the claim different sectors have on the land use. With these claims in mind land use planners can decide about the final land use configuration.

2.7 Model description

2.7.1 Overview of CLUE Model

The Conversion of Land Use and its Effects modeling framework (CLUE) was developed to simulate land use change using empirically quantified relations between land use and its affecting factors in combination with dynamic modeling of competition between land use types. The model was developed for the national and continental level and applications for Central America, Ecuador, China and Java, Indonesia are available. For study areas with such a large extent the spatial resolution for analysis was coarse and, as a result, each land use is represented by assigning the relative cover of each land use type to the pixels (Verburg and Veldkamp, 2004).

Land use data for study areas with a relatively small spatial extent is often based on land use maps or remote sensing images that denote land use types respectively by homogeneous polygons or classified pixels. This results in only one dominant land use type occupying one unit of analysis. Because of the differences in data representation and other features that are typical for regional applications, the CLUE model cannot directly be applied at the regional scale. Therefore the modeling approach has been modified and is now called CLUE-s (the Conversion of Land Use and its Effects at Small regional extent). CLUE-s is specifically developed for the spatially explicit simulation of land use change based on an empirical analysis of location suitability combined with the dynamic simulation of competition and interactions between the spatial and temporal dynamics of land use systems. More information on the development of the CLUE-s model can be found in Verburg et al. (2002) and Verburg and Veldkamp (2003).

2.7.2 Model structure

The CLUE-s model can be divided into two modules, a non-spatial demand module and a spatially explicit allocation module (Figure 2-13). In the non-spatial demand module the changes in land use are estimated for a series of years at the aggregate level.

The spatial allocation module has to translate the changes in demand into changes in land use pattern. For every year of simulation a land use prediction map is created. The allocation module needs decision rules and the results of the statistical analysis as input, indicating the potential locations for conversion (Verburg and Veldkamp, 2004).

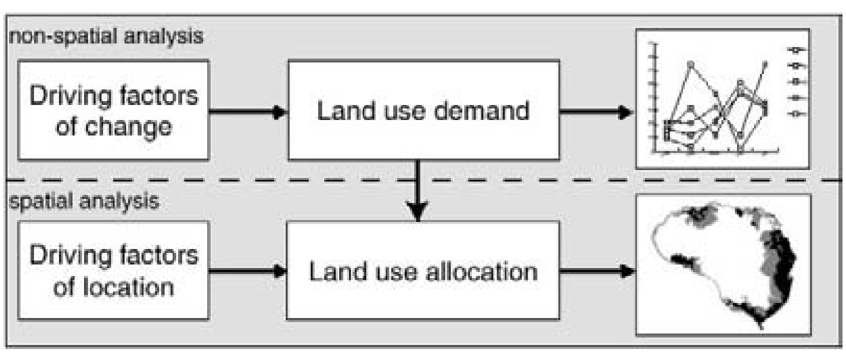


Figure 2-13 Overview of the modeling procedure (Verburg and Veldkamp, 2004).

2.7.3 Land use requirements (demand)

Land use requirements (demand) are calculated at the aggregate level (the level of the case-study as a whole) as part of a specific scenario. The land use requirements constrain the simulation by defining the totally required change in land use. All changes in individual pixels should add up to these requirements. In the approach, land use requirements are calculated independently from the CLUE-s model itself. The calculation of these land use requirements is based on a range of methods, depending on the case study and the scenario. The extrapolation of trends in land use change of the recent past into the near future is a common technique to calculate land use requirements. When necessary, these trends can be corrected for changes in population growth and/or diminishing land resources. For policy analysis it is also possible to base land use requirements on advanced models of macro-economic changes, which can serve to provide scenario conditions that relate policy targets to land use change requirements (Verburg and Veldkamp, 2004).

2.7.4 Statistical analysis

The relations between land use and its affecting factors are evaluated using stepwise logistic regression. Logistic regression is an often used methodology in land use change research (Serneels & Lambin 2001).

This statistical method is used to provide the model response functions for each land use type. Out of the results of the regression, probability maps can be calculated. For every year of the simulation a new probability map is calculated with updated values of the affecting factors that are changing in time (e.g. population density). In this study we did not do this since we assumed all drivers to be constant in time.

The stepwise procedure is used to help us select the relevant affecting factors from a larger set of factors that is assumed to influence the land use pattern. Variables that have no significant contribution to the explanation of the land use pattern are excluded from the final regression equation (Verburg 2001).

The statistical analysis is explained in more detail in Chapter 4.3.

2.7.5 Decision rules

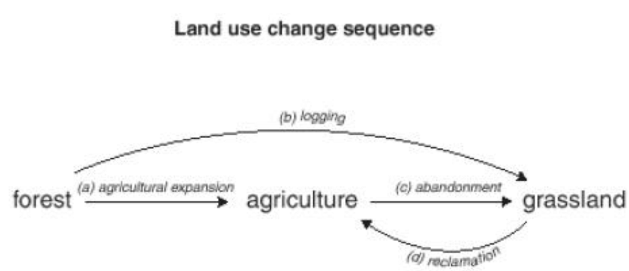
Decision rules are used to determine which conversions are allowed. Two different types of decision rules are used in the model. The first type is the stability of a land use type. The second can indicate a certain area as a protected area that is not allowed to change.

The stability setting is a value between 0 and 1. The value of the stability settings is valid for all cells covered by that land use type. The value of 1 is given to a land use type that is stable. This value, for example, is given to the land use type urban. After the conversion to urban land use it is not likely that this land is changed into another land use type (Figure 2-14).

Land use types with opposite characteristics are given a value of 0. These land use types are very dynamic; when this value is selected for a land use type there are no restrictions to change are considered in the allocation module.

There are also a couple of land use types that operate in between these two extremes. This situation is representative for the land use types that are not likely to change after their first establishment. But on the long term, when there is a land use type that is more profitable, the land use will change.

The stability settings are based on the knowledge of the experts on the location. The settings can also be tuned during the calibration of the model.



Land use conversion matrix

present land use ↓ / future land use →	Forest	Agriculture	Grassland
Forest	+	+(a)	+(b)
Agriculture	-	+	+(d)
Grassland	-	+(e)	+

\+ conversion possible
\- conversion not possible

Figure 2-14 Illustration of the translation of a hypothetical land use change sequence into a land use conversion matrix (Verburg and Veldkamp, 2004).

2.7.6 Allocation procedure

In the allocation module the demand of the different land use types is allocated. This allocation procedure follows 5 steps (Verburg et al, 2002) (Figure 2-15)

1. In this first step the number of grid cells that are taken into account in the allocation is determined. The grid cells that are either part of a protected area or not allowed to change for another reason are excluded from further calculations.

2. For all grid cells i the total probability (*TPROPi,u*)is calculated for each of the land use types u. The total probability is calculated according to the following equation:

$$TPROP_{i,u} = P_{i,u} + ELAS_u + ITER_u \qquad \text{(Equation 3-8)}$$

Where $ITER_u$ is an iteration variable that is specific to the land use. $ELAS_u$ is the relative elasticity for change specified in the decision rules and is only given a value if grid cell *i* is already under land use type u in the year considered.

3. A preliminary allocation is made with an equal iteration variable for each land use type. In this step the land use type with the highest probability is allocated in the considered grid cell.

4. The total allocated area of the different land use types is now compared to the demand. If the number of allocated grid cells of a certain land use type is too high, the iteration variable is decreased. If the number of allocated grid cells is too low compared to the demand, the iteration variable is increased.

5. The steps 2 to 4 are repeated until the allocated land use matches with the demand. When the allocation matches the demand the final result is saved. Now the model can proceed to the next time step (usually years).

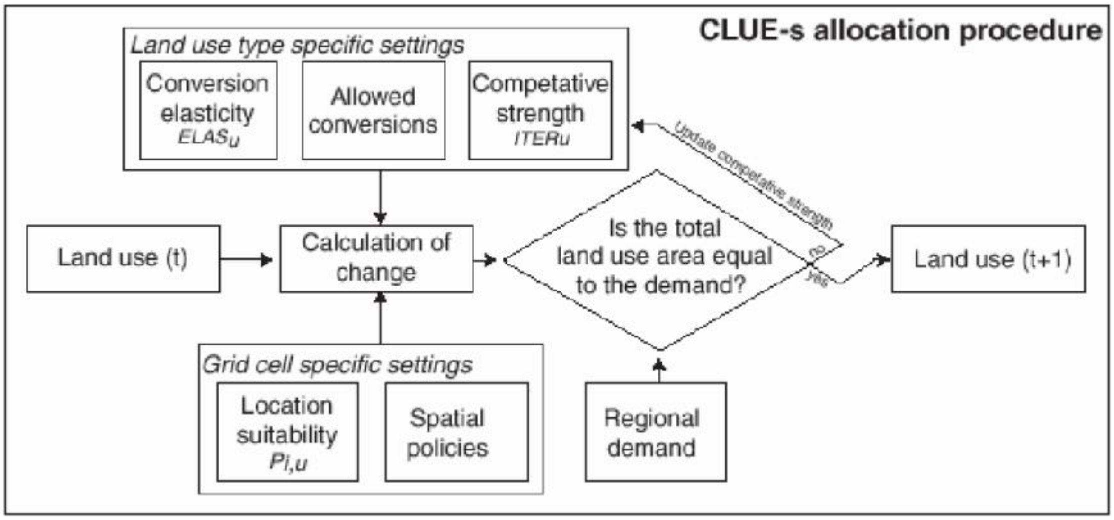


Figure 2-15 Flow chart of the allocation module of the CLUE-s model (Verburg et al., 2002).

2.8 Previous investigations on land use changes assessment

The previous investigations on land use changes assessment have been studied in many parts of the world. Some important literatures have been briefly reviewed below in chronological order to be the background information.

Geist and Lambin (2002) focused the study on land use changes originated by evidence from empirical case studies that identify both proximate causes and underlying forces of tropical deforestation suggests that no universal link between cause and effect exists. Rather than providing support for dominant theories of global deforestation (neoclassical, impoverishment, political ecology), analysis of these studies showed that tropical forest decline was determined by different combinations of various proximate causes and underlying affecting factors in varying geographical and historical contexts. Some of these combinations were robust geographically (such as the development of market economies and the expansion of permanently cropped land for food), whereas most of them were region specific. The observed causal factor synergized challenge single-factor explanations that put most of the blame of deforestation upon shifting cultivators and population growth (caused by natural increment).

Verburg et al. (2002) conducted a study land use change models were important tools for integrated environmental management. Through scenario analysis they could help to identify near-future critical locations in the face of environmental change. A dynamic, spatially explicit, land use change model was presented for the regional scale: CLUE-s. The model was specifically developed for the analysis of land use in small regions (e.g., a watershed or province) at a fine spatial resolution. The model structure was based on systems theory to allow the integrated analysis of land use change in relation to socio-economic and biophysical affecting factors. The model explicitly addressed the hierarchical organization of land use systems, spatial connectivity between locations and stability. Stability was incorporated by a set of variables that defined the relative elasticity of the actual land use type to conversion. The user could specify these settings based on expert knowledge or survey data. Two applications of the model in the Philippines and Malaysia were used to illustrate the functioning of the model and its validation.

Verburg and Veldkamp (2004) conducted a study on two applications of a spatially explicit model of land use change at two spatial scales: a nation-wide application for the Philippines at relatively coarse resolution and an application with high spatial resolution for one island of the Philippines: Sibuyan island, Romblon province. The model was based on integrated analysis of socio-economic and biophysical factors that determine the allocation of land use change in combination with the simulation of the temporal dynamics (path-dependence and reversibility of changes), spatial policies and land requirements. It was concluded that spatially explicit modeling of land use change yields important information for environmental management and land use planning. The applications illustrated that the scale of analysis was an important determinant of the model configuration, the interpretation of the results and the potential use by stakeholders. There was no single, optimal, scale for land use change assessments. Each scale enables different types of analysis and assessment: applications at multiple scales therefore gave complementary information needed for environmental management.

Orékan (2005) conducted a study a dynamic, spatially explicit model for local scale: the CLUE-s was adapted to analyze land use changes in small area (900 km^2) at a fine resolution (32 m x 32 m) from Landsat 5TM satellite. By simulating the land use changes based on socio-economic and biophysical factors, the research outputs helped to identify hot spots of critical development by the horizon 2025. Most of the changes occurred along the main road where an agricultural land expansion and a forest decrease were recorded. The main factors of changes were distances to roads, to settlements, and population density. After assessing the model sensitivity, some validation approaches were applied for deriving errors relative to simulation for model validation. Finally some scenarios based on main relevant settings were applied to conclude the main outputs, source of information and tools for decision makers for sustainable environmental management and land use planning.

Zhan et al. (2007) conducted a study on modeling land use scenario changes and its potential impacts on the structure and function of the ecosystem and economy in the typical regions were helpful to understanding the interactive mechanism between land use system and ecological system or and economic factors. The CLUE-s model integrated with System Dynamics (SD) model was developed with three land use scenario changes in Taips County of China from 2001 to 2020 simulated in this paper. System Dynamics model could predict the complex system change under the different "what-if" scenarios, which makes it a good tool and be widely used in different fields of natural science, social science and engineering technology. The simulated results indicated that obvious land use changes would take place in the unused area and farming-pastoral zone of Taips County from 2001 to 2020 with unused land and urban land being the most active land use types.

Wang (2009) concluded that resources and management in the watershed and the role of the bamboo forest industry in social development, economic growth and ecosystem protection; the impact of infrastructure development on soil erosion; patterns of land use change in the Min River over, Fujian, China the last 20 years using Landsat 5TM imagery; and public perceptions of watershed management in the watershed. Particular emphasis had been placed on the evaluation of forest policy and national programs to combat flooding. Watersheds were holistic systems where social, cultural, economic and environmental issues interact. Forestry is only one of several factors affecting watershed sustainability. Watershed management was a complex, dynamic and continually improving process. It needed to bring together personnel from diverse disciplines, to integrate data from multiple dimensions and to develop a comprehensive management tool that would enable managers, stakeholders and third party interest groups to work together more effectively in solving watershed problems.

Gonzales (2009) conducted a study land cover and land use change process and its implication for environmental condition and ecosystem functioning, it was essential to identify and recognized the services provided by the ecosystem. Remotely sensed data together with GIS increase the capability to analyze the human impact on the environment in quantitative, qualitative and spatial form. The main goal of this study was to generate the land cover and land use multi-temporal information, to quantify and to analyze the land cover and land use change and its impacted on watershed soil erosion and sediment yield regulation services, and to identify the upstream and downstream relationship on sediment control in Huatanay watershed of Cusco region in the tropical Andes of Peru.

In Thailand, the literatures on land use changes assessment and similar phenomena are also reviewed in chronological order as follow.

Krittika Bunyachatphisuth (1999) conducted a study relation between land use/land cover and coastline change in Changwat Phetchaburi and Changwat Prachuap Khiri Khun was investigated by remote sensing technique. Aerial photographs and landsat 5TM image from 1954-1994 were used for detection of coastline change and classification of land use/land cover and used logistic regression to evaluate the relationship between coastline change and categories of land use/land cover. The results showed that high density built-up area always has high probability of erosion, while bare soil always has low probability of erosion.

Delang (2002) presented that the effects of deforestation in Thailand are as follows:

- Population Growth as populations increased, the need for food increased, and much forest land had to be cleared to increase food production capacity to meet demand.
- Agricultural Policy had on deforestation was the construction of roads following World War 2. These roads were built to help farmers bring food products from rural areas into the more densely populated urban centers. This encouraged farmers to move away from subsistence farming and begin to farm on a larger scale.
- Land Ownership Policy consist property rights in Thailand are extremely ambiguous and are often interpreted differently by the various branches of the Thai government. The inability of many Thai citizens to secure property had resulted in them going out into the forests to find space to farm.

Patcharapa Limpongstorn (2004) conducted a study land use change around Khao Chet Luk in Changwat Phichit between 2512 B.E. and 2543 B.E. The analysis of change pattern of land use by using geographic information system (GIS) revealed greatest change in 2512 B.E. to 2543 B.E. was especially the conservation forest, which was destroyed lavishly for agricultural purpose. And to study on population, socials and economics of the area indicated no increasing along time of population from 2513 B.E. to 2545 B.E. Instead, it tended to decrease, probably due to the remoteness and drought nature of this undeveloped area. However between 2537 B.E. to 2541 B.E. the population largely increased due to gold finding and production area here. After then the population slightly decreased to return to its previous decreasing trend.

Komsan Kiriwongwattana (2007) conducted a study on land use and land cover change (LULCC) projection was carried out at Mae Yod watershed, Maechaem district, Changwat Chiang Mai, northern Thailand by using LULCC data that interpreted from satellite images, Landsat 5TM from 1989 to 1997. Beside, the model was used to predict LULCC based on deferent management scenarios by CLUE-s model. The results revealed that the projection of LULCC according to different management scenarios including 1) based on LULCC evolution, 2) demand of agricultural area is increase 15 percent from normal trend and 3) forest area in watershed class 1 is intensively protected, has been carried out.

Trisurat et al. (2010) concluded that rapid deforestation has occurred in northern Thailand over the last few decades and it was expected to continue. The study combined a dynamic land use change model (Dyna-CLUE) with a model for biodiversity assessment. The results revealed that forest cover in 2050 would mainly persist in the west and upper north of the region, which was rugged and not easily accessible. In contrast, the highest deforestation was expected to occur in the lower north. The high-threat areas covered 1.6 and 0.3% of the region for the integrated management and conservation-oriented scenarios, respectively. Based on the model outcomes, conservation measures were recommended to minimize the impacts of deforestation on biodiversity. The model results indicated that only establishing a fixed percentage of forest was not efficient in conserving biodiversity. Measures aimed at the conservation of locations with high biodiversity values, limited fragmentation, and careful consideration of road expansion in pristine forest areas may be more efficient to achieve biodiversity conservation.

CHAPTER III

METHODOLOGY AND DATA PREPARATION

The sources of input data and the steps in image processing used remote sensing are comprehensively explained hereafter. These are the most cumbersome and time consuming steps of GIS and remote sensing techniques in this research. The prepared and processed thematic data that were used in this thesis will be mainly explained in this chapter. Meanwhile, phases of land use mapping analysis in GIS-based land use change detection techniques are also reviewed. Whereas, the detailed statistic analysis of the land use database and the parameter maps will be explained in the following chapter.

3.1 Phases of land use changes mapping analysis in Remote Sensing and GIS-based deforestation detection techniques

The following phases can be distinguished in the process of land use change analysis using GIS (Van Westen, 1993 and 1994 cited in Yumuang, 2005). They are listed in logical order or sequence though sometimes they may be overlapping (Figure 3-1) as follow:

- Preliminary phase:

    Phase 1: Defining of objective of study and the methods of analysis which will be applied.

- Data collection phases:

    Phase 2: Collection of existing data (collection of existing maps and reports with relevant data)

    Phase 3: Image interpretation (interpretation of images and creation of new input maps)

Phase 4: Data base design (design of the database and definition of the way in which the data will be collected and stored)

Phase 5: Fieldwork (to verify the image interpretation)

Phase 6: Laboratory analysis

- GIS work:

Phase 7: Data entry (digitizing of maps and attribute data)

Phase 8: Data validation (validation of the entered data)

Phase 9: Data manipulation (manipulation and transformation of the raw data in a form which can be used in the analysis)

Phase 10: Data analysis and modeling (analysis of data for preparation of land use change maps)

Phase 11: Presentation of output maps (final production of land use change maps and adjoining report)

An ideal Remote Sensing and GIS for land use analysis combines conventional GIS procedures with image processing capabilities and a relational data base. Map overlaying, modeling, and integration with satellite images are required, thus a raster system is preferred. The program should be able to perform spatial analysis on multiple-input maps and connected attribute data tables for map overlay, reclassification, and various other spatial functions.

3.2 Thematic data preparation from Remote Sensing and GIS techniques

Remote sensing data can be readily merged with other sources of geo-coded information as a GIS. This allows the overlapping of several layers of information with the remotely sensed data, and the application of a virtually unlimited number of forms of data analysis.

The input data used for land use changes detection in this thesis consists of several spatial data categories from the available resources (as shown in Table 3-1), being digitized from available maps and prepared from image interpretation, and from field investigation data. These input data will be further used to analyze the dynamic behavior of land use and deforestation locations by the statistic analysis in the Chapter 4.

The brief techniques and thematic maps of the input data produced in this thesis, namely, elevation (slope and hillshade), hydrology, geology, soil properties, land use, human settlement, infrastructure, forest reserve areas, and meteorology are consequently presented as below.

Table 3-1 Overview of the important input data themes that were pre-processed and invented in this thesis.

Main themes	Year	Sub-themes	Data preparation methodology
Elevation	2004	Digital elevation data	Derived from 1:50,000 scale digital map of the Royal Thai Survey Department
		Digital Elevation Model (DEM)	Derived from elevation data with GIS
		Slope	Derived from DEM with GIS
		Hillshade	Derived from DEM with GIS
Hydrology	2004	Drainage system	Derived from 1:50,000 scale digital map of Land Development Department (LDD)
		The distance raster of drainage-line	Interpolated grid theme contains a Euclidean distance from Drainage system
Geology		Rock unit	Digitized from a 1:50,000 scale geological map of Department of Mineral Resources (DMR)
Soil properties	2001	Soil group unit	Derived from 1:50,000 scale digital map of Land Development Department (LDD)
Land use	1988, 1997, 2007	Land use	Derived from interpretation of remote sensing imageries and field investigation
Infrastructure and human settlement	2005	Roads and villages	Derived from 1:50,000 scale digital map of Land Development Department (LDD)
Reserved areas	2000	National park and Wildlife Sanctuaries area	Derived from 1:50,000 scale digital map of Department of National Park, Wildlife and Plant Conservation
Meteorology	1988 to 2007	Mean annual precipitation	Interpolated from existing rainfall information of the observation stations of Thai Meteorological Department (TMD)

3.3 Elevation

Instead of using a discrete elevation map such as contour points, it is more advantageous to work with a continuous map. Regarding this advantage, the contour data was converted into a color-coded continuous map (Digital Elevation Model-DEM). DEM is used to create a slope, aspect and landform topographic shape. In order to increase visual interception of DEM, it had been chosen to convert into a color-coded DEM (Figure 3-1) and a color-draped relief model (Figure 3-2). The produced DEM would be used as the elevation input data for the elevation attributes of land use change factor.

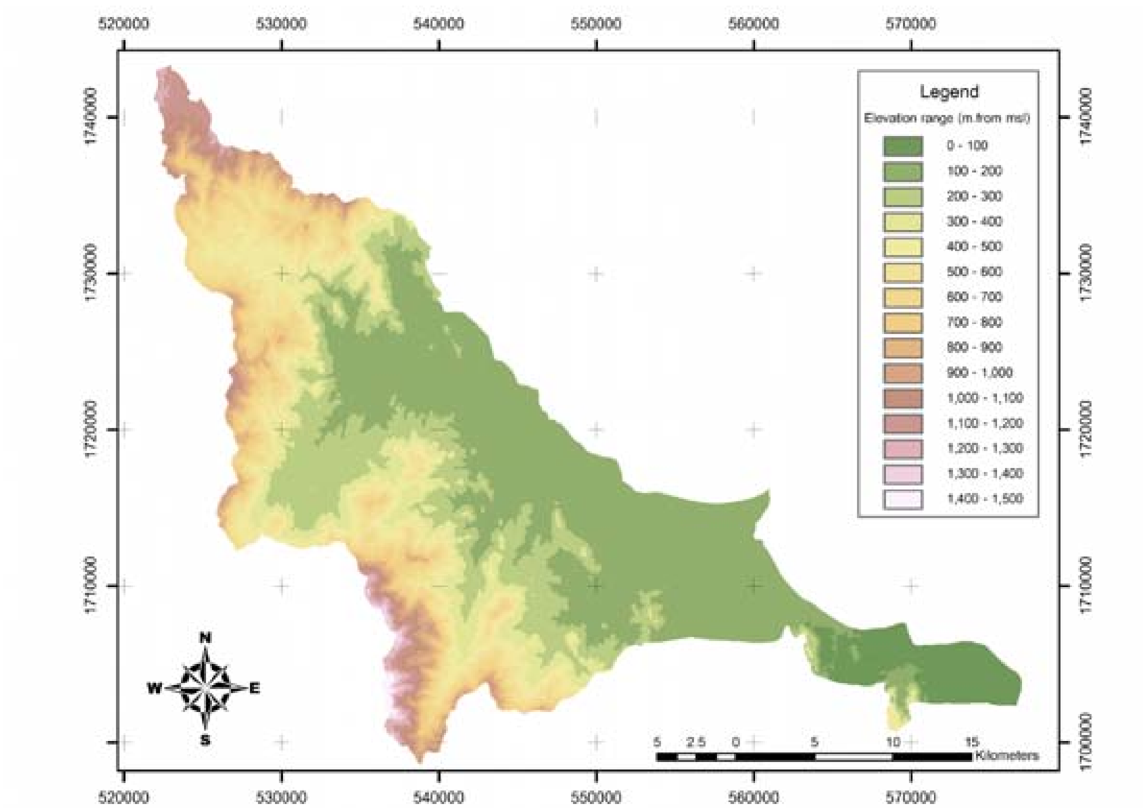


Figure 3-1 Color-coded DEM of the study area.

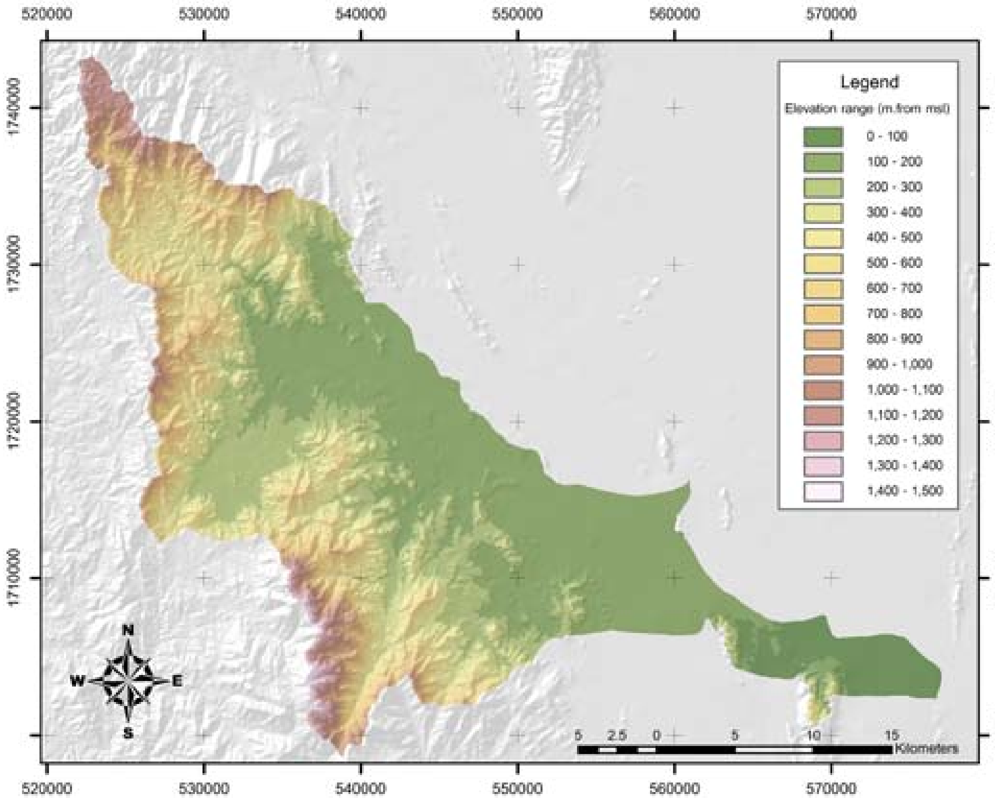


Figure 3-2 Color-draped relief model of the study area.

3.4 Slope

The slope is a measurement of surface steepness and is calculated in degrees of inclination. The color-coded slope map is conducted in Figure 3-3. The slope has a range between 0 degree and 90 degrees, 0 degree representing the flat lying areas and 90 degrees as the vertical ones. Any other value indicates the inclined areas. In the eastern and central of the study area consists of gentle slope that range between 0 to 5 degree while the western of the area consists of steep slope that range between 15 to greater than 40 degree.

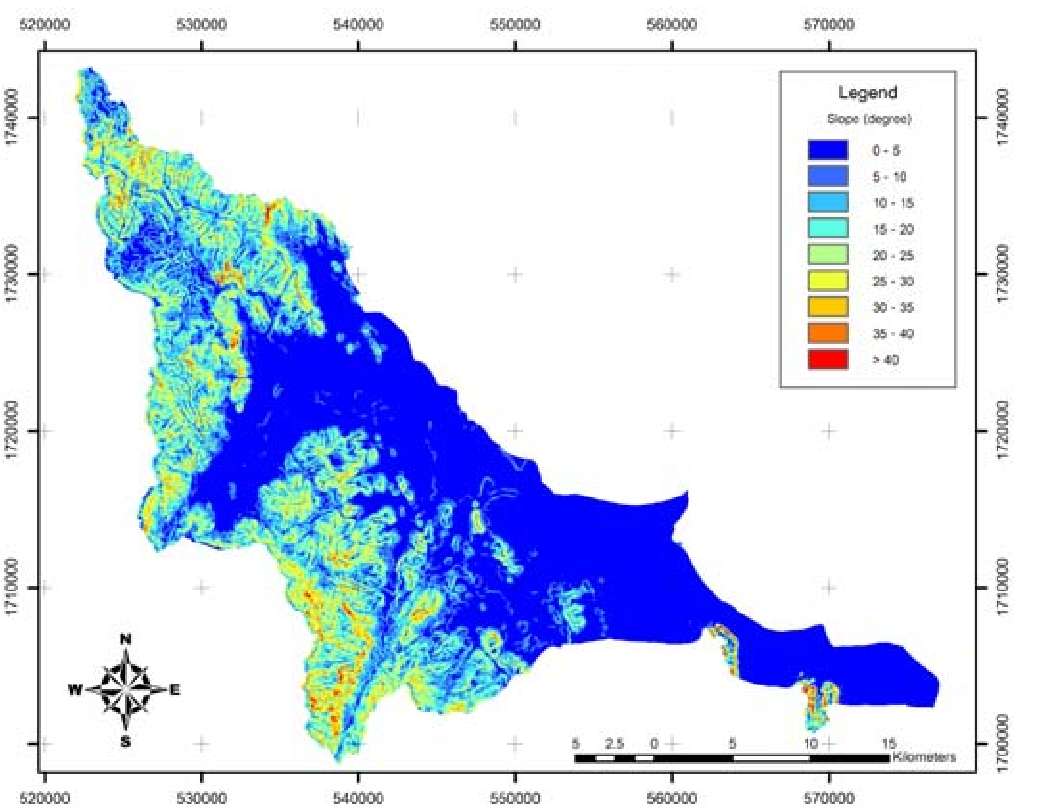


Figure 3-3 Slope map of the study area.

3.5 Hydrology

The drainage-lines of the Huai Thap Salao watershed were also available in a digital format. This digital river map was used as an overlay of a grid map of the study area. The distance of the middle of every pixel to the nearest river was calculated with the Euclidean distance function in ArcMap GIS version 9.2 as shown in Figure 3-4.

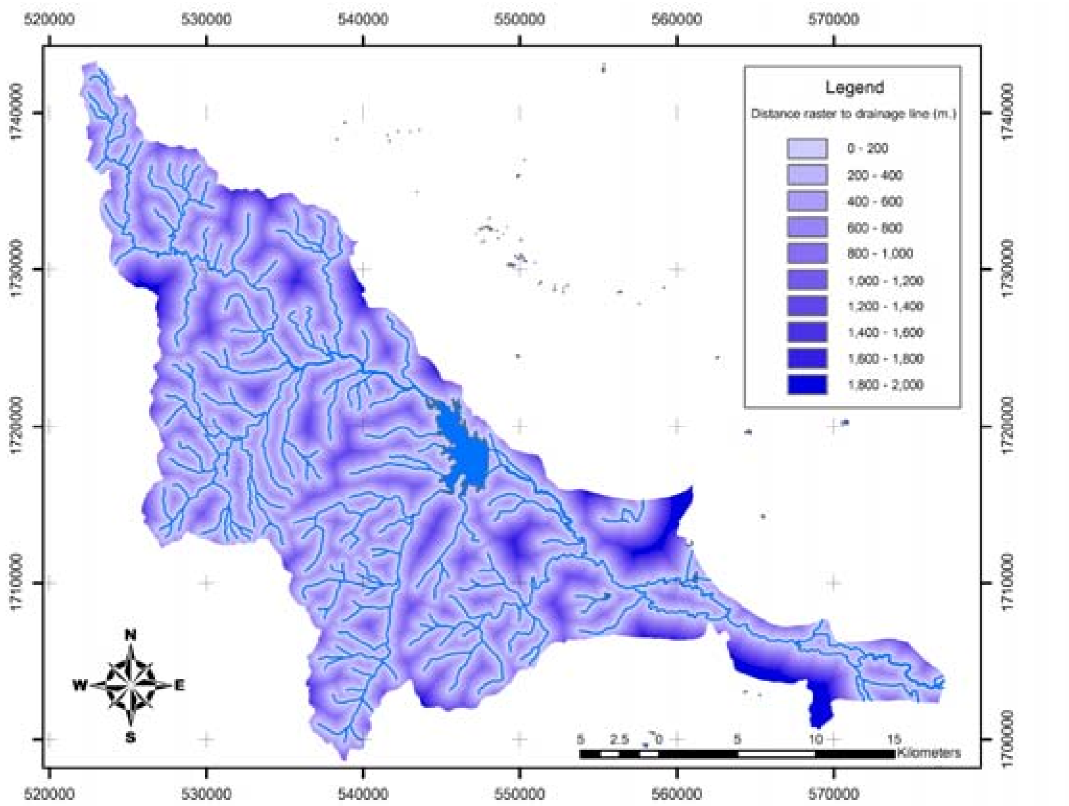


Figure 3-4 Distance raster of every pixel to the nearest drainage-line in the study area.

3.6 Geology

Unconformably above that, Pre-Cambrian Sedimentary and metamorphic rock (PE) covers the most part of the study area, especially adjacent to the central stream channel. Cambrian Sedimentary and metamorphic rock (E) and Triassic Igneous rock (Trgr) mainly exposed on the steepest and highest western, to the tops of a flat highland in the study area. Stratigraphically, the lowest rock unit, generally exposed in the eastern part of the study area, is Permian Ratburi Group (Pr) that consists of limestone, dolomitic limestone, brachiopods, corals, and bryozoans.

The younger unconsolidated sediments of Terrace deposits (Qt) of Quaternary age are those of mainly stream deposits, composing of river sands and gravels, silts, clays and laterite along the drainage system here. The sediments of Quaternary age also form in the alluvial fan as alluvial fan deposits (Qaf) at the canyon mouth to the southeastern limit of the study area as shown in Figure 3-5.

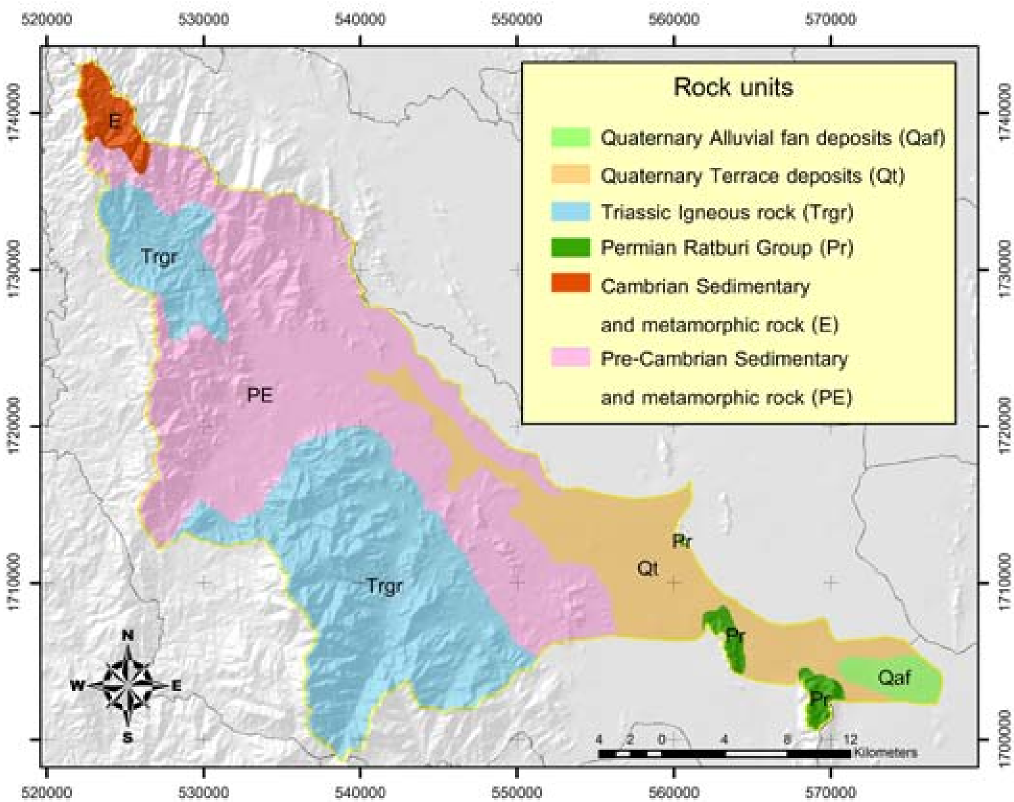


Figure 3-5 Geologic map of the study area.

3.7 Soil properties

The soil properties, was collected in a form of soil group unit map of the study area prepared by compiling data from the available reports, publications, and analogue map of Land Development Department. The compiled analogue maps were transformed into digital image, via digitizing and edit using ArcMap GIS version 9.2 software. (as shown in Figure 3-6 and Figure 3-7)

In the study area, Group Unit 62 of soil covers 54.86 percent of total area, located on headwater source. This group of soils includes all steep lands with more than 35 percent slopes (SC: slope complex). Soil qualities vary according to the geological settings of the areas. This group of soils should restrict their uses to forest land, watershed protection and wildlife conservation. Group Unit 37 (Thap Salao series: Tas) of soil covers 16.95 percent of total area, located on Huai Tap Salao stream. This group of soils is well-drained, moderately deep coarse-textured that developed from weathered rocks in dry areas. They have low fertility. Soil pH of this group unit varied from 4.5-5.5.

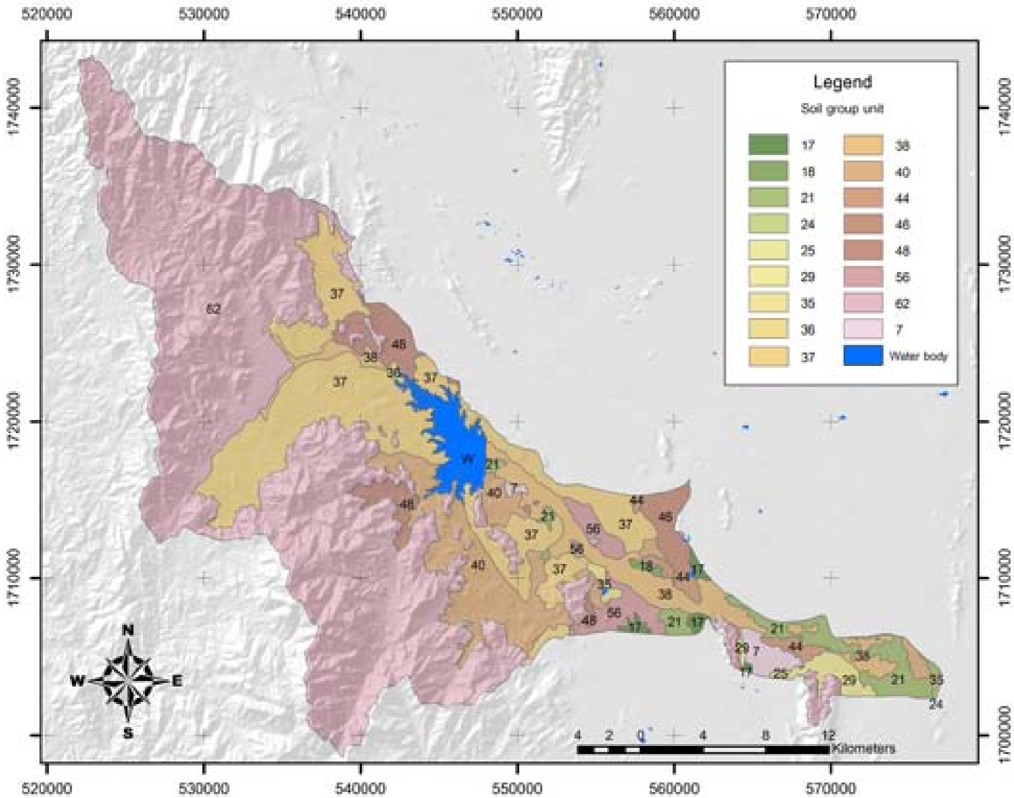


Figure 3-6 Soil group unit map of the study area.

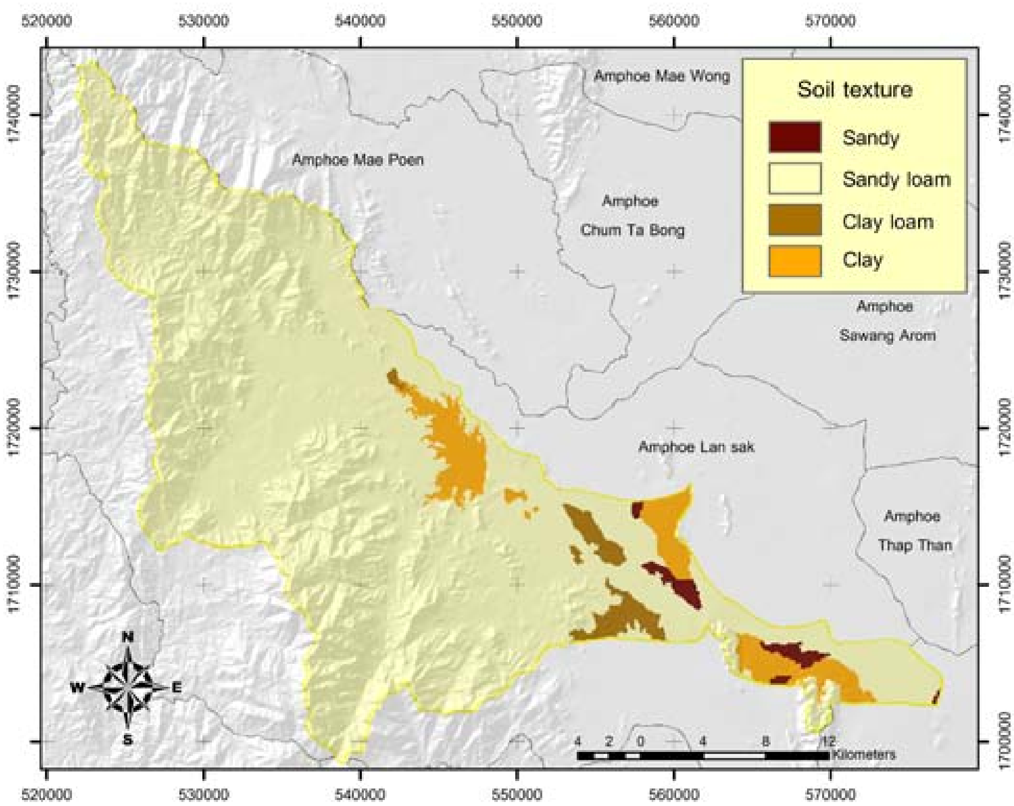


Figure 3-7 Soil texture map of the study area.

3.8 Land use

The land use classification system presented in this study includes only the more generalized first and second levels. The system satisfies the three major attributes of the classification process as outlined by Land Development Department (LDD) (2003) in conjunction with U.S. Geological Survey (USGS) (2007):

- It gives names to categories by simply using accepted terminology
- It enables information to be transmitted; and
- It allows inductive generalizations to be made.

The classification system is capable of further refinement on the basis of more extended and varied use. At the more generalized levels it should meet the principal objective of providing a land use and land cover classification system for use in land use planning and management activities. Attainment of the more fundamental and long-range objective of providing a standardized system of land use and land cover classification for national and regional studies will depend on the improvement that should result from widespread use of the system.

A systematic study of image interpretation usually involves several basic characteristics of features shown on an image. The elements of image interpretation are tone, color, size, shape, texture, pattern, site, height and association (Table 3-2). These are routinely used when interpreting a satellite images as shown in Figure 3-8 (Jensen and Kiefer, 2007). This study used satellite images Landsat 5TM in the years 1988, 1997, and 2007 representing the land use and then they were classified as 13 land use categories as shown in Table 3-3.

Table 3-2 Elements of Image Interpretation (Jensen and Kiefer, 2007).

No.	Interpretation elements	General characteristics
1	tone/ color	Relative brightness of black and white image and hue for colored pictures
2	size	Relative dimension of different objects
3	shape	Form also height of an object (in 3D)
4	texture	Relates to the frequency of tonal change and is expressed as coarse, fine, smooth or rough, even or uneven, etc
5	pattern	Spatial arrangement of objects and implies characteristic repetition of certain forms or relationship. It can be described as concentric, radial, check board, etc
6	site	Occurrence of an object to a particular easily identifiable feature
7	height	z-elevation, slop, aspect, volume
8	association	Close relationship/links of different or combination of objects.

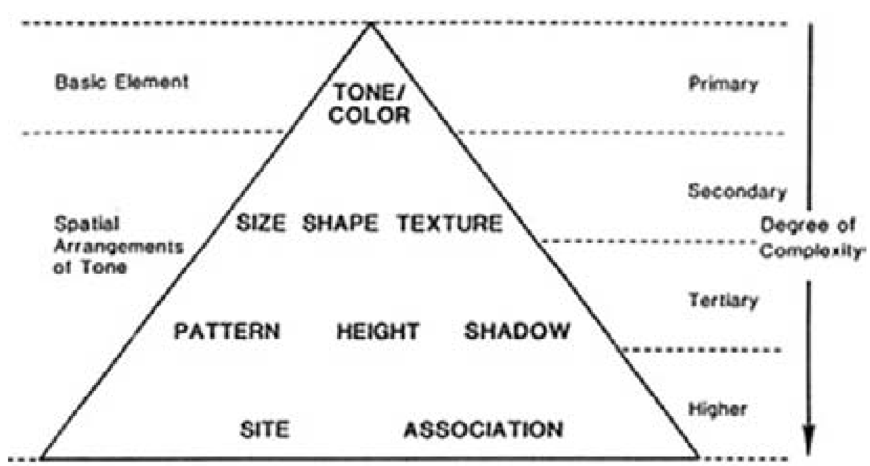


Figure 3-8 Primary ordering of image elements fundamental to the analysis process.

Table 3-3 Land use and land cover classification system (Land Development Department, LDD) used in remote sensing data interpretation in Huai Thap Salao watershed, Changwat Uthai Thani.

LU_CODE					
Level I		Level II		Level III	
A	Agricultural land	A01	Paddy field	A0102	Broadscasted paddy field
		A02	Field crops	A0202	Corn
				A0203	Sugarcane
				A0204	Cassava
		A03	Perennial crops	A0302	Para rubber
F	Forest land	F01	Evergreen forest	F0102	Dry evergreen forest
		F02	Deciduous forest	F0201	Mixed deciduous forest
				F0202	Dry dipterocarp forest
		F03	Forest plantation	F0300	Forest plantation
				F0301	Teak plantation
				F0303	Eucalyptus plantation
W	Water Bodies	W00	Water bodies	W0000	Water bodies
U	Urban and built-up land	U00	Urban and built-up land	U0000	Urban and built-up land

The land use patterns of Huai Thap Salao watershed were classified using both visual and computer automated interpretation. The procedures were as follow:

3.8.1 Data Sources

Remote sensing data used in this study comprises of Landsat 5TM satellite images in the year 1988, 1997, and 2007. These data will be used for land use change analysis and input for trend extrapolation to calculate land use requirements future year that will be further presented in Chapter 4. Table 3-4 showed the remote sensing data attribute and accessing periods that were used in this study.

Table 3-4 The remote sensing data attributes and accessing periods that were used in this study.

Image type	Path/Row	Band (R:G:B)	Acquisition date	Original		
				Format	Scale and Resolution	Source
Landsat 5TM	130/49	5:4:3	1988-04-06	TIFF	25 m.	GISTDA
	130/49	5:4:3	1997-01-25	TIFF	25 m.	GISTDA
	130/49	5:4:3	2007-03-26	TIFF	25 m.	GISTDA

Remarks: GISTDA is Geo-Informatics and Space Technology Development Agency (Public Organization)

3.8.2 Data Processing

Satellite imagery was analyzed using the program ERDAS Imagine version 8.7 to obtain the results for land use classification and grid interpolation. This study used ArcMap GIS version 9.2 for analyzing previous secondary data and classifying results. Digital data analysis techniques employed in this study involved the following two steps. The first step, image classification is the process of making quantitative decision from image data, grouping pixels of the image into classes to represent different physical object. The second step, the procedures of the classification consisted of unsupervised classification and supervised classification.

Unsupervised classification was performed using algorithm called the Iterative Self-Organizing Data Analysis Technique or ISODATA (Tou and Gonzalez, 1974 cited in Lillesand et. al., 2008). Performed an unsupervised classification with 30 clusters a)

b)

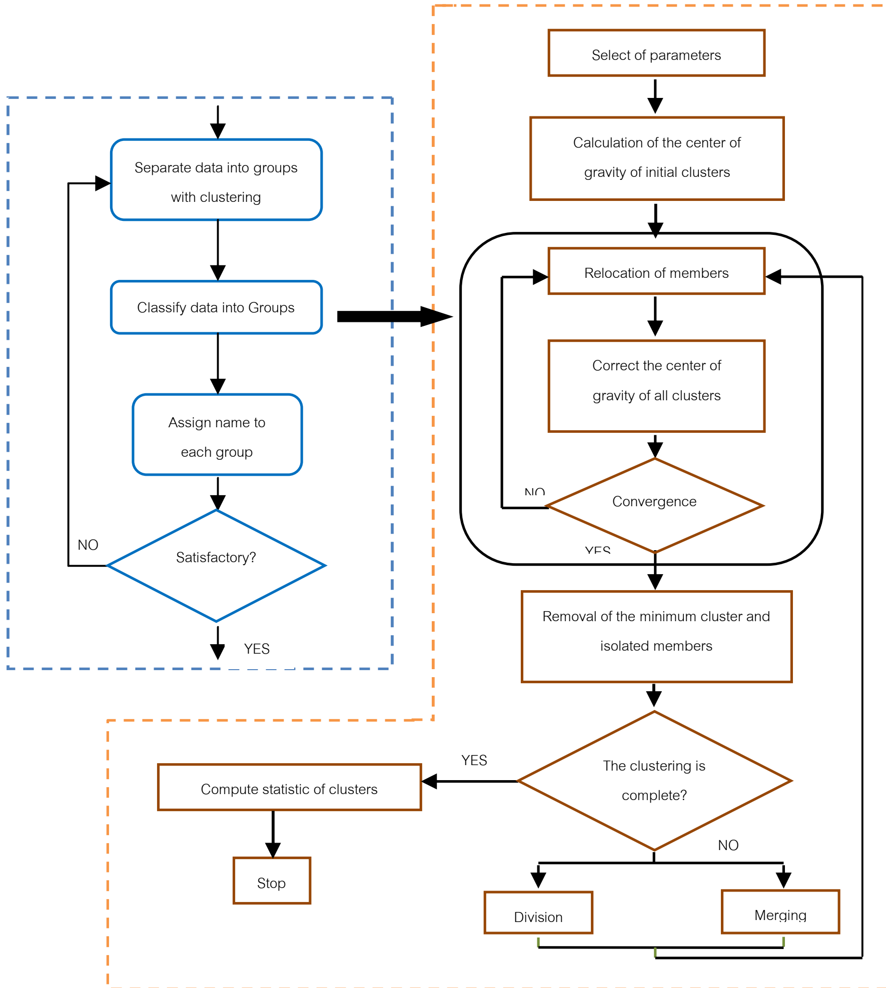


Figure 3-9 a) unsupervised classification.

b) Iterative Self-Organizing Data Analysis Technique (ISODATA).

Source: Adapted from F.F. Sabins (2007) cited in Lillesand et. al. (2008)

In unsupervised classification any individual pixel was compared to each discrete cluster to see which one it was closest to. A map of all pixels in the image, classified as to which cluster each pixel was most likely to belong, was produced (in black and white or more commonly in colors assigned to each cluster) as shown in Figure 3-9. This must be interpreted by the user as to what the color patterns may mean in terms of classes that were actually presented in the real world scene; this required some knowledge of the scene's feature/class/material content from general experience or personal familiarity with the area imaged (Lillesand et. al., 2008).

The supervised classification performed by the method of Maximum likelihood was to delineate a given pixel to the class that generated from the spectral signature analysis. For avoiding bias, each training area was not least than 30 pixels distributed around study area. In this study, land use was classified into 7 categories. The random samplings were rechecked by field observation convincing the correct classification as shown in Figure3-10.

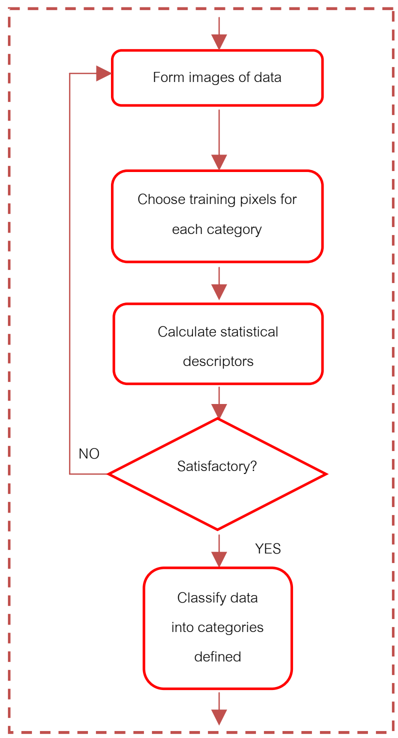


Figure 3-10 Supervised classification.

Source: Adapted from F.F. Sabins (2007) cited in Lillesand et. al. (2008)

Maximum likelihood classification (MLC) technique was employed to perform the classification of an unknown pixel. This technique had been found to be the most accurate procedure in quantitatively evaluate both the variance and correlation of the category spectral reflectance patterns. In this study land use was classified into seven categories based on vegetation characteristics and field investigation.

3.8.3 Post-processing

During the classification process, the "island themes" might appear. These were single pixel themes that were most likely classification errors. These island themes could be assigned the same gray level as their phenomenon-surrounding theme using a mode filter. The mode filter was a filter algorithm that replaces a pixel gray value with the mode of the gray levels within the filter windows surrounding that pixel. This research applied mode filter with 5x5 windows size to reduce the island themes.

3.8.4 Accuracy assessment

A complete accuracy test of a classification map would be a verification of the class of every pixel. Obviously this is impossible and indeed defeats the purpose of the image classification. Therefore, representative test areas must be used instead to estimate the map accuracy with as little error as possible. Classified image accuracy consists of two accuracy types. Firstly, overall accuracy which represents the accuracy of the entire product and secondly, user's accuracy (or map accuracy) which a map user is interested in the reliability of the map in how well the map represents what be really on the ground.

Overall accuracy is the accuracy of total number of correctly classified pixels, defined as:

$$\text{Overall accuracy} = \sum_{i=1}^{k} x_{ij} / N \quad \text{.................................. (Equation 3-1)}$$

where

x_{ij} = a value of the contingency matrix for an element in column i row j

k = the number of classes

N = the total number of sampling cells

i = class i^{th} as classified by classified image

j = class j^{th} as classified by ground truth

The Kappa coefficient ($\hat{k}$ or KHAT) is a measure of the difference between the actual agreement between reference data and an automated classifier and the chance agreement between the reference data and a random classifier (Lillesand et. al, 2008). Conceptually, $\hat{k}$ can be defined as

$$\hat{k} = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}(x_{i+} \cdot x_{+i})}{N^2 - \sum_{i=1}^{r}(x_{i+} \cdot x_{+i})} \quad \text{...} \text{(Equation 3-2)}$$

where

r	=	number of rows in the error matrix
x_{ii}	=	number of observations in row i and column i (on the major diagonal)
x_{i+}	=	total of observations in row i (shown as marginal total to right of the matrix)
x_{+i}	=	total of observations in row i (shown as marginal total at bottom of the matrix)
N	=	total number of observations included in matrix

Qualitative classification of overall accuracy value and Kappa coefficient value as degree of agreement (USGS, 1971 and 2007)

< 0	Less than chance agreement
0.01-0.40	Poor agreement
0.41-0.60	Moderate agreement
0.61-0.80	Substantial agreement
0.81-1.00	Almost perfect agreement

3.8.5 Accuracy assessment results for land use classification in the year 1988, 1997 and 2007

Accuracy assessment for land use classification was conducted for land use categories that were interpreted from Landsat 5TM satellite images in the year 2007. This method was done by using 110 sample points from Landsat 5TM satellite images in the year 2007 and field investigations that were selected using stratified proportional random samplings. In this method, each land use category was used as sampling measurement pixel. The result of overall accuracy assessment was 80.99% (or 0.81) and Kappa coefficient ($\hat{k}$) was 0.78.

Table 3-5 Accuracy assessment of land use classification in the year 2007.

Classified map	Reference map								Row Total	CA (%)
	F01	F02	F03	A01	A02	A03	W01	U01		
F01	510	0	0	0	0	0	0	0	510	100
F02	0	333	5	106	0	0	32	59	535	62.24
F03	0	2	517	0	5	0	1	0	525	98.48
A01	0	39	0	231	12	36	27	22	367	62.94
A02	0	0	12	35	380	25	2	107	561	67.74
A03	0	0	0	12	20	310	0	25	367	84.47
W00	0	0	0	9	0	0	486	6	501	97.01
U00	0	27	1	28	52	3	43	441	595	74.12
Column Total	510	401	535	421	469	374	591	660		
PA (%)	100	83.04	96.64	54.87	81.02	82.89	82.23	66.82		
Overall accuracy = 80.99% or 0.81					Kappa Index ($\hat{k}$) = 0.78					

Table 3-5 showed evergreen forest area had the highest producer's accuracy (PA value), which was 100%, followed by forest plantation area, deciduous forest area, perennial crops area, water bodies area, field crops area, and urban and built-up area. Land use 'paddy field area' had the least producer accuracy, which was 54.87%. The accuracy values indicated that evergreen forest had the highest probability of a reference site being correctly classified. It was calculated by dividing the total number of correctly classified pixels for a class by the total number of reference site for the class. In the user's accuracy (consumer's accuracy-CA value) calculation, evergreen forest area had the highest user's accuracy, which was 100%, followed by forest plantation area, water bodies area, perennial crops area, urban and built-up area, field crops area, and paddy field area. Land use 'deciduous forest area' had the least user's accuracy, which was 62.24%.

Accuracy assessment for land use classification was conducted for land use categories that were interpreted from Landsat 5TM satellite images in the year 1997. This method was done by using 110 sample points from Landsat 5TM satellite images in the year 1997 and field investigations that were selected using stratified proportional random samplings. In this method, each land use category was used as sampling measurement pixel. The result of overall accuracy assessment was 77.98% (or 0.78) and Kappa coefficient ($\hat{k}$) was 0.75 as shown in Table 3-6.

Table 3-6 Accuracy assessment of land use classification in 1997.

Classified map	Reference map								Row Total	CA (%)
	F01	F02	F03	A01	A02	A03	W01	U01		
F01	617	39	1	0	0	0	0	0	657	93.91
F02	51	444	72	4	1	3	5	0	580	76.55
F03	3	68	546	30	51	3	0	14	715	76.36
A01	0	14	15	290	27	12	1	66	425	68.24
A02	0	3	71	137	412	2	11	31	667	61.77
A03	0	0	2	8	60	370	12	32	484	76.45
W00	1	40	0	0	0	0	522	0	563	92.72
U00	0	0	1	51	28	12	0	276	368	75.00
Column Total	672	608	708	520	579	402	551	419		
PA (%)	91.82	73.03	77.12	55.77	71.16	92.04	94.74	65.87		
Overall accuracy = 77.98% or 0.78					Kappa Index ($\hat{k}$) = 0.75					

Accuracy assessment for land use classification was conducted for land use categories that were interpreted from Landsat 5TM satellite images in the year 1988. This method was done by using 110 sample points from Landsat 5TM satellite images in the year 1988 and field investigations that were selected using stratified proportional random samplings. In this method, each land use category was used as sampling measurement pixel. The result of overall accuracy assessment was85.99% (or 0.86) and Kappa coefficient ($\hat{k}$) was 0.84 as shown in Table 3-7.

Table 3-7 Accuracy assessment of land use classification in 1988.

Classified map	Reference map								Row Total	CA (%)
	F01	F02	F03	A01	A02	A03	W01	U01		
F01	598	0	0	0	0	0	0	0	598	100
F02	0	560	78	0	0	0	5	0	643	87.09
F03	0	121	486	0	81	35	6	1	730	66.58
A01	0	0	2	453	3	7	43	1	509	89.00
A02	0	3	16	42	598	23	13	57	752	79.52
A03	0	0	0	32	12	380	0	2	426	89.20
W00	0	4	0	11	9	0	412	1	437	94.28
U00	0	0	0	0	29	0	3	441	473	93.23
Column Total	598	688	582	538	732	445	482	503	4568	
PA (%)	100	81.40	83.51	84.20	81.69	85.39	85.48	87.67		
Overall accuracy = 85.99% or 0.86				Kappa Index ($\hat{k}$) = 0.84						

It implied that a pixel on the map presented that land use category on the ground. This accuracy was calculated by dividing the number of correct accuracy sites for a land use category by the total number of accuracy assessment sites that were classified in that land use category.

3.8.6 Land use classification in the year 1988, 1997 and 2007 in Huai Thap Salao watershed

According to the land use classification processes by Landsat 5TM satellite images, there were 8 land use categories were identified, namely, paddy field, field crops, perennial crops, evergreen forest, deciduous forest, forest plantation, urban and built-up land, and water bodies. The trends of land use changes of the area during 1988-2007 were presented in Table 3-8 and Figure 3-11. The areal distributions and locations of land use categories were presented in the Figure 3-12 to 3-17.

Table 3-8 Land use classification in Huai Thap Salao watershed by Landsat 5TM satellite images in the year 1988, 1997 and 2007.

Land use code	Land use category	1988		1997		2007	
		km^2	%	km^2	%	km^2	%
A01	Paddy field	20.08	2.61	27.86	3.62	66.50	8.65
A02	Field crops	166.63	21.66	160.93	20.92	116.07	15.09
A03	Perennial crops	14.83	1.93	31.34	4.08	40.09	5.21
F01	Evergreen forest	122.14	15.88	155.17	20.17	204.21	26.55
F02	Deciduous forest	436.54	57.05	361.93	47.35	306.34	40.12
F03	Forest plantation	0.56	0.07	5.73	0.75	7.51	0.98
U00	Urban and built-up land	2.77	0.36	3.78	0.49	16.38	2.13
W00	Water bodies	3.30	0.43	20.10	2.61	9.75	1.27
Total		766.85	100.00	766.85	100.00	766.85	100.00

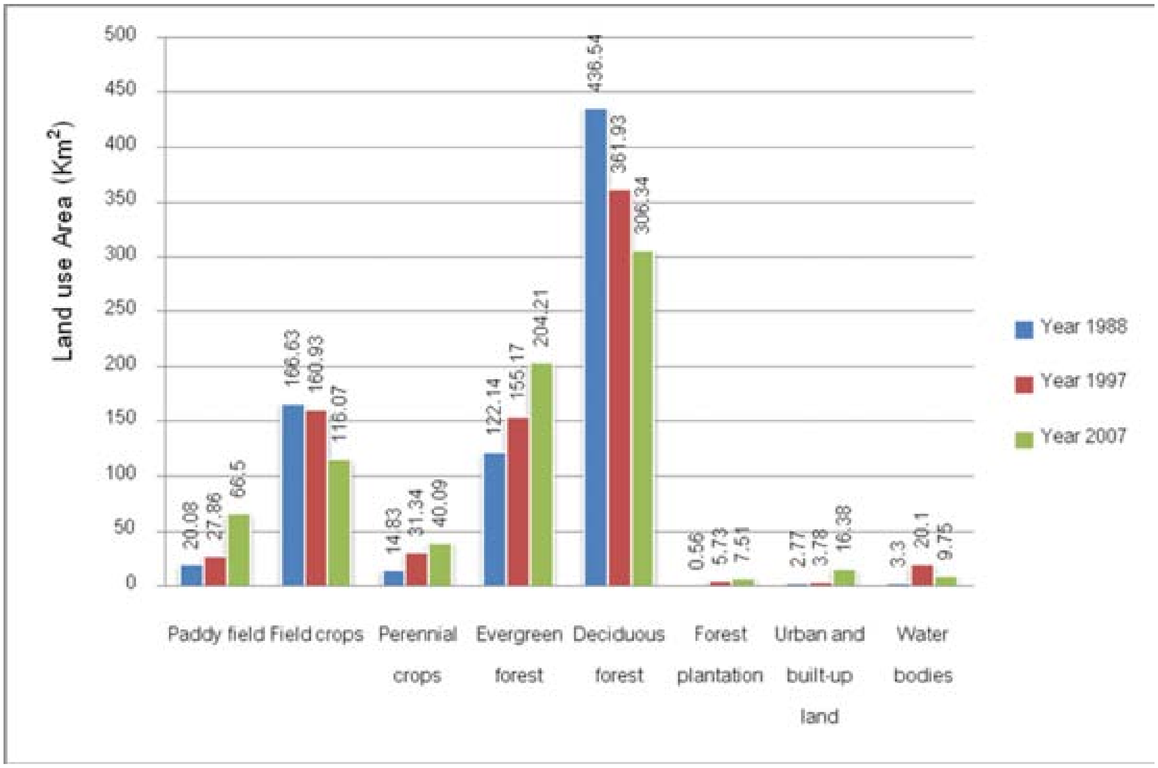


Figure 3-11 Graph showing the areal distributions of land use categories in Huai Thap Salao watershed during 1988-2007.

The result revealed that the change detection for the land use classification in the 1988, 1997 and 2007, that paddy field, perennial crops, evergreen forest, forest plantation, and urban and built-up land were increasing over time, whereas deciduous forest and field crops tended to decrease. Besides, water bodies tended to increase in the year 1997 and decrease in the year 2007 according to the construction of Thap Salao dam.

Several western parts of deciduous forest tended to decrease because changing to be evergreen forest. It appeared undulating plains and ridges, low levels of rainfall, porous, heavily eroded and leached sandy or lateritic soils of both granitic and sandstone origin.

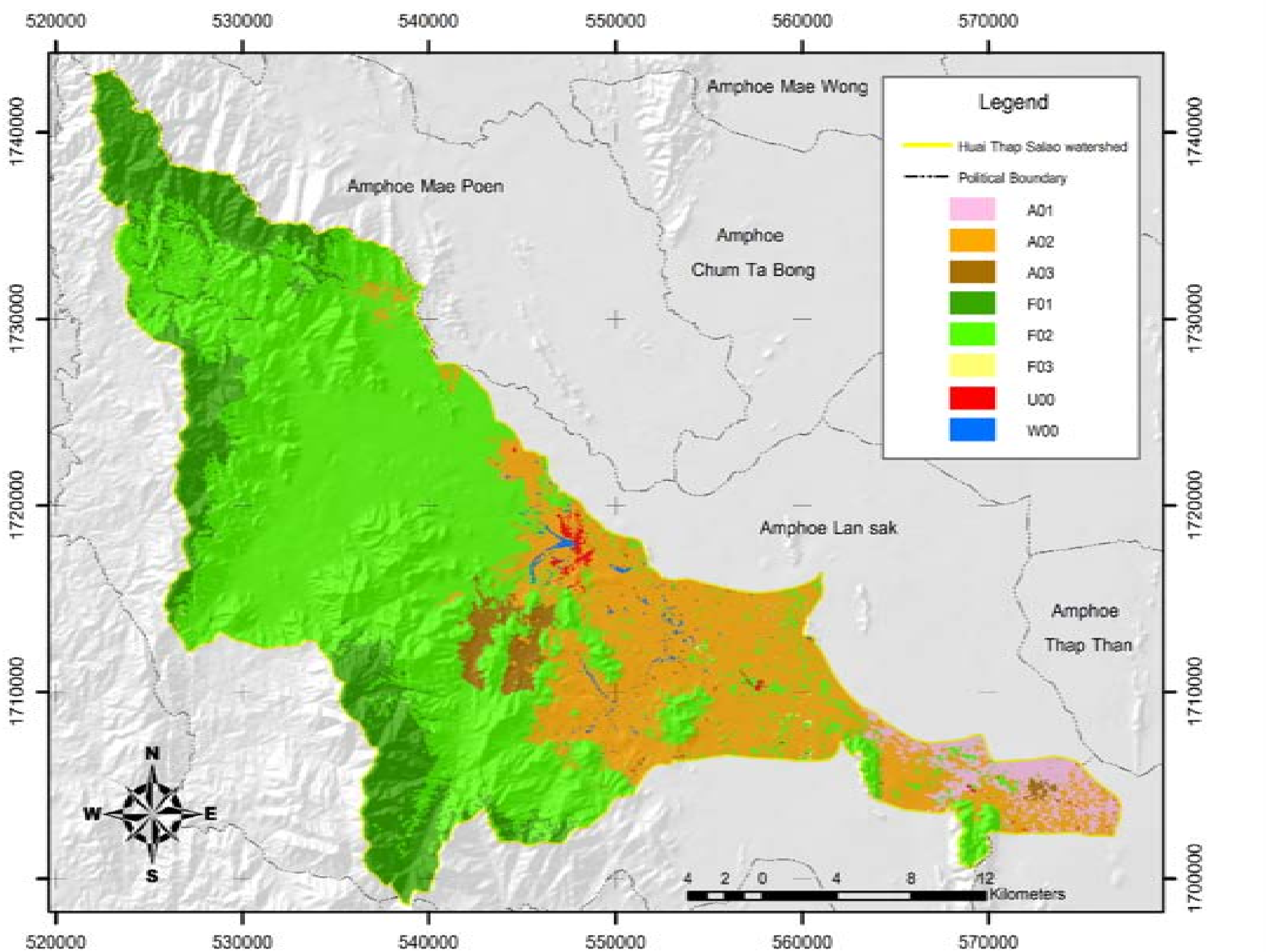


Figure 3-12 Classification of land use categories in Huai Thap Salao watershed in 1988.

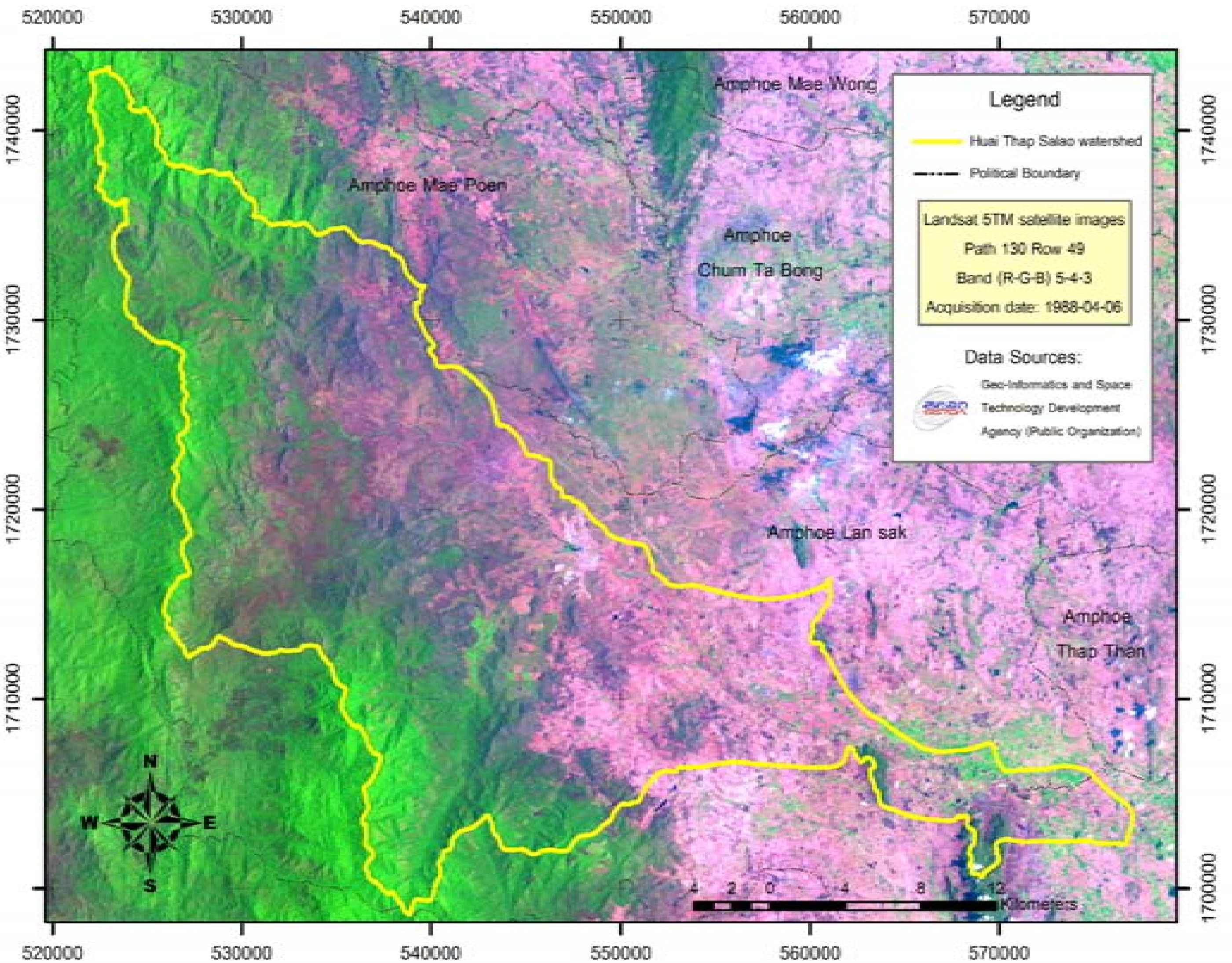


Figure 3-13 Landsat 5TM satellite image of Huai Thap Salao watershed in 1988.

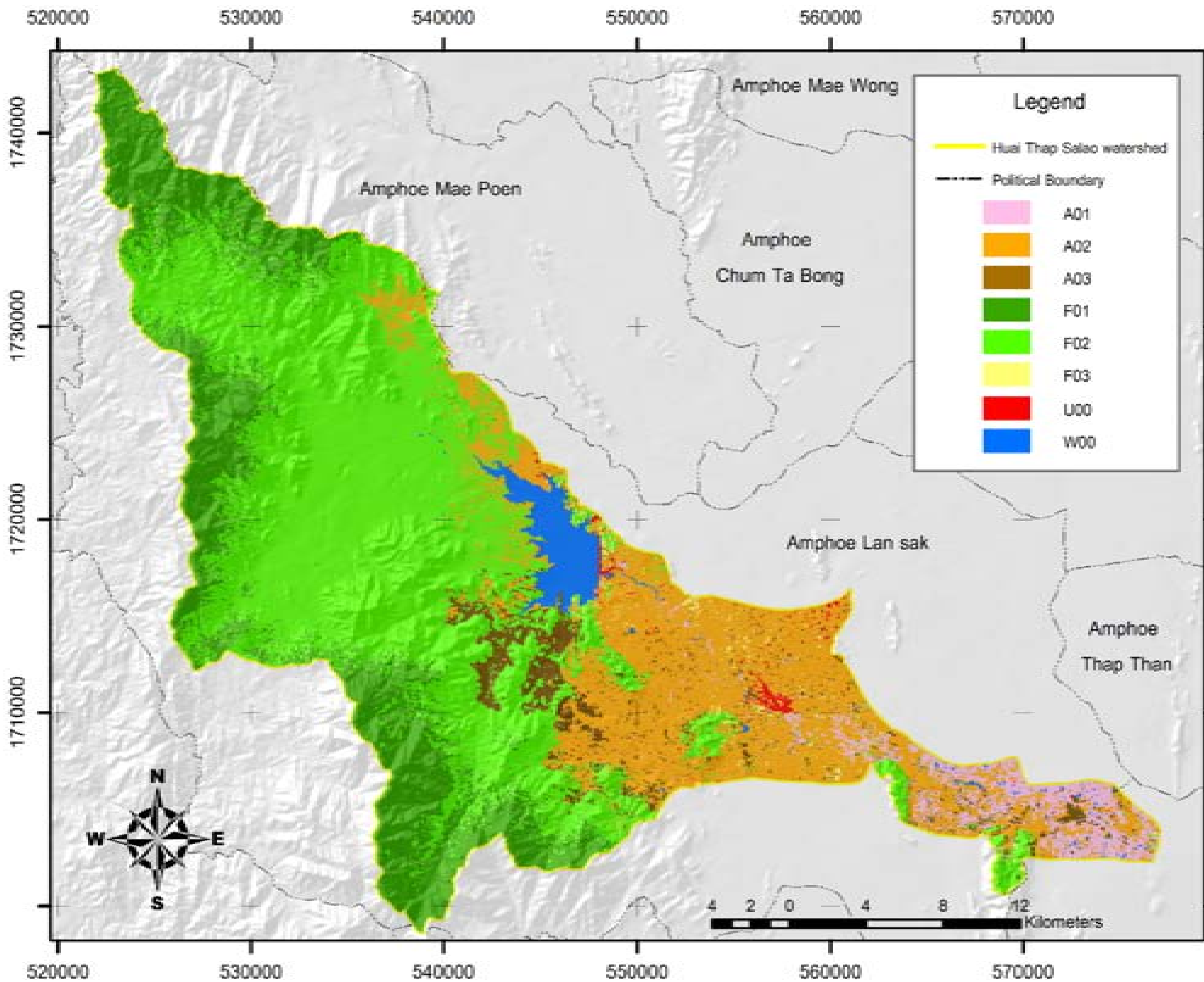


Figure 3-14 Classification of land use categories in Huai Thap Salao watershed in 1997.

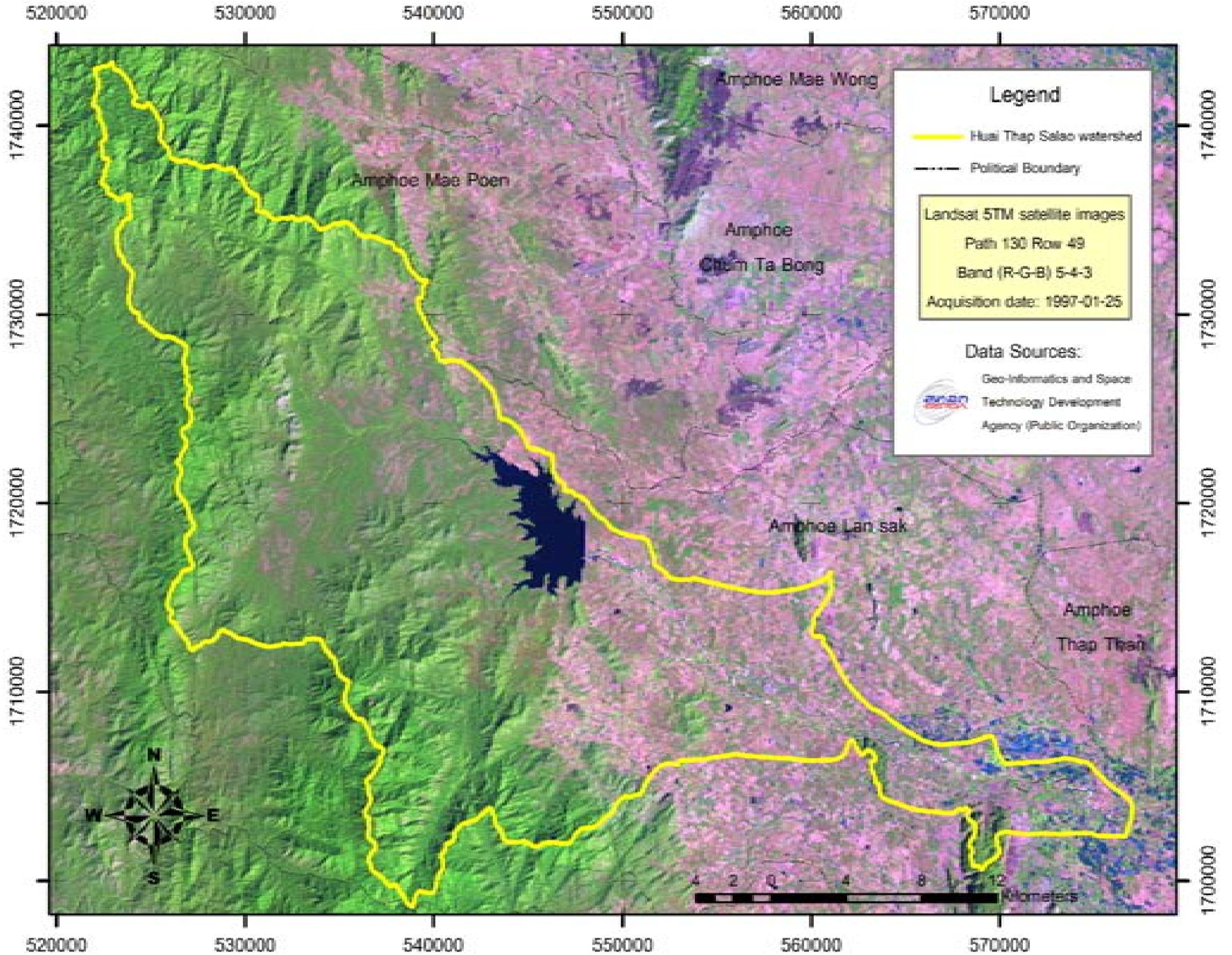


Figure 3-15 Landsat 5TM satellite image of Huai Thap Salao watershed in 1997.

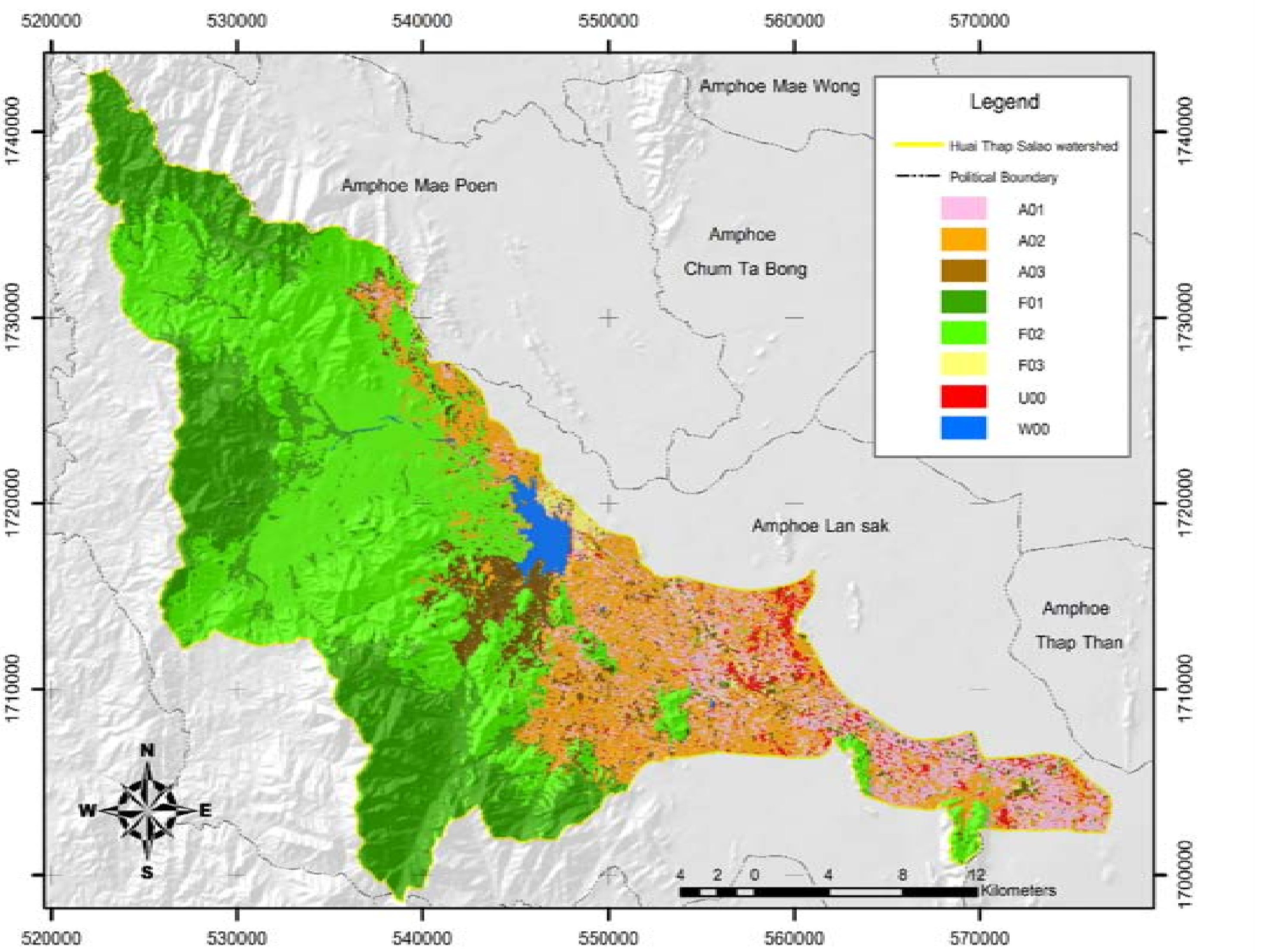


Figure 3-16 Classification of land use categories in Huai Thap Salao watershed in 2007.

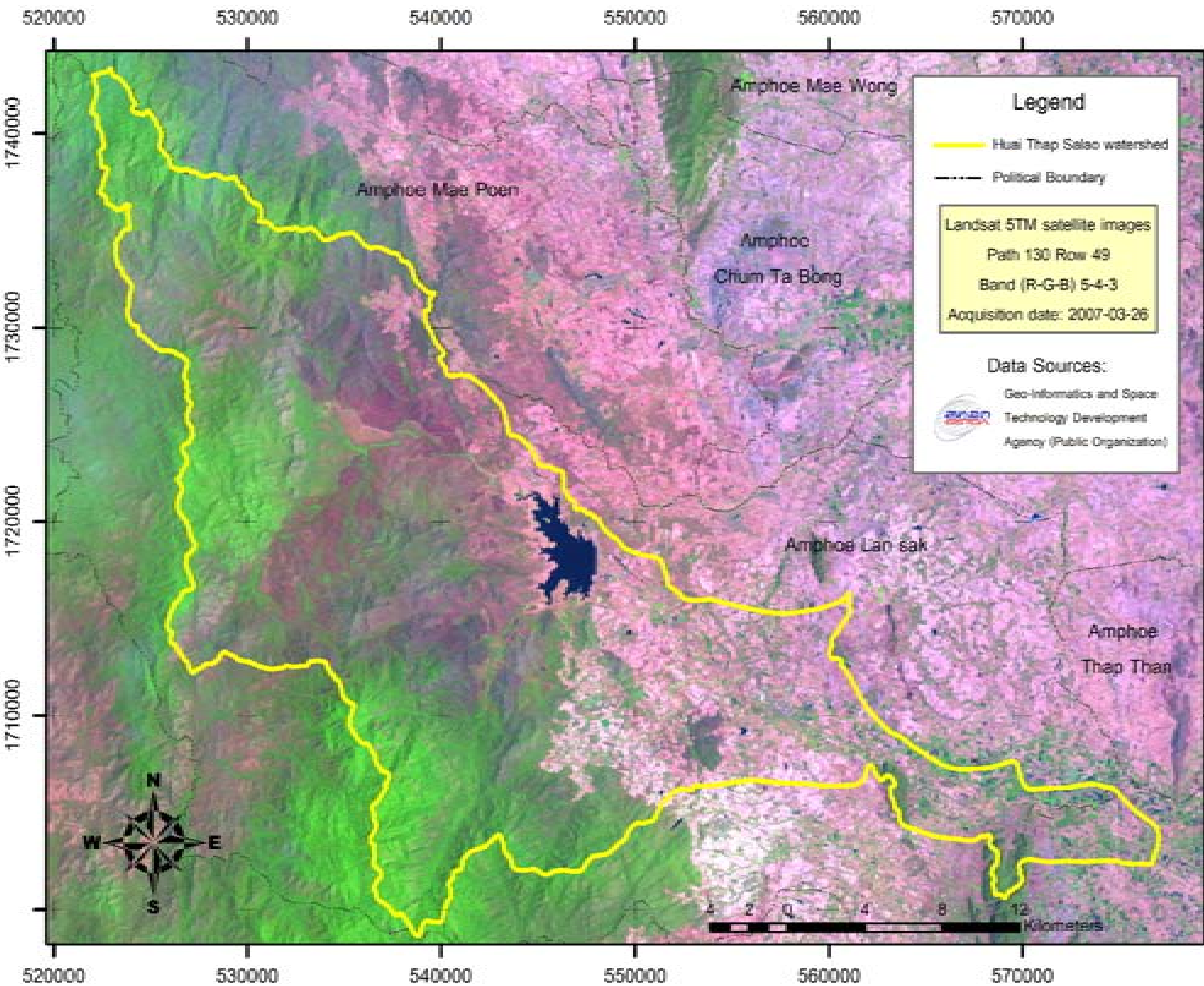


Figure 3-17 Landsat 5TM satellite image of Huai Thap Salao watershed in 2007.

3.9 Infrastructure and human settlement

Geographic Information System (GIS) tools were used to determine either stable or dynamic variables based on features such as points (settlements) or lines (roadss). The resulting grid theme contains a Euclidean distance (the straight line distance between two points) which is calculated between each of the output cells that doesn't contain a feature, to the closest feature.

The presence of transportation such as roads network might contribute to the evolution of land use change in the study area. For the construction of transportation map, the necessary features were derived from 1:50,000 scale digital maps of Land Development Department as shown in Figure 3-18.

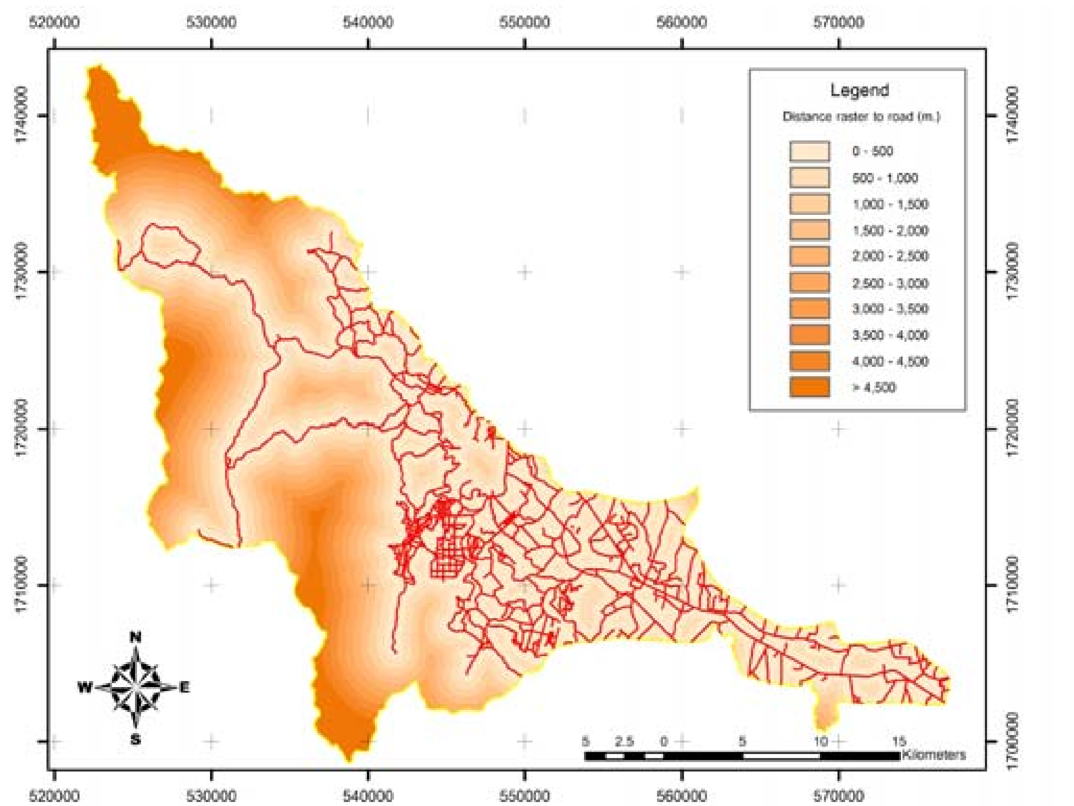


Figure 3-18 Distance raster of every pixel to the nearest roads in the study area.

The presence of human settlement might contribute to the evolution of land use change in the area. For the construction of human settlement map, the necessary features were derived from 1:50,000 scale digital maps of Land Development Department as shown in Figure 3-19.

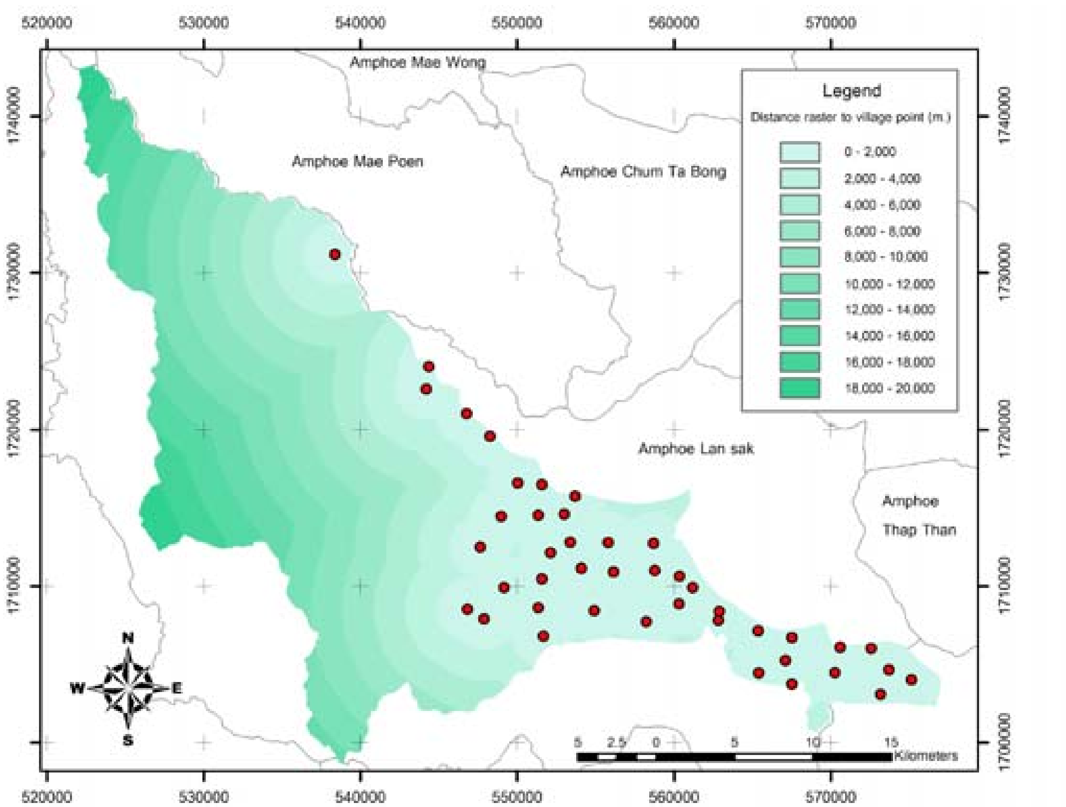


Figure 3-19 Distance raster of every pixel to the nearest village point in the study area.

3.10 Reserved areas

The presence of forest reserve area such as Wildlife Sanctuary and National park might contribute to the protection of land use change in the study area. For the construction of restriction map, the necessary features were derived from 1:50,000 scale digital maps of Department of National Park, Wildlife and Plant Conservation as shown in Figure 3-20.

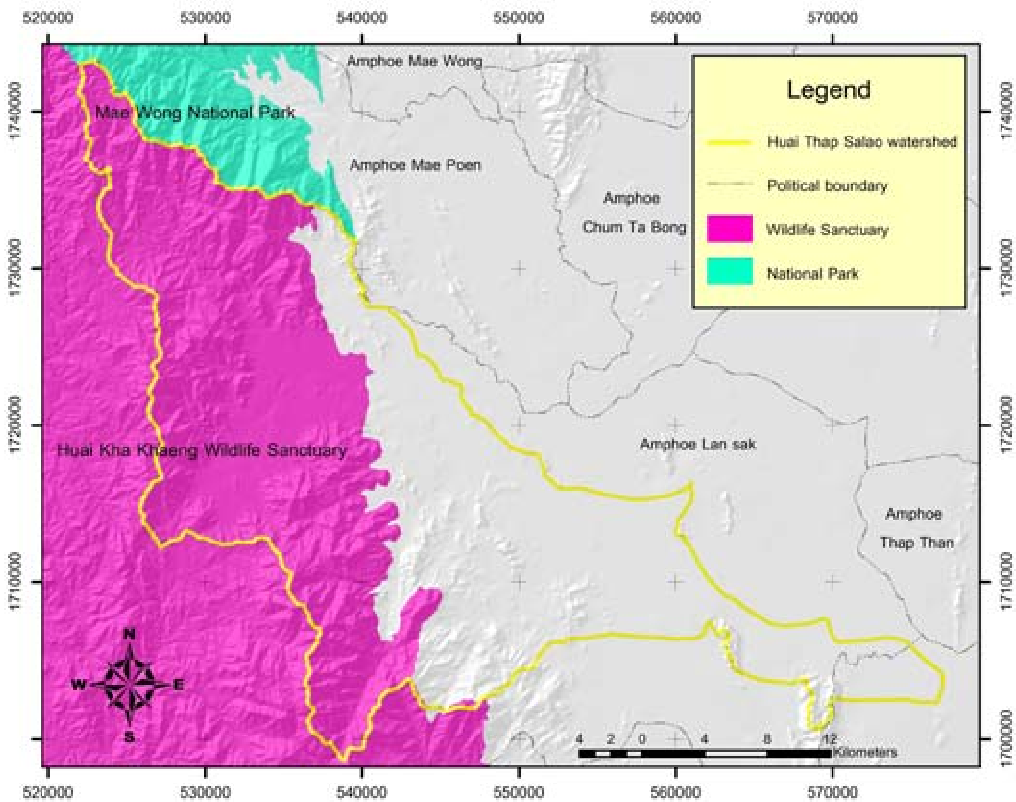


Figure 3-20 Reserved area of the study area.

3.11 Mean annual precipitation

In this study, rainfall data were received from observation stations of Thai Meteorology Department during 1st January 1988 to 31st December 2007 being put into database surrounding Huai Tap Salao watershed (as show in Figure 3-21).

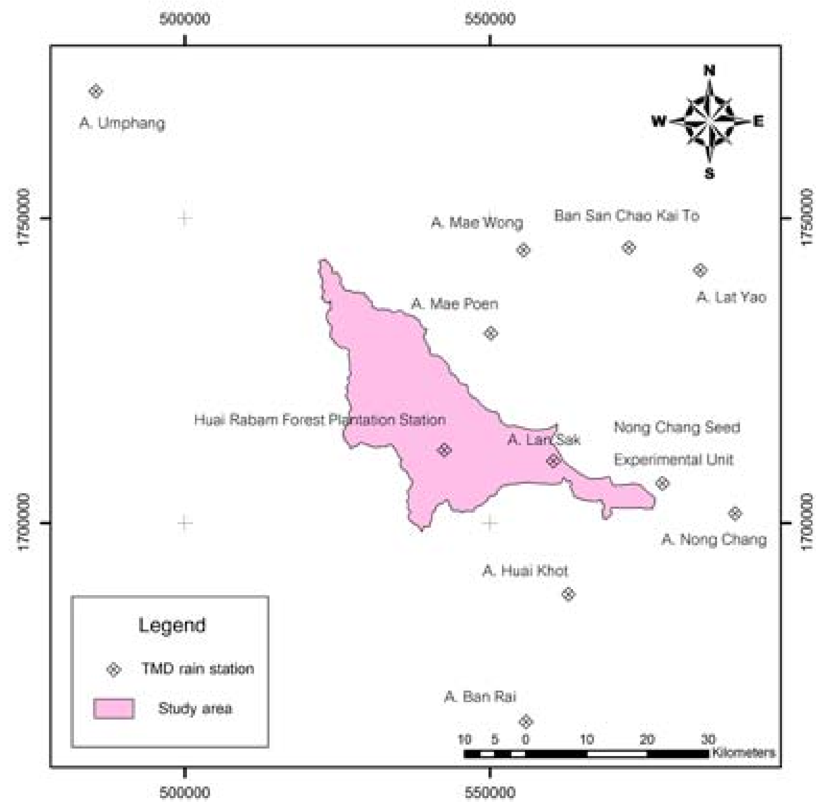


Figure 3-21 Location of eleven rainfall-measurement stations of Thai Meteorological Department (TMD) surrounding the study area.

Supported by the data from 11 precipitation-observation stations on precipitation and the Inverse Distance Weighted (IDW) interpolation methods, the changing trends of mean precipitation were represented as the grid scale of 30 m x 30 m. percentage of sunlight is also a supposed driving factor for land use change and was also disaggregated into the spatial dimension based on the data collection from 11 observation station (Figure 3-22).

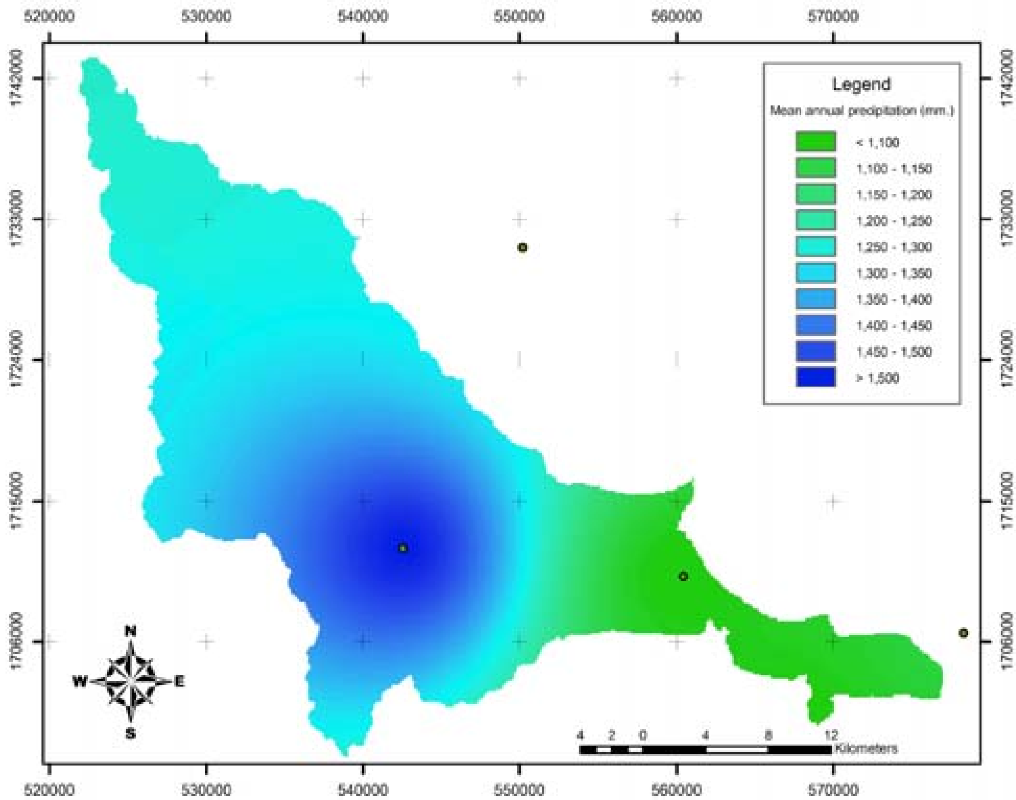


Figure 3-22 Isohyte map of mean precipitation during 1st January 1988 to 31st December 2007 in the study area.

3.12 Field investigation

Field investigation was an essential part to verify the image interpretation process, as it was important to be confident of the validity of the desk-based assessment. The aim of field investigation was to confirm as many of the land use patterns as possible in Huai Thap Salao watershed, Amphoe Lan Sak, Changwat Uthai Thani. Selective field investigation was carried out to verify specific questions of interpretation that could not be resolved through the use of the data sources outlined above (SWALIM, 2007).

In preparation for field investigation using the topography map at scale 1:50,000 of L7018 series. The required map sheet included map number 4839I, 4840II, 4939IV and 4940III prepared and published by the Royal Thai Survey Department. Moreover land use mapping was accomplished through interpretation of satellite images from unsupervised classification process, was analyzed using the program ERDAS Imagine version 8.7. The images were prepared to show the best possible visual interpretation of target land cover types using Landsat bands 5, 4, 3, (RGB). Land use mapping were then overlay with the outlines and labels of the draft vectors supplied by main roads, rural tracks, and villages, to help field checking (Figure 3-23).

Most of the field investigation was done by travelling in a vehicle and a set of intensive 110 ground truth points was organized during 18^{th}-20^{th} March 2011 to localize different land cover and land use categories in order to refine the aforementioned classification.

The intensity of field investigation varied between map sheets depending on accessibility, and the nature of the land cover. Intensively managed landscapes were assessed to greater detail than natural landscapes, as they showed a finer mosaic of land cover types, and some of the classes present in these areas could not be reliably identified in the satellite imagery (Grüner and Gapare, 2004).

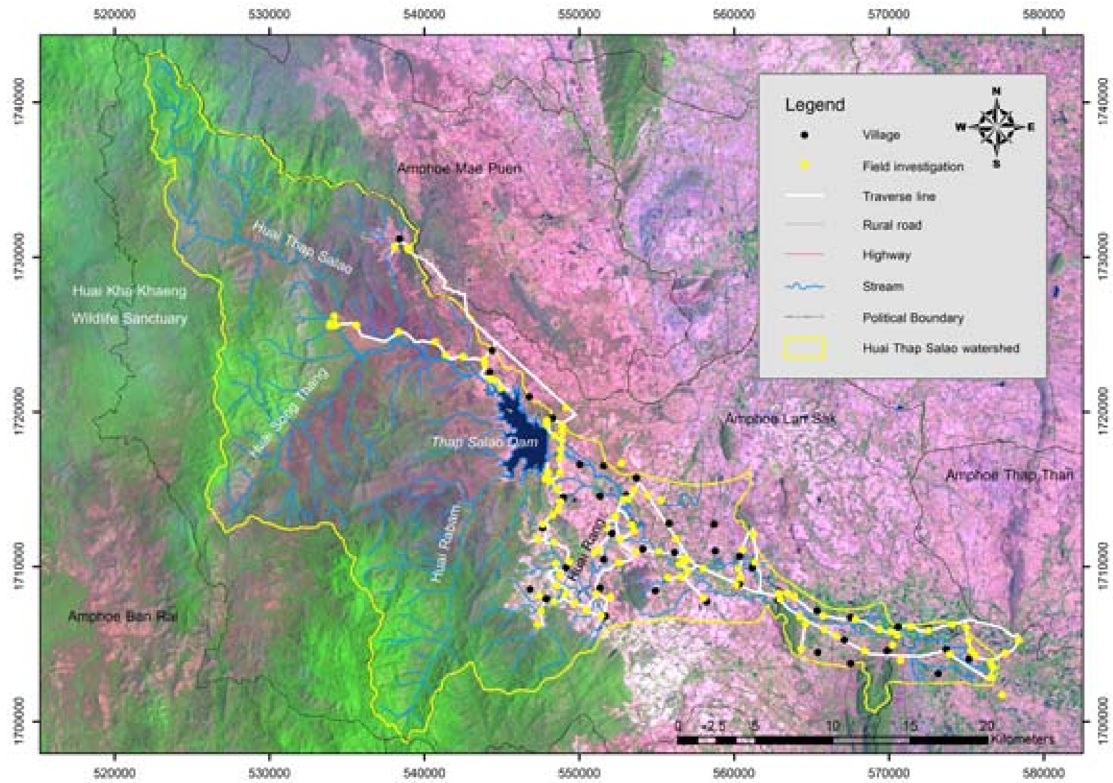


Figure 3-23 Traverse lines and field investigation points in the study area that were located in Landsat 5TM (R=5, G=4, B=3) acquired on 18th-20th March 2011.

In the field, GPS (global positioning system) can be used to precisely detect land use in the study area. The GPS uses a network of satellites to precisely pinpoint the device's location on Earth at any moment. GPS uses the principle of trilateration, using the location of several satellites to pinpoint an exact location. A receiver can determine the latitude, longitude, and elevation of a point using four or more satellites; there are a total of 24 Global Positioning System satellites currently in use (Earth Science Australia, 2010).

The field teams usually consisted of three people, with one person being solely responsible for driving. The other two worked with the setting GPS and the prepared hardcopy of the image to accomplish the following tasks (Grüner and Gapare, 2004):

(1) Check whether the land cover types identified in the draft vectors are in fact present on the ground (errors of commission)

(2) Check whether land cover types observed on the ground are correctly captured in the draft vectors (errors of omission)

(3) Identify land cover classes of unknown or questionable spectral signatures

(4) Identify characteristic signatures of the target land cover classes

This work required constant decisions with respect to class allocation. These decisions were made using two criteria: field observation and the signatures in the satellite imagery. The photographs of field observation locations were illustrated in Appendix.

On 18thMarch 2011, the field investigation was mainly done in Ban Khao Khiao; Ban Ko Mo 52; Ban Bueng Charoen, Tambon Rabam, Amphoe Lan Sak, Changwat Uthai Thani. Moreover, there were an information interviews at Ban Bueng Charoen, Tambon Rabam, Amphoe Lan Sak, Changwat Uthai Thani (Figure 3-24).

On 19thMarch 2011, the field investigation was mainly done in Huai Kha Khaeng Wildlife Sanctuary; Ban Huai Plao; Ban Phet Charoen; Ban Ang Huai Dong; Ban Pong Makha; Ban Khao Hin Thoen; Ban Pong Sam Sip; Ban Khao Mai Nuan; Ban Sap Sombun; Ban Kiri Wong; Ban Tha Ma-nao, Tambon Rabam, Amphoe Lan Sak, Changwat Uthai Thani; Ban Pak Mueang, Tambon Lan Sak, Amphoe Lan Sak, Changwat Uthai Thani Moreover, there were an information interviews at Ban Huai Plao; Ban Ang Huai Dong; Ban Pong Sam Sip; Ban Kiri Wong; Ban Tha Ma-nao; Tambon Rabam, Amphoe Lansak, Changwat Uthai Thani (Figure 3-25).

On 20thMarch 2011, the field investigation was mainly done in Ban Pang Mai Pai; Ban Huai Rang; Ban I Dang, Tambon Rabam, Amphoe Lan Sak, Changwat Uthai Thani; Ban Khao Din; Ban Na Rai Dieo; Ban Phu Lhum , Tambon Lan Sak, Amphoe Lan Sak, Changwat Uthai Thani; Ban Khao Wong; Ban Khao Kongchai, Tambon Pa O, Amphoe Lan Sak, Changwat Uthai Thani; Ban Pradu Yeun; Ban Takhlo; Ban Prada Huk, Tambon Pradu Yeun, Amphoe Lan Sak, Changwat Uthai Thani; Ban Din Deang; Ban Bung Fang; Ban Nikhom

Samakkhi Tambon Khao Kwang Thong, Amphoe Nong Chang, Changwat Uthai Thani; Ban Wang To Yang; Ban Tap Salao, Tambon Thung Na Ngam, Amphoe Nong Chang, Changwat Uthai Thani; Moreover, interviewing information with the people were also conducted at Pang Mai Pai, Ban I Dang, Khao Wong, Ban Khao Kongchai, Ban Pradu Yeun, Amphoe Lan Sak, Changwat Uthai Thani (Figure 3-26).

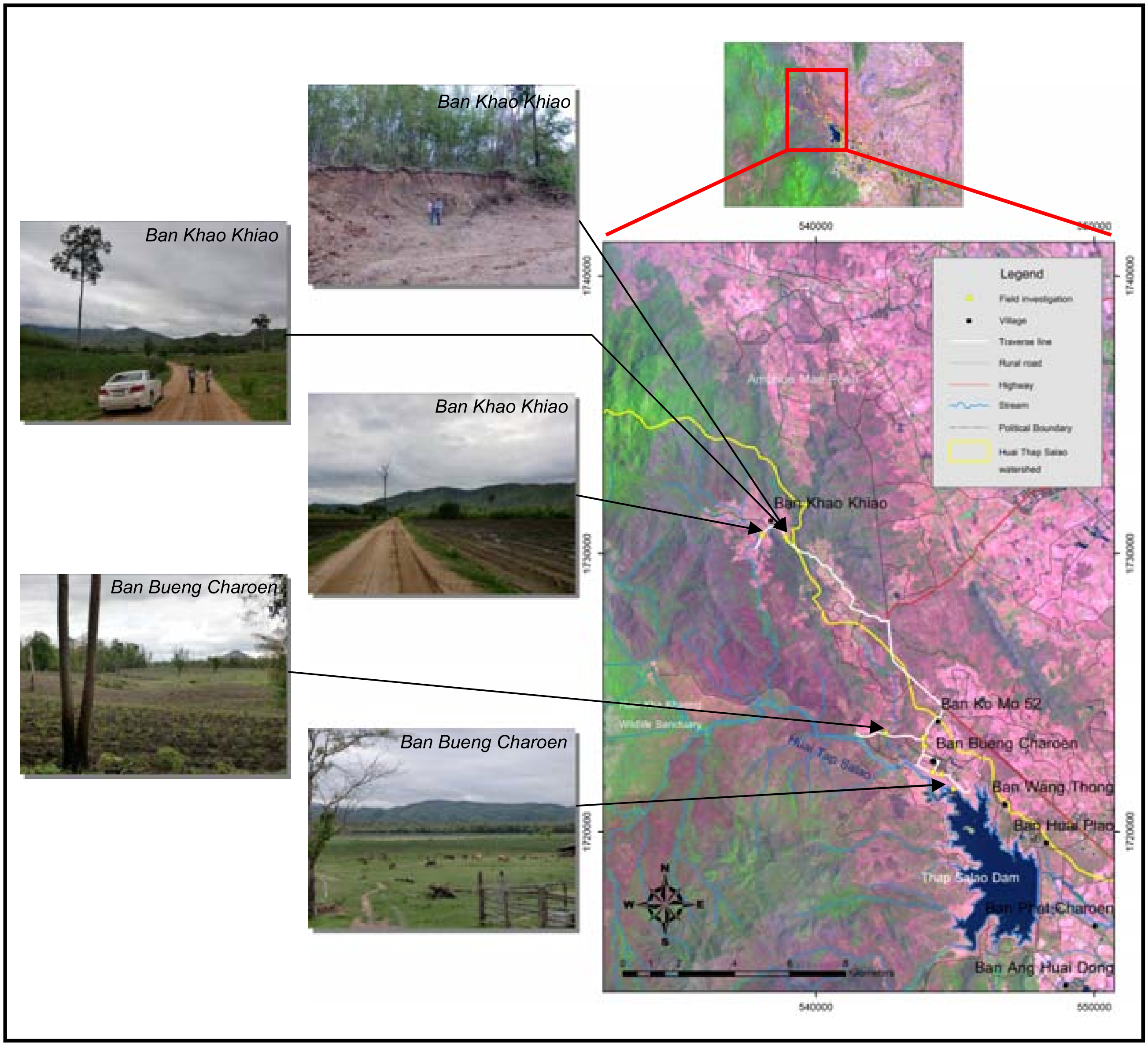


Figure 3-24 Field investigation located in northern of Huai Tap Salao watershed acquired on 18th March 2011.

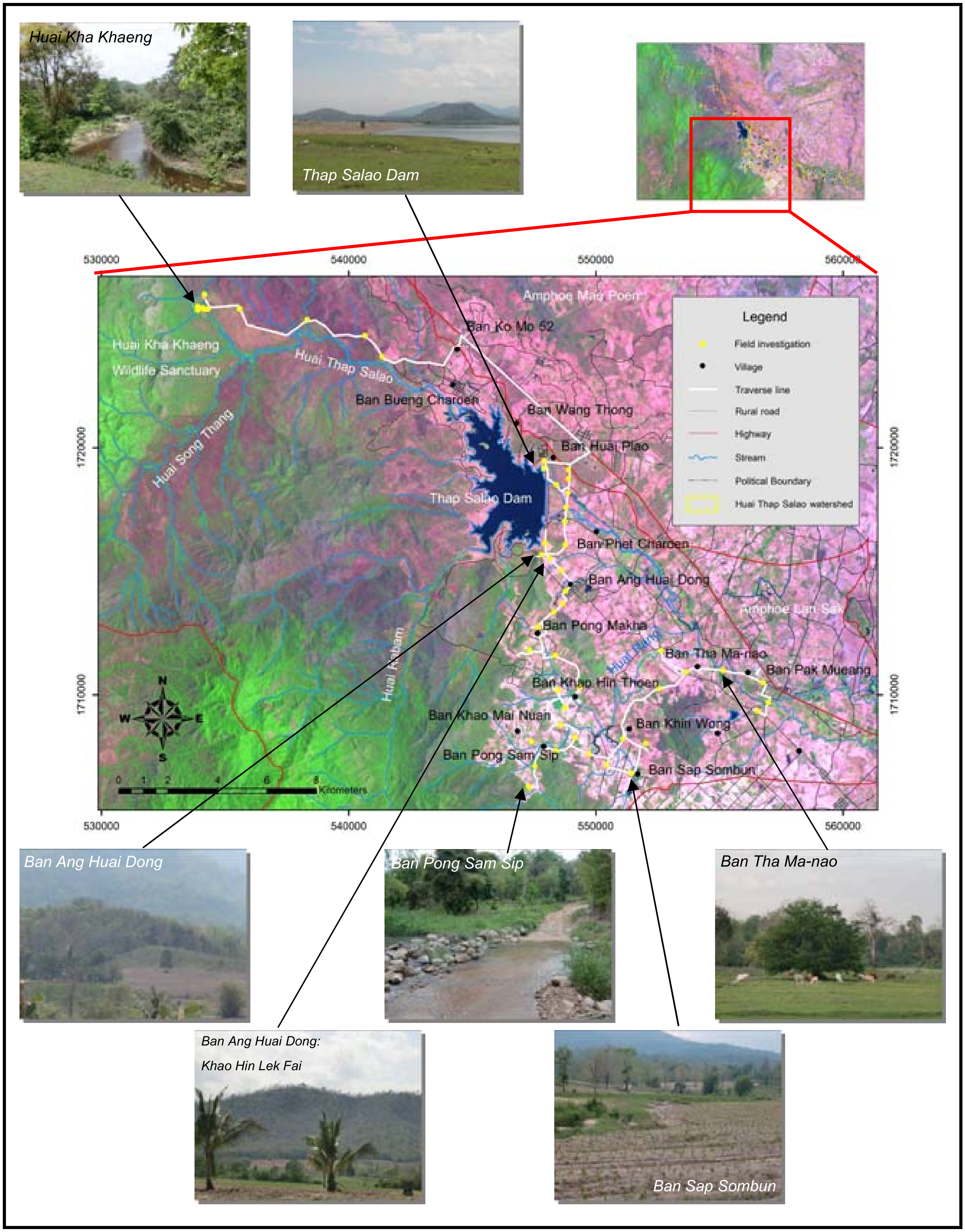


Figure 3-25 Field investigation located in central of Huai Tap Salao watershed acquired on 19th March 2011.

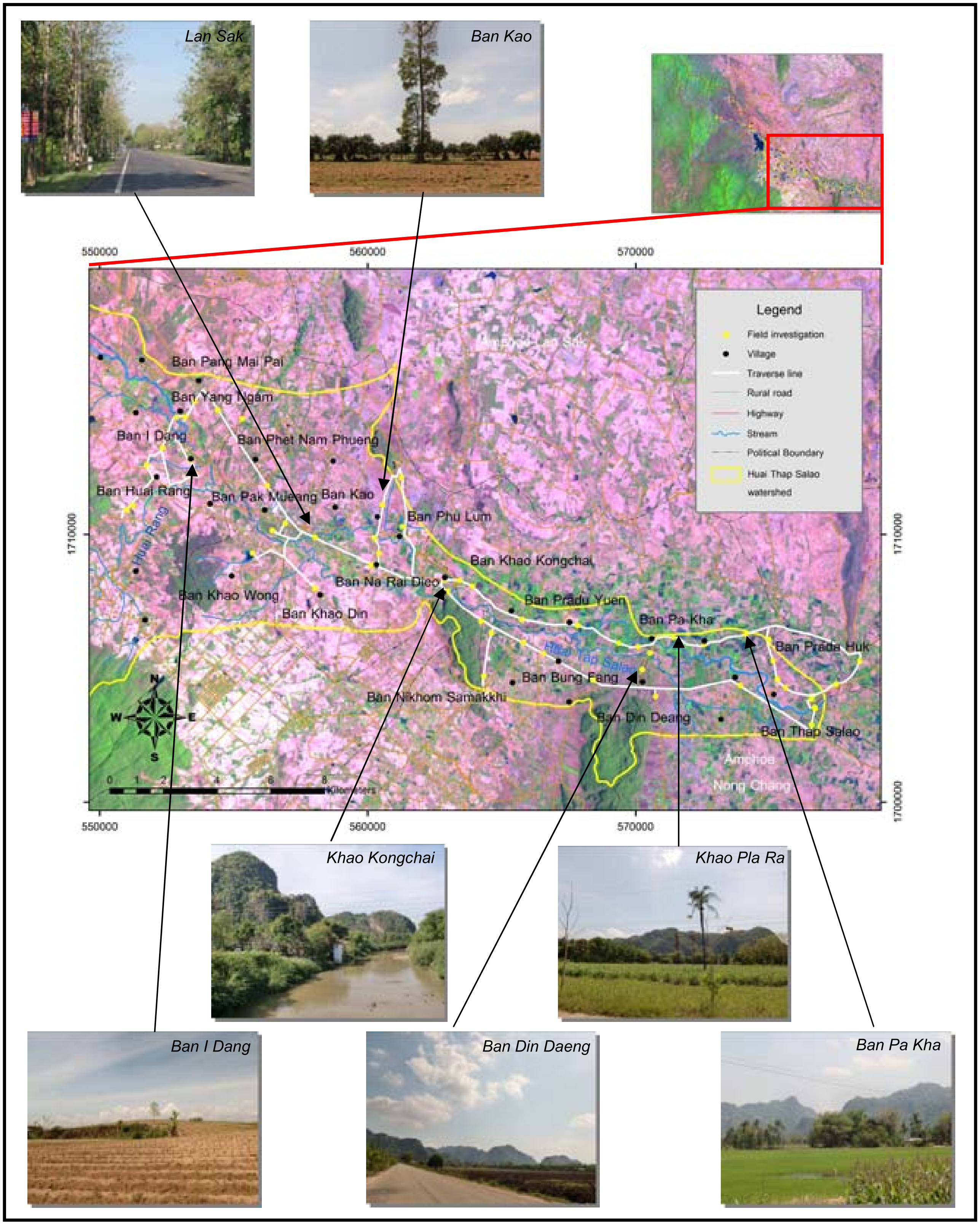


Figure 3-26 Field investigation located in southeast of Huai Tap Salao watershed acquired on 20th March 2011.

CHAPTER IV

ANALYSIS AND RESULTS

This chapter mainly presents the results of overall analysis, including analysis of land use changes, examination of affecting factors in logistic regression and land use scenarios developed by using relevant variables in the CLUE-s model. The first part of this chapter explained the result of dynamic spatial patterns of land use changes. The second part of this chapter identifies affecting factors that caused land use changes. The final part of this chapter presents the simulation and extrapolation of land use changes by the CLUE-s model for predicting of the future scenarios. All of the results in this chapter will be further discussed and finally concluded in Chapter 5.

4.1 Dynamic spatial patterns of land use changes in Huai Thap Salao watershed

The combination bands (R:G:B = 5:4:3) of Landsat 5TM in 1988, 1997 and 2007 with supervised classification process were used for land use classification. The classification of land use categories in Huai Thap Salao watershed was presented in Chapter 3.2.5. This part showed dynamic spatial patterns of land use changes that were interpreted from Landsat 5TM satellite images in the year 1988, 1997, and 2007.

Change detection technique was calculated cross-tabulated areas between two datasets. This approach used the Tabulate Areas tool in ArcMap GIS version 9.2 to produce a cross-tabulation table and Microsoft Excel for graphing. This was used to compare and calculate coincident areas. As an example, using Tabulate Area, one could calculate the area of each land use category in each zoning district. The first input was a land use raster, and the second was zoning (ESRI, 2010).

Detecting of land use changes in Huai Thap Salao watershed was conducted by import map of land use in the year 1988, 1997 and 2007 into GIS database as raster format to overlay with land use map for all 3 years by using tabulate area in spatial analysis. Land use area for each type was calculated and compared the changing during year 1988 to 1997 and year 1997 to 2007 with the application of cross classification (Figure 4-1).

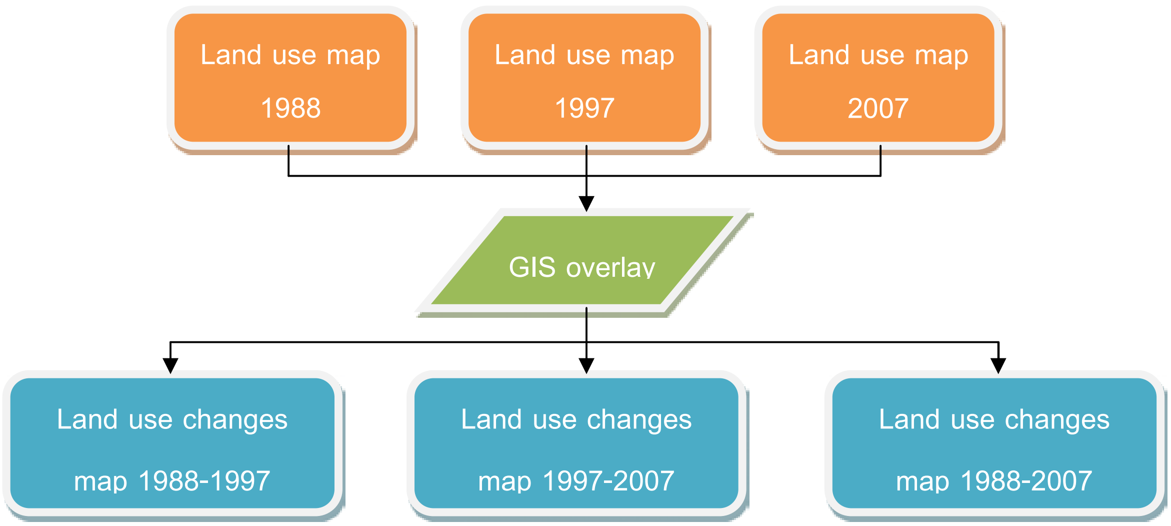


Figure 4-1 Method for land use changes analysis.

Estimation of land use changes was employed on three independent classification results with different time, which were classified results of Landsat 5TM in the year 1988, 1997 and 2007. The change estimation technique is used for identifying the “from-to” change of land use and quantifying the different rates and magnitude of change. The formula to calculate the annual change of land use was:

$$\Delta = \left(\frac{A_2 - A_1}{A_1} \times 100 \right) / \left(T_2 - T_1 \right) \qquad \text{(Equation 4-1)}$$

where

Δ = Average annual rates of change (%)

A_1 = Amount of land use category in time 1 (T_1)

A_2 = Amount of land use category in time 2 (T_2)

Land use maps were derived from classification of Landsat 5TM image in the year 1988, 1997 and 2007. In this study, the images were reclassified in 4 classes (90 x 90 m raster grid resolution) as shown in Figure 4-2. The results of the comparison study on land use changes during 1988 to1997, 1997 to 2007, and 1988 to 2007 were as follow:

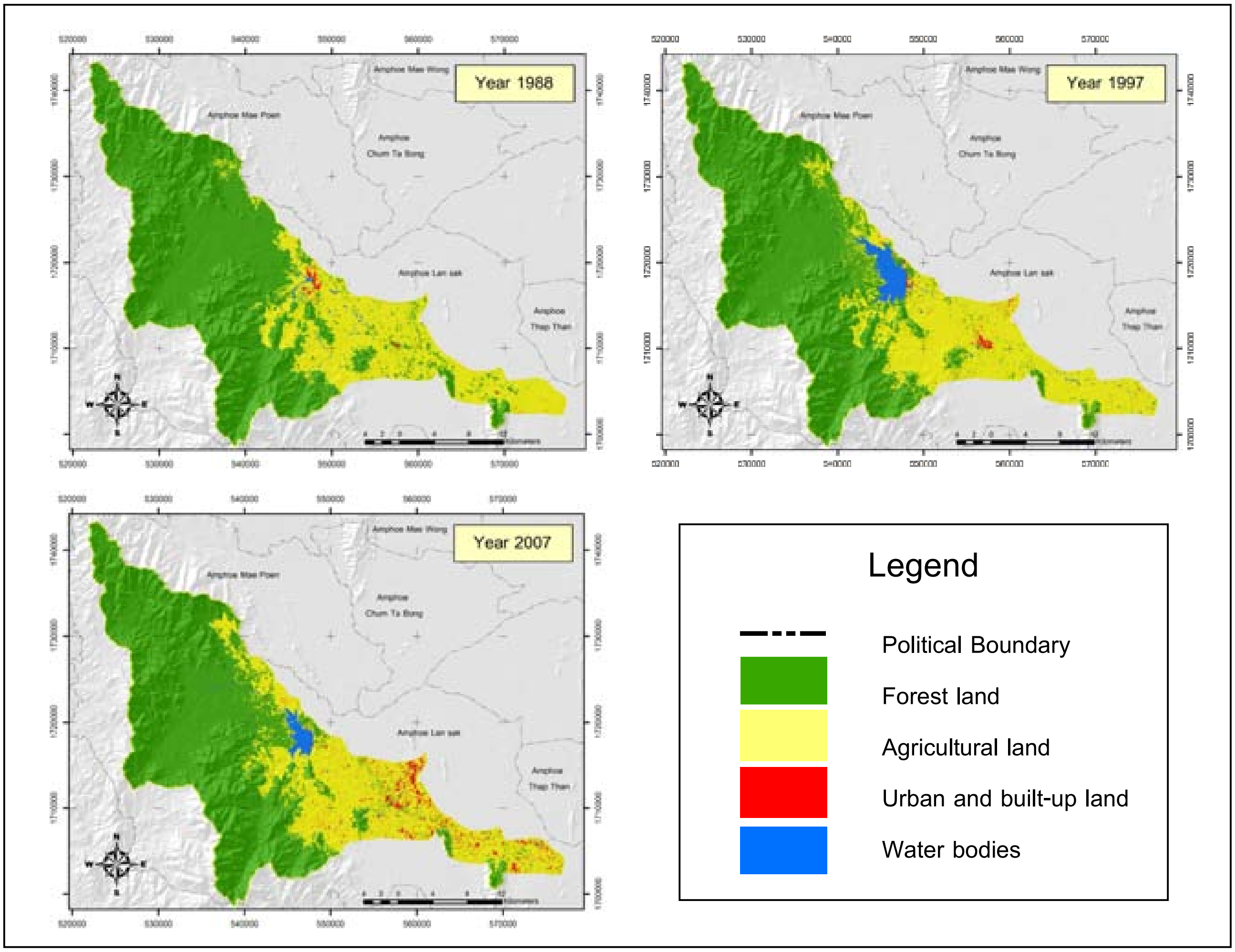


Figure 4-2 Reclassification land use level 1 in Huai Thap Salao watershed.

The result revealed that the change detection for the land use classification in the year 1988, 1997 and 2007, it could be seen that agricultural land, and urban and built-up land were increasing over time, whereas forest land tended to decrease. Besides, water bodies tended to increase in the year 1997 and decrease in the year 2007 because Thap

Salao dam was constructed. The trends of land use changes of the area during 1988-2007 were presented in Table 4-1 and Figure 4-3.

Table 4-1 Comparative land use class 1 in Huai Thap Salao watershed in the year 1988, 1997 and 2007.

Land use category	1988		1997		2007	
	km^2	%	km^2	%	km^2	%
Agricultural land	200.82	26.19	219.32	28.60	221.91	28.94
Forest land	559.97	73.02	523.69	68.29	518.92	67.67
Urban and built-up land	2.76	0.36	3.75	0.49	16.28	2.12
Water bodies	3.29	0.43	20.10	2.62	9.74	1.27
Total	766.85	100.00	766.85	100.00	766.85	100.00

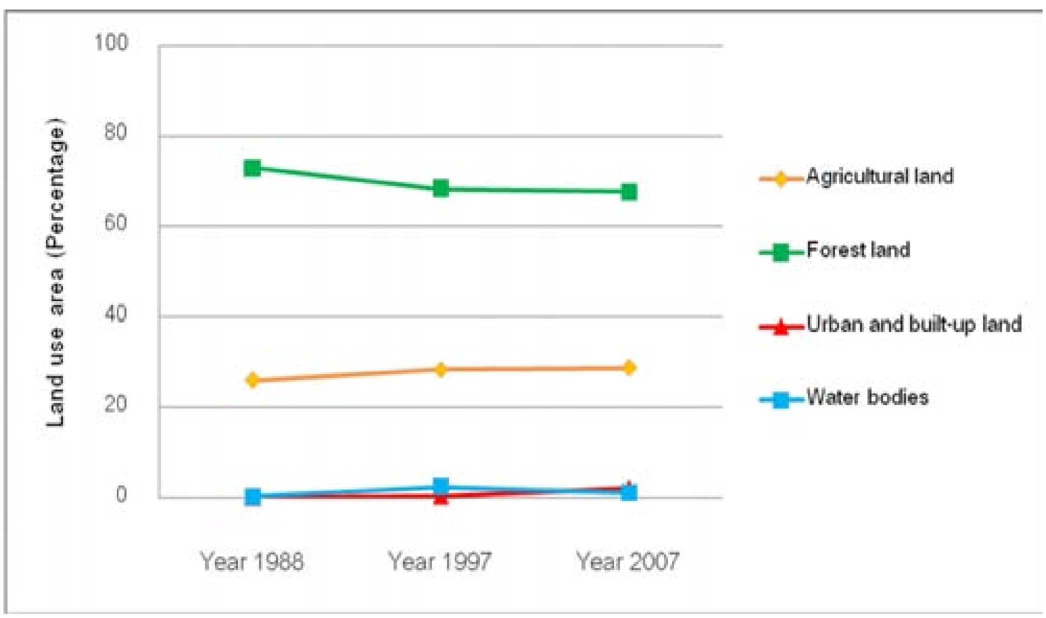


Figure 4-3 Graph showing trend (in percentage) of land use changes in Huai Thap Salao watershed during 1988 to 2007.

4.1.1 Land use changes during 1988 to 1997

The land use map in the year 1988 was overlaid with the land use map in the year 1997 and the results were showed in Table 4-2, Table 4-3, Table 4-4 and Figure 4-4. The results of the land use changes within 10 years period (1988 to 1997) were shown as follows:

Agricultural land was increased with an area of 18.50 km^2 or 25.29% of the land use changes. Furthermore, the most of agricultural land was transformed to be forest land with an area of 14.39 km^2 (Ratio = 0.0716), followed by water bodies area with an area of 11.60 km^2 (Ratio = 0.0578), and urban and built-up land with an area of 2.51 km^2 (Ratio = 0.0125), respectively.

Forest land was decreased with an area of 36.29 km^2 or 50% of the land use changes. Furthermore, the most of forest land was transformed to be agricultural land with an area of 44.59 km^2 (Ratio = 0.0796), followed by water bodies area with an area of 5.92 km^2 (Ratio = 0.0106), and urban and built-up land with an area of 0.67 km^2 (Ratio = 0.0012), respectively.

Urban and built-up land was increased with an area of 0.98 km^2 or 1.36% of the land use changes. Furthermore, the most of urban and built-up land was transformed to be water bodies area with an area of 1.17 km^2 (Ratio = 0.4223).

Water bodies area was increased with an area of 16.80 km^2 or 23.16% of the land use changes. Furthermore, the most of water bodies area was transformed to be agricultural land with an area of 1.68 km^2 (Ratio = 0.5088), and urban and built-up land with an area of 0.01 km^2 (Ratio = 0.0020), respectively.

Table 4-2 Changes in areas of different land use categories in Huai Thap Salao watershed, 1988-1997.

Land use	Area (Square kilometers)			
	Year 1988	Year 1997	Land use changes	Percentage of total land use changes
Agricultural land	200.82	219.32	18.50	25.49
Forest land	559.97	523.69	-36.29	50.00
Urban and built-up land	2.76	3.75	0.98	1.36
Water bodies	3.29	20.10	16.80	23.16
Total	766.85	766.85	72.57	100

Remark: Changing with positive value (+) was defined as increasing area, and Changing with negative value (-) was defined as decreasing area

Table 4-3 Matrix of land use changes in Huai Thap Salao watershed, 1988-1997 (km^2).

Year 1997 / Year 1988	Agricultural land	Forest land	Urban and built-up land	Water bodies	Total area
Agricultural land	172.32	14.39	2.51	11.60	200.82
Forest land	44.59	508.79	0.67	5.92	559.97
Urban and built-up land	0.00	0.00	1.60	1.17	2.76
Water bodies	1.68	0.00	0.01	1.61	3.29
Total area	218.59	523.18	4.78	20.30	766.85

Table 4-4 Matrix of land use changes in Huai Thap Salao watershed, 1988-1997 (Ratio).

Year 1997 / Year 1988	Agricultural land	Forest land	Urban and built-up land	Water bodies	Total area
Agricultural land	0.8581	0.0716	0.0125	0.0578	1.0000
Forest land	0.0796	0.9086	0.0012	0.0106	1.0000
Urban and built-up land	0.0000	0.0000	0.5777	0.4223	1.0000
Water bodies	0.5088	0.0000	0.0020	0.4892	1.0000

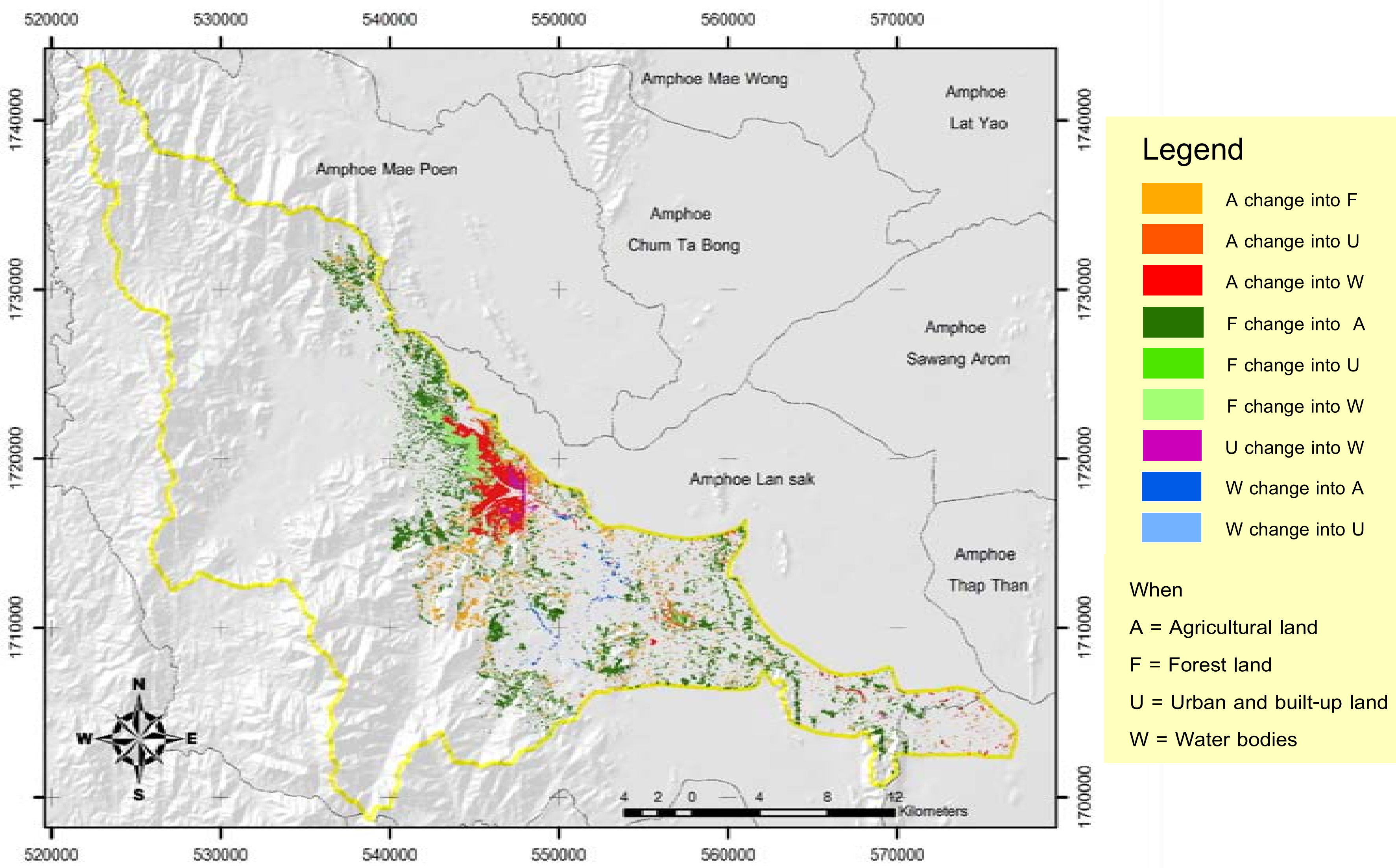


Figure 4-4 Land use changes of Huai Thap Salao watershed during 1988-1997.

4.1.2 Land use changes during 1997 to 2007

The land use map in the year 1997 was overlaid with the land use map in the 2007 and the results were showed in Table 4-5, Table 4-6, Table 4-7 and Figure 4-5. The results of the land use changes within 10 years period (1997-2007) were shown as follows:

Agricultural land was increased with an area of 2.59 km^2 or 8.56% of the land use changes. Furthermore, the most of agricultural land was transformed to be forest land with an area of 24.49 km^2 (Ratio = 0.1117), followed by urban and built-up land with an area of 14.37 km^2 (Ratio = 0.0655), and water bodies area with an area of 0.14 km^2 (Ratio = 0.0006), respectively.

Forest land was decreased with an area of 4.76 km^2 or 15.75% of the land use changes. Furthermore, the most of forest land was transformed to be agricultural land with an area of 31.84 km^2 (Ratio = 0.0608), followed by urban and built-up land with an area of 0.51 km^2 (Ratio = 0.0010), and water bodies area with an area of 0.39 km^2 (Ratio = 0.0007), respectively.

Urban and built-up land was increased with an area of 12.53 km^2 or 11.44% of the land use changes. Furthermore, the most of urban and built-up land was not transformed.

Water bodies area was decreased with an area of 10.36 km^2 or 34.25% of the land use changes. Furthermore, the most of water bodies area were transformed to be forest land with an area of 7.41 km^2 (Ratio = 0.3689), followed by forest land with an area of 0.34 km^2 (Ratio = 0.1511), and urban and built-up land with an area of 0.45 km^2 (Ratio = 0.0223), respectively.

Table 4-5 Changes in areas of different land use categories in Huai Thap Salao watershed, 1997-2007.

Land use	Area (Square kilometers)			
	Year 1997	Year 2007	Land use changes	Percentage of total land use changes
Agricultural land	219.32	221.91	2.59	8.56
Forest land	523.69	518.92	-4.76	15.75
Urban and built-up land	3.75	16.28	12.53	41.44
Water bodies	20.10	9.74	-10.36	34.25
Total	766.85	766.85	30.24	100

Remark: Changing with positive value (+) was defined as increasing area, and Changing with negative value (-) was defined as decreasing area

Table 4-6 Matrix of land use changes in Huai Thap Salao watershed, 1997-2007 (km^2).

Year 2007 / Year 1997	Agricultural land	Forest land	Urban and built-up land	Water bodies	Total area
Agricultural land	180.32	24.49	14.37	0.14	219.32
Forest land	31.84	490.94	0.51	0.39	523.69
Urban and built-up land	0.00	0.00	3.75	0.00	3.75
Water bodies	7.41	3.04	0.45	9.20	20.10
Total area	219.58	518.46	19.08	9.73	766.85

Table 4-7 Matrix of land use changes in Huai Thap Salao watershed, 1997-2007 (Ratio).

Year 2007 / Year 1997	Agricultural land	Forest land	Urban and built-up land	Water bodies	Total area
Agricultural land	0.8222	0.1117	0.0655	0.0006	1.0000
Forest land	0.0608	0.9375	0.0010	0.0007	1.0000
Urban and built-up land	0.0000	0.0000	1.0000	0.0000	1.0000
Water bodies	0.3689	0.1511	0.0223	0.4578	1.0000

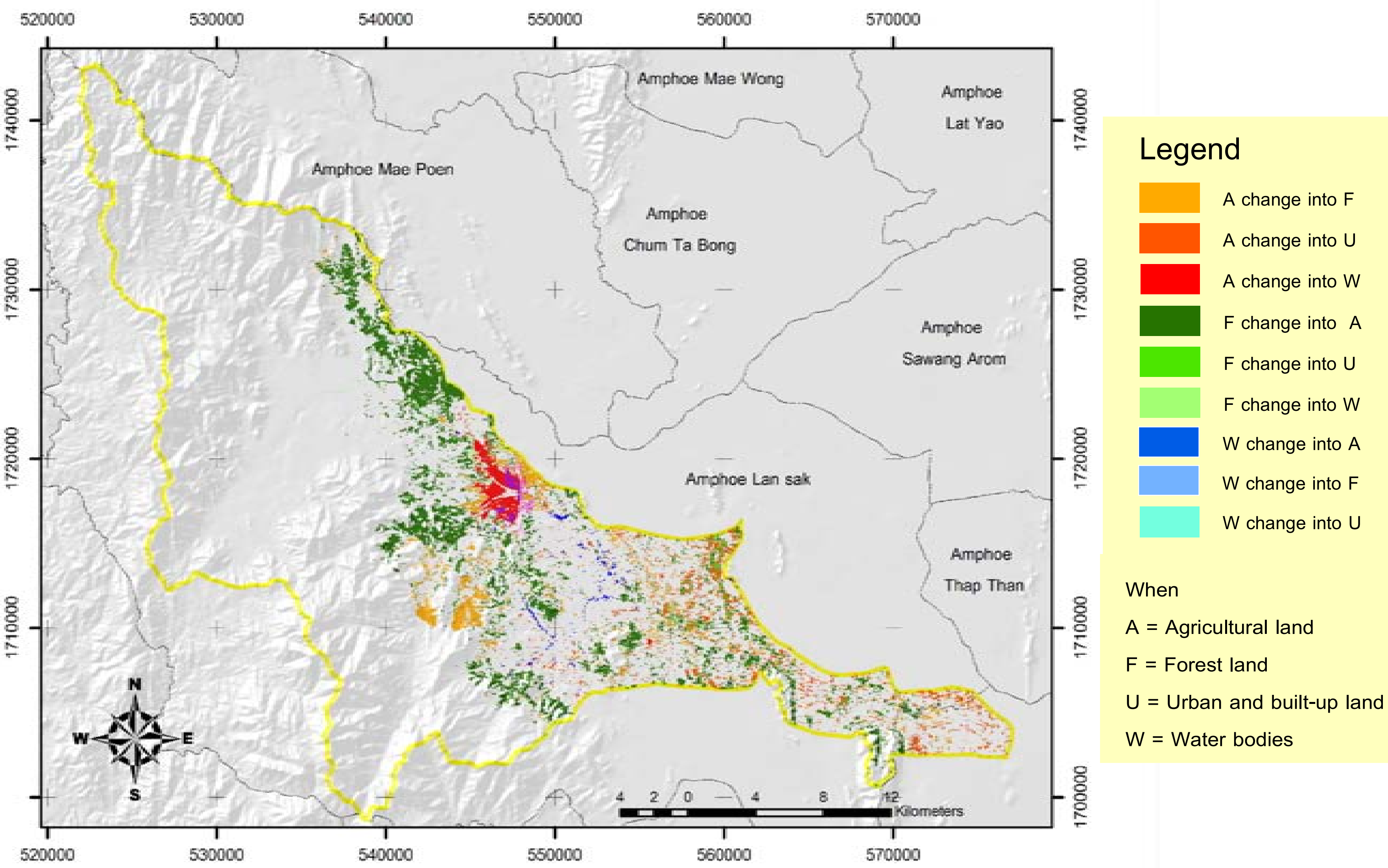


Figure 4-5 Land use changes of Huai Thap Salao watershed during 1997-2007.

4.1.3 Land use changes during 1988 to 2007

The land use map in the year 1988 was overlaid with the land use map in the in the year 2007 and the results were showed in Table 4-8, Table 4-9, Table 4-10 and Figure4-6. The results of the land use changes within 20 years period (1988-2007) were shown as follows:

Agricultural land was increased with an area of 21.08 km^2 or 25.68% of the land use changes. Furthermore, the most of agricultural land was transformed to be forest land with an area of 16.56 km^2 (Ratio = 0.0825), followed by urban and built-up land with an area of 13.18 km^2 (Ratio = 0.0656), and water bodies area with an area of 5.73 km^2 (Ratio = 0.0285), respectively.

Forest land was decreased with an area of 41.05 km^2 or 50% of the land use changes. Furthermore, the most of forest land was transformed to be agricultural land with an area of 53.54 km^2 (Ratio = 0.0956), followed by urban and built-up land with an area of 2.61 km^2 (Ratio = 0.0047), and water bodies area with an area of 1.96 km^2 (Ratio = 0.0035), respectively.

Urban and built-up land was increased with an area of 13.52 km^2 or 16.46% of the land use changes. Furthermore, the most of urban and built-up land was transformed to be water bodies area with an area of 0.84 km^2 (Ratio = 0.3050).

Water bodies area was increased with an area of 6.45 km^2 or 7.85% of the land use changes. Furthermore, the most of water bodies area was transformed to be agricultural land with an area of 1.84 km^2 (Ratio = 0.5598), followed by forest land with an area of 0.17 km^2 (Ratio = 0.0513), and urban and built-up land with an area of 0.07 km^2 (Ratio = 0.0217), respectively.

Table 4-8 Changes in areas of different land use categories in Huai Thap Salao watershed, 1988-2007.

Land use	Area (Square kilometers)			
	Year 1988	Year 2007	Land use changes	Percentage of total land use changes
Agricultural land	200.82	221.91	21.08	25.68
Forest land	559.97	518.92	-41.05	50.00
Urban and built-up land	2.76	16.28	13.52	16.46
Water bodies	3.29	9.74	6.45	7.85
Total	766.85	766.85	82.10	100.00

Remark: Changing with positive value (+) was defined as increasing area, and
Changing with negative value (-) was defined as decreasing area

Table 4-9 Matrix of land use changes in Huai Thap Salao watershed, 1988-2007 (km^2).

Year 2007 / Year 1988	Agricultural land	Forest land	Urban and built-up land	Water bodies	Total area
Agricultural land	165.36	16.56	13.18	5.73	200.82
Forest land	53.54	501.86	2.61	1.96	559.97
Urban and built-up land	0.00	0.00	1.92	0.84	2.76
Water bodies	1.84	0.17	0.07	1.21	3.29
Total area	220.74	518.59	17.78	9.74	766.85

Table 4-10 Matrix of land use changes in Huai Thap Salao watershed, 1997-2007 (Ratio).

Year 2007 / Year 1988	Agricultural land	Forest land	Urban and built-up land	Water bodies	Total area
Agricultural land	0.8234	0.0825	0.0656	0.0285	1.0000
Forest land	0.0956	0.8962	0.0047	0.0035	1.0000
Urban and built-up land	0.0000	0.0000	0.6950	0.3050	1.0000
Water bodies	0.5598	0.0513	0.0217	0.3673	1.0000

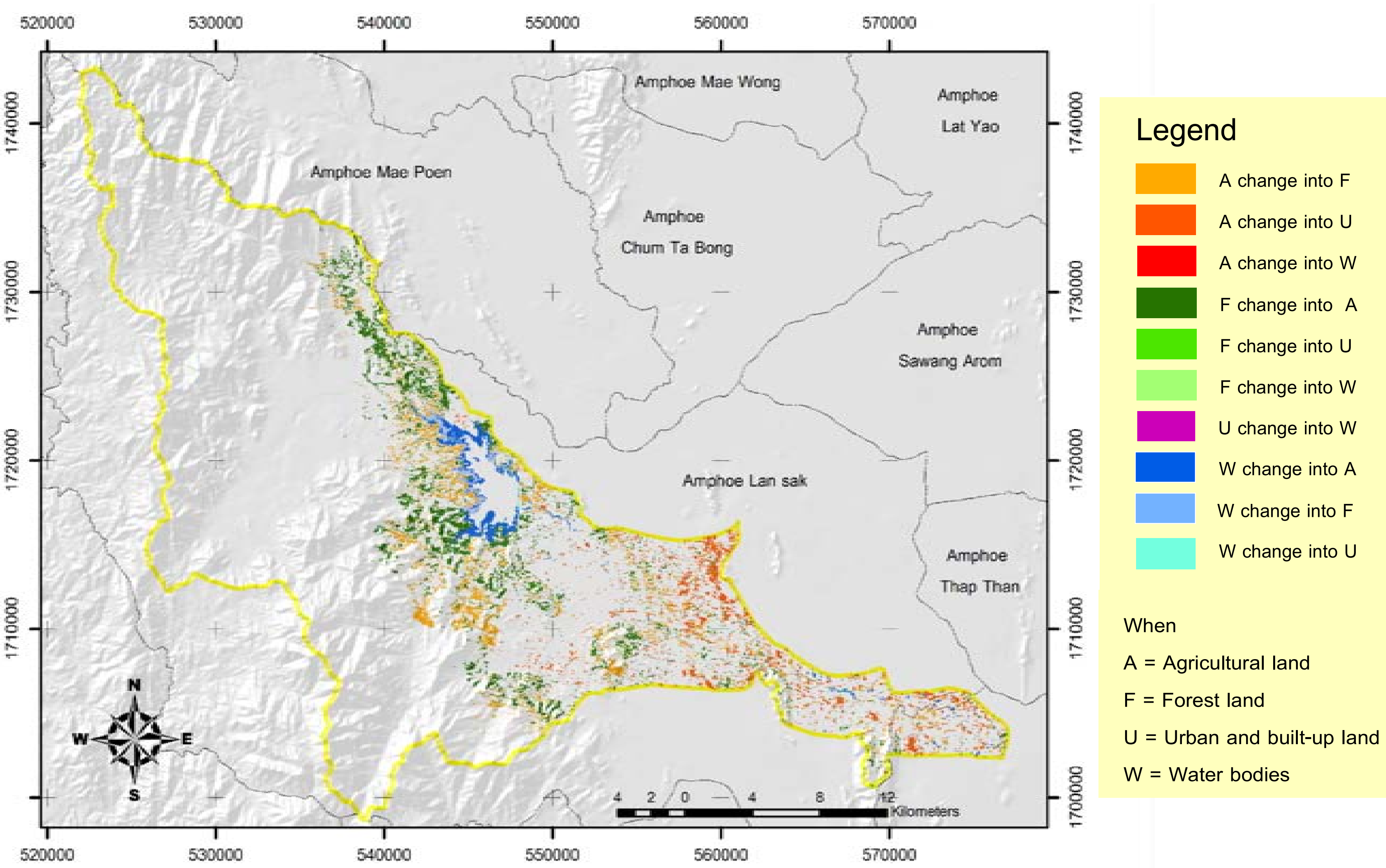


Figure 4-6 Land use changes of Huai Thap Salao watershed during 1988-2007.

4.2 Identify affecting factors that caused land use changes during 1988 to 2007 in Huai Thap Salao watershed

Binomial logistic regression was used to define the relationships between the land use categories and its affecting factors. It calculated the occurrence of an event, using the independent variables as predictor values (Garson, 2001). This method was used when a dependent was a dichotomy (0 or 1) and the independents were continuous variables or categorical variables (Garson, 2001). Logistic regression equation:

$$\log\left(\frac{P_i}{1-P_i}\right) = \beta_0 + \beta_1 x_{1,i} + \beta_2 x_{2,i} + \ldots \beta_n x_{n,i} \qquad \text{(Equation 4-2)}$$

Where

P	= Probability of the occurrence of the land use category
β_n	= Regression values, output of the regression model
x_n	= Affecting factors

Logistic regression produced odds ratios associated with each predictor value. These ratios were the exponents of the logit coefficient and therefore also called the exponent β (Exp (β)). The odds of an event were defined as the probability of the event occurring divided by the probability of the event not occurring. The odds ratio for a predictor tells the relative amount by which the odds of the outcome increase (odds ratio > 1) or decrease (odds ratio < 1) when the value of the predictor value was increased by 1 unit.

Because all independents had different units it was not easy to find the most important variable in the model. If categorical values (0 or 1) change with 1 unit the maximum change was taken. But if a continuous variable changes 1 unit, only a small percentage of the possible change had happened.

The results of logistic regression between land use and independent variables were presented in this section. Each land use had independent variables or affecting factors that influence to its patterns. In logistic regression analysis, four classes of land use were included in the regression calculation.

The number of affecting factors used in this regression analysis was 7 variables. Each affecting factors had a different effect on every type of land use. The effect of each affecting factors was indicated by the coefficient β in logistic regression result, which presents how much variance from the use of land that could be explained by the affecting factors. A large positive β value indicated a strong positive relationship between the independent and dependant variable (land use changes), while a large negative β value indicates a strong negative correlation with land use changes as shown Table 4-11.

Table 4-11 Results of logistic regression between land use categories and affecting factors.

Variables	Land use category			
	Forest land	Agricultural land	Urban and built-up land	Water bodies
Elevation	.0110	-.0079	*	-.1452
Degree of Slope	.0805	-.0466	-.2717	-1.0406
Mean annual precipitation	.0023	-.0011	-.0167	.0663
Distance to streams	*	*	.0006	.0020
Distance to roads	.0010	-.0015	-.0011	.0069
Distance to villages	.0009	-.0008	-0.0002	-.0016
Soil texture	.4846	.5729	-.2393	-2.4515
Constant	-10.4171	4.4741	17.6632	-69.6117
ROC Value	0.97	0.929	0.92	0.984

All variables significant at 0.05 level

Remark: * not statistically significant at 0.05 level

The selection of the significant and non-significant independent variables was based on a forward stepwise procedure. The variables, which had coefficient values below 0.05 significant thresholds, were categorized as significant and the variables above 0.05 would be classified as non-significant and automatically removed in the calculation process. All of significant variables were automatically selected in the results of forward stepwise procedure and would be used in the calculation of land use probability. Practically, forward stepwise procedure in logistic regression was done by putting each independent variable in the process one by one until all of variables were involved in the iteration process.

The regression equation was created to indicate the influence of the affecting factors and the overall probability for each land use changes. By using ROC (Relatively Operating Characteristics), the probability of each land use was evaluated and compared to the existing land use. The comparison was based on the number of cells that equal between the maps. The percentage of ROC showed how the regression equation was used to predict the future land use changes based on its probability. According to the results, the values of ROC for probability of forest land, agricultural land, urban and built-up land and water bodies were 0.970, 0.929, 0.92 and 0.984 respectively. Based on the literatures reviewed, these ROC values were categorized as very strongly correlated between the all affecting factors and each land use category.

4.3 Factors and their relationship affecting forest land

Table 4-11 showed the relative importance of affecting factors to the forest land in the study area. According to the stepwise procedure in the logistic regression for forest land, some variables had significant values, including soil texture (β = 0.4846), degree of slope (β = 0.0.085), elevation (β = 0.0110), mean annual precipitation (β = 0.0023), distance to roads (β = 0.001), and distance to villages (β = 0.0009), respectively. In the other hand, distance to streams had non-significant values and was removed from the calculation process of the logistic regression.

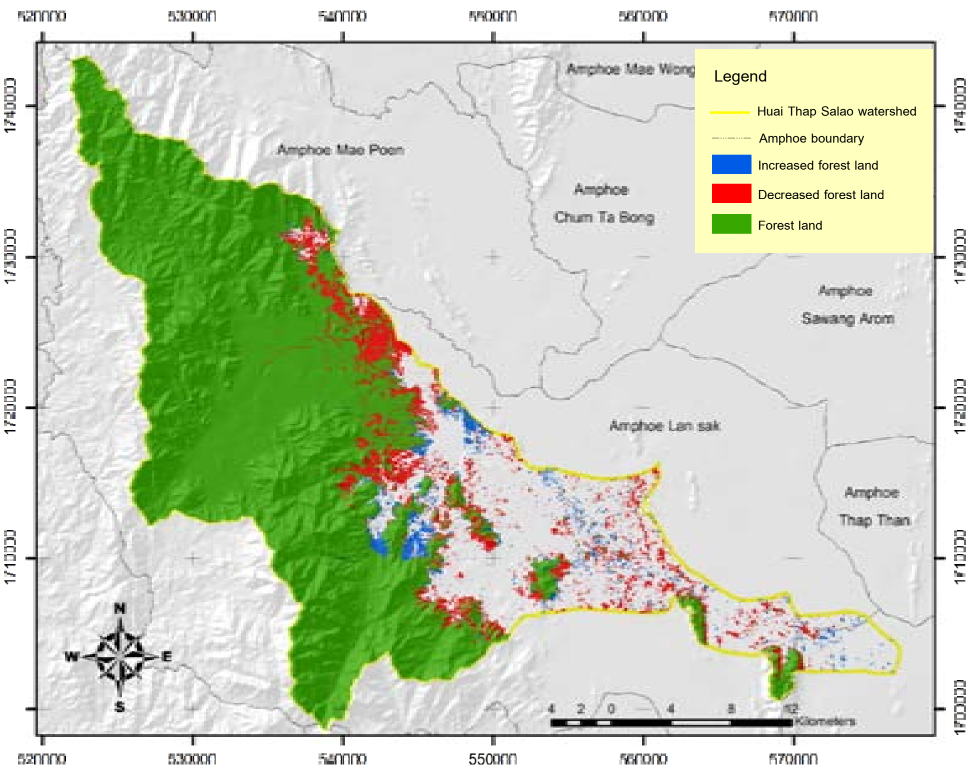
The results revealed that the change of forest land had relationship between the 6 affecting factors and a positive value of probability factors was explained as follows: The most affecting factor was soil texture factor that a high influence to the forest land changes in the area compared to the other affecting factors followed by degree of slope, elevation, mean annual precipitation, distance to roads, and distance to villages, respectively.

4.3.1 **Relationship between factors of soil texture and forest land**

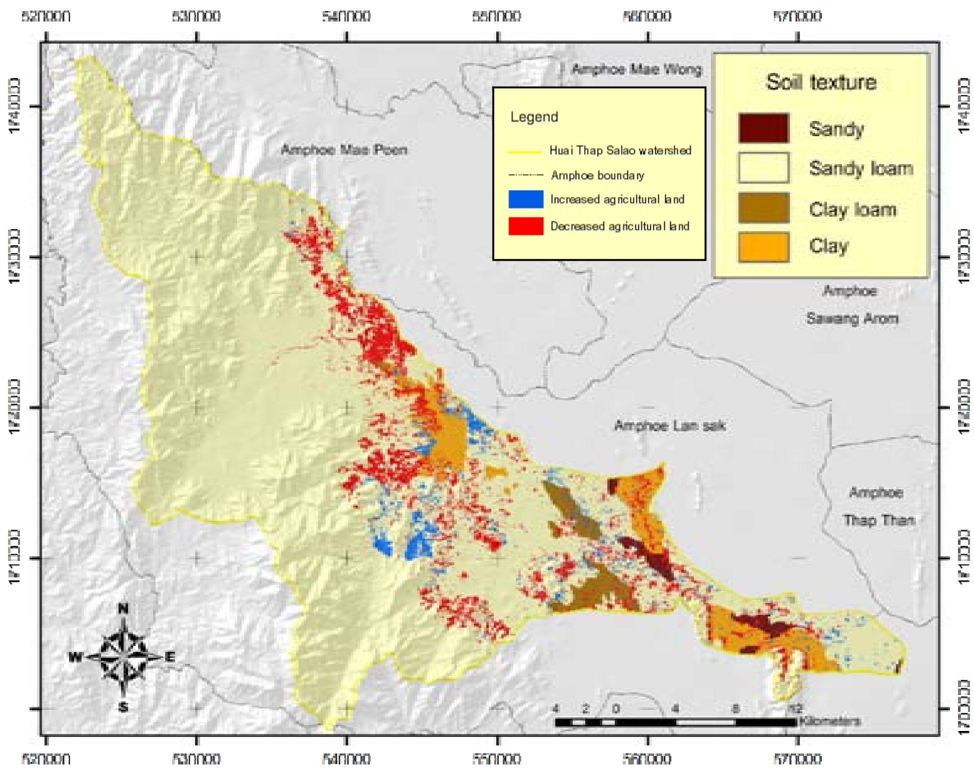
In relationship between factors of soil texture and forest land, the frequencies were determined by calculating the forest land areas for each 4 soil texture (Table 4-12 and Figures 4-7, 4-8).

Forest land was decreased in the sandy loam; the ratio was 0.825 or 47.968 km^2 of the forest land change decreased, indicating a high probability to change. Moderate probabilities were commonly observed in the areas which soil texture was in the clay; the ratio was 0.128 or 7.46 km^2 of the forest land change decreased. It was noted that low probabilities were observed in the area which from the soil texture were in the clay loam and sandy, which the ratio was 0.031 and 0.016.

Forest land was increased in the sandy loam; the ratio was 0.842 or 14.297 km^2 of the forest land change decreased, indicating a high probability to change. Moderate probabilities were commonly observed in the areas which soil texture was in the clay; the ratio was 0.102 or 1.733 km^2 of the forest land change decreased. It was noted that low probabilities were observed in the area which from the soil texture were in the clay loam and sandy, which the ratio was 0.044 and 0.011.



a)



b)

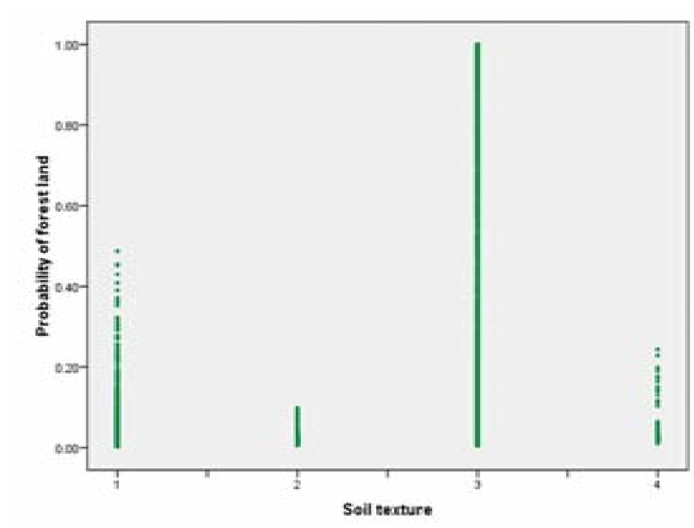
c)


Figure 4-7 Relationship between land use (a) and the soil texture factor (b) that had positive effects to the forest land category (c).

Table 4-12 Relationship between factors of soil texture and forest land change in Huai Thap Salao watershed.

Soil texture	Agricultural land change decrease		Agricultural land change increase	
	Area (km^2)	Ratio	Area (km^2)	Ratio
Clay	7.460	0.128	1.733	0.102
Clay loam	1.782	0.031	0.753	0.044
Sandy loam	47.968	0.825	14.297	0.842
Sandy	0.948	0.016	0.194	0.011
Total	58.158	1.000	16.978	1.000

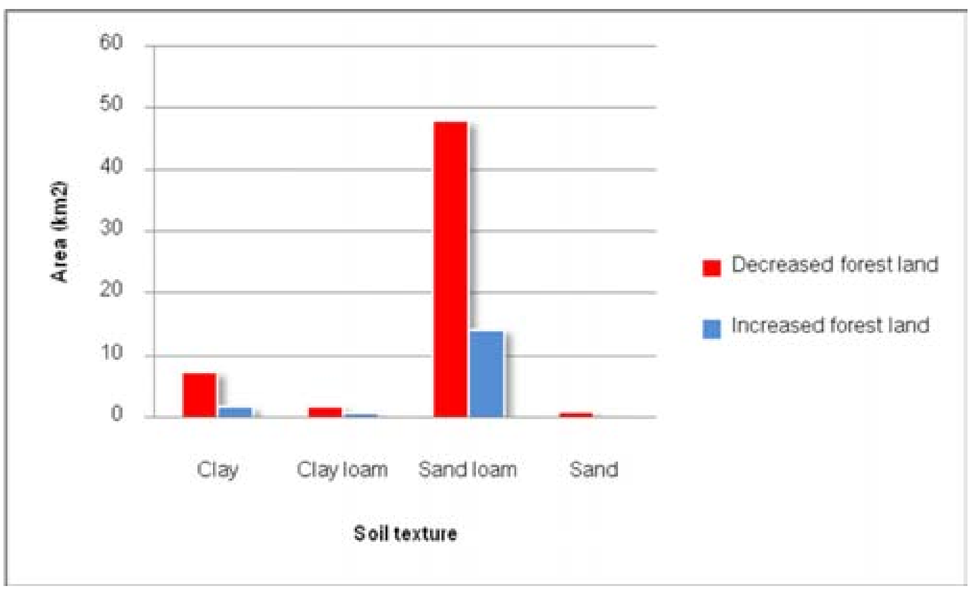


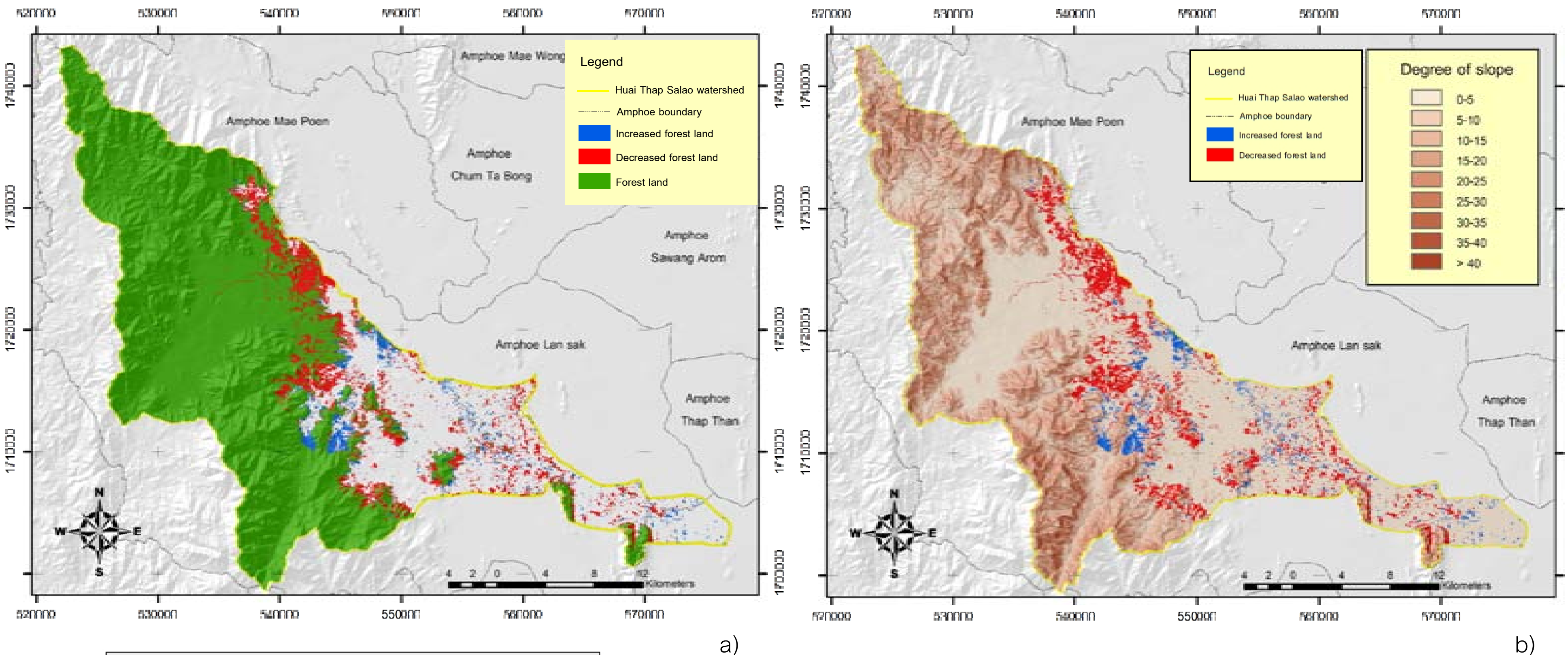
Figure 4-8 Histogram distribution of forest land change on soil texture.

4.3.2 Relationship between factors of degree of slope and forest land

In relationship between factors of degree of slope and forest land, the frequencies were determined by calculating the forest land areas for each 5 degree interval of slope angle (Table 4-13 and Figures 4-9, 4-10).

Forest land was decreased in slope below 5%; the ratio was 0.777 or 45.214 km^2 of the forest land change decreased, indicating a high probability to change. Followed by interval 5 to 10%; the ratio was 0.118 or 6.869 km^2, indicating a moderate probability to change. It was noted that low probabilities were observed in the area which from the slope were in the range of between 10 to 15%, 15 to 20%, 20 to 25%, 25 to 30%, 30 to 35%, 35 to 40%, and more than 40%, that the ratio was 0.051, 0.024, 0.017, 0.006, 0.004, 0.002, and 0.001, respectively.

Forest land was increased in slope below 5%; the ratio was 0.743 or 12.62 km^2 of the forest land change increased, indicating a high probability to change. Followed by interval 5 to 10%; the ratio was 0.163 or 2.777 km^2, indicating a moderate probability to change. It was noted that low probabilities were observed in the area which from the slope were in the range of between 10 to 15%, 15 to 20%, 20 to 25%, 25 to 30%, and 30 to 35%, that the ratio was 0.056, 0.027, 0.009, 0.001, and 0.001, respectively.



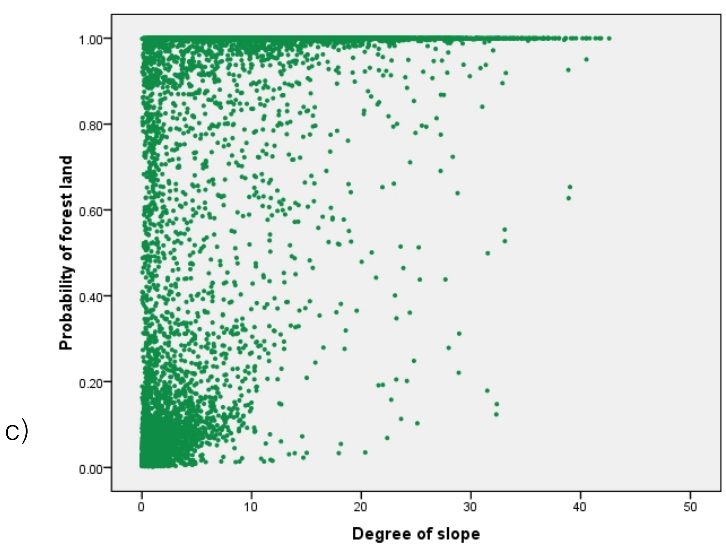


Figure 4-9 Relationship between land use (a) and the degree of slope factor (b) that had positive effects to the forest land category (c).

Table 4-13 Relationship between factors of degree of slope and forest land change in Huai Thap Salao watershed.

Degree of slope (%)	Forest land change decrease		Forest land change increase	
	Area (km^2)	Ratio	Area (km^2)	Ratio
0-5	45.214	0.777	12.620	0.743
5-10	6.869	0.118	2.762	0.163
10-15	2.981	0.051	0.948	0.056
15-20	1.369	0.024	0.454	0.027
20-25	0.972	0.017	0.154	0.009
25-30	0.340	0.006	0.024	0.001
30-35	0.243	0.004	0.016	0.001
35-40	0.122	0.002	0.000	0.000
>40	0.049	0.001	0.000	0.000
Total	58.158	1.000	16.978	1.000

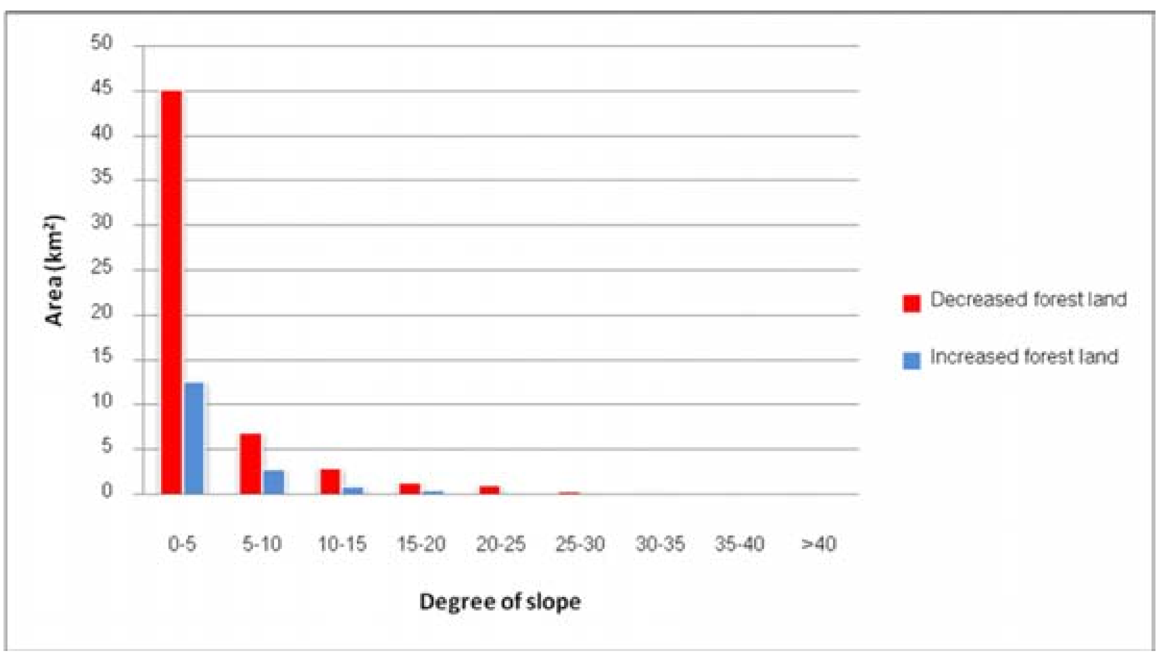


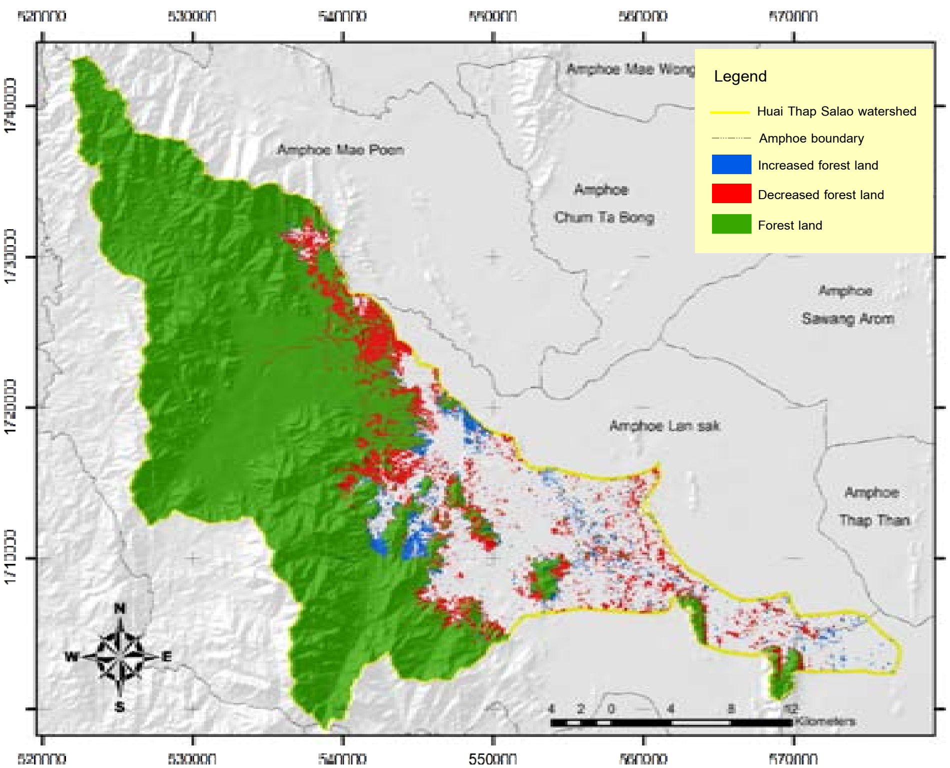
Figure 4-10 Histogram distribution of forest land change on slope.

4.3.3 Relationship between factors of elevation and forest land

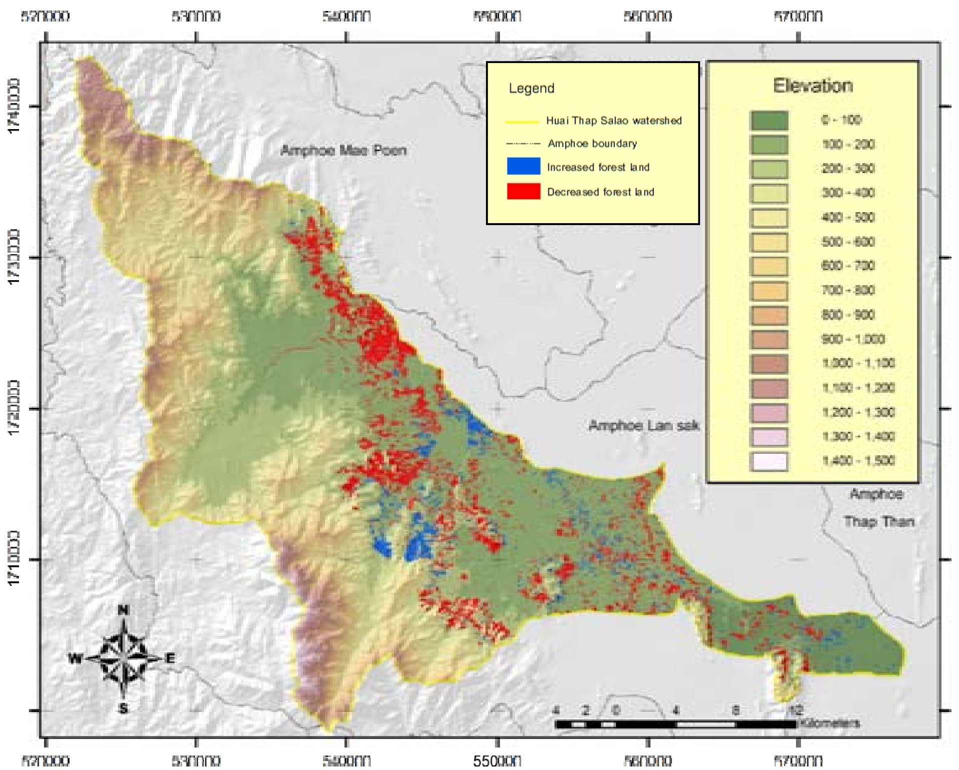
In relationship between factors of elevation and forest land, the frequencies were determined by calculating the forest land areas for each 100 meters interval of mean sea level (Table 4-14 and Figures 4-11, 4-12).

Forest land was decreased in contour interval 100 to 200 meters; the ratio was 0.726 or 42.217 km^2 of the forest land change decreased, indicating a high probability to change. Followed by interval 200 to 300 meters; the ratio was 0.195 or 11.316 km^2, indicating a moderate probability to change. It was noted that low probabilities were observed in the area which from the elevation were in the range of between 0 to 100m., 300 to 400m., 400 to 500m., and 600 to 700m., that the ratio was 0.044, 0.029, 0.004, and 0.001, respectively.

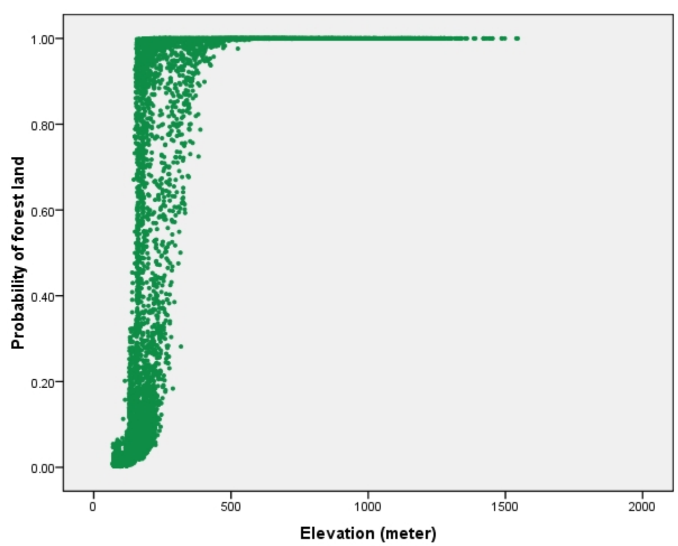
Forest land was increased in contour interval100 to 200 meters; the ratio was 0.578 or 9.817 km^2 of the forest land change increased, indicating a high probability to change. Followed by interval 200 to 300 meters; the ratio was 0.305 or 5.176 km^2, indicating a moderate probability to change. It was noted that low probabilities were observed in the area which from the elevation were in the range of between 0 to 100m., and 300 to 400m., which the ratio was 0.099, and 0.017, respectively.



a)



b)



c)

Figure 4-11 Relationship between land use (a) and the elevation factor (b) that had positive effects to the forest land category (c).

Table 4-14 Relationship between factors of elevation and forest land change in Huai Thap Salao watershed.

Elevation (meters)	Forest land change decrease		Forest land change increase	
	Area (km^2)	Ratio	Area (km^2)	Ratio
0-100	2.560	0.044	1.677	0.099
100-200	42.217	0.726	9.817	0.578
200-300	11.316	0.195	5.176	0.305
300-400	1.709	0.029	0.284	0.017
400-500	0.251	0.004	0.000	0.000
500-600	0.008	0.000	0.008	0.000
600-700	0.032	0.001	0.000	0.000
700-800	0.016	0.000	0.000	0.000
800-900	0.008	0.000	0.000	0.000
900-1000	0.008	0.000	0.008	0.000
1000-1100	0.008	0.000	0.008	0.000
1100-1200	0.008	0.000	0.000	0.000
1200-1300	0.016	0.000	0.000	0.000
1300-1400	0.000	0.000	0.000	0.000
1400-1500	0.000	0.000	0.000	0.000
Total	58.158	1.000	16.978	1.000

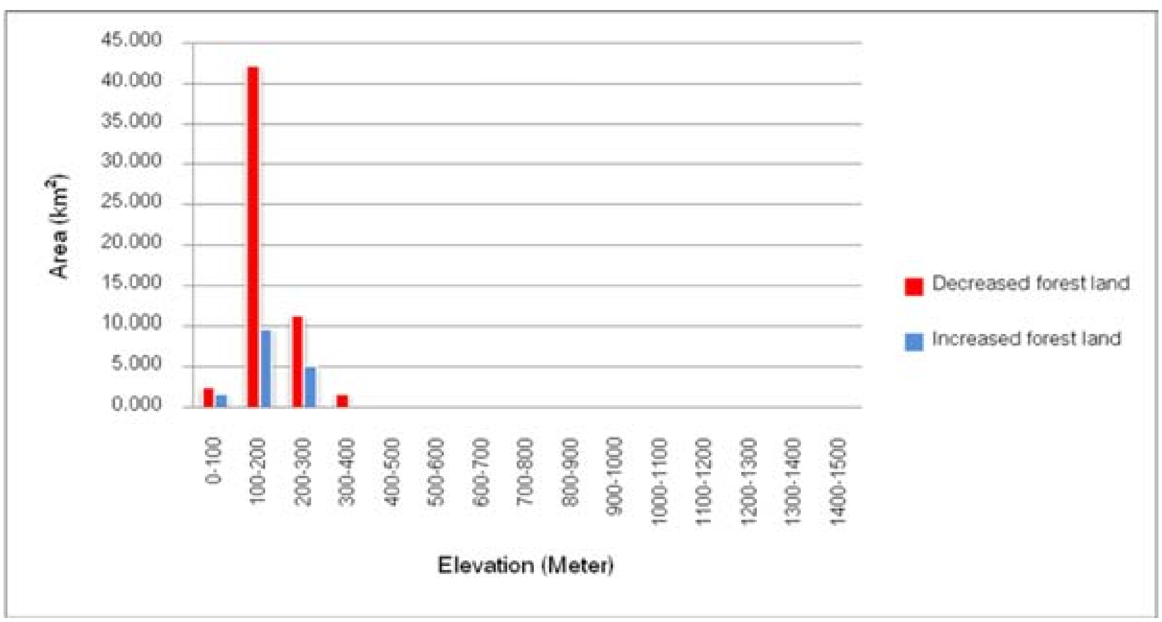


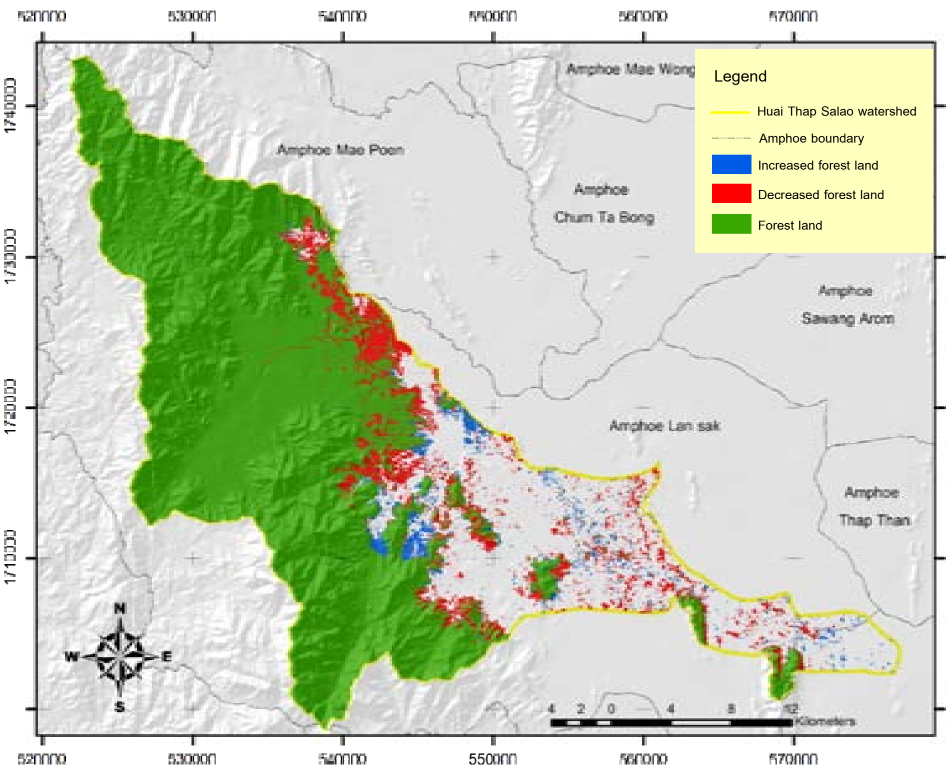
Figure 4-12 Histogram distribution of forest land change on elevation.

4.3.4 Relationship between factors of distance from roads and forest land

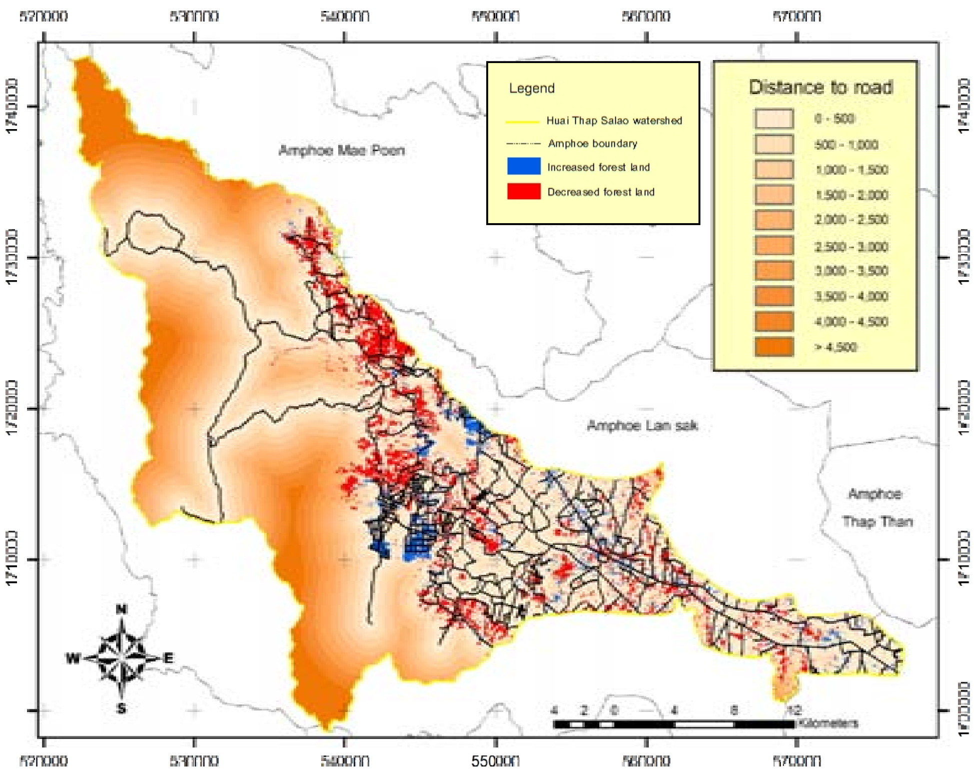
In relationship between factors of distance from roads and forest land, the frequencies were determined by calculating the forest land areas for each 500 meters range of buffering distance from roads (Table 4-15 and Figures 4-13, 4-14).

Forest land was decreased in the range of 0 to 500 meters; the ratio was 0.842 or 48.981 km^2 of the forest land change decreased, indicating a high probability to change. Followed by interval 500 to 1,000 meters; the ratio was 0.117 or 6.796 km^2, indicating a moderate probability to change. It was noted that low probabilities were observed in the area which from the buffering distance from roads were in the range of between 1,000 to 1,500m., 1,500 to 2,000m., and 2,000 to 2,500m., that the ratio was 0.021, 0.015, and 0.003, respectively.

Forest land was increased in the range of 0 to 500 meters; the ratio was 0.931 or 15.811 km^2 of the forest land change increased, indicating a high probability to change. Followed by interval 500 to 1,000 meters; the ratio was 0.063 or 1.069 km^2, indicating a moderate probability to change. It was noted that low probabilities were observed in the area which from the buffering distance from roads were in the range of between 1,000 to 1,500m., and 1,500 to 2,000m., which the ratio was 0.004, and 0.001, respectively.



a)



b)

c)

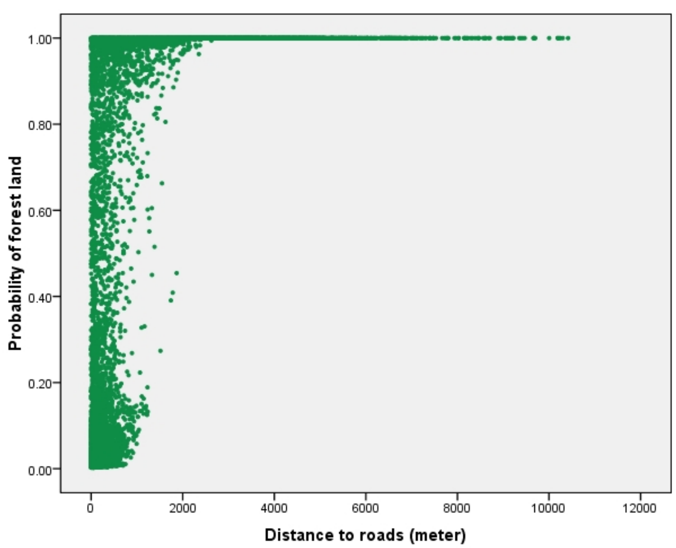


Figure 4-13 Relationship between land use (a) and the distance to roads factor (b) that had positive effects to the forest land category (c).

Table 4-15 Relationship between factors of distance from roads and forest land change in Huai Thap Salao watershed.

Distance to roads (Meter)	Forest land change decrease		Forest land change increase	
	Area (km^2)	Ratio	Area (km^2)	Ratio
0-500	48.981	0.842	15.811	0.931
500-1,000	6.796	0.117	1.069	0.063
1,000-1,500	1.247	0.021	0.065	0.004
1,500-2,000	0.883	0.015	0.016	0.001
2,000-2,500	0.170	0.003	0.000	0.000
2,500-3,000	0.024	0.000	0.000	0.000
3,000-3,500	0.016	0.000	0.000	0.000
3,500-4,000	0.016	0.000	0.000	0.000
4,000-4,500	0.008	0.000	0.008	0.000
> 4,500	0.016	0.000	0.008	0.000
Total	58.158	1.000	16.978	1.000

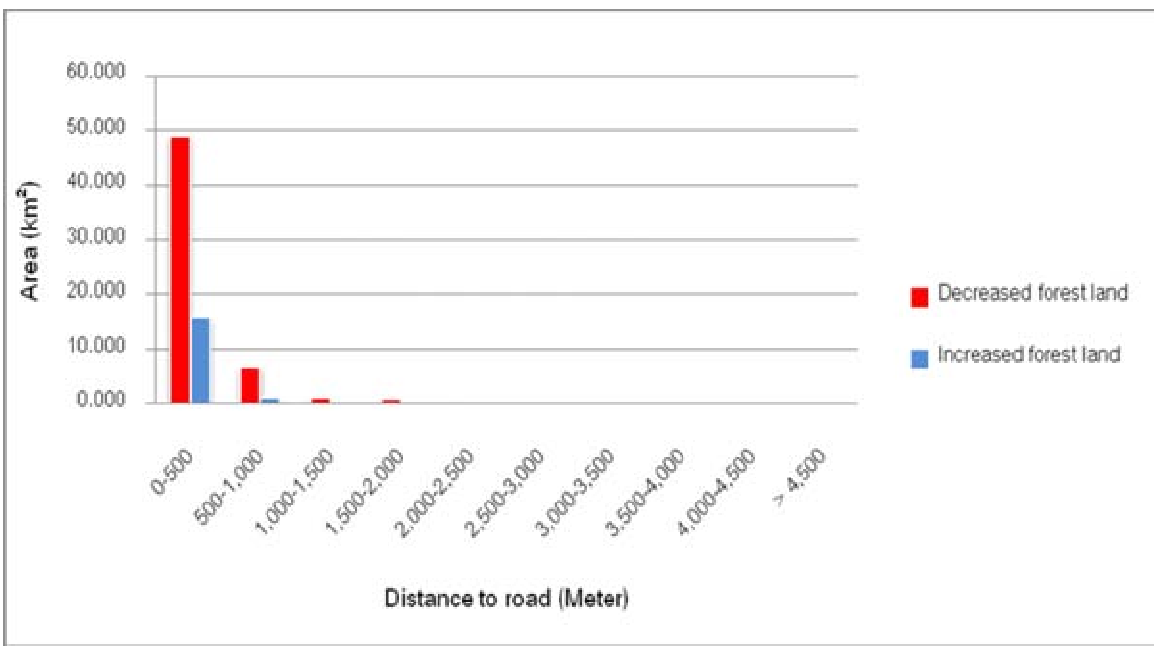


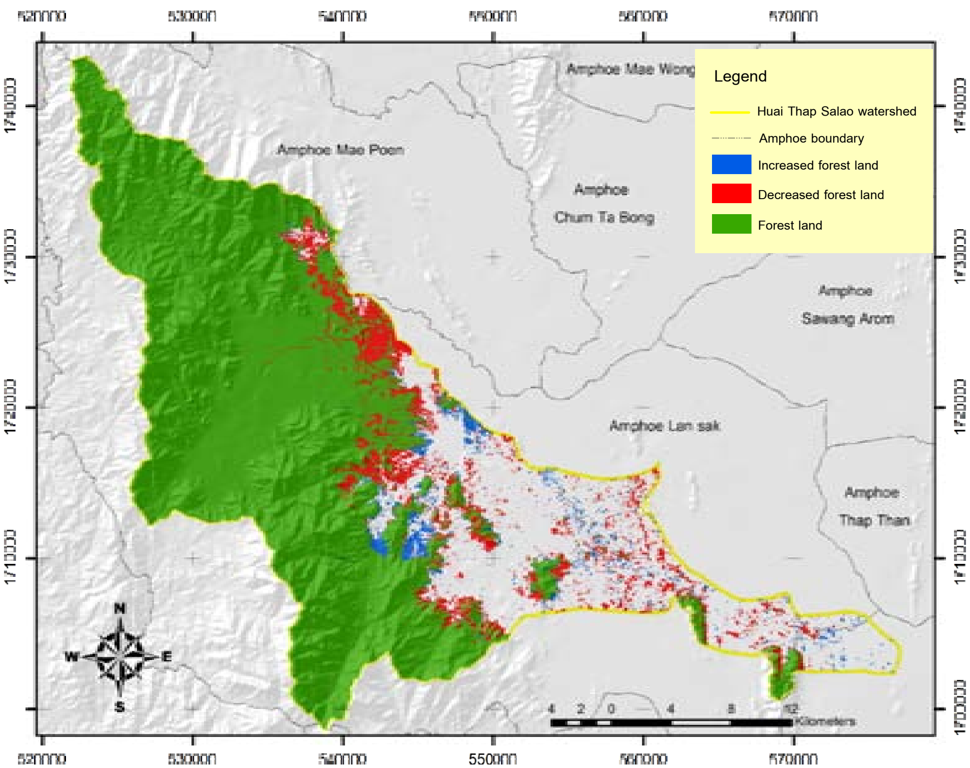
Figure 4-14 Histogram distribution of forest land change on buffering distance from roads.

4.3.5 Relationship between factors of distance from villages and forest land

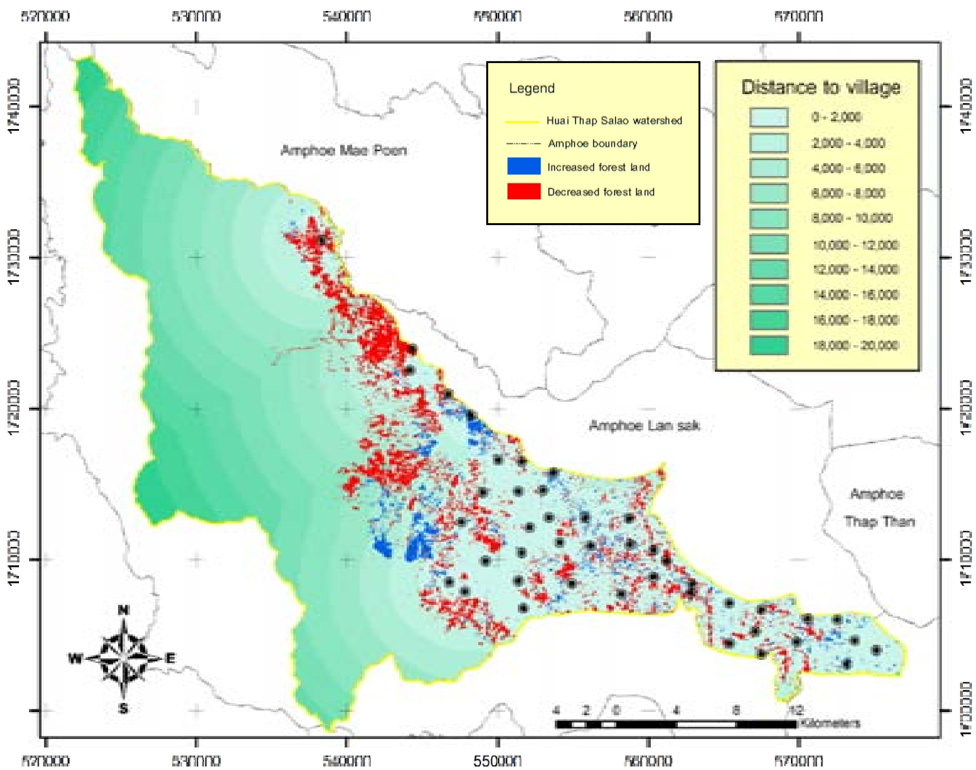
In relationship between factors of distance from villages and forest land, the frequencies were determined by calculating the forest land areas for each 2,000 meters range of buffering distance from villages (Table 4-16 and Figures 4-15, 4-16).

Forest land was decreased in the range of 0 to 2,000 meters; the ratio was 0.565 or 32.878 km^2 of the forest land change decreased, indicating a high probability to change. Followed by interval 2,000 to 4,000 meters; the ratio was 0.245 or 14.232 km^2, indicating a moderate probability to change. It was noted that low probabilities were observed in the area which from the buffering distance from villages were in the range of between 4,000 to 6,000m., 6,000 to 8,000m., and 8,000 to 10,000m., that the ratio was 0.133, 0.051, and 0.004, respectively.

Forest land was increased in the range of 0 to 2,000 meters; the ratio was 0.588 or 9.979 km^2 of the forest land change increased, indicating a high probability to change. Followed by interval 2,000 to 4,000 meters; the ratio was 0.272 or 4.617 km^2, indicating a moderate probability to change. It was noted that low probabilities were observed in the area which from the buffering distance from villages were in the range of between 4,000 to 6,000m., and 6,000 to 8,000m., which the ratio was 0.128, and 0.012, respectively.



a)



b)

c)

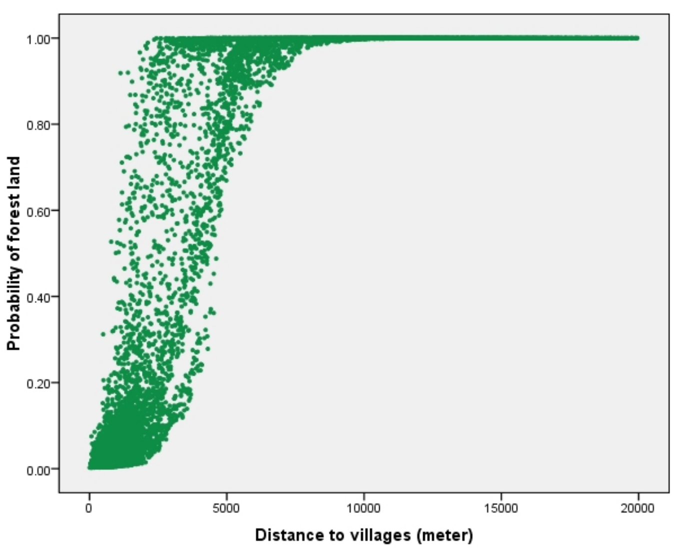


Figure 4-15 Relationship between land use (a) and the distance to villages factor (b) that had positive effects to the forest land category (c).

Table 4-16 Relationship between factors of distance to villages and forest land change in Huai Thap Salao watershed.

Distance to villages (Meter)	Forest land change decrease		Forest land change increase	
	Area (km^2)	Ratio	Area (km^2)	Ratio
0-2,000	32.878	0.565	9.979	0.588
2,000-4,000	14.232	0.245	4.617	0.272
4,000-6,000	7.752	0.133	2.171	0.128
6,000-8,000	2.973	0.051	0.203	0.012
8,000-10,000	0.251	0.004	0.000	0.000
10,000-12,000	0.016	0.000	0.000	0.000
12,000-14,000	0.024	0.000	0.008	0.000
14,000-16,000	0.008	0.000	0.000	0.000
16,000-18,000	0.016	0.000	0.000	0.000
18,000-20,000	0.008	0.000	0.000	0.000
Total	58.158	1.000	16.978	1.000

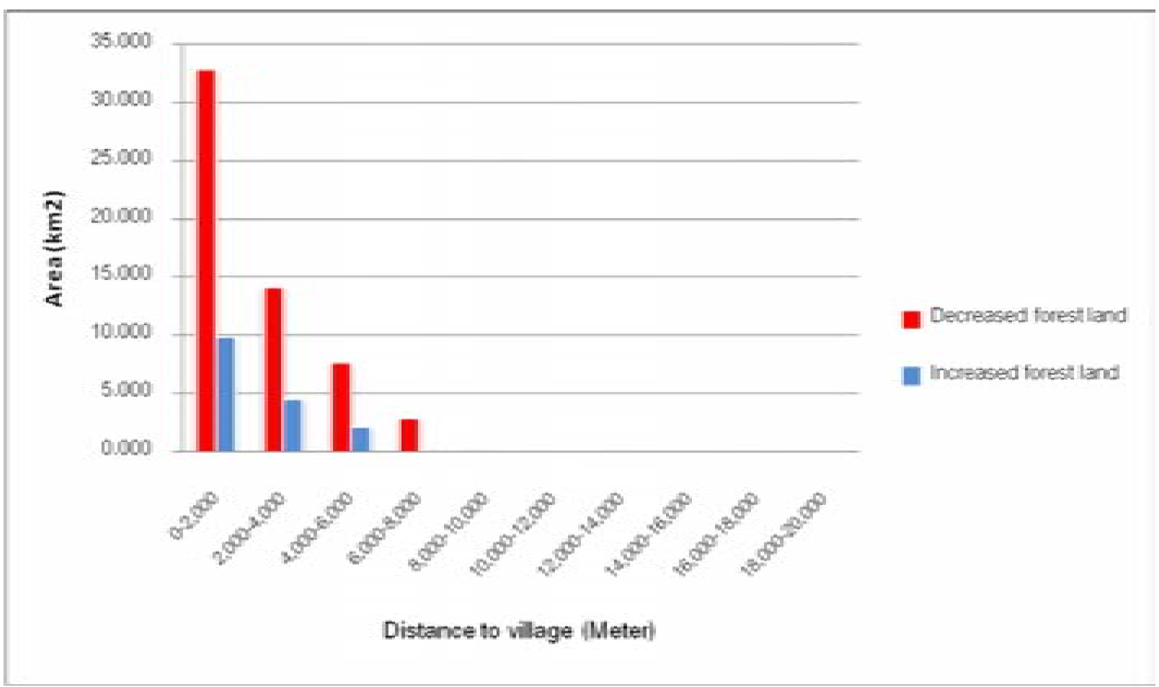


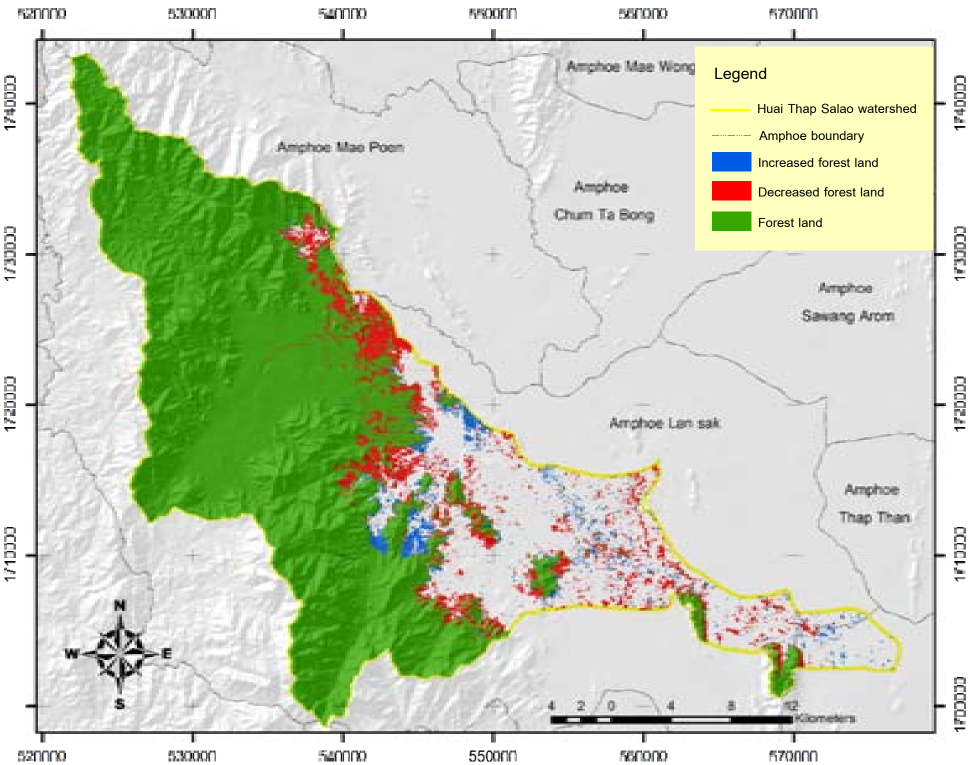
Figure 4-16 Histogram distribution of forest land change on buffering distance from villages.

4.3.6 Relationship between factors of mean annual precipitation and forest land

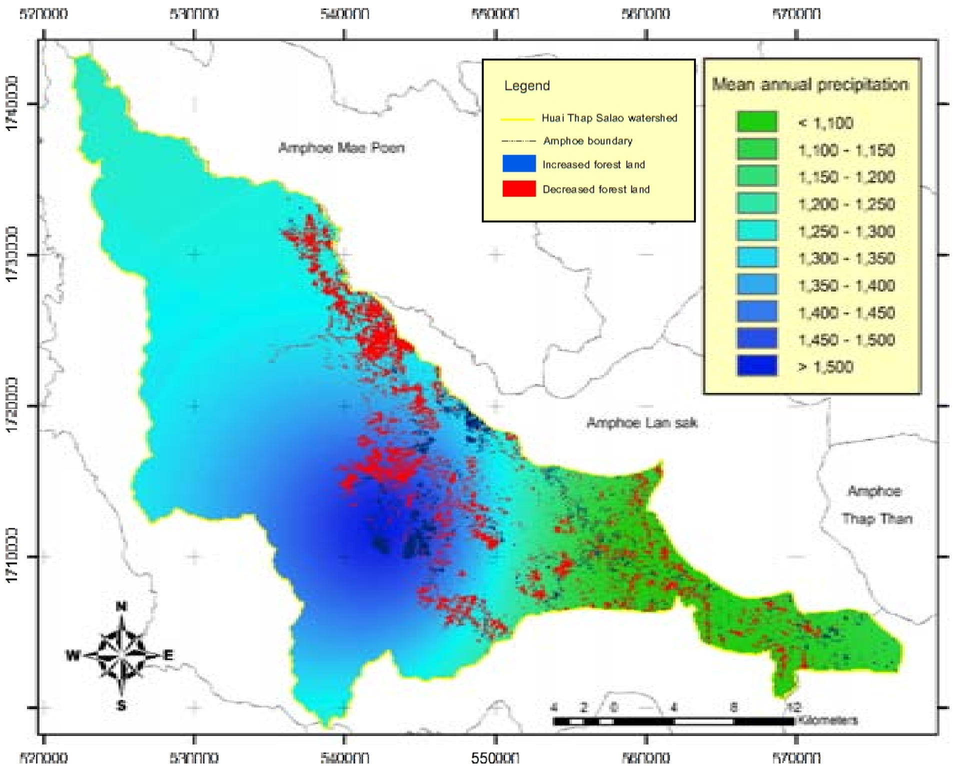
In relationship between factors of mean annual precipitation and forest land, the frequencies were determined by calculating the forest land areas for each 50 mm. interval of mean annual precipitation (Table 4-17 and Figures 4-17, 4-18).

Forest land was decreased in the range of 1,300 to 1,350 mm; the ratio was 0.271 or 15.763 km^2 of the forest land change decreased, indicating a high probability to change. Moderate probabilities were commonly observed in the areas which mean annual precipitation was in the ranges between 1,100 to 1,150 mm, 1,250 to 1,300 mm, 1,400 to 1,450 mm, 1,350 to 1,400 mm, and 1,450 to 1,500 mm; the ratio was 0.165, 0.153, 0.118, 0.095 and 0.077, respectively. It was noted that low probabilities were observed in the area which from the mean annual precipitation were in the range of less than 1,000mm, 1,150 to 1,200m., 1,250 to 1,300 m., and more than 1,500 mm, which the ratio was 0.057, 0.042, 0.023, and 0.001, respectively.

Forest land was increased in the range of 1,450 to 1,500 mm, 1,100 to 1,150 mm, and 1,300 to 1,350 mm; the ratio was 0.379, 0.230, and 0,160, respectively; indicating a moderate probability to change. It was noted that low probabilities were observed in the area which from the mean annual precipitation were in the range of between 1,400 to 1,450 mm, 1,150 to 1,200 mm, 1,350 to 1,400 mm, 1,250 to 1,300 mm, less than 1,100 mm, 1,200 to 1,250 mm, and more than 1,500 mm, which the ratio was 0.064, 0.063, 0.050, 0.041, 0.038, 0.036 and 0.011, respectively.



a)



b)

c)

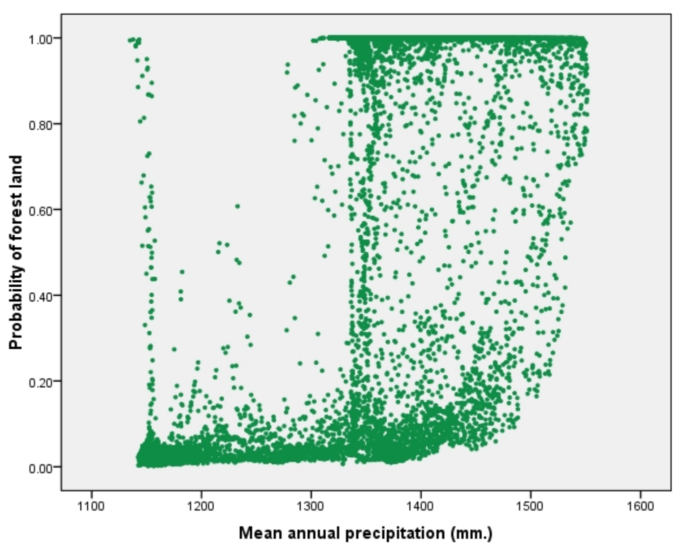


Figure 4-17 Relationship between land use (a) and the mean annual precipitation factor (b) that had negative effects to the forest land category (c).

Table 4-17 Relationship between factors of mean annual precipitation and forest land change in Huai Thap Salao watershed.

Mean annual precipitation (mm.)	Forest land change decrease		Forest land change increase	
	Area (km^2)	Ratio	Area (km^2)	Ratio
<1,100	3.289	0.057	0.640	0.038
1,100-1,150	9.574	0.165	3.904	0.230
1,150-1,200	2.422	0.042	1.061	0.063
1,200-1,250	1.320	0.023	0.608	0.036
1,250-1,300	8.918	0.153	0.689	0.041
1,300-1,350	15.763	0.271	2.722	0.160
1,350-1,400	5.500	0.095	0.851	0.050
1,400-1,450	6.885	0.118	1.094	0.064
1,450-1,500	4.455	0.077	5.225	0.308
>1500	0.032	0.001	0.186	0.011
Total	58.158	1.000	16.978	1.000

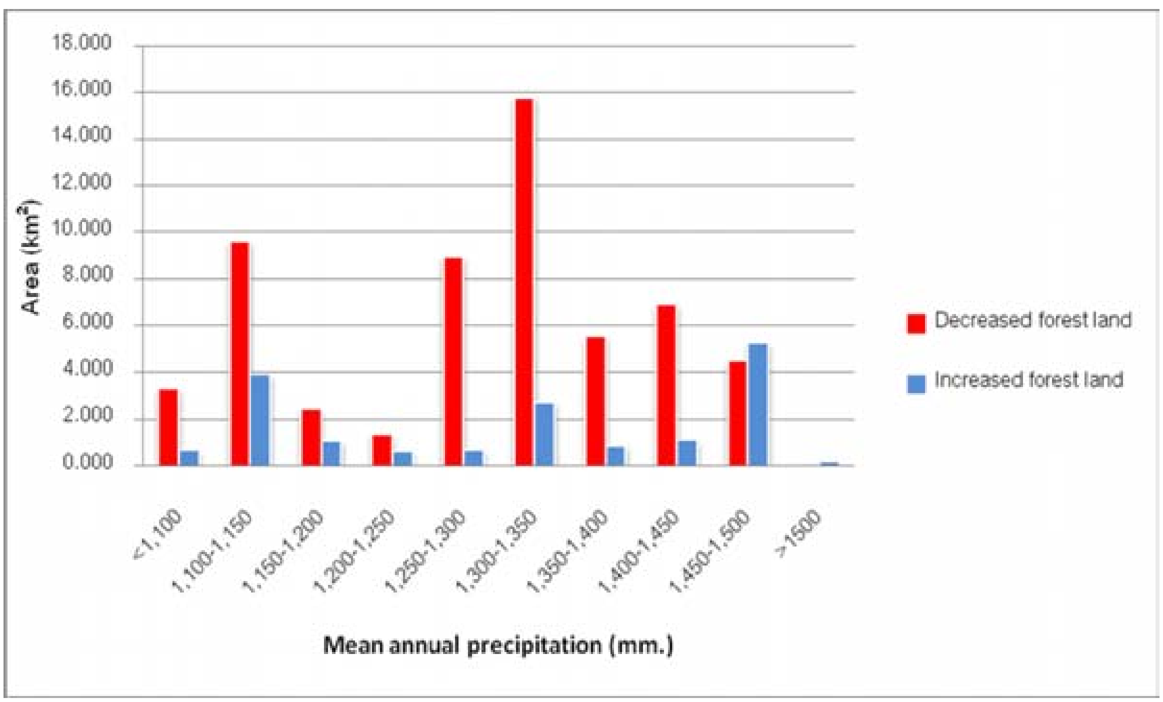


Figure 4-18 Histogram distribution of forest land change on mean annual precipitation.

4.4 Factors and their relationship affecting agricultural land

Table 4-11 shows the relative importance of affecting factors to the agricultural land in the study area. According to the stepwise procedure in the logistic regression for agricultural land, some variables had significant values, including soil texture (β = 0.5729) had positive effects to the agricultural land. In the other hand, it could be seen that degree of slope (β = -0.0466), elevation (β = -0.0079), distance to roads (β = -0.0015), mean annual precipitation (β = -0.0011), and distance to villages (β = -0.0008) had negative effect to the probability of agricultural land to change.

The results revealed that the change of agricultural land had relationship between the 6 affecting factors and a positive value of probability factors was explained as follows: The most affecting factor was soil texture factor that a high influence to the forest land changes in the area compared to the other affecting factors. As followed by degree of slope, elevation, distance to roads, mean annual precipitation, and distance to villages, respectively.

4.4.1 Relationship between factors of soil texture and agricultural land

In relationship between factors of soil texture and agricultural land, the frequencies were determined by calculating the agricultural land areas for each 4 soil texture (Table 4-18 and Figures 4-19, 4-20).

Agricultural land was decreased in the sand loam; the ratio was 0.622 or 21.846 km^2 of the agricultural land change decreased, indicating a high probability to change. Moderate probabilities were commonly observed in the areas which soil texture was in the clay; the ratio was 0.309 or 10.839 km^2 of the agricultural land change decreased. It was noted that low probabilities were observed in the area which from the soil texture were in the clay loam and sand, which the ratio was 0.046 and 0.022.

Agricultural land was increased in the sand loam; the ratio was 0.863 or 49.50 km^2 of the agricultural land change decreased, indicating a high probability to change. Moderate probabilities were commonly observed in the areas which soil texture was in the clay; the ratio was 0.091 or 5.25 km^2 of the agricultural land change decreased. It was noted that low probabilities were observed in the area which from the soil texture were in the clay loam and sand, which the ratio was 0.03 and 0.016.

Table 4-18 Relationship between factors of soil texture and agricultural land change in Huai Thap Salao watershed.

Soil texture	Agricultural land change decrease		Agricultural land change increase	
	Area (km^2)	Ratio	Area (km^2)	Ratio
Clay	10.838	0.309	5.225	0.091
Clay loam	1.628	0.046	1.701	0.030
Sand loam	21.846	0.622	49.499	0.863
Sand	0.786	0.022	0.915	0.016
Total	35.097	1.000	57.340	1.000

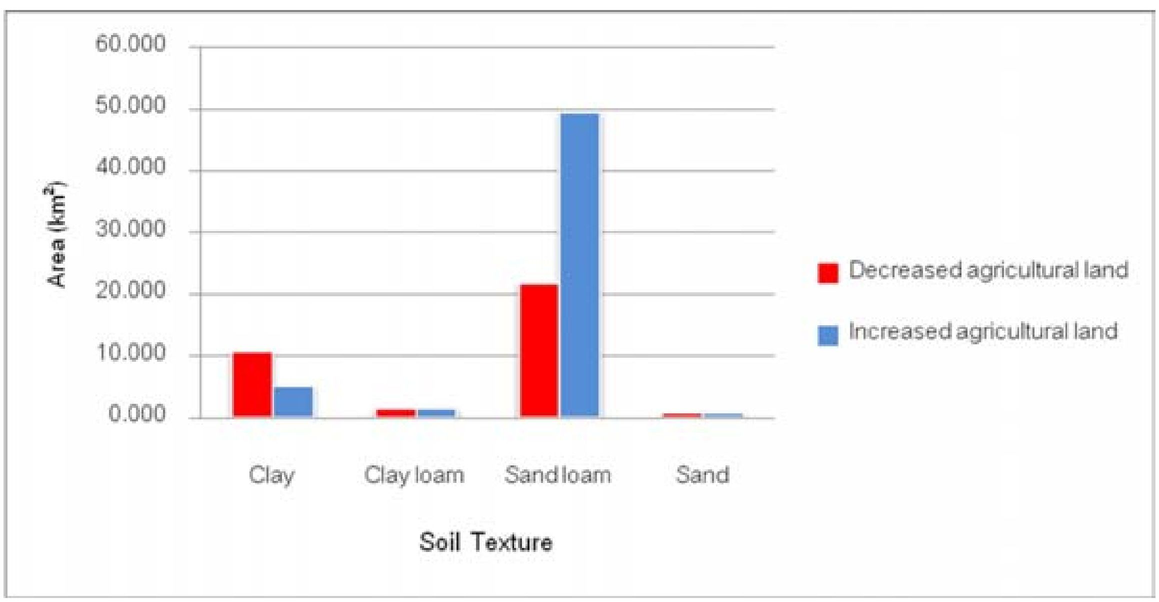
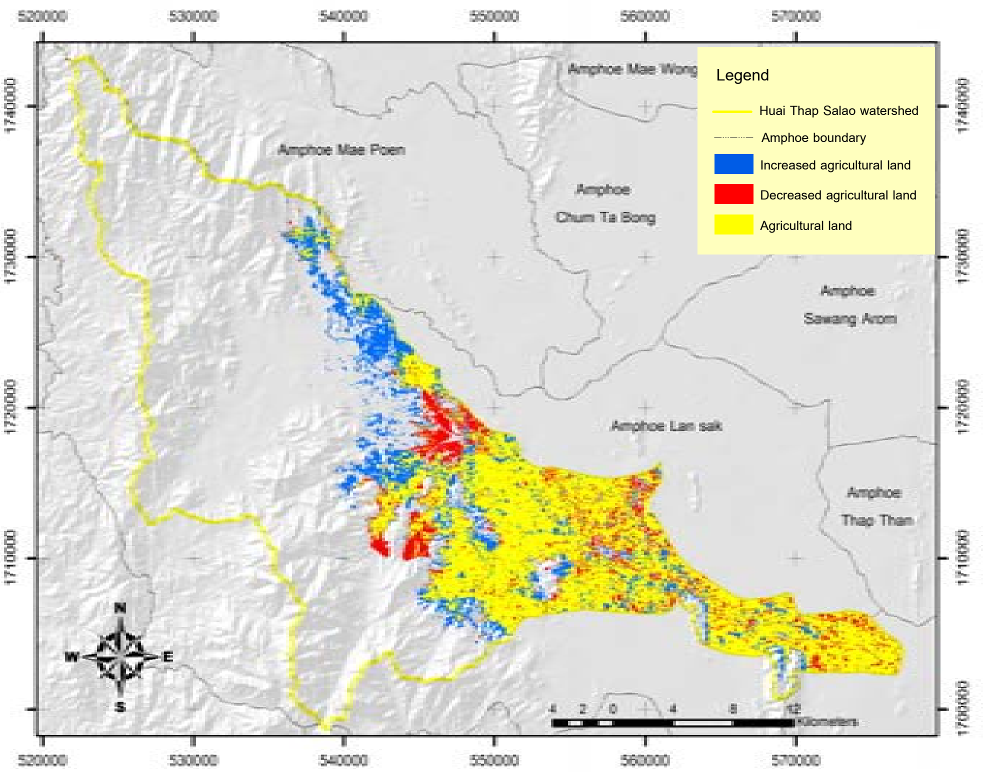
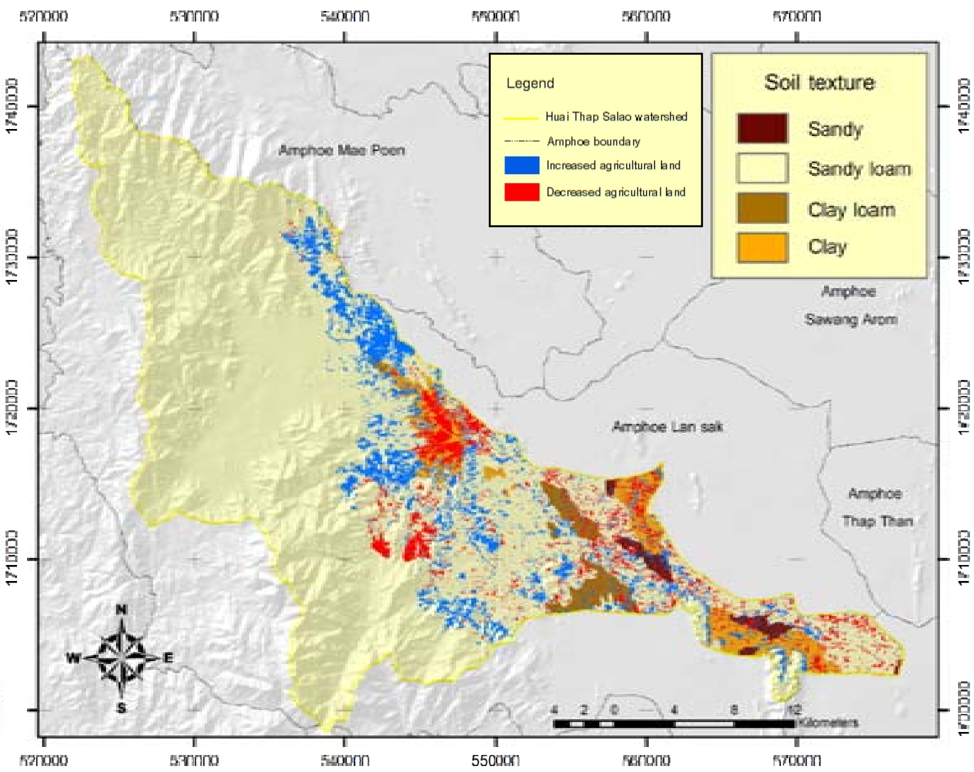


Figure 4-19 Histogram distribution of agricultural land change on soil texture.



a)



b)

c)

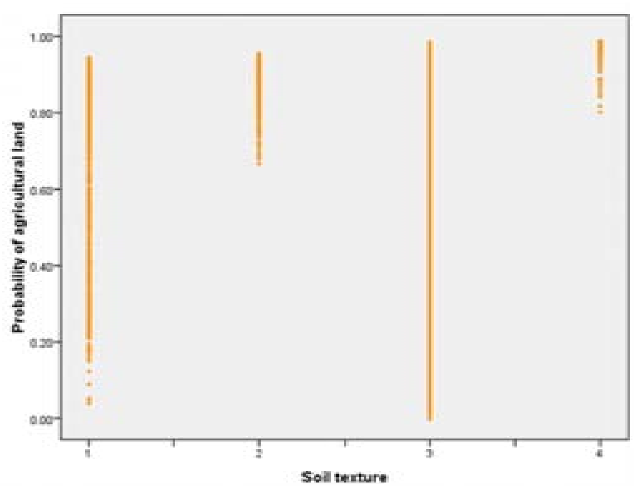


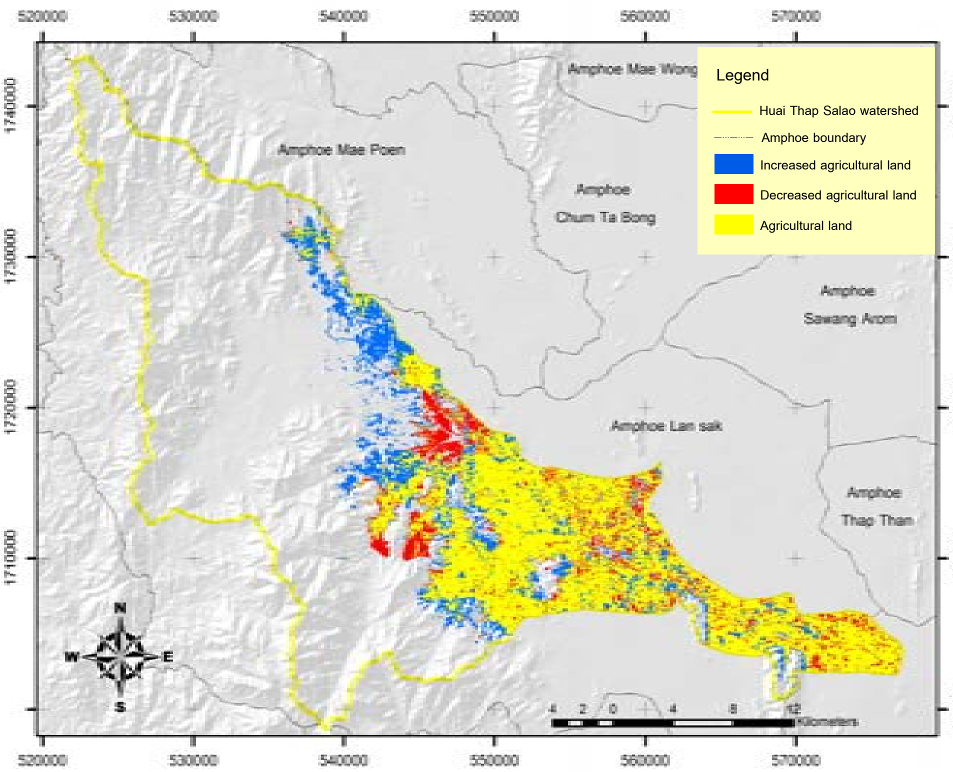
Figure 4-20 Relationship between land use (a) and the soil texture factor (b) that had positive effects to the agricultural land category (c).

4.4.2 Relationship between factors of degree of slope and agricultural land

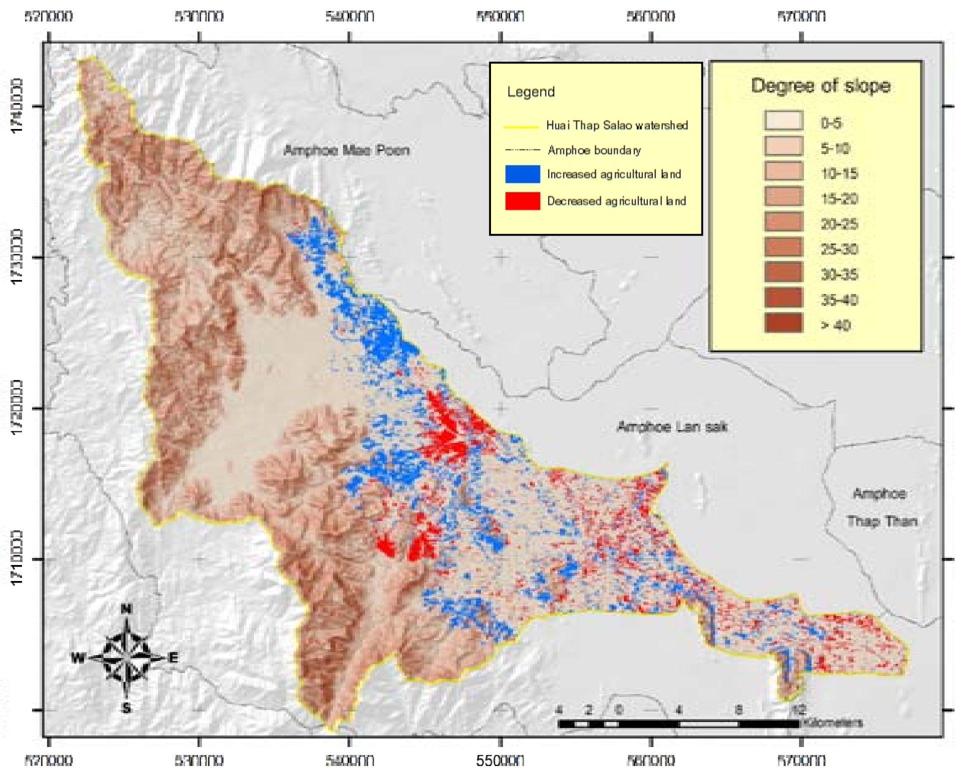
In relationship between factors of degree of slope and agricultural land, the frequencies were determined by calculating the agricultural land areas for each 5 degree interval of slope angle (Table 4-19 and Figures 4-21, 4-22).

Agricultural land was decreased in slope below 5%; the ratio was 0.883 or 30.999 km^2 of the agricultural land change decreased, indicating a high probability to change. It was noted that low probabilities were observed in the area which from the slope were in the range of between 5 to 10%, 10 to 15%, 15 to 20%, 20 to 25%, and 25 to 30%, that the ratio was 0.074, 0.027, 0.011, 0.003, and 0.001, respectively.

Agricultural land was increased in slope below 5%; the ratio was 0.770 or 44.137 km^2 of the agricultural land change increased, indicating a high probability to change. It was noted that low probabilities were observed in the area which from the slope were in the range of between 5 to 10%, 10 to 15%, 15 to 20%, 20 to 25%, 25 to 30%, 30 to 35%, 35 to 40%, and more than 40%, that the ratio was 0.121, 0.054, 0.027, 0.015, 0.007, 0.004 0.002 and 0.001, respectively.



a)



b)

c)

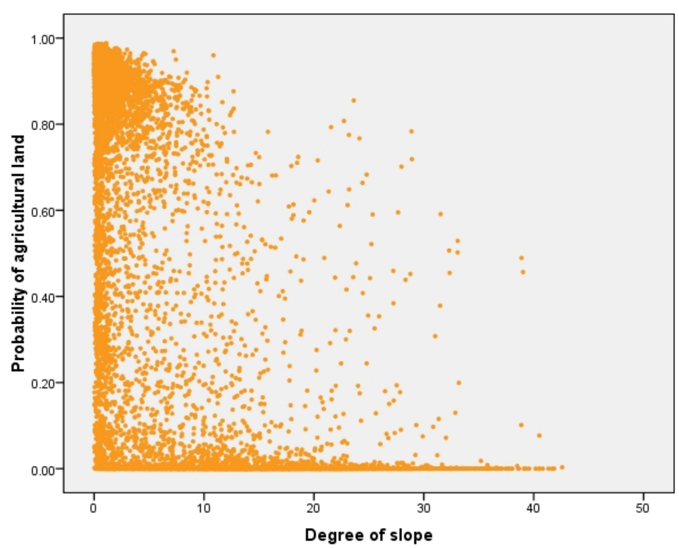


Figure 4-21 Relationship between land use (a) and the degree of slope factor (b) that had negative effects to the agricultural land category (c).

Table 4-19 Relationship between factors of degree of slope and agricultural land change in Huai Thap Salao watershed.

Degree of slope (%)	Agricultural land change decrease		Agricultural land change increase	
	Area (km^2)	Ratio	Area (km^2)	Ratio
0-5	30.999	0.883	44.137	0.770
5-10	2.600	0.074	6.950	0.121
10-15	0.956	0.027	3.110	0.054
15-20	0.389	0.011	1.531	0.027
20-25	0.113	0.003	0.842	0.015
25-30	0.041	0.001	0.405	0.007
30-35	0.000	0.000	0.219	0.004
35-40	0.000	0.000	0.113	0.002
>40	0.000	0.000	0.032	0.001
Total	35.097	1.000	57.340	1.000

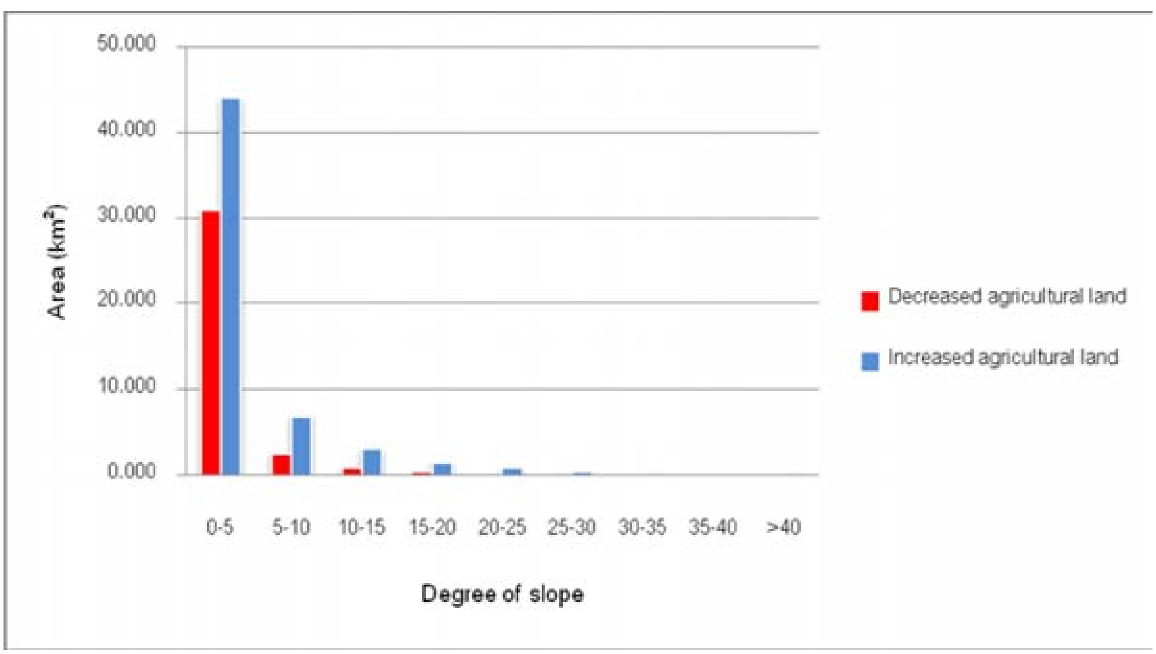


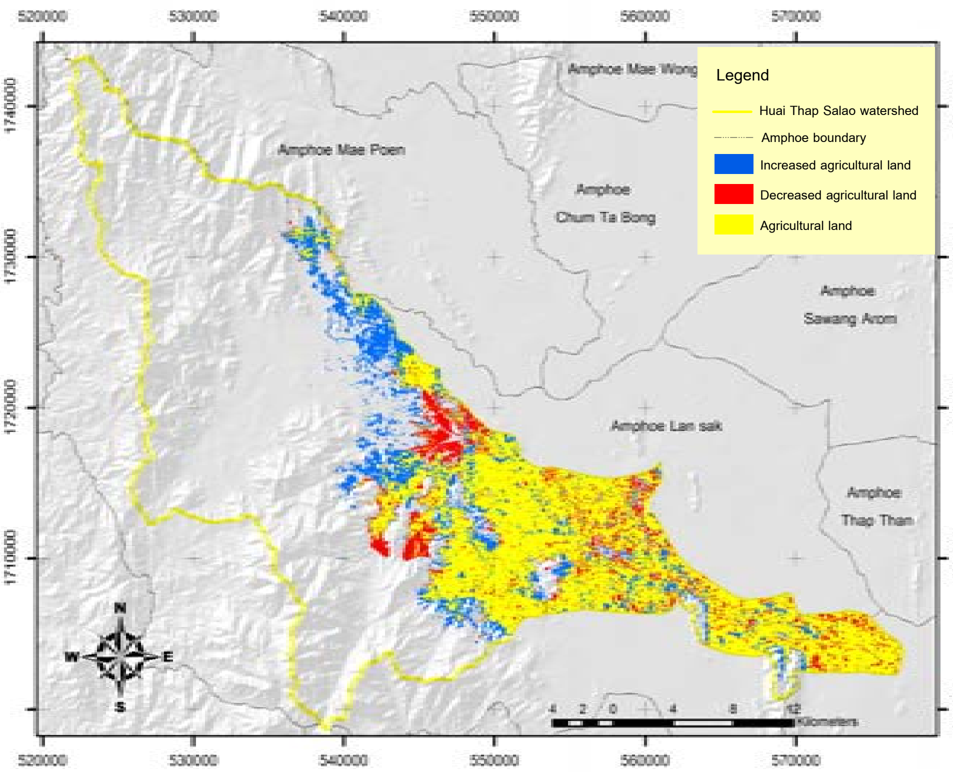
Figure 4-22 Histogram distribution of agricultural land change on slope.

4.4.3 Relationship between factors of elevation and agricultural land

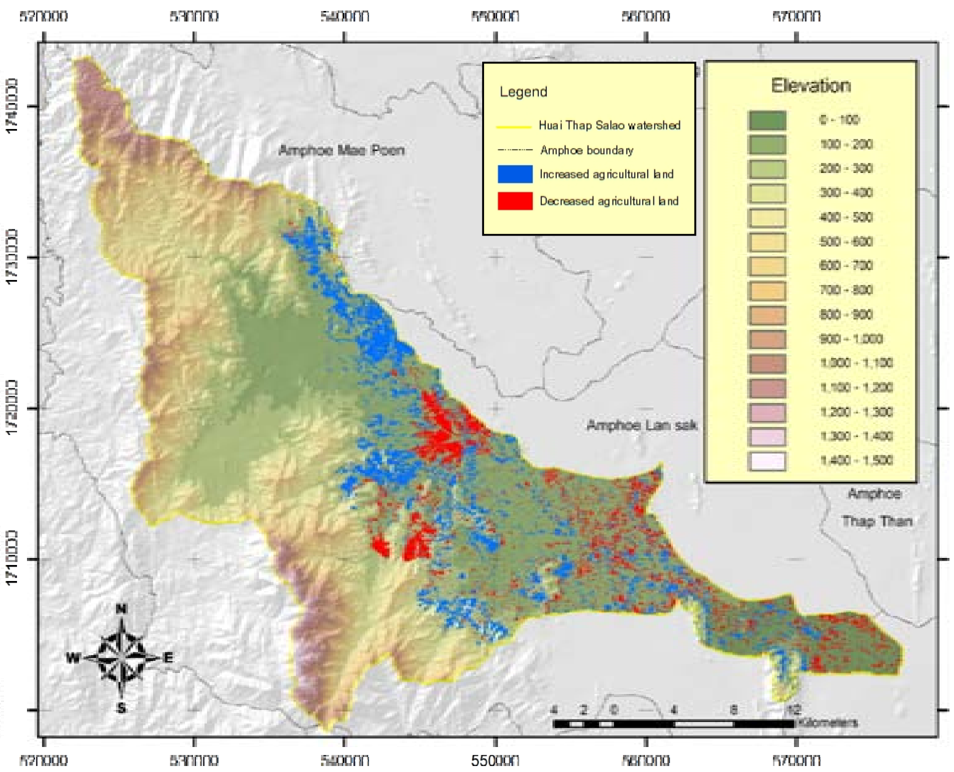
In relationship between factors of elevation and agricultural land, the frequencies were determined by calculating the agricultural land areas for each 100 meters interval of mean sea level (Table 4-20 and Figures 4-23, 4-24).

Agricultural land was decreased in contour interval 100 to 200 meters; the ratio was 0.690 or 24.227 km^2 of the agricultural land change decreased, indicating a high probability to change. Followed by interval 0 to 100m and 200 to 300 m.; the ratio was 0.151 and 0.150, respectively, indicating a moderate probability to change. It was noted that low probabilities were observed in the area which from the elevation were in the range of between 300 to 400m., that the ratio was 0.009 or 0.316 km^2 of the agricultural land change decreased.

Agricultural land was increased in contour interval100 to 200 meters; the ratio was 0.716 or 41.059 km^2 of the agricultural land change increased, indicating a high probability to change. Followed by interval 200 to 300 meters; the ratio was 0.202 or 11.575 km^2, indicating a moderate probability to change. It was noted that low probabilities were observed in the area which from the elevation were in the range of between 0 to 100m., 300 to 400m., 400 to 500m., and 500 to 600m., which the ratio was 0.045, 0.032, 0.004 and 0.001, respectively.



a)



b)

c)

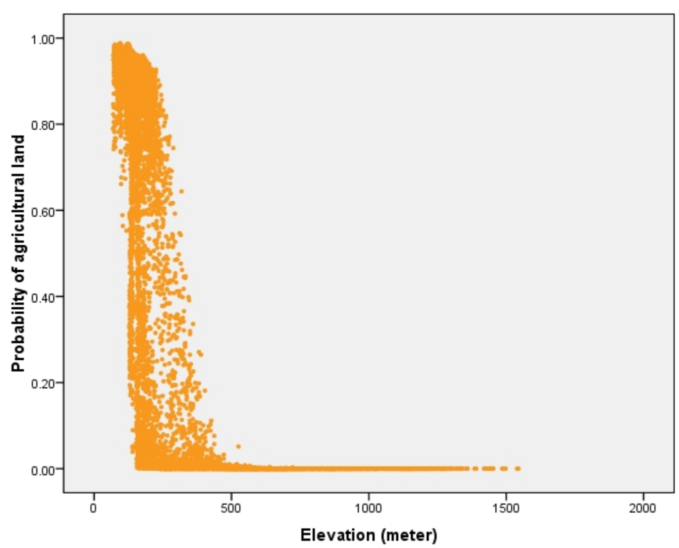


Figure 4-23 Relationship between land use (a) and the elevation factor (b) that had negative effects to the agricultural land category (c).

Table 4-20 Relationship between factors of elevation and agricultural land change in Huai Thap Salao watershed.

Elevation (meters)	Agricultural land change decrease		Agricultural land change increase	
	Area (km^2)	Ratio	Area (km^2)	Ratio
0-100	5.297	0.151	2.576	0.045
100-200	24.227	0.690	41.059	0.716
200-300	5.257	0.150	11.575	0.202
300-400	0.316	0.009	1.863	0.032
400-500	0.000	0.000	0.203	0.004
500-600	0.000	0.000	0.041	0.001
600-700	0.000	0.000	0.008	0.000
700-800	0.000	0.000	0.008	0.000
800-900	0.000	0.000	0.000	0.000
900-1000	0.000	0.000	0.008	0.000
1000-1100	0.000	0.000	0.000	0.000
1100-1200	0.000	0.000	0.000	0.000
1200-1300	0.000	0.000	0.000	0.000
1300-1400	0.000	0.000	0.000	0.000
1400-1500	0.000	0.000	0.000	0.000
Total	35.097	1.000	57.340	1.000

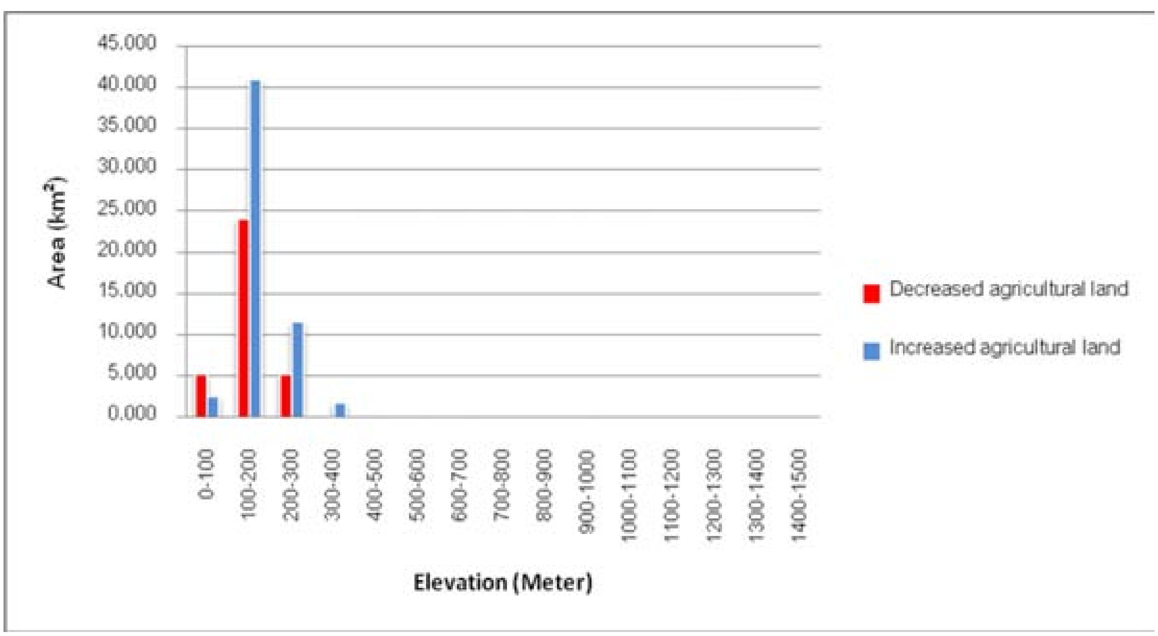


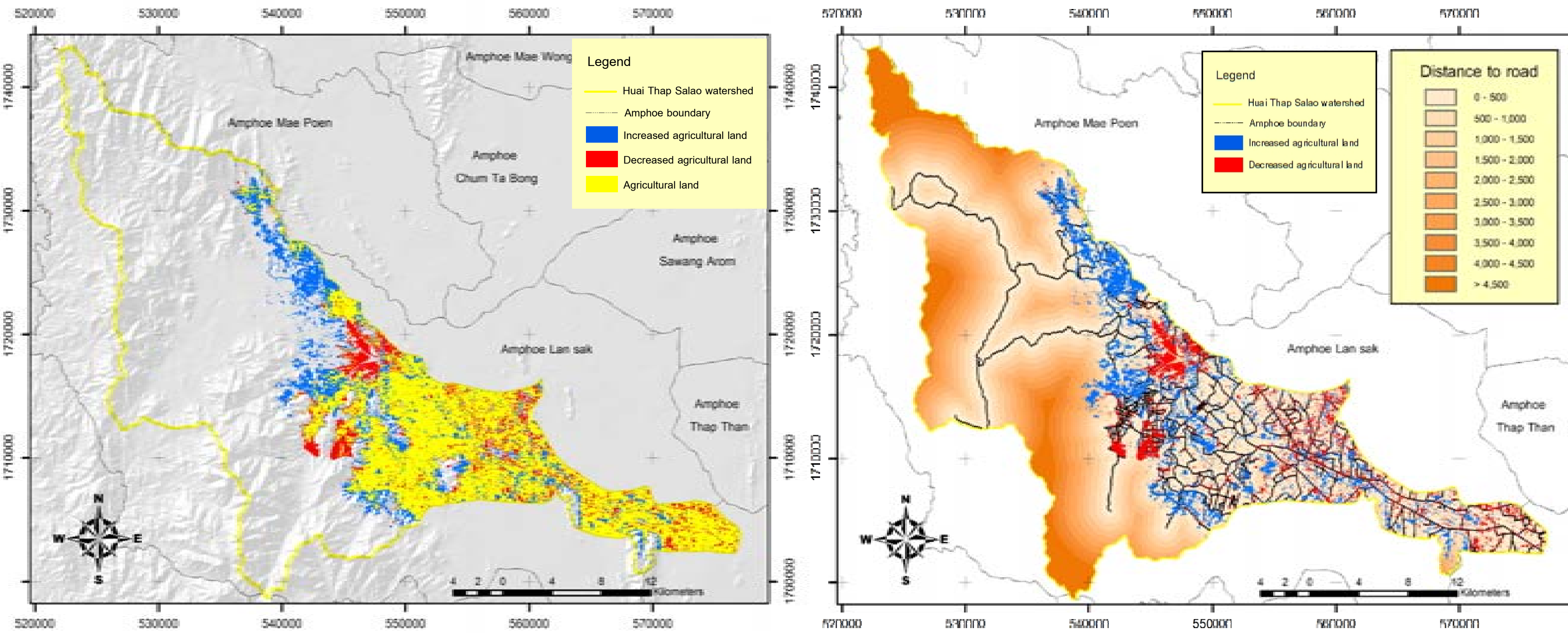
Figure 4-24 Histogram distribution of agricultural land change on elevation.

4.4.4 Relationship between factors of distance from roads and agricultural land

In relationship between factors of distance from roads and agricultural land, the frequencies were determined by calculating the agricultural land areas for each 500 meters range of buffering distance from roads (Table 4-21 and Figures 4-25, 4-26).

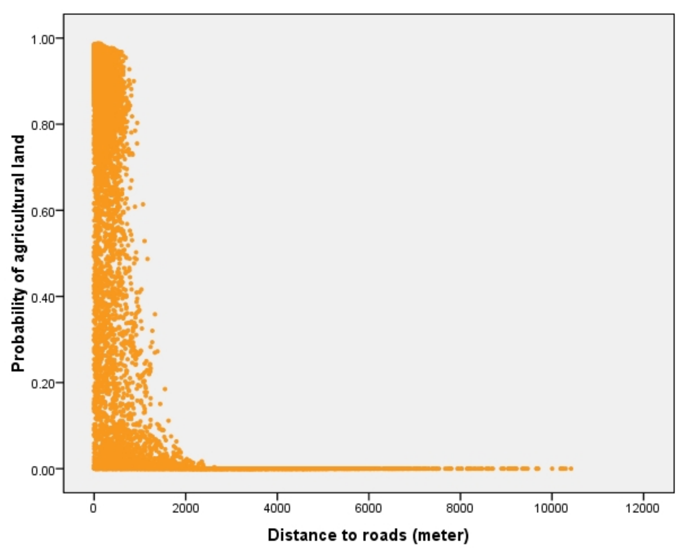
Agricultural land was decreased in the range of 0 to 500 meters; the ratio was 0.573 or 20.096 km^2 of the agricultural land change decreased, indicating a high probability to change. Followed by interval 500 to 1,000 meters; the ratio was 0.218 or 7.663 km^2, indicating a moderate probability to change. It was noted that low probabilities were observed in the area which from the buffering distance from roads were in the range of between 1,000 to 1,500m., 1,500 to 2,000m., 2,000 to 2,500m., 2,500 to 3,000m., 3,000 to 3,500m., 3,500 to 4,000m., 4,000 to 4,500m., and more than 4,500m., that the ratio was 0.113, 0.051, 0.024, 0.015, 0.004, 0.002, 0.001 and 0.000, respectively.

Agricultural land was increased in the range of 0 to 500 meters; the ratio was 0.525 or 30.075 km^2 of the agricultural land change increased, indicating a high probability to change. Followed by interval 500 to 1,000 meters; the ratio was 0.253 or 14.523 km^2, indicating a moderate probability to change. It was noted that low probabilities were observed in the area which from the buffering distance from roads were in the range of between 1,000 to 1,500m., 1,500 to 2,000m., 2,000 to 2,500m., 4,000 to 4,500m., 2,500 to 3,000m., more than 4,500m., 3,000 to 3,500m., and 3,500 to 4,000m., that the ratio was 0.118, 0.046, 0.020, 0.009, 0.009, 0.007, 0.007 and 0.006, respectively.



a)

b)



c)

Figure 4-25 Relationship between land use (a) and the distance to roads factor (b) that had negative effects to the agricultural land category (c).

Table 4-21 Relationship between factors of distance from roads and agricultural land change in Huai Thap Salao watershed.

Distance to roads (Meter)	Agricultural land change decrease		Agricultural land change increase	
	Area (km^2)	Ratio	Area (km^2)	Ratio
0-500	20.096	0.573	30.075	0.525
500-1,000	7.663	0.218	14.523	0.253
1,00-1,500	3.953	0.113	6.747	0.118
1,500-2,000	1.774	0.051	2.649	0.046
2,000-2,500	0.842	0.024	1.150	0.020
2,500-3,000	0.510	0.015	0.502	0.009
3,000-3,500	0.146	0.004	0.389	0.007
3,500-4,000	0.065	0.002	0.365	0.006
4,000-4,500	0.041	0.001	0.405	0.007
> 4,500	0.008	0.000	0.535	0.009
Total	35.097	1.000	57.340	1.000

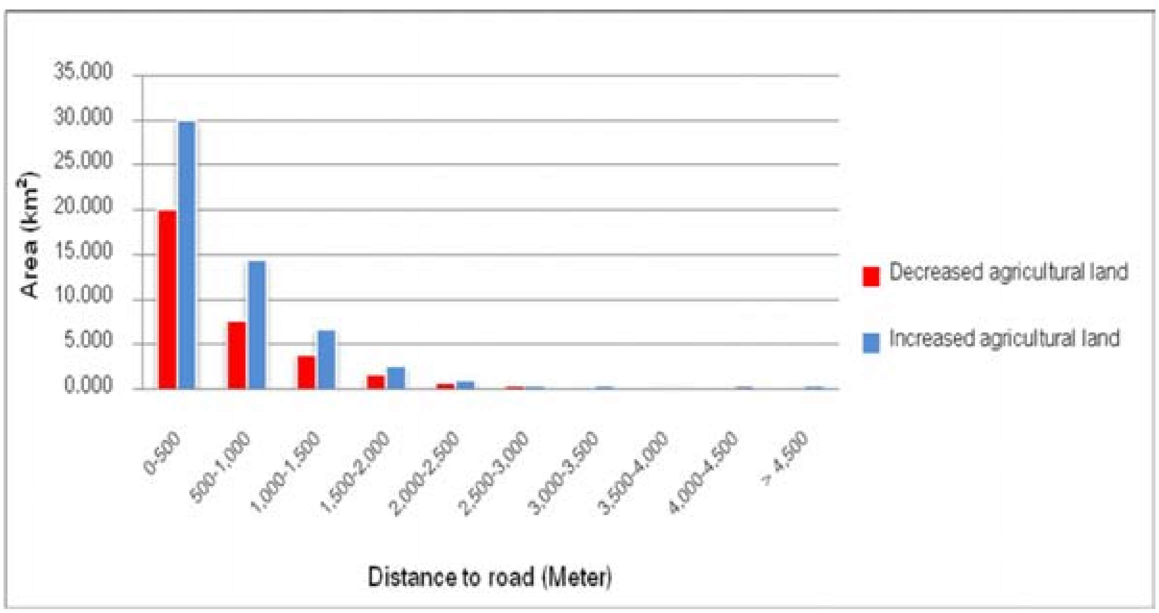


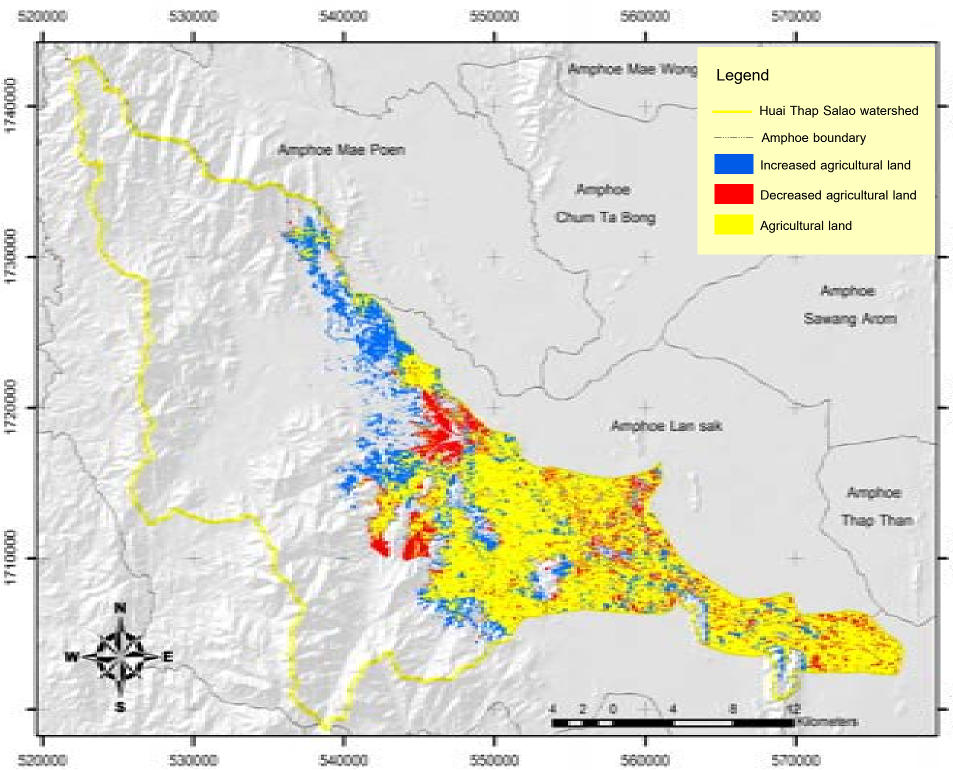
Figure 4-26 Histogram distribution of agricultural land change on buffering distance from roads.

4.4.4 Relationship between factors of mean annual precipitation and agricultural land

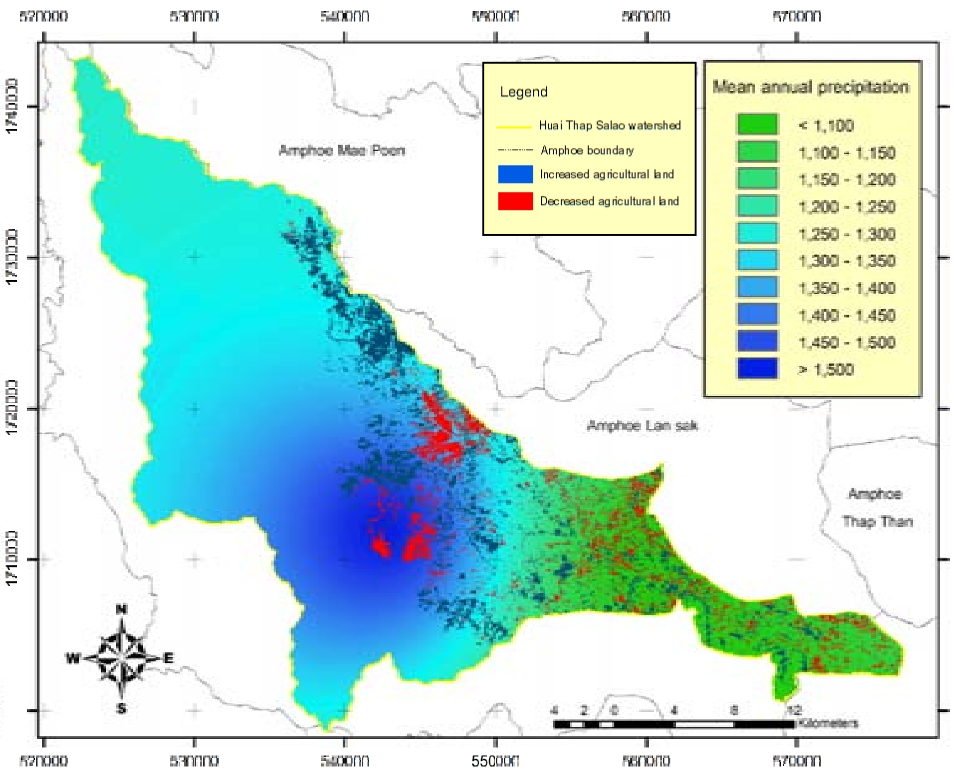
In relationship between factors of mean annual precipitation and agricultural land land, the frequencies were determined by calculating the agricultural land land areas for each 50 mm. interval of mean annual precipitation (Table 4-22 and Figures 4-27, 4-28).

Agricultural land was decreased in the range of 1,100 to 1,150 mm; the ratio was 0.365 or 12.814 km^2 of the agricultural land change decreased, indicating a high probability to change. Moderate probabilities were commonly observed in the areas which mean annual precipitation was in the ranges between 1,300 to 1,350 mm, 1,450 to 1,500 mm, and 1,350 to 1,400 mm; the ratio was 0.158, 0.146, and 0.120 respectively. It was noted that low probabilities were observed in the area which from the mean annual precipitation were in the range of less than 1,000mm, 1,150 to 1,200m., 1,400 to 1,450 m., 1,250 to 1,300m., 1,200 to 1,250m., and more than 1,500 mm, which the ratio was 0.064, 0.046, 0.063, 0.032, 0.028 and 0.005, respectively.

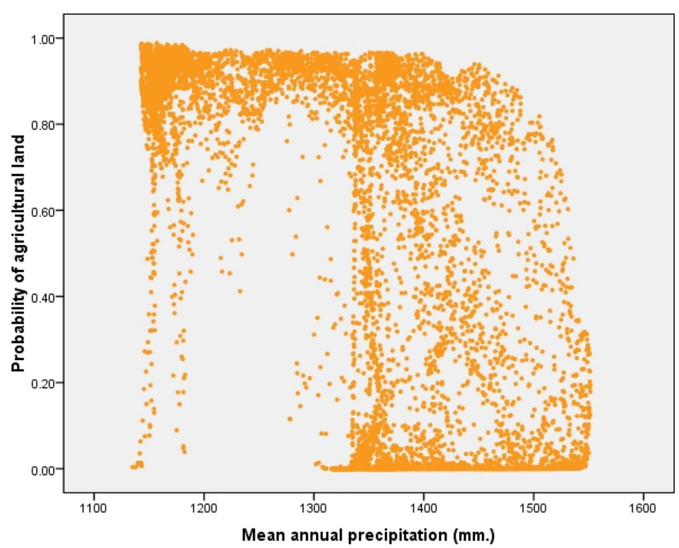
Agricultural land was increased in the range of 1,300 to 1,350 mm; the ratio was 0.270 or 15.455 km^2 of the agricultural land change decreased, indicating a high probability to change. Moderate probabilities were commonly observed in the areas which mean annual precipitation was in the ranges between 1,250 to 1,300 mm, 1,100 to 1,150 mm, and 1,400 to 1,450 mm; the ratio was 0.164, 0.142, and 0.122 respectively. It was noted that low probabilities were observed in the area which from the mean annual precipitation were in the range of between 1,350 to 1,400 mm, 1,450 to 1,500 mm, less than 1,100 mm, 1,150 to 1,200 mm, 1,200 to 1,250 mm, and more than 1,500 mm, which the ratio was 0.094, 0.078, 0.051, 0.044, 0.035, and 0.001, respectively.



a)



b)



c)

Figure 4-27 Relationship between land use (a) and the mean annual precipitation factor (b) that had positive effects to the agricultural land category (c).

Table 4-22 Relationship between factors of mean annual precipitation and agricultural land change in Huai Thap Salao watershed.

Mean annual precipitation (mm.)	Agricultural land change decrease		Agricultural land change increase	
	Area (km^2)	Ratio	Area (km^2)	Ratio
<1,100	2.236	0.064	2.932	0.051
1,100-1,150	12.814	0.365	8.116	0.142
1,150-1,200	1.620	0.046	2.527	0.044
1,200-1,250	0.996	0.028	2.025	0.035
1,250-1,300	1.134	0.032	9.388	0.164
1,300-1,350	5.540	0.158	15.455	0.270
1,350-1,400	4.196	0.120	5.411	0.094
1,400-1,450	1.247	0.036	6.990	0.122
1,450-1,500	5.135	0.146	4.447	0.078
>1500	0.178	0.005	0.049	0.001
Total	35.097	1.000	57.340	1.000

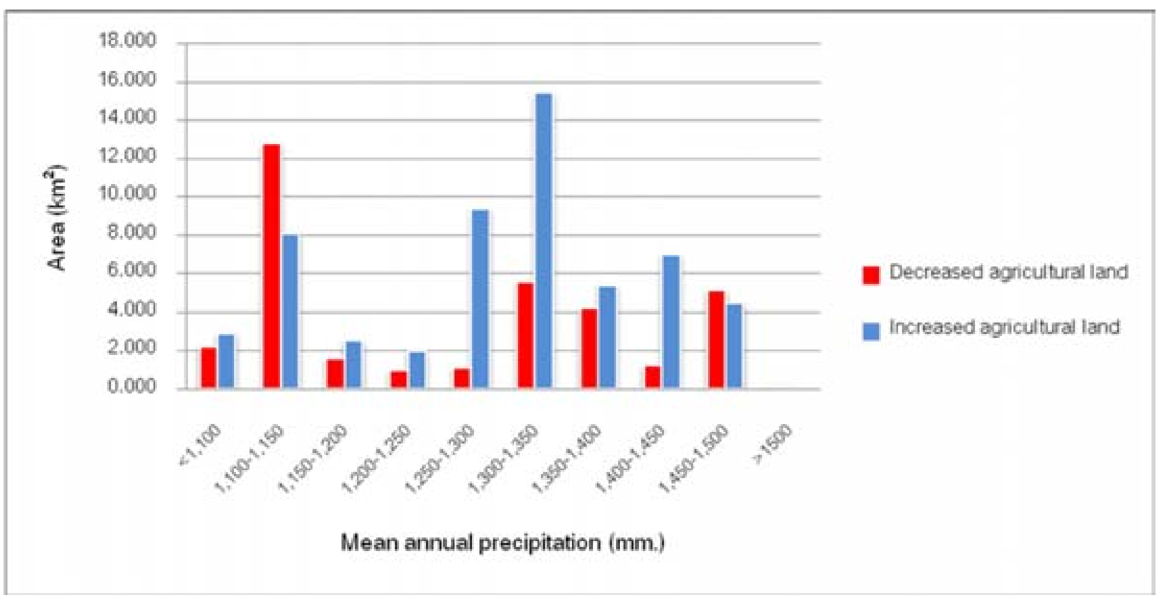


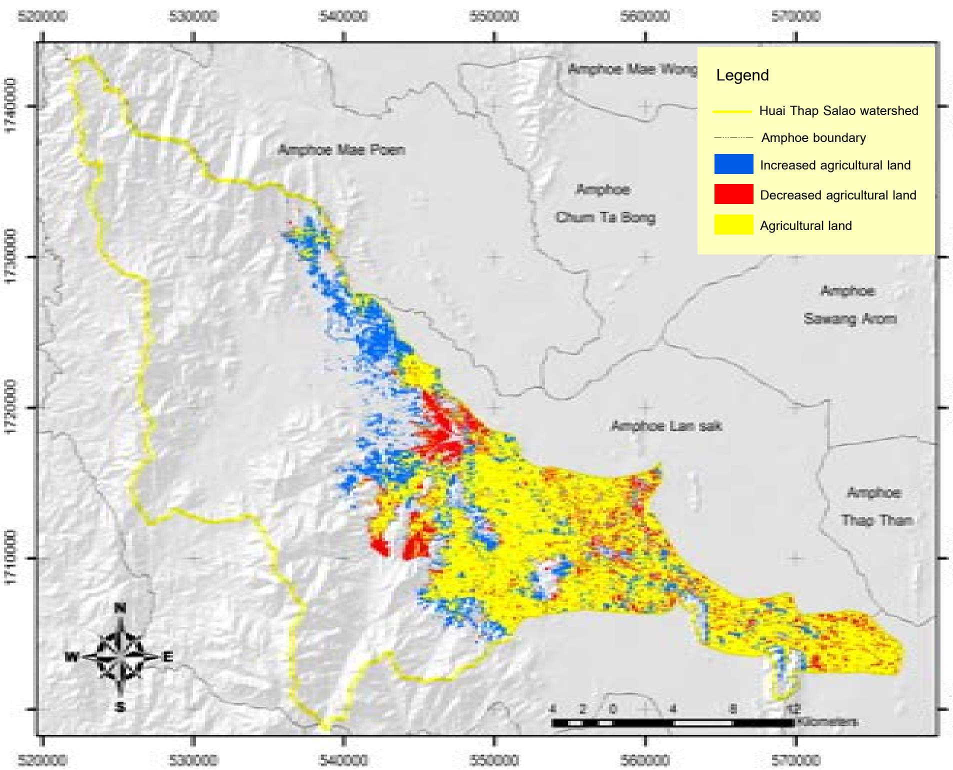
Figure 4-28 Histogram distribution of agricultural land change on mean annual precipitation.

4.4.5 Relationship between factors of distance from villages and agricultural land

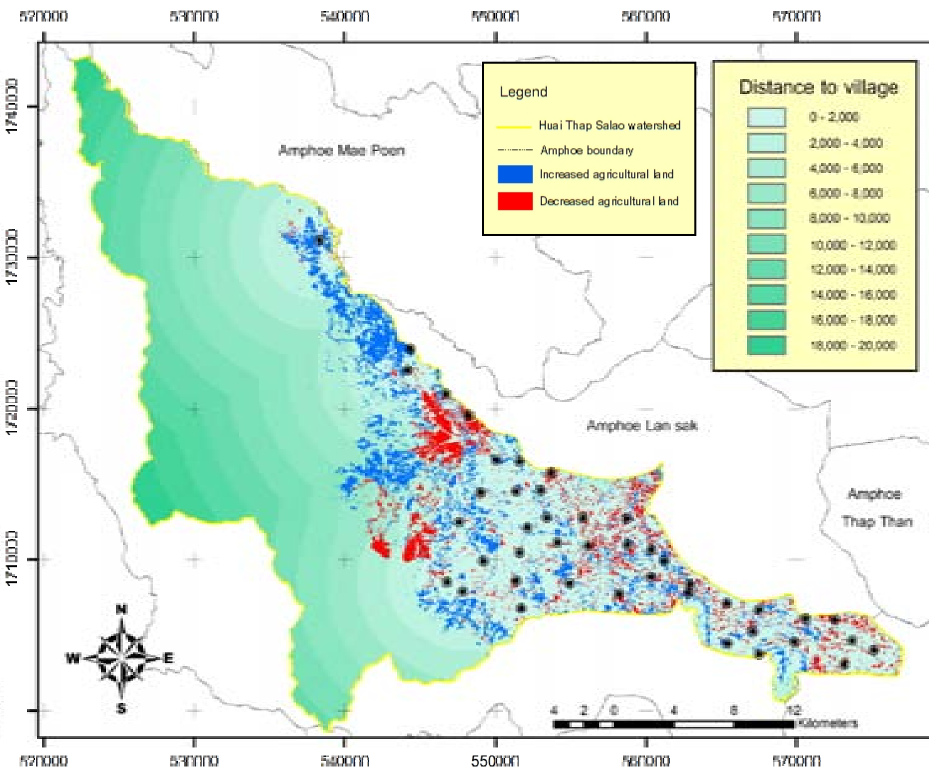
In relationship between factors of distance from villages and agricultural land, the frequencies were determined by calculating the agricultural land areas for each 2,000 meters range of buffering distance from villages (Table 4-23 and Figures 4-29, 4-30).

Agricultural land was decreased in the range of 0 to 2,000 meters; the ratio was 0.681 or 23.911 km^2 of the agricultural land change decreased, indicating a high probability to change. It was noted that low probabilities were observed in the area which from the buffering distance from villages were in the range of between 2,000 to 4,000 m., 4,000 to 6,000m., and 6,000 to 8,000m., that the ratio was 0.248, 0.066, and 0.005, respectively.

Agricultural land was increased in the range of 0 to 2,000 meters; the ratio was 0.577 or 33.133 km^2 of the agricultural land change increased, indicating a high probability to change. Followed by interval 2,000 to 4,000 meters; the ratio was 0.235 or 13.478 km^2, indicating a moderate probability to change. It was noted that low probabilities were observed in the area which from the buffering distance from villages were in the range of between 4,000 to 6,000m., 6,000 to 8,000m., and 8.000 to 10,000m., which the ratio was 0.134, 0.049 and 0.004, respectively.



a)



b)

c)

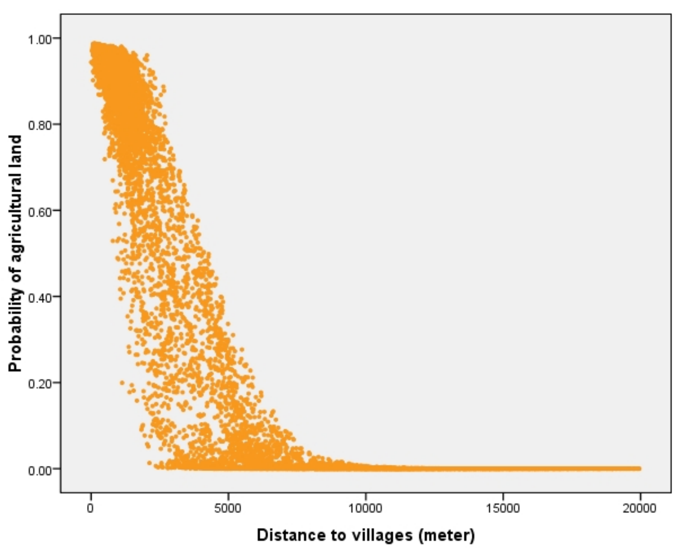


Figure 4-29 Relationship between land use (a) and the distance to villages factor (b) that had negative effects to the agricultural land category (c).

Table 4-23 Relationship between factors of distance to villages and agricultural land change in Huai Thap Salao watershed.

Distance to villages (Meter)	Agricultural land change decrease		Agricultural land change increase	
	Area (km^2)	Ratio	Area (km^2)	Ratio
0-2,000	23.911	0.681	33.113	0.577
2,000-4,000	8.691	0.248	13.478	0.235
4,000-6,000	2.325	0.066	7.695	0.134
6,000-8,000	0.170	0.005	2.819	0.049
8,000-10,000	0.000	0.000	0.227	0.004
10,000-12,000	0.000	0.000	0.008	0.000
12,000-14,000	0.000	0.000	0.000	0.000
14,000-16,000	0.000	0.000	0.000	0.000
16,000-18,000	0.000	0.000	0.000	0.000
18,000-20,000	0.000	0.000	0.000	0.000
Total	35.097	1.000	57.340	1.000

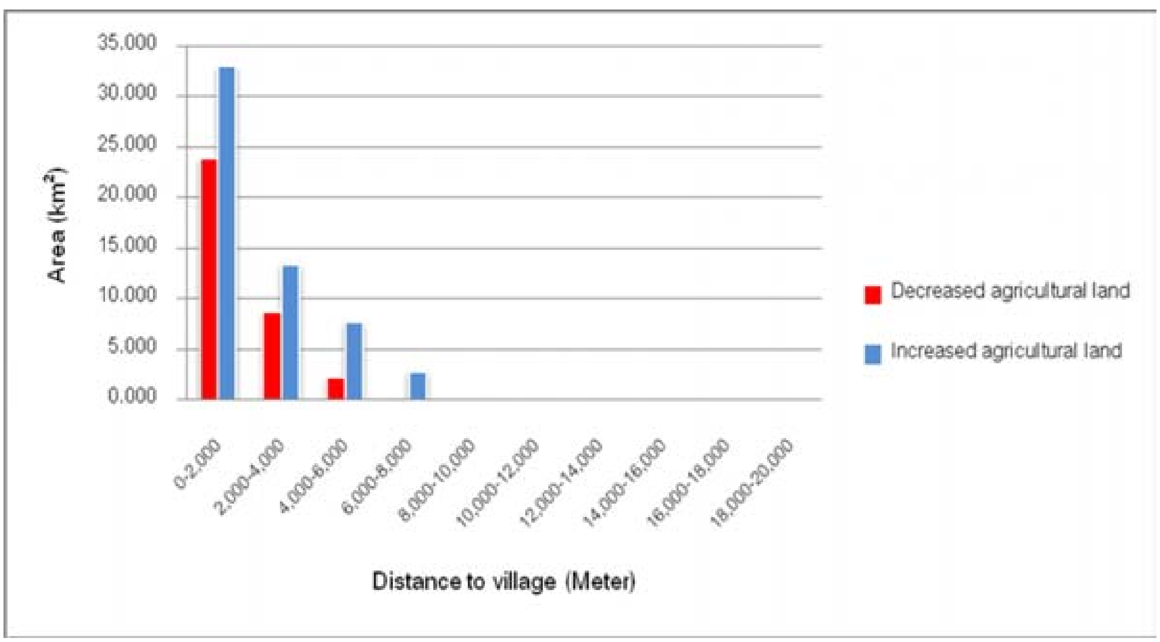


Figure 4-30 Histogram distribution of agricultural land change on buffering distance from villages.

The results of this research revealed that usability of statistical analysis by using logistic regression to examine the relationship between affecting factors and land use changes in study area. The results gave evidence about the influence of each affecting factors on each land use category, the magnitude of its effect and the most influencing affecting factors for each land use category. Regardless the limitation in data, the method use and the results were satisfactory because they capable to reveal the relationships that were not known before and provided new insight about land use behavior in the area, such as the growth of agricultural land in the adjacent of roads and at a specific distance from near roads and villages. Moreover, the combination between logistic regression and CLUE-s framework becomes the solution for the limitation of logistic regression model where it could only be used to predict the location of land use changes probability but it could not be used to predict when the change would occur. Based on these reasons, logistic regression model in this research was combined with CLUE-s framework to predict future land use changes in the study area.

4.5 Simulating and extrapolating land use changes by the CLUE-s model for predicting of the future scenarios

The CLUE-s model could be divided into two modules, a non-spatial demand module and a spatially explicit allocation module (Figure 4-31). In the non-spatial demand module the changes in land use were estimated for a series of years at the aggregate level.

The spatial allocation module had to translate the changes in demand into changes in land use patterns. For every year of simulation a land use prediction map was created. The allocation module needs decision rules and the results of the statistical analysis as input, indicating the potential locations for conversion.

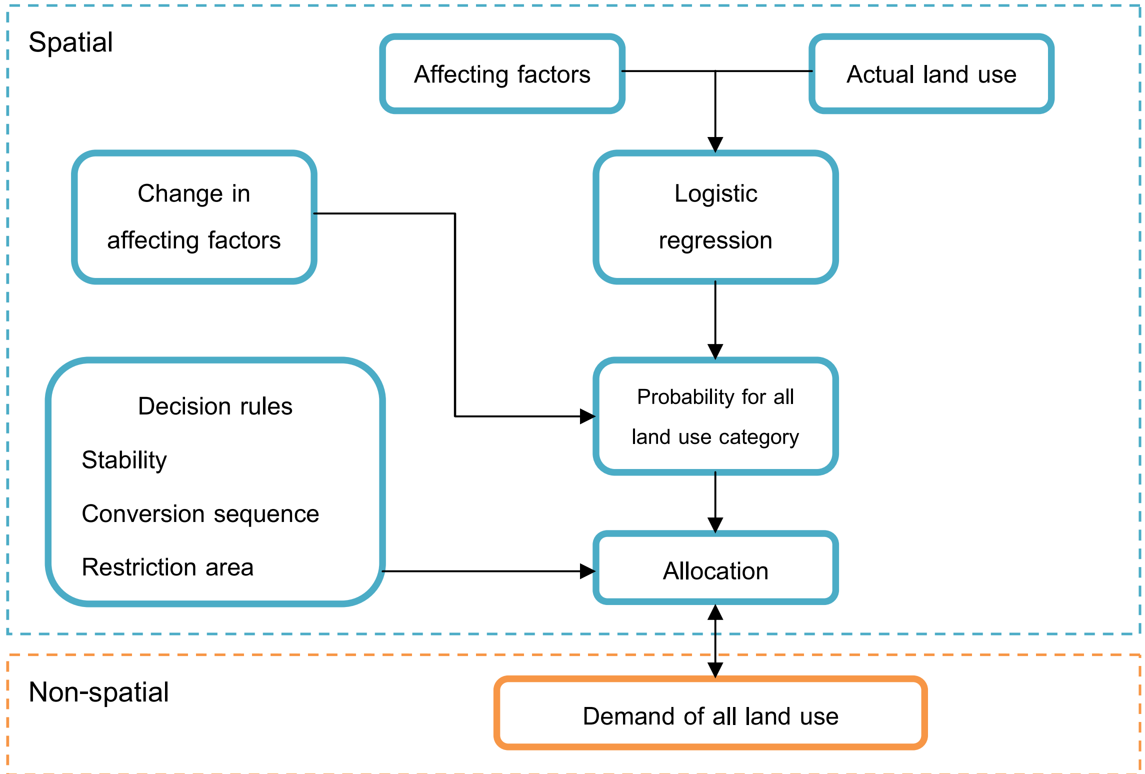


Figure 4-31 The CLUE-s model structure.

(Adapted from Verburg et al., 2002)

The demand module was a totally separate module from the model. The results of the demand module were used as input for the spatial module of the CLUE-S model.

The demand could be determined with the Marchov Chain analysis method, was use to analyze the probability of each land use patterns The probability of moving from one state j to another state k was called a transition probability, P_{jk} and it was given for every ordered set of states. These probabilities could be represented in the transition matrix P.

$$V_j \times P_{jk} = \left[V_1, V_2, V_3, \ldots, V_n\right] \begin{bmatrix} P_{11} & P_{12} & P_{13} & \ldots P_{1m} \\ P_{21} & P_{22} & P_{23} & \ldots P_{2m} \\ P_{31} & P_{32} & P_{33} & \ldots P_{3m} \\ \vdots & \vdots & \vdots & \vdots \\ P_{n1} & P_{n2} & P_{n3} & \ldots P_{nm} \end{bmatrix} \quad \text{(Equation 4-3)}$$

Where

$V_j \times P_{jk}$	= Proportion of land use of second year
P_{jk}	= f (Land use activities)
	= Matrix of probability of land use changes
V_j	= Proportion of land use of first year
j	= Type of land use in first year
k	= Type of land use in second year

In this study the demand was a simple trend scenario, the trend between during 1988-2007 was extrapolated to 2027

The scenarios for future land utilization were based on two considerations:

- Scenario without restriction

In this scenario, the demand was a simple trend scenario; the trend during 1988-2007 was extrapolated to the in 2027 without area restrictions.

- Scenario with reserved area

The second decision rule enables the user to protect a certain area from change. This area restriction was used for example to prevent the model from converting protected forest reserves into another land use category.

Scenario-based land use modeling was used in this research to understand the phenomena of deforestation dynamic, especially related to land use changes in this watershed. In order to understand the dynamic of land use in recent and future time, the model would be used as a tool to link between present and future of land use condition and the scenarios would be built to design different alternative conditions of land use. The important thing that becomes the main purpose of this research was how to select the relevant variables that could be used to represent the future land use and how to simulate the scenarios of land use in Huai Thap Salao watershed by involving those relevant variables. In order to design the plausible scenarios of deforestation area in the future, the most important things were the understanding of relationship between land use and the affecting factors and the understanding of pressures that caused by those affecting factors.

In this research, two scenarios of land use changes were simulated. These scenarios had been explained in the Chapter 2.7, including scenario without restriction and scenario with reserved area. These scenarios were demonstrated to verify the usability of scenario based modeling to support land use analysis in Huai Thap Salao watershed. Each scenario and the results would be explained in the following section.

4.5.1 Scenario without restriction area (baseline scenario)

In this scenario, it was assumed that land use changes in future were the continuity of land use changes in the past time. Land use changes in the past time had been calculated in the land use changes section. The scenario without restriction area (baseline scenario) does not consider land use plan or regulation. In this model, the initial land use was land use map in 2007 created from image interpretation. The demand of land use in the future (until the in 2027) was the continuity of the demand of land use changes during 1988-2007 (Marchov Chain). Spatial allocation maps of Huai Thap Salao watershed could be seen in the following Figure 4-32 and 4-33.

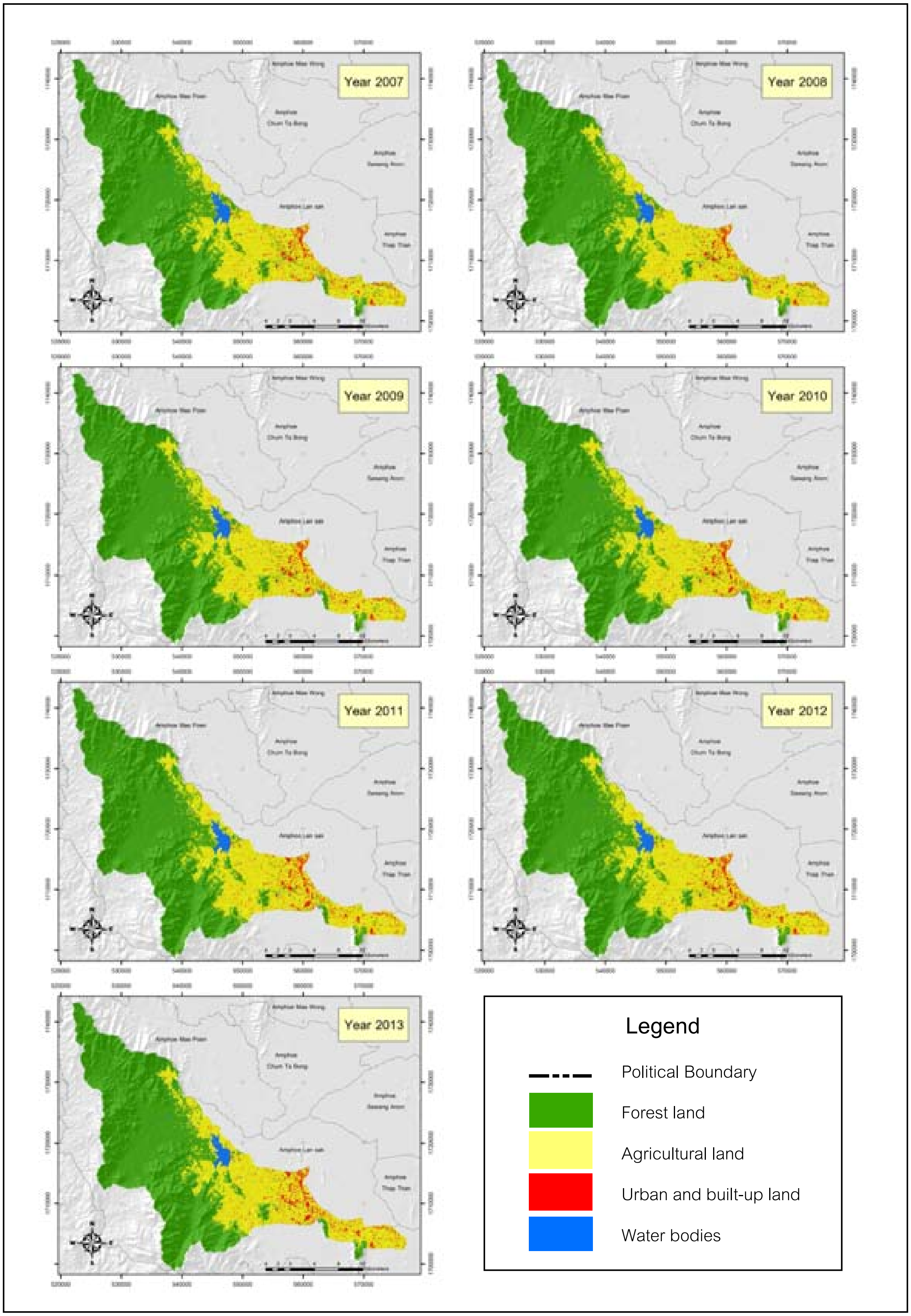


Figure 4-32 Spatial allocation maps during 2007-2027 with scenario without restriction area (baseline scenario) by CLUE-s model in Huai Thap Salao watershed.

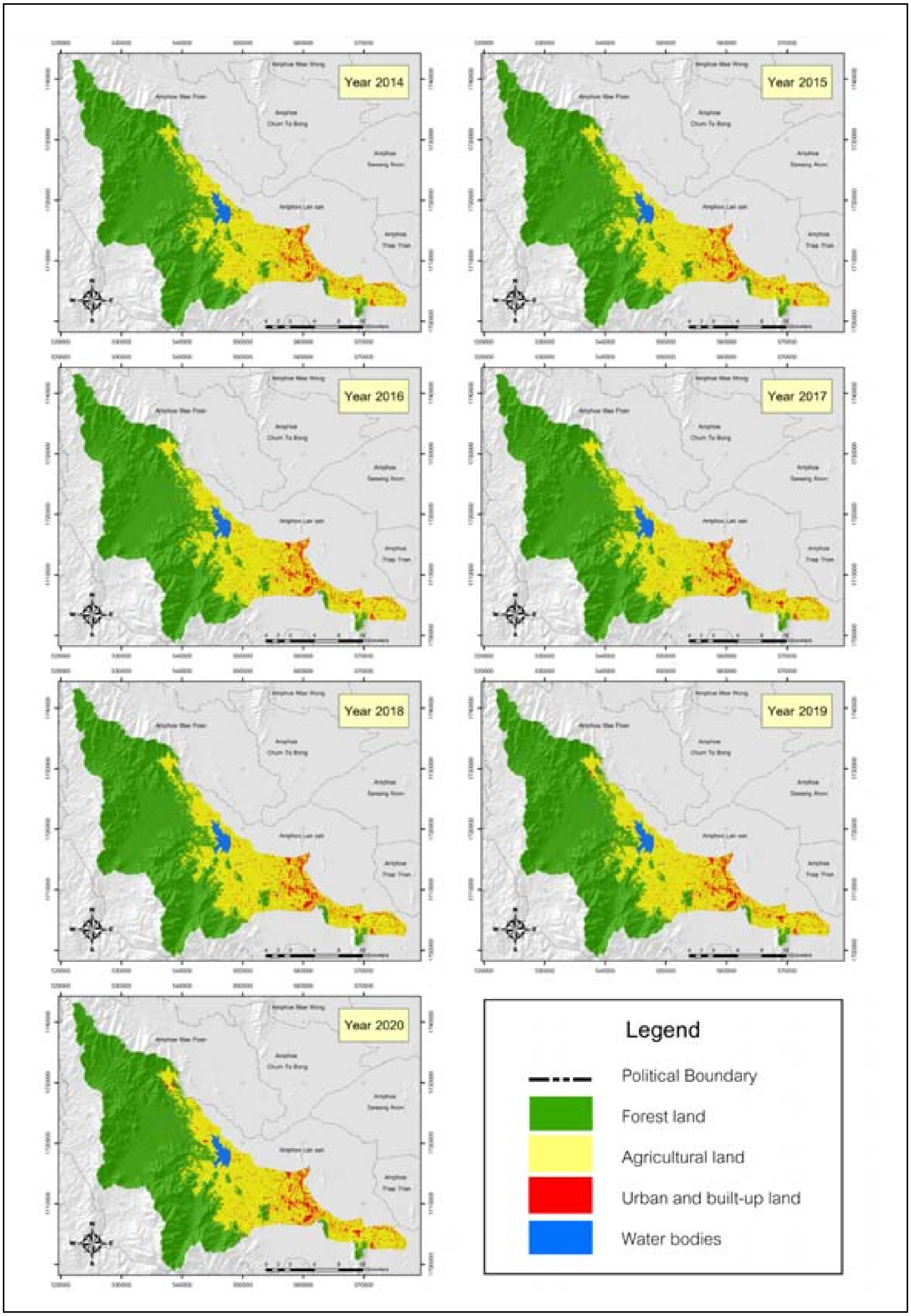


Figure 4-32 Spatial allocation maps during 2007-2027 with scenario without restriction area (baseline scenario) by CLUE-s model in Huai Thap Salao watershed (continued).

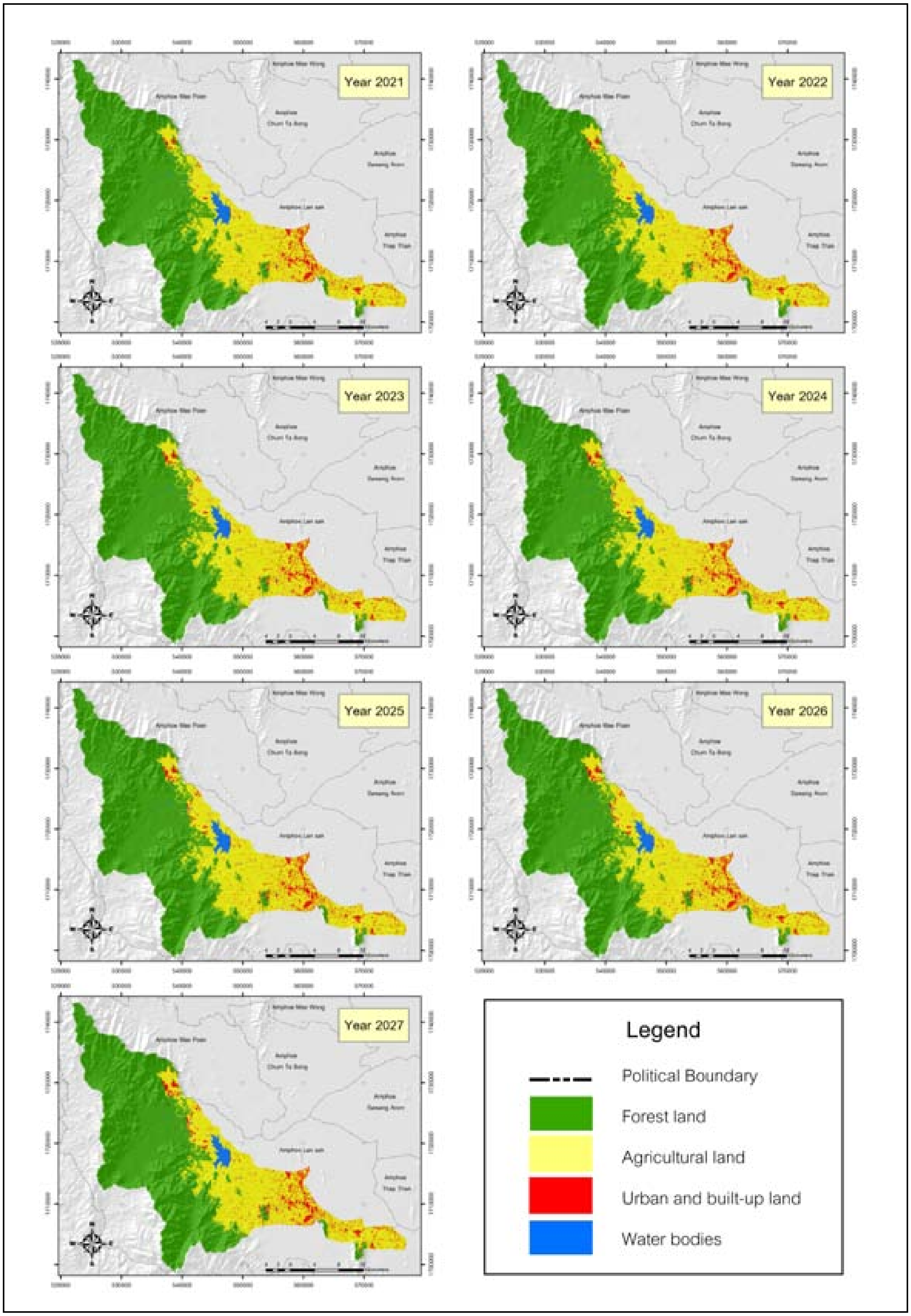


Figure 4-32 Spatial allocation maps during 2007-2027 with scenario without restriction area (baseline scenario) by CLUE-s model in Huai Thap Salao watershed (continued).

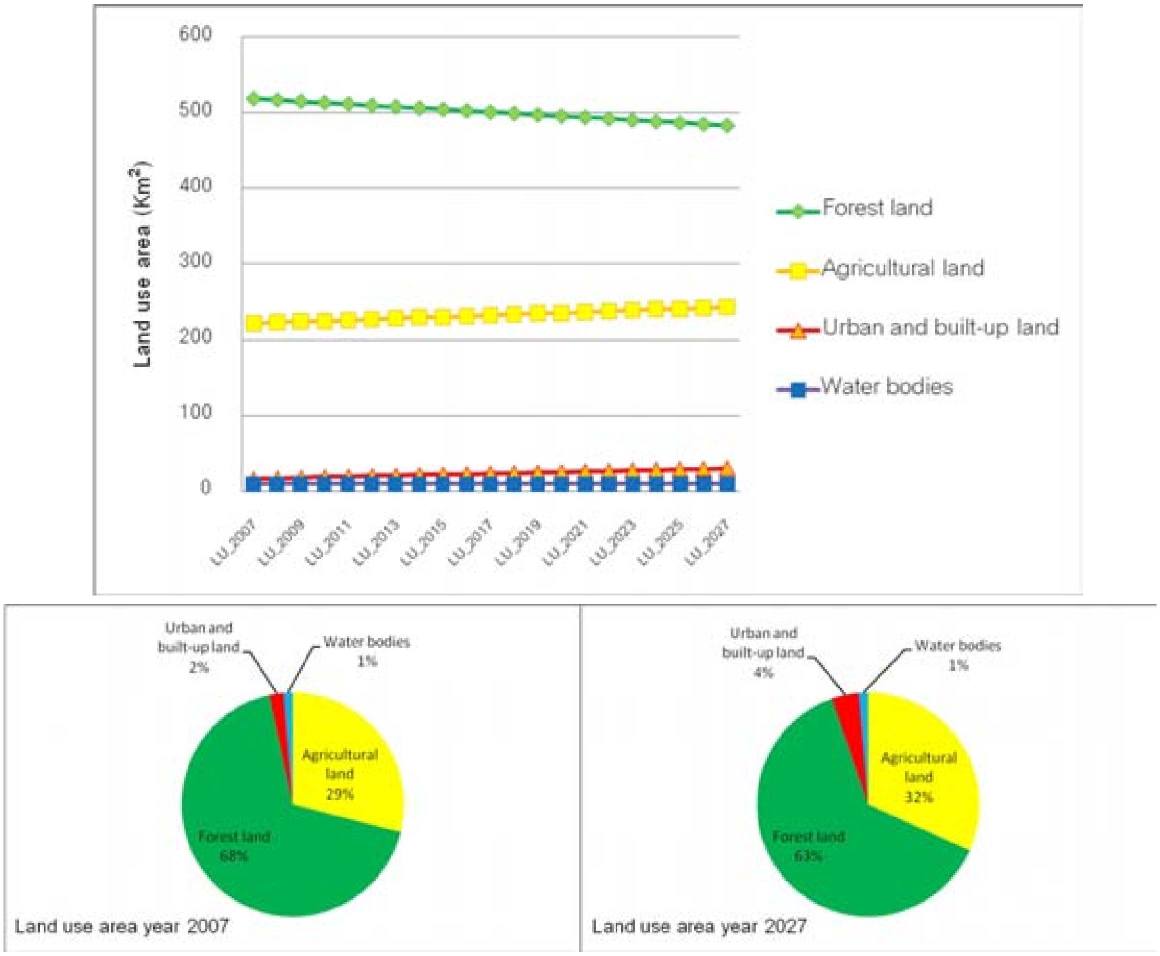


Figure 4-33 Graph shows trend to land use changes in Huai Thap Salao watershed during 2007-2027 (km^2).

The results of the scenario without restriction area (baseline scenario) showed that the highest rate of deforestation year 2027 would be 63% (previously 68%) of total study area, which decreased forest land 24% per year. In addition, agricultural land would be 32% (previously 29%) of total study area, which increased forest land 0.14% per year. Urban and built-up land would be 4% (previously 2%) of total study area, which decreased forest land 10% per year. And water bodies would be unchanged.

The results of the CLUE-s model revealed that the trend scenario without spatial policies and restrictions showed that the highest rate of deforestation and a low percentage of forest cover were found in central Huai Thap Salao watershed. The dominant topography in central of watershed was flat to gently sloping terrain with alluvial deposits, which were highly suitable for agriculture and development to settlement. Forest land had been converted to agriculture and urban and built-up land in eastern of Huai Kha Khaeng wildlife sanctuary during 2007-2027.

4.5.2 Scenario with reserved area (conservation-oriented scenario)

These indicated areas where land use changes were restricted through strict protection measures, such as protected areas as shown in Figure 4-34. In the trend scenario, no spatial policies were implemented, thus forest encroachment could occur in protected areas if the location characteristics were favorable. In contrast, land-use policies were imposed for the integrated management and conservation-oriented scenarios. Under the latter scenarios, Huai Kha Khaeng wildlife sanctuary, which cover approximately 404.70 km^2, or 52.77% of the study area, were designated restricted areas; so that no further encroachment was allowed in these areas and natural succession was possible.

The scenario of the simulation result with reserved area in Huai Thap Salao watershed was presented maps as shown in Figure 4-35 that showed the spatial land use patterns as simulated during 2007 to 2027. The results of the conservation-oriented scenario showed that the extent and distribution patterns of the remaining forest in 2027 were relatively similar to the conditions in 2007. Similar to baseline scenarios, high deforestation was found Ban Khao Khiao, Ban Bueng Charoen, Ban Wang Thong, Ban Huai Plao, Ban Ang Huai Dong, Ban Pong Makha and Ban Khao Mai Nuan, Tambon Rabam, Amphoe Lan Sak, Changwat Uthaithani. In addition, agricultural land in the villages mentioned had been limited area on the east side of Huai Kha Khaeng wildlife sanctuary where was prevented converting into another land use category.

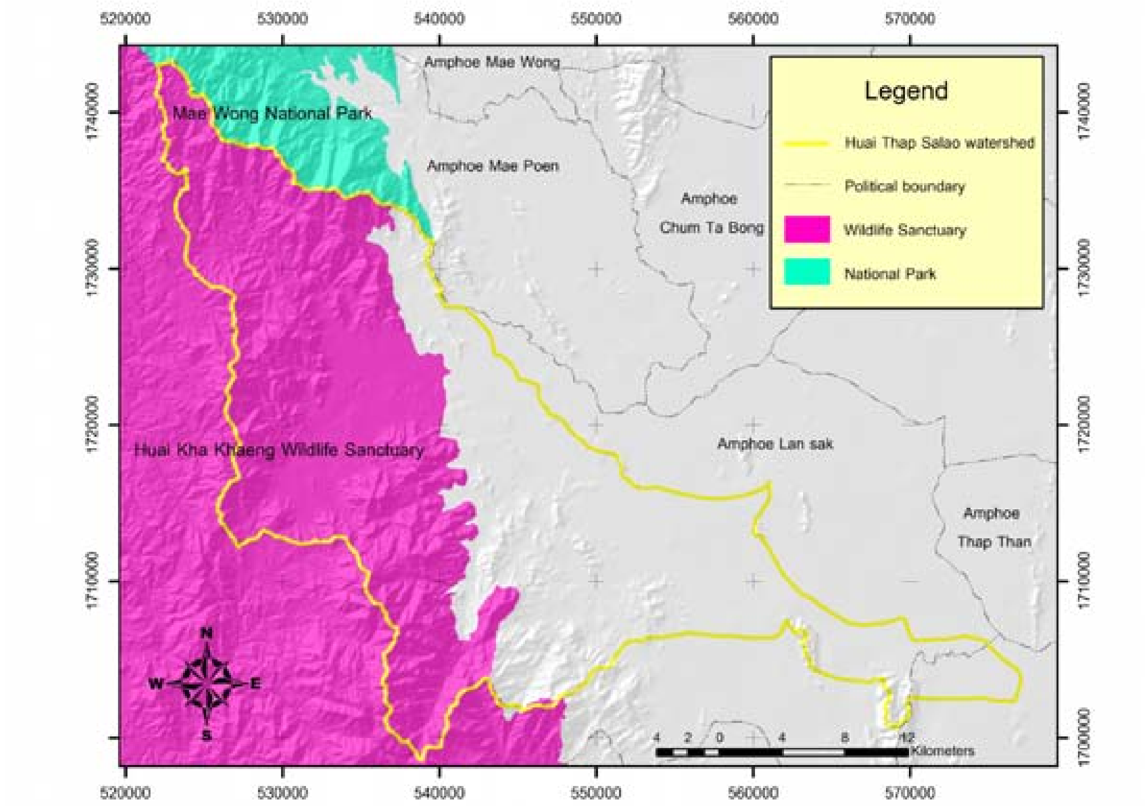


Figure 4-34 Reserved area map is prevented converting into another land use category.

Most increase in urban and built-up land would found in Amphoe Lan Sak, which were expand to the near the villages and roads. Such the availability of adequate infrastructure and facilities influences the development of urban built-up area in this location. In the location, agricultural and mix vegetation were intensively converted to urban land use. This expansion patterns was appropriate to the result of logistic regression where the nearest from roads and villages had significant contribution to urban built-up area change. Forest land hasn’t been converted to urban and built-up land in eastern of Huai Kha Khaeng wildlife sanctuary during 2007-2027.

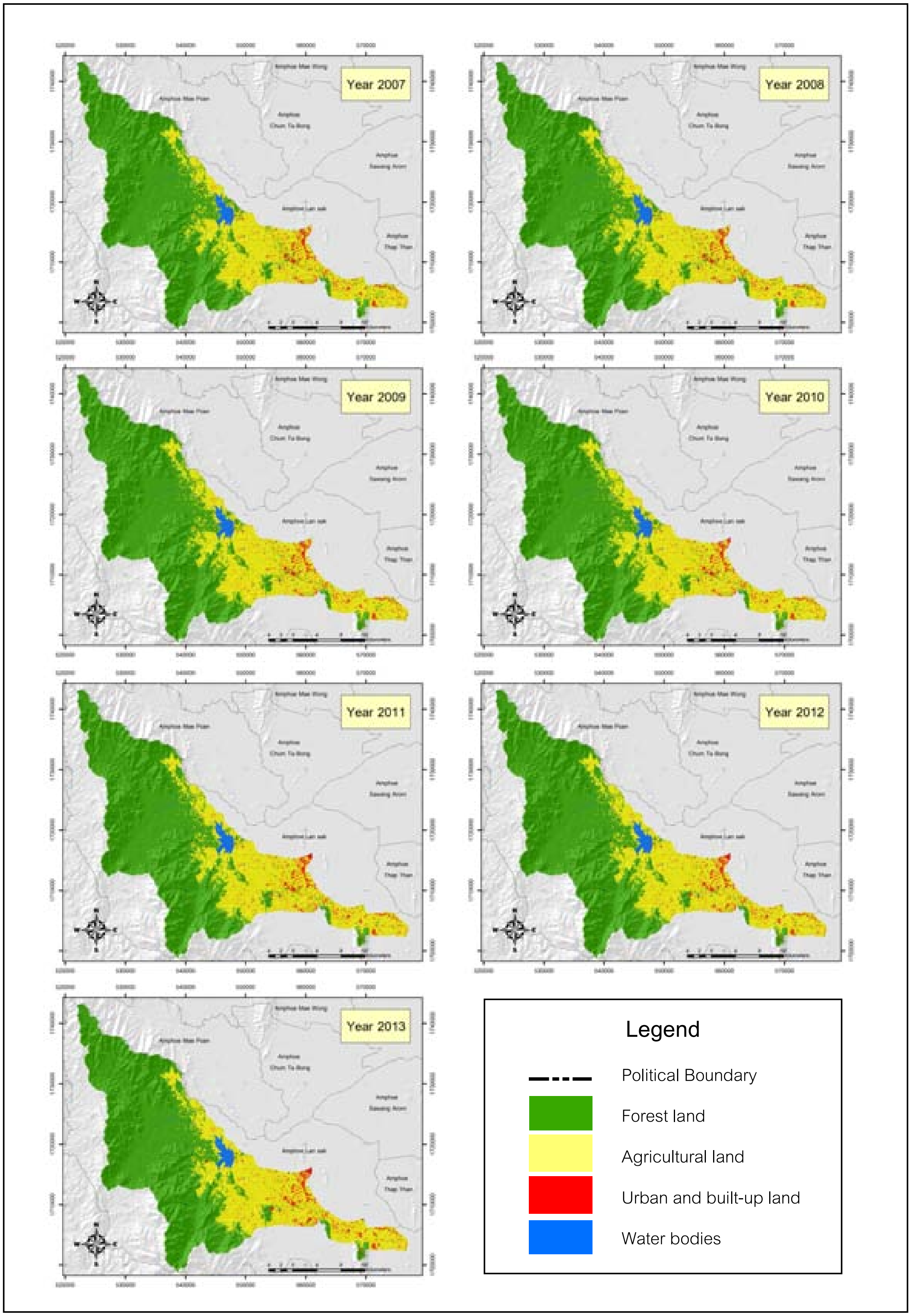


Figure 4-35 Spatial allocation maps during 2007-2027 with scenario reserved area (conservation-oriented scenario) by CLUE-s model in Huai Thap Salao watershed.

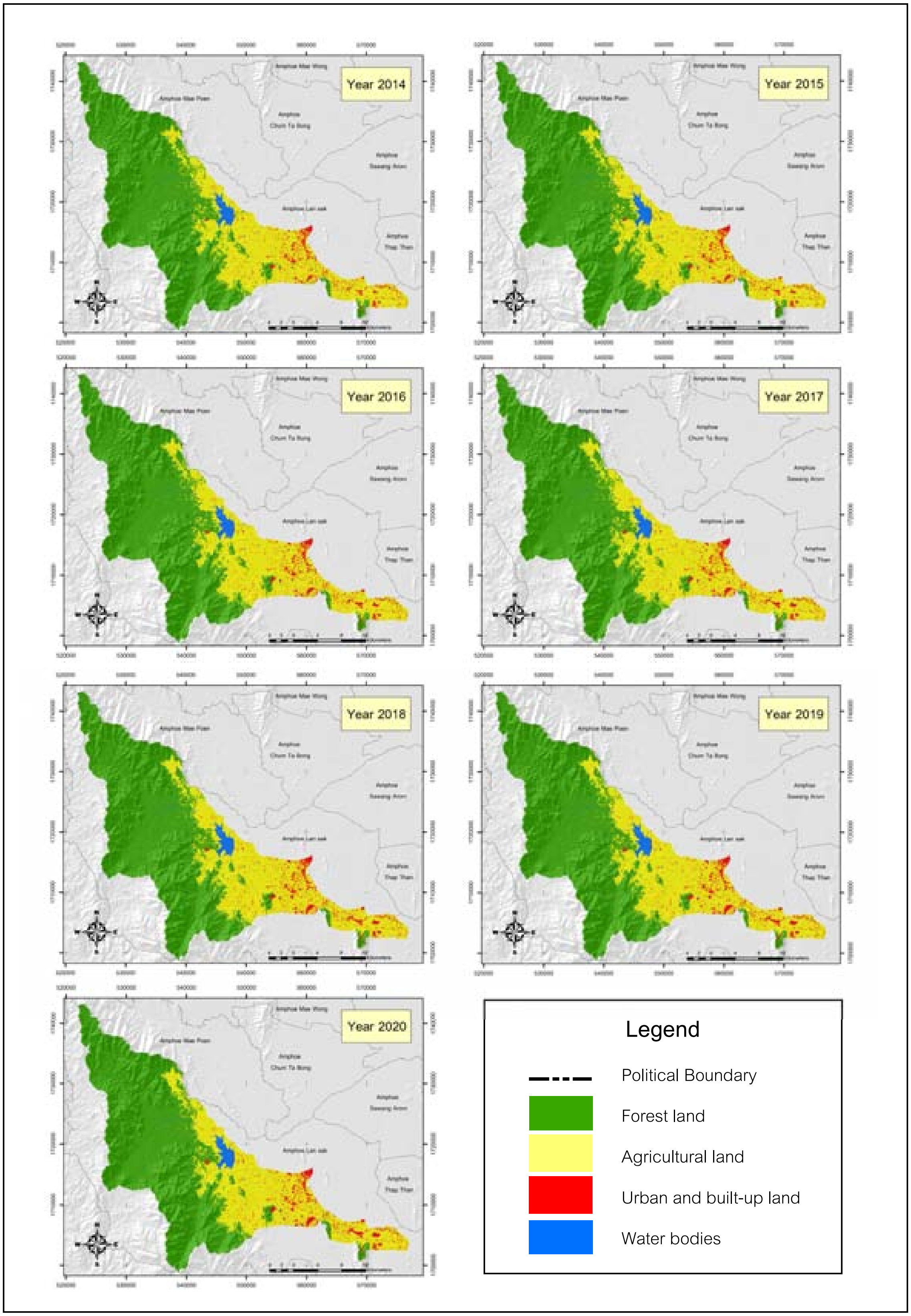


Figure 4-35 Spatial allocation maps during 2007-2027 with scenario reserved area (conservation-oriented scenario) by CLUE-s model in Huai Thap Salao watershed (continued).

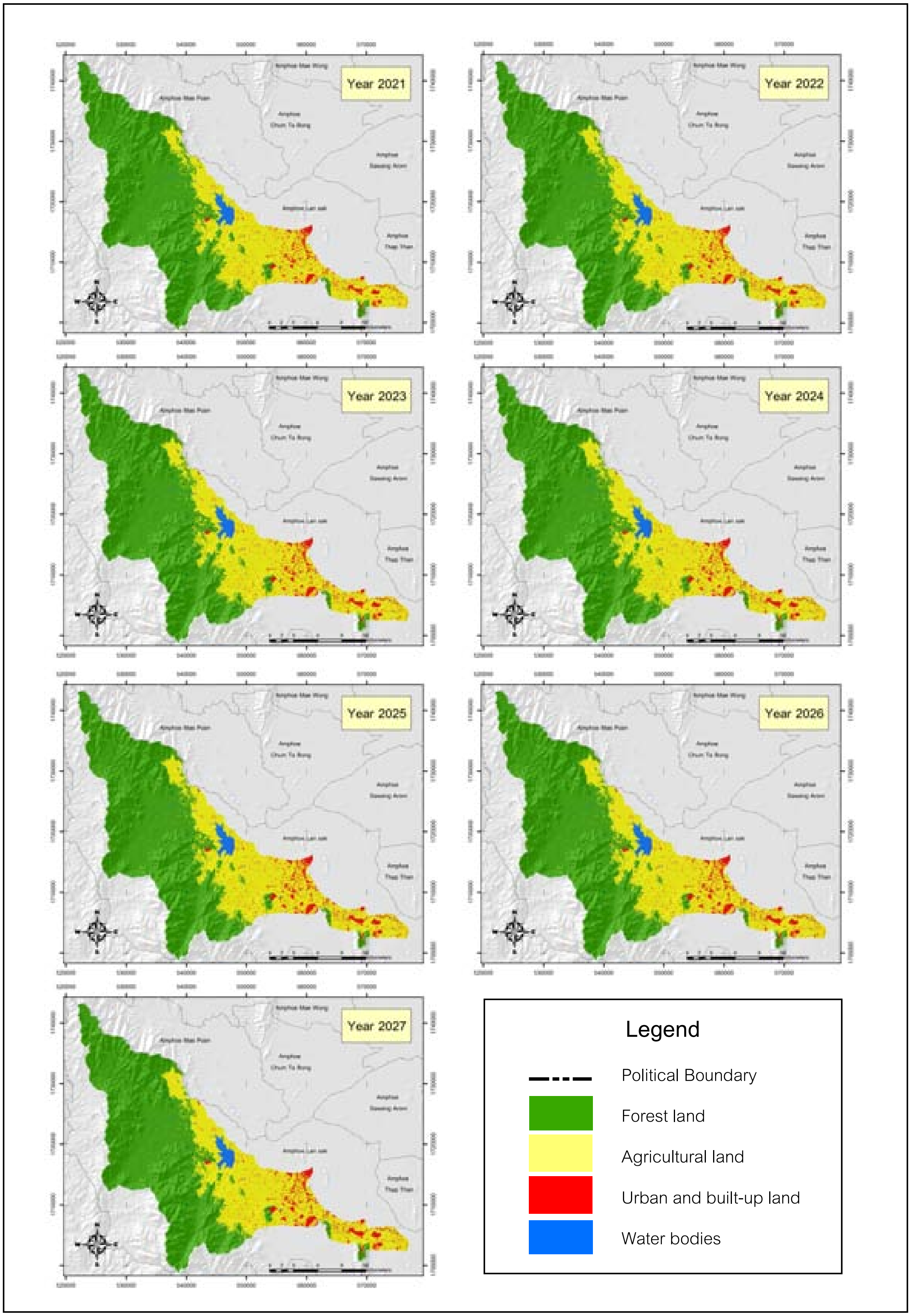


Figure 4-35 Spatial allocation maps during 2007-2027 with scenario reserved area (conservation-oriented scenario) by CLUE-s model in Huai Thap Salao watershed (continued).

The results of these scenarios indicated that the combination of statistical analysis and CLUE-s model was valuable in representing land use behavior on Huai Thap Salao watershed and it had capacity to explain the causal factors in a complete process model. All of the significant variables derived from logistic regression could be accommodated in this model and used as a preference of scenario development. The only use of significant variables in the model with known cause-effect relationship between affecting factors and land use changes was one of advantages of CLUE-s model. By involving significant factors, the model could avoid spurious relationship and subjective human intervention. Moreover, in this research, the cause-effect relationship was proved by logistic regression results to improve the understanding of underlying factors.

CHAPTER V

DISCUSSION AND CONCLUSION

5.1 Discussion

In this part, the results of the study methods as previously mentioned were discussed in three categories. Firstly, dynamic spatial patterns of land use changes relating deforestation processes results were proposed and discussed. Secondly, affecting factors were caused land use changes in Huai Thap Salao watershed. Thirdly, the predicting future land use conditions to forecast possible land use patterns based on their affecting factors during 1988 to 2007 were discussed. Finally, conclusion and recommendation in this research were summarized and proposed.

5.1.1 Dynamic spatial patterns of land use changes relating deforestation processes in Huai Thap Salao watershed, Changwat Uthaithani during 1988-2007

The majority of western area in the Huai Thap Salao watershed was a source of abundant forest resources in Huai Kha Khaeng Wildlife Sanctuary covering an area of about 404 km^2 or 53 % of the study area. Even though there were control measures and protections to reserve forest by forest officers, but it was still very sensitive to be effected from the invasion of the upstream forest by human activities. Since the wildlife sanctuary areas were surrounded by communities and they were strongly changed in land use and deforestation during 1988 to 2007 by the invasion of land for agriculture and settlement.

In this research, the combination bands (R=5, G=4, B=3) of Landsat 5TM satellite imageries in the year 1988, 1997 and 2007 with supervised classification process were used for land use classification. The results revealed that land use categories in Huai Thap Salao watershed were classified as 8 land use categories, namely, paddy field, field crops, perennial crops, evergreen forest, deciduous forest, forest plantation, urban and built-up land, and water bodies. The total overall accuracy assessments of land use classifications in 1988, 1997 and 2007 were 85.99%, 77.98% and 80.99%, respectively.

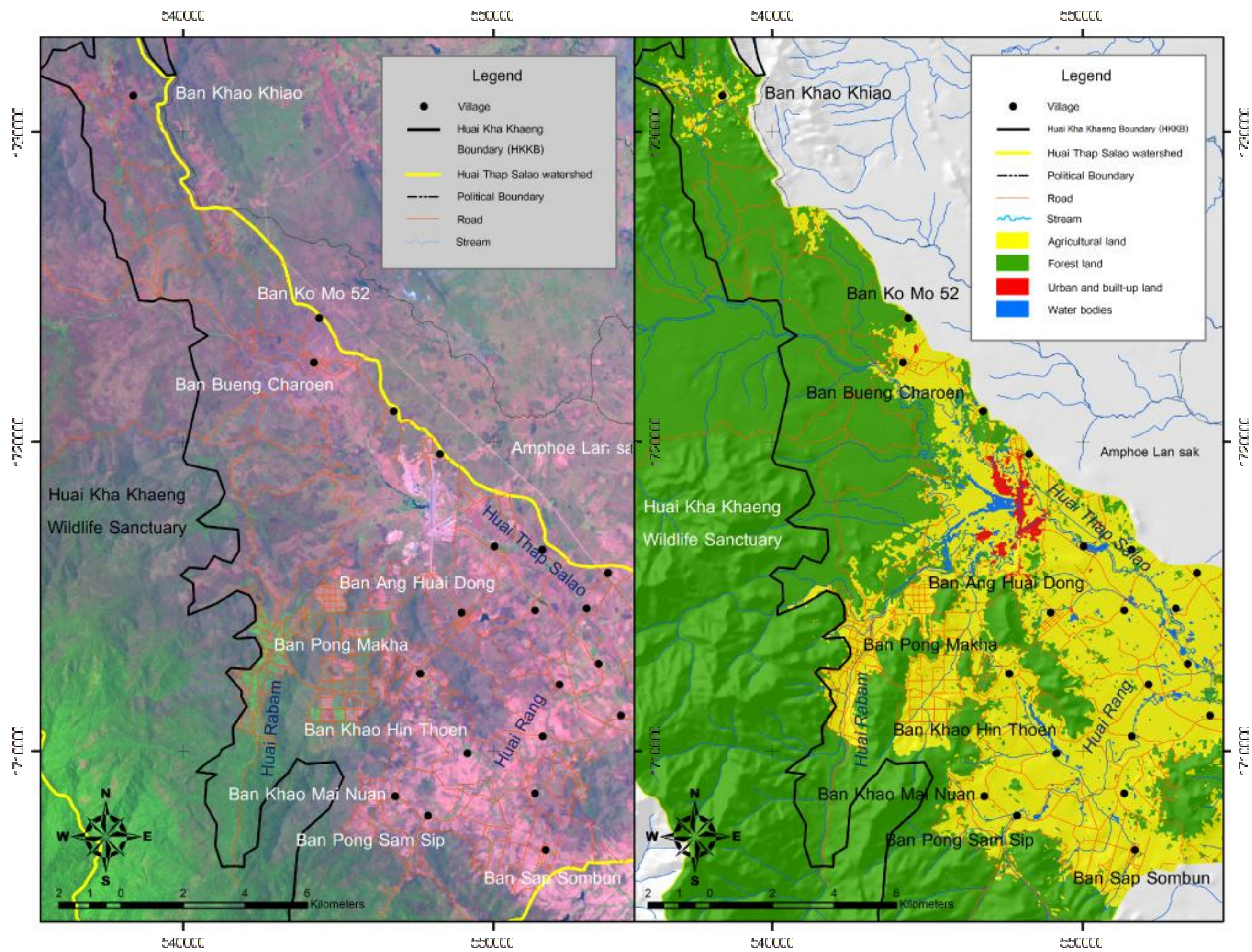


Figure 5-1 In the year 1988, the geometric pattern of deforestation appeared in the most of central areas and the diffuse pattern of deforestation appeared in the northern areas.

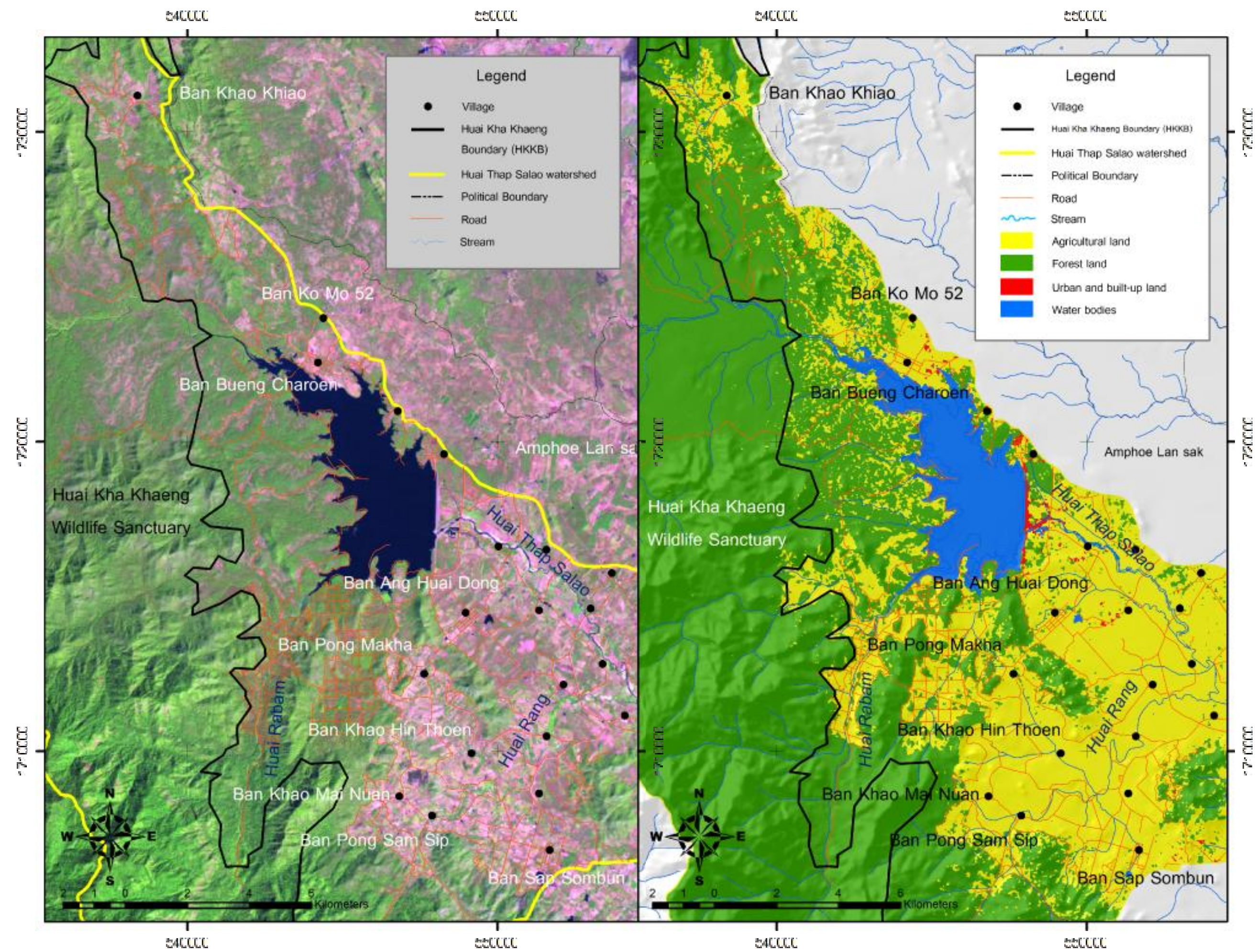


Figure 5-2 In the year 1997, the geometric pattern of deforestation appeared in the most of central areas and the diffuse pattern of deforestation appeared in the northern areas and the western areas of Ban Bueng Charoen.

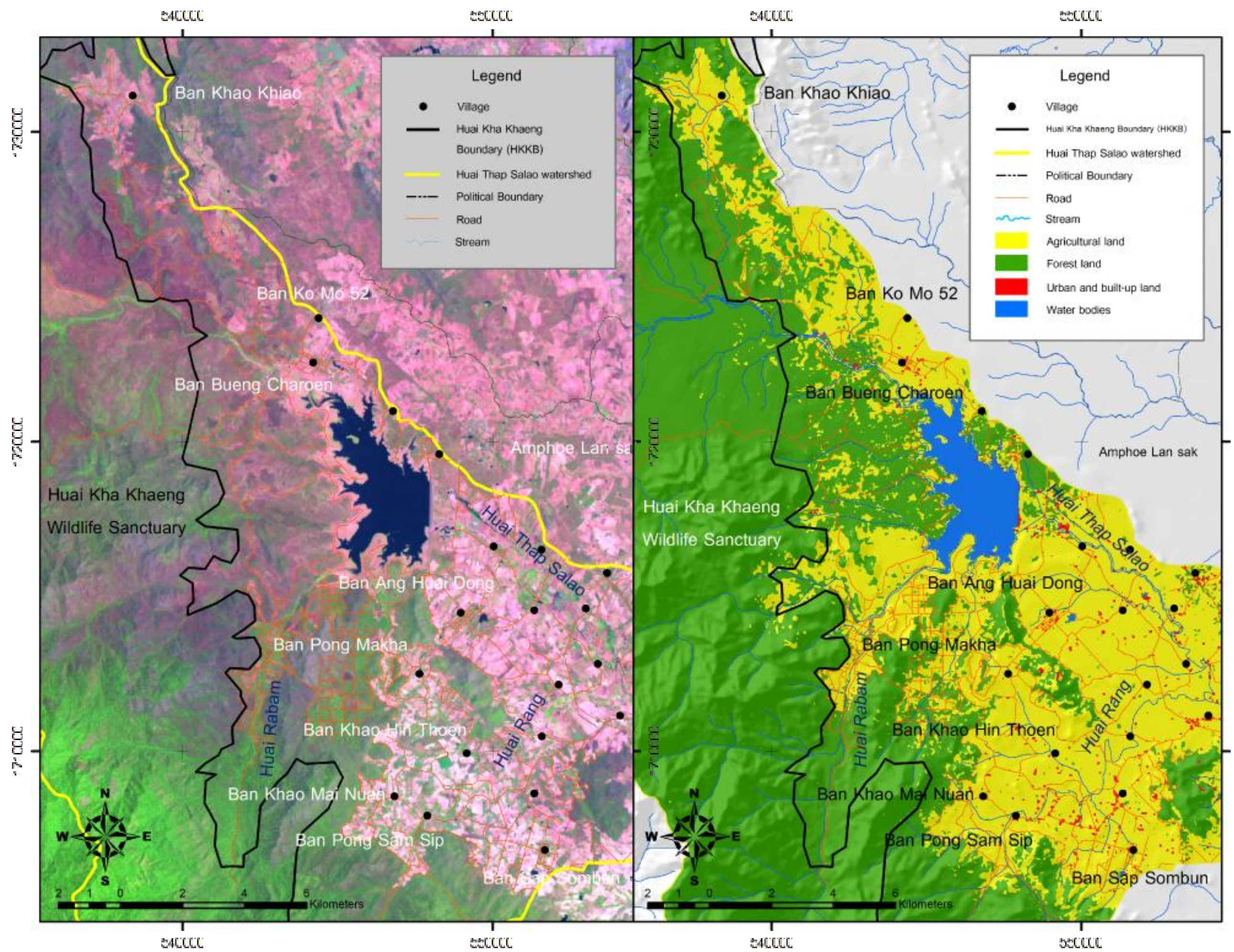


Figure 5-3 In the year 2007, the geometric pattern of deforestation appeared in the most of central areas and the Island pattern of deforestation appeared in the northern areas and the western areas of Ban Bueng Charoen.

Change detections of land use in Huai Thap Salao watershed during 1988 to 2007 were analyzed using overlay technique in ArcMap GIS version 9.2. The results revealed that the total change areas were 82.10 km^2 (10.71% of total change areas). The most proportion of change areas was forest land that was decreased 41.05 km^2 or 50.00% of total change areas), whereas agricultural land, urban and built-up land, and water bodies were increasing from 1988 to 2007.

The result revealed that during 1988 to 2007, the geometric pattern of deforestation was appeared in the most of central areas (as shown in Figures 5-1, 5-2, and Figure 5-3). The geometric pattern of deforestation appeared to be a unique, individual case of large-scale clearing. It impacted the large expansion of settlements and agriculture areas causing the invasion of the upstream forests since 1961. But the current still affected from the invasion of the upstream forest by human activities in Ban Ang Huai Dong, Ban Pong Makha, Ban Pong Sam Sip, and Ban Sap Sombun.

Beside, in the northern areas appeared the diffuse pattern of deforestation during 1988 to 1997 (as shown in Figures 5-1 and 5-2). The diffuse pattern of deforestation was commonly associated with traditional and smallholder subsistence agriculture. This pattern was also related to cases of traditional shifting cultivation and permanent cultivation by smallholders in Ban Khao Kiao and the western areas of Ban Bueng Charoen. During 1997 to 2007, Ban Khao Kiao and the western areas of Ban Bueng Charoen appeared to change the spatial patterns as the diffuse pattern that was changed to the island pattern of deforestation was commonly associated with settlement areas as shown in Figure 5-3. It was commonly associated with settlement areas, had been related here to cases of deforestation occurring around settlements in Ban Khao Khiao and Ban Bueng Charoen, Tambon Rabam, Amphoe Lan Sak, Changwat Uthaithani.

5.1.2 Affecting factors that caused land use changes in Huai Thap Salao watershed, Changwat Uthaithani

From Chapter 4, the relationship affecting factors, namely, elevation, slope, mean annual precipitation, distance to streams, distance to roads, distance to villages and soil textures were analyzed by logistic regression analysis. The result revealed that the most of forest land was changed to be agricultural land with an area of 53.54 km^2 as shown in Table 5-1.

Table 5-1 The main parameters, with its weight of main affecting factors, were evaluated according to their relations with each land use changes.

Variables	Land use category							
	Forest land		Agricultural land		Urban and built-up land		Water bodies	
	β	Ratio	β	Ratio	β	Ratio	β	Ratio
Elevation	.0110	0.0190	.0079	0.0126	*	0	.1452	0.0391
Degree of Slope	.0805	0.1387	.0466	0.0739	.2717	0.5130	1.0406	0.2802
Mean annual precipitation	.0023	0.0040	.0011	0.0018	.0167	0.0316	.0663	0.0179
Distance to streams	*	0	*	0	.0006	0.0011	.0020	0.0005
Distance to roads	.0010	0.0018	.0015	0.0023	.0011	0.0021	.0069	0.0019
Distance to villages	.0009	0.0016	.0008	0.0012	.0002	0.0004	.0016	0.0004
Soil texture	.4846	0.8350	.5729	0.9081	.2393	0.4518	2.4515	0.6601
Total	.5804	1.0000	.6309	1.0000	.5296	1.0000	3.7141	1.0000

Table 5-1, the weight of main affecting factors, namely elevation, degree of slope, mean annual precipitation, distance to streams, distance to roads, and distance to villages, and soil texture were evaluated according to their relations with each land use changes in Huai Thap Salao watershed.

In addition, figure 5-4 also showed the relative importance of affecting factors to the forest land in the study area. The results revealed that the change of forest land had relationship between the 6 affecting factors and a value of probability factors was explained as follows: The most affecting factor was soil texture factor (Ratio = 0.8350) that a high influence to the forest land changes in the area compared to the other affecting factors followed by degree of slope, elevation, mean annual precipitation, distance to roads, and distance to villages, respectively.

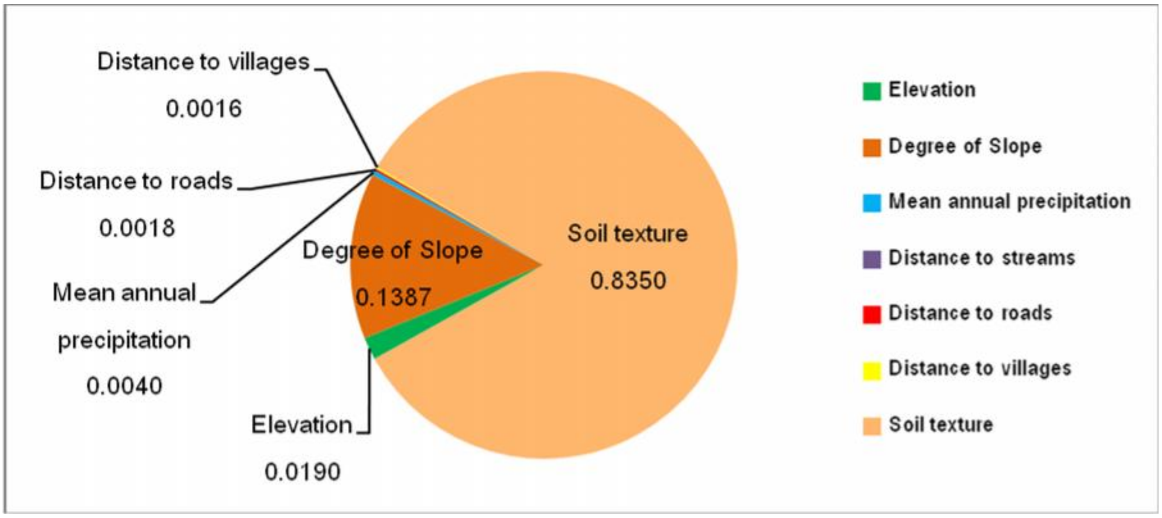


Figure 5-4 The relative importance of affecting factors to the forest land in the study area.

While the relative importance of affecting factors to the agricultural land in the study area. The results revealed that the change of agricultural land had relationship between the 6 affecting factors and a positive value of probability factors was explained as follows: The most affecting factor was soil texture factor (Ratio = 0.9081) that a high influence to the forest land changes in the area compared to the other affecting factors. As followed by degree of slope, elevation, distance to roads, mean annual precipitation, and distance to villages, respectively (as shown Figure 5-5).

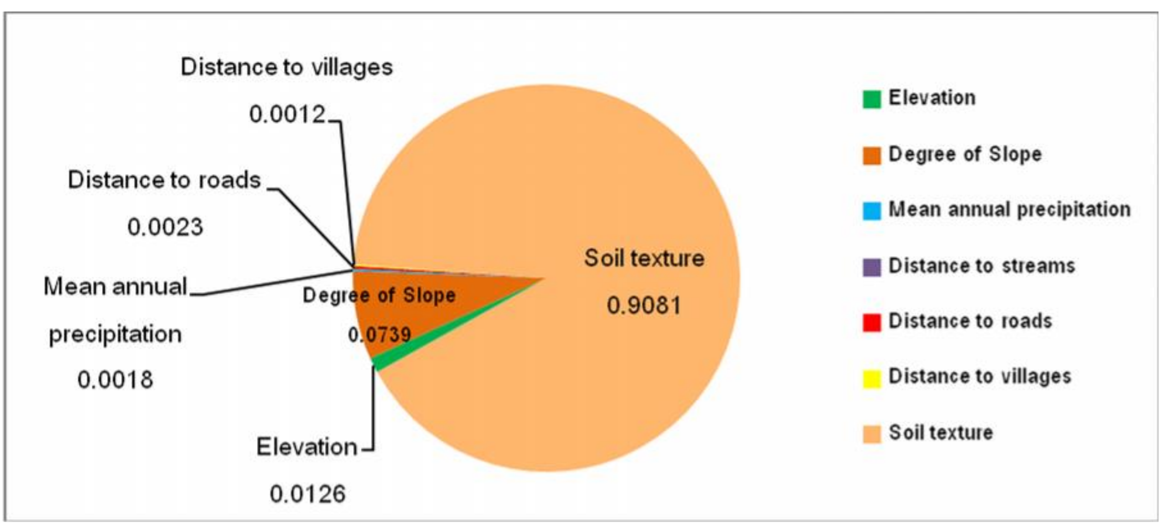


Figure 5-5 The relative importance of affecting factors to the agricultural land in the study area.

The most affecting factors were the land characteristics, namely soil texture, degree of slope, elevation and mean annual precipitation, effected the deforestation in Huai Thap Salao watershed during 1988 to 2007. It could be explained that group unit 62 of soil covers 54.86 percent of total area, located on mainly forest land in western of Huai Thap Salao watershed. This group of soil is fertility soils. On the other hand, Group Unit 37 (Thap Salao series: Tas) of soil covers 16.95 percent of total area, located on central watershed. This group of soils is sandy loam and well-drained, moderately deep coarse-textured that developed from weathered rocks in dry areas. They have low fertility. Agricultural expansion and intensive farming invaded forest areas from the east to the west.

In addition, topography factors, namely degree of slope, elevation and mean annual precipitation, affected the forest land and agricultural land. It could be explained that forest land due to the expanded of high terrain, steep slope, and increased rainfall in the watershed. Several western parts of deciduous forest tended to decrease because changing to be evergreen forest. It could be found on undulating plains and ridges, low levels of rainfall, porous, heavily eroded and leached sandy or lateritic soils of both granitic and sandstone origin. On the other hand, agricultural land tended to expand in the areas of low elevation (about 0-400 meters from msl.) and plain area (about 0-30 degree of slope). The study area was appeared agricultural land such as corn, sugarcane, cassava, para rubber, and eucalyptus in the central part of Huai Thap Salao watershed. The deforestation in Huai Thap Salao watershed appeared in Ban Khao Khiao, Ban Bueng Charoen, Ban Wang Thong, Ban Ang Huai Dong, Ban Pong Makha, Ban Huai Pong Sam Sip and Ban Khao Mai Nuan, Tambon Rabam, Amphoe Lan Sak, Changwat Uthaithani. These villages were in buffer zone as shown in Figure 5-6.

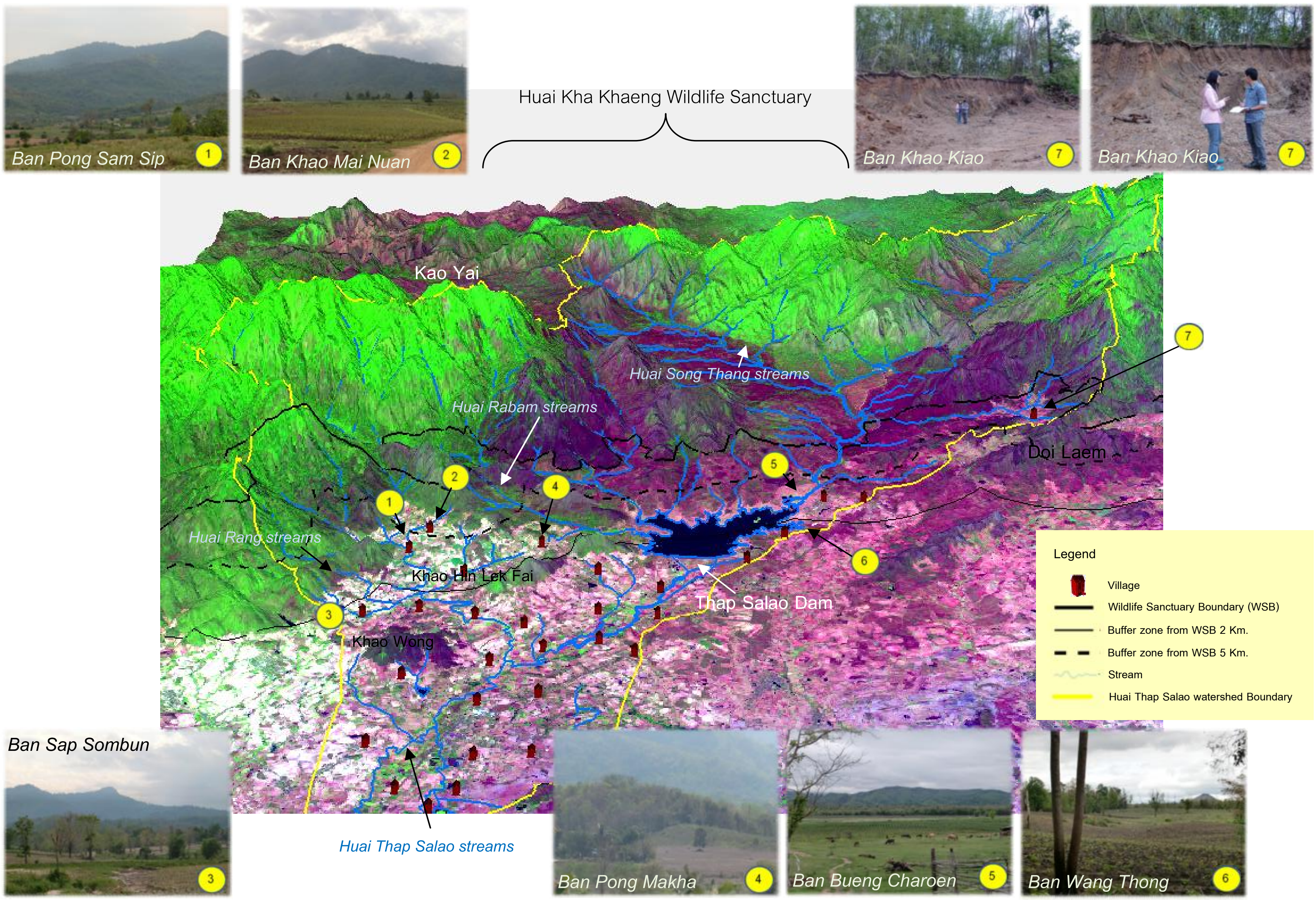


Figure 5-6 Three-dimensional map showing the deforestation found on the and plain low elevation areas in Huai Thap Salao watershed.

Besides, the land use changes had relationship with social-economic factors and accessibility. It could be explained that the nearest the distance to villages (about 0-8 km.) and distance to roads (about 0-3.5 km.) effected transporting crops from the agricultural land to the rural market or CBD (central business district) in Amphoe Lan Sak. In conclusion, those main affecting factors were caused human activities that directly affect the environment, that were proximate causes in the central and eastern parts of Huai Thap Salao watershed (as shown in Figure 5-7).

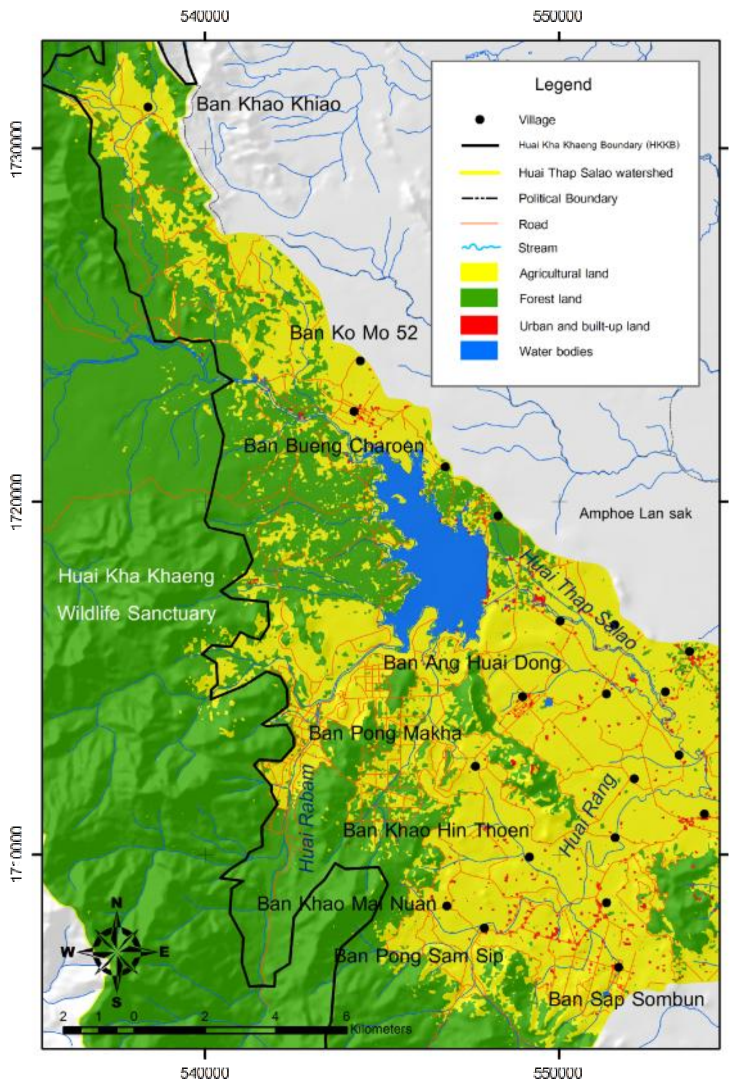


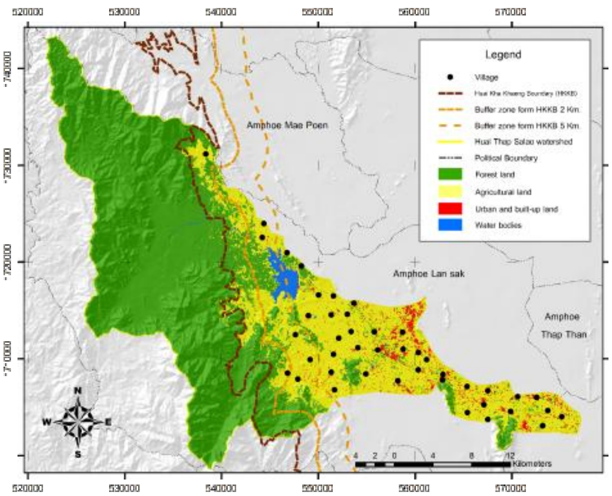
Figure 5-7 Agricultural expansion and intensive farming (Yellow color), urban and infrastructure development (Red color) in the central of Huai Thap Salao watershed during 1988 to 2007.

5.1.3 The predicting future land use conditions to forecast possible land use patterns

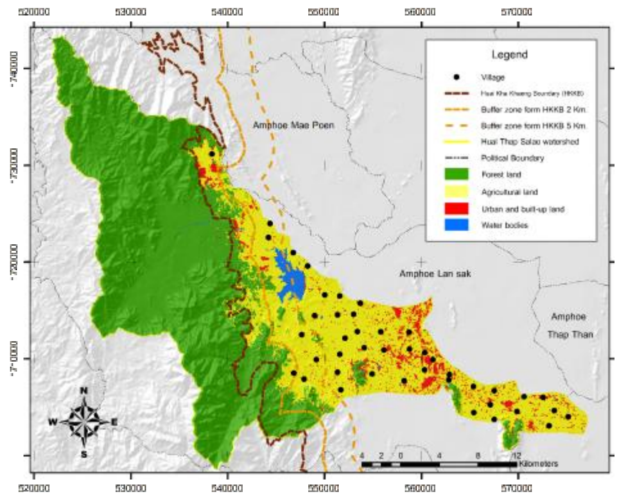
From Chapter 4, the CLUE-s model was simulated from two scenarios, namely, scenario without restriction area and scenario with reserved area in 2027. The scenario without restriction area was revealed that the highest rate of deforestation would be 63% (from previously 68% in 2007) and mostly in the central part of Huai Thap Salao watershed whereas the scenario with reserved area was revealed that the mostly increased land use category would be urban and built-up land surrounding Amphoe Lan Sak in the eastern part of Huai Thap Salao watershed.

The result revealed that the scenario without restriction area (baseline scenario) showed the highest rate of deforestation year 2027 which would be 63% (previously, 68% in the year 2007) of total study area. The few forest areas were found in the central parts of Huai Thap Salao watershed. The dominant topography in central parts of watershed consisted of flat and gentle slope area with alluvial deposits, which were highly suitable for agriculture and development to settlement. Forest land had been changed into agriculture land, as well as urban and built-up land during 2007 to 2027 as shown in Figure 5-8.

Besides, scenario with reserved area (conservation-oriented scenario) revealed that the mostly increased land use category would be urban and built-up land in Amphoe Lan Sak, which expanded to the surrounding villages and roads. Such the availability of infrastructure and facilities influenced the development of urban built-up area in this location. In addition, Similar to the scenario without restriction area, high deforestation was found Ban Khao Khiao, Ban Bueng Charoen, Ban Wang Thong, Ban Huai Plao, Ban Ang Huai Dong, Ban Khao Hin Thoen, Ban Pong Makha and Ban Khao Mai Nuan, Ban Pong Sam Sip, Ban Sap Sombun Tambon Rabam, Amphoe Lan Sak, Changwat Uthaithani as shown in Figure 5-9.



Land use map in 2007



Land use map in 2027

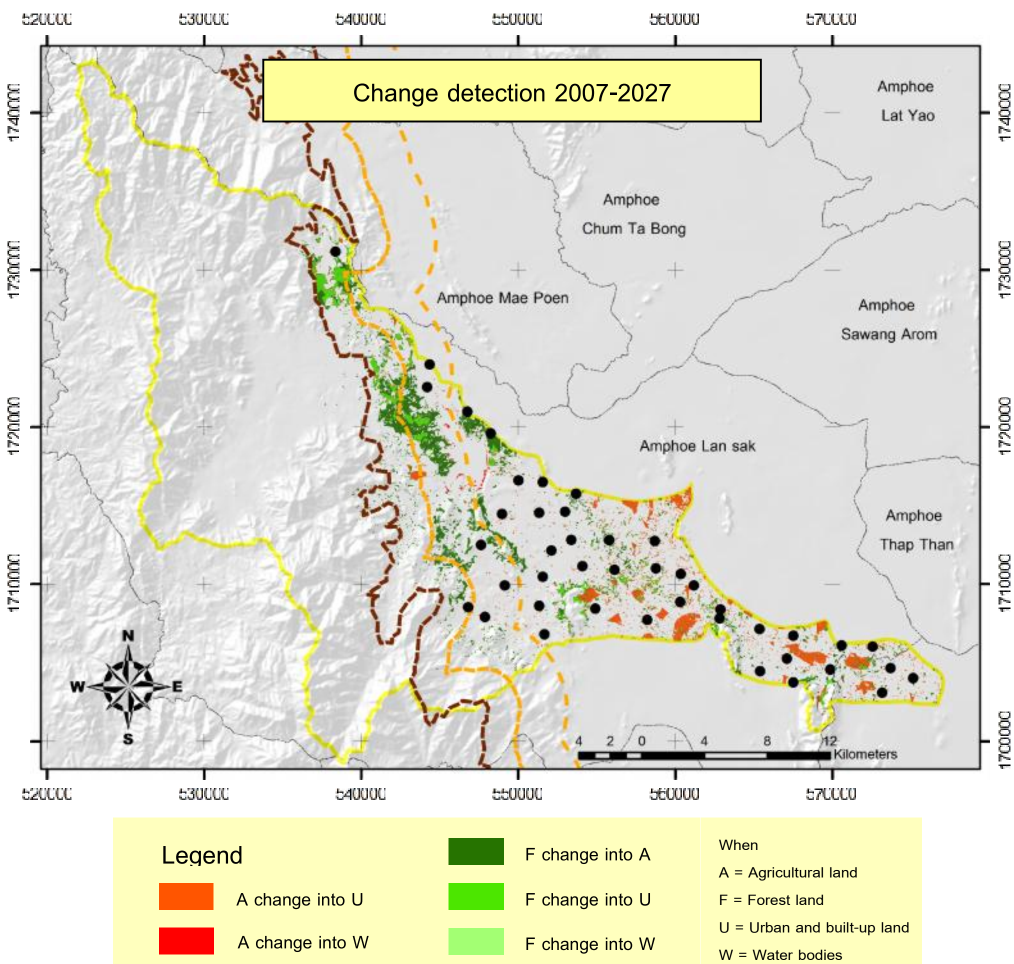
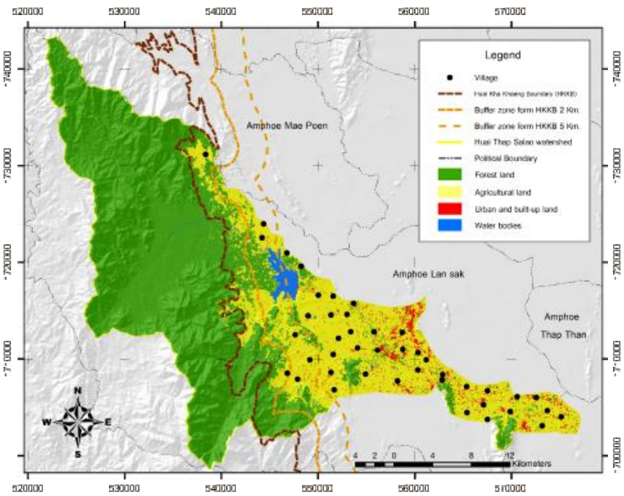
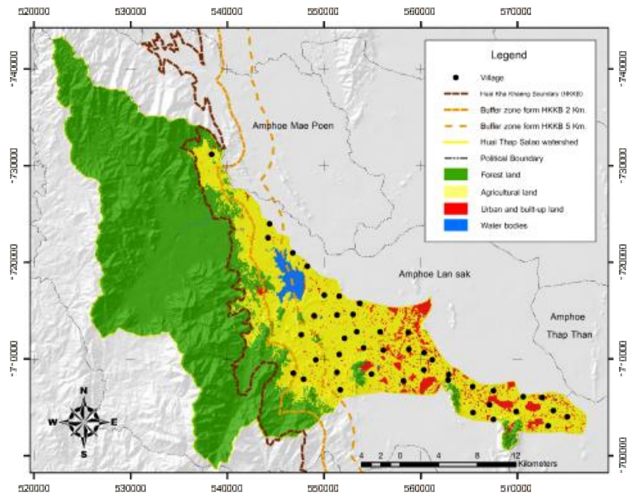


Figure 5-8 Land use changes with scenario without restriction area (baseline scenario) by CLUE-s model of Huai Thap Salao watershed during 2007-2027.



Land use map in 2007



Land use map in 2027

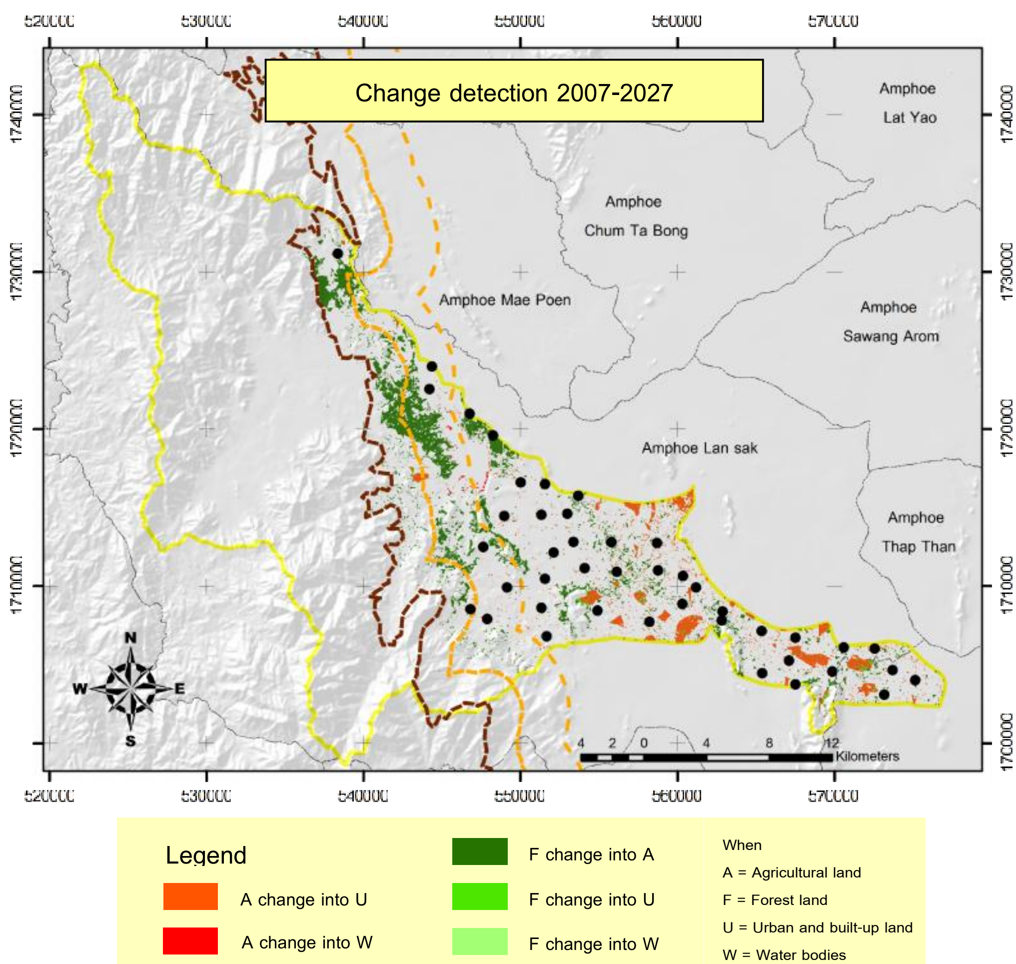
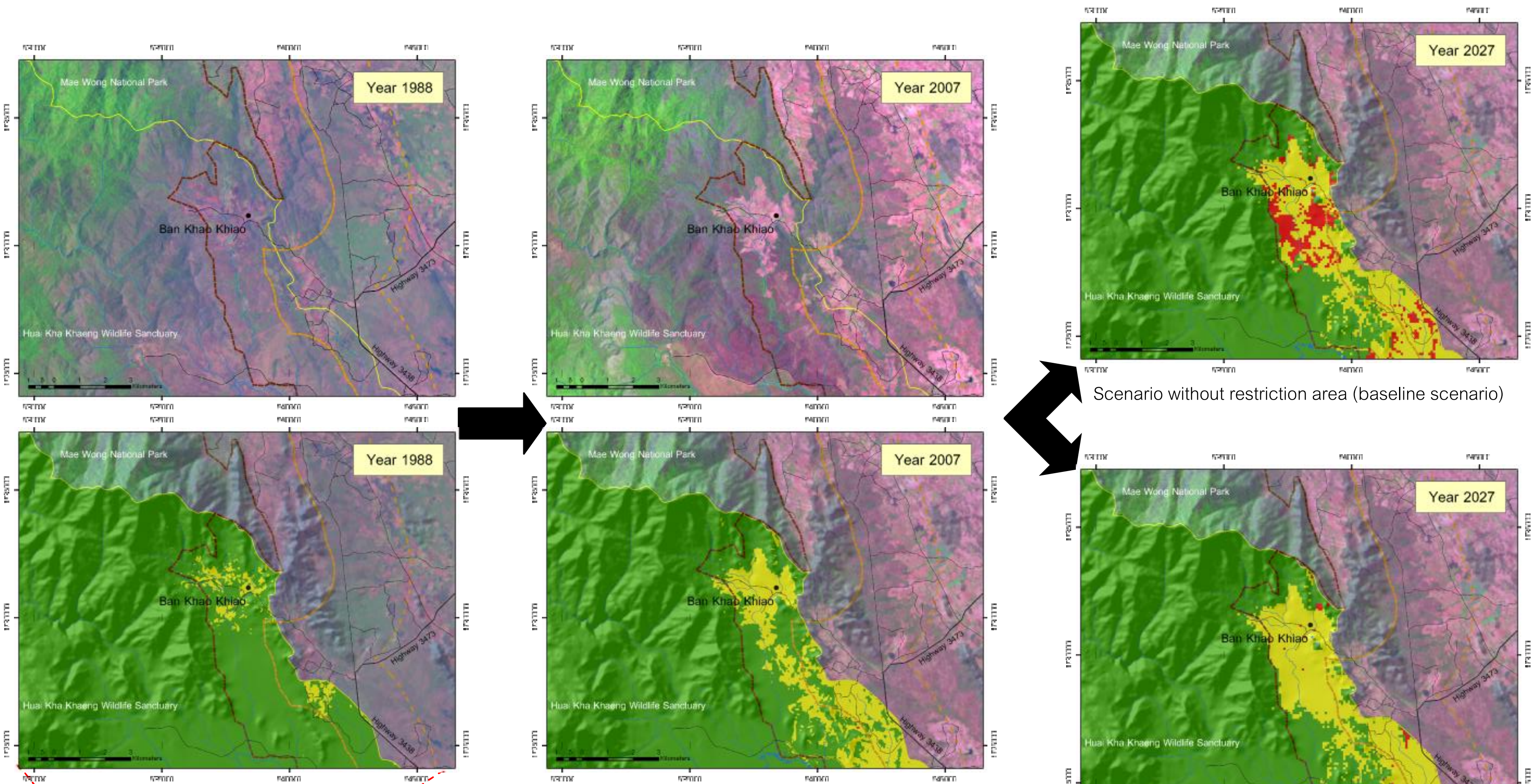


Figure 5-9 Land use changes with scenario reserved area (conservation-oriented scenario) by CLUE-s model of Huai Thap Salao watershed during 2007-2027.

For this reason the CLUE-s model used to simulate the characteristics of watershed and environmental resources management systems for a variety of planning, design and operation applications. The simulations of the spatial-temporal patterns of land use change in Huai Thap Salao watershed under two kinds of scenarios will form an important foundation for the decision-making on land use planning and sustainable development.

The results from this research can be used as basic data to assist deforestation and forest management planning. An example for the map in details that could be used to helps planning forest management in the specific area as shown in Figure 5-10. The map showed the occurrences of deforestation in Ban Khao Khiao, Tambon Rabam, Amphoe Lan Sak, Changwat Uthaithani during 1988-2007. The map also showed the increasing trends of deforestation from 1988 to 2007. In 1988, the deforestation occurred in the eastern part of the Huai Kha Khaeng Wildlife Sanctuary, after that they moved to the eastern and southern part of the study area in 2007. However, in 2007 most of the deforestation occurred in the eastern part of the study area. Moreover, it could be noticed that the sizes of deforestation change to agricultural land in each year were became larger in future in 2027.



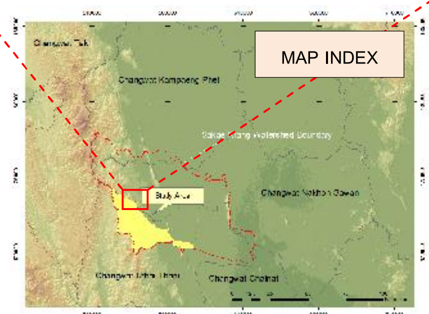


Figure 5-10 Thematic map for the decision-making on deforestation and forest management planning in the specific area, Ban Khao Khiao, Tambon Rabam, Amphoe Lan Sak, Changwat Uthaithani during 1988-2027.

5.2 Conclusion

In this research, three data input, which were thematic (GIS and remote sensing) data preparation, field investigation, and laboratory analysis were carried out to investigate dynamic spatial patterns of land use changes and to identify driving factors that caused land use changes during 1988-2007 in Huai Thap Salao watershed, Changwat Uthaithani. Besides, the purpose of study was to simulate model of land use changes in current period and extrapolate to predict the CLUE-s model of the future change in Huai Thap Salao watershed, Changwat Uthaithani, Central Thailand.

This research used the temporal Landsat-5 TM imageries covered the Huai Thap Salao watershed, acquired during 1988-2007, and were chosen to create the false color composite (Bands R=5, G=4, B=3) for the land use classification system with supervised classification process. According to the study, that Huai Thap Salao watershed were 8 land use categories that was identified as paddy field, field crops, perennial crops, evergreen forest, deciduous forest, forest plantation, urban and built-up land and water bodies. Field investigations were used to test for accuracy against the land use interpretation. The total overall accuracy assessments of land use classifications in 1988, 1997 and 2007 were 85.99%, 77.98% and 80.99%, respectively.

Change detection of land use in Huai Thap Salao watershed during 1988-2007 was analyzed using overlay technique in ArcMap GIS version 9.2. The results revealed that the total change area was 82.10 km^2 (10.71% of total change area). The most proportion of change area was forest land (decrease 41.05 km^2 or 50.00% of total change area) whereas agricultural land, urban and built-up land and water bodies were increasing over time.

The affecting factors and associated land use changes occurrence during 1988-2007, the relationship of land use changes and each affecting factors was analyzed for deforestation susceptibility assessment using the logistic regression method and deforestation susceptibility map.

The most affecting factors were the land characteristics, namely soil texture, degree of slope, elevation and mean annual precipitation, effected the deforestation in Huai Thap Salao watershed during 1988 to 2007. It could be explained that the group of soils is sandy loam and well-drained, moderately deep coarse-textured that developed from weathered rocks in dry areas. They have low fertility. Agricultural expansion and intensive farming invaded forest areas from the east to the west. In addition, agricultural land tended to expand in the areas of low elevation (about 0-400 meters from msl.) and plain area (about 0-30 degree of slope). The study area was appeared agricultural land such as corn, sugarcane, cassava, para rubber, and eucalyptus in the central part of Huai Thap Salao watershed. The deforestation in Huai Thap Salao watershed appeared in Ban Khao Khiao, Ban Bueng Charoen, Ban Wang Thong, Ban Ang Huai Dong, Ban Pong Makha, Ban Huai Pong Sam Sip and Ban Khao Mai Nuan, Tambon Rabam, Amphoe Lan Sak, Changwat Uthaithani. These villages were in buffer zone. Besides, The land use changes had relationship with social-economic factors and accessibility. The nearest the distance to villages (about 0-8 km.) and distance to roads (about 0-3.5 km.) effected transporting crops from the agricultural land to the rural market or CBD (central business district) in Amphoe Lan Sak. In conclusion, those main affecting factors were caused human activities that directly affect the environment, that were proximate causes in the central and eastern parts of Huai Thap Salao watershed.

The CLUE-s model was used to link between present and future of land use condition based on combination between empirical analysis, spatial analysis and dynamic modeling in raster base iterative procedure and the scenarios were demonstrated to design different alternative conditions of land use.

The result revealed that the scenario without restriction area (baseline scenario) showed the highest rate of deforestation year 2027 which would be 63% (previously, 68% in the year 2007) of total study area. The few forest areas were found in the central parts of Huai Thap Salao watershed. The dominant topography in central parts of watershed consisted of flat and gentle slope area with alluvial deposits, which were highly suitable for agriculture and development to settlement. Forest land had been changed into agriculture land, and urban and built-up land during 2007 to 2027. Besides, scenario with reserved area (conservation-oriented scenario) revealed that the mostly increased land use category would be urban and built-up land in Amphoe Lan Sak, which expanded to the surrounding villages and roads. Such the availability of infrastructure and facilities influenced the development of urban built-up area in this location. In addition, Similar to the scenario without restriction area, high deforestation was found Ban Khao Khiao, Ban Bueng Charoen, Ban Wang Thong, Ban Huai Plao, Ban Ang Huai Dong, Ban Khao Hin Thoen, Ban Pong Makha and Ban Khao Mai Nuan, Ban Pong Sam Sip, Ban Sap Sombun Tambon Rabam, Amphoe Lan Sak, Changwat Uthaithani.

Although in recent years technologies using GIS and remote sensing had greatly increased in Thailand, many of these GIS and remote sensing applications were not fully integrated with organization processes as well as being used to their greatest potential in resources analysis. Success will also require the government initiative in data management and in the integration of data flows within and between agencies. The results presented here suggest that co-operative forest management program that monitors assesses and reports on the long-term status, changes and trends in forest ecosystem health, based on the new technologies, should be initiated, developed and incorporated within the regional forest service or public sector.

The model outputs, conservation measures were recommended to minimize the impacts of deforestation on biodiversity. The model results indicated that only establishing a fixed percentage of forest was not efficient in conserving biodiversity. Measures aimed at the conservation of locations with high biodiversity values, limited fragmentation, and careful consideration of roads expansion in pristine forest areas may be more efficient to achieve biodiversity conservation.

5.3 Recommendation and suggestion for further studies

Although the methodology of evaluation is appropriate for this preliminary stage of investigation in the present study area, the derivation using this methodology are based on incomplete or unavailable information in some parameters according to the limitation of accessibility and rarely records in the past. Their relationship affecting land use change and predicting future land use could be substantially improved if the same methodology is applied systematically and carefully over the entire area. Studies needed for careful evaluation of potential should address the following questions:

1) Validation of the accuracy of a prediction model is always important, in order to convince stakeholders and decision makers to accept the results. In this study, it was not possible to validate the predicted land use map because land use data beyond 2009 were not available. An absence of appropriate data for validation is a common problem in land use modeling. The purpose of monitoring may also appear many environments in the central of Huai Thap Salao watershed.

2) The third scenario of the CLUE-s model that was used economic factors was not addressed in this research because the economic data was not available and too complex to be simulated and extrapolated.

3) Integrated watershed management can be improved for more effective implementation at regional and local levels. Scoping in Huai Thap Salao watershed can be divided into 4 sub-watersheds for more reliable and practical in implementation using the modified model and GIS technique as shown in Figure 5-11.

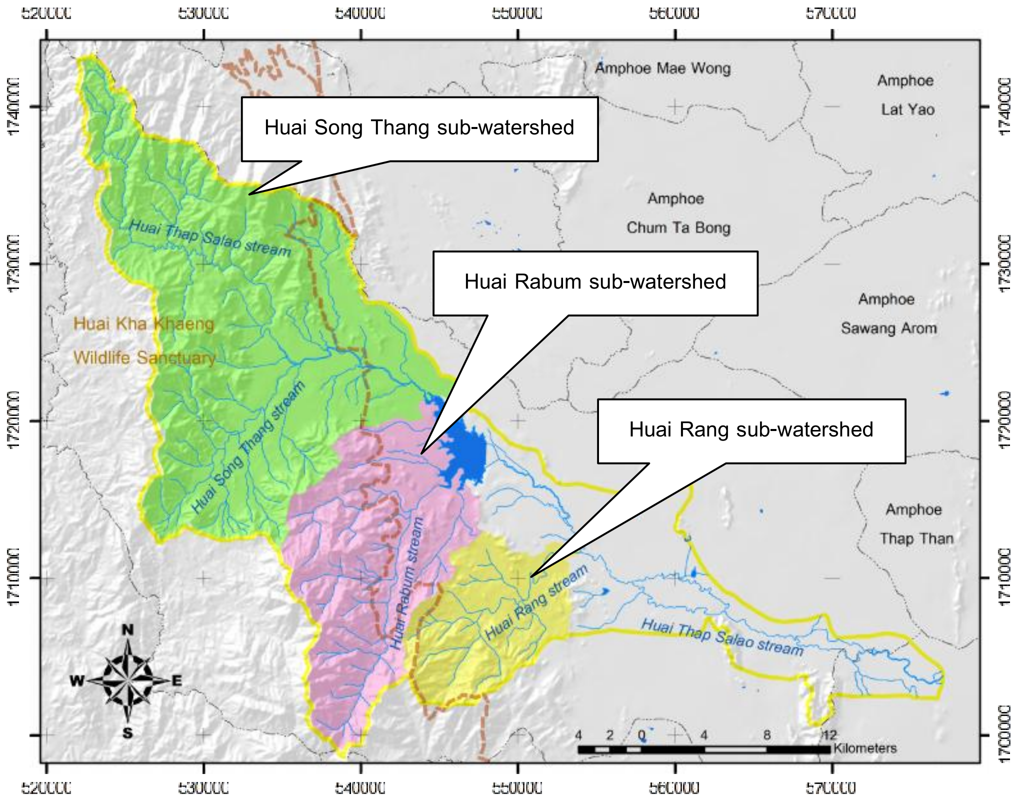


Figure 5-11 Four sub-watersheds for integrated watershed management can be improved for more effective implementation for further studies.

4) Protected area should be defined clearly to prevent intrusion into invasion in the Huai Kha Khaeng Wildlife Sanctuary. In addition, the area should be more protected from the Royal Forestry Department of Thailand. For examples, it should be recommended that the corridor or the legal boundary of Huai Kha Khaeng Wildlife Sanctuary must be implemented to prevent the protected area from invasion, and the changed monitoring should be continuously undertaken to ensure that the protected area will be maintained. In particular, the "agricultural and settlement agreement" for the corridor area should be strongly enforced in Huai Kha Khaeng Wildlife Sanctuary. Besides, more efforts for sustainable understanding and public participations should be conducted to upgrade the more effective of the corridor. It is essential that the rural communities, adjacent to buffer zone beside the corridor around Huai Kha Khaeng Wildlife Sanctuary, who should exclusively use the area following the above agreement as primarily proposed as shown in Figure 5-12.

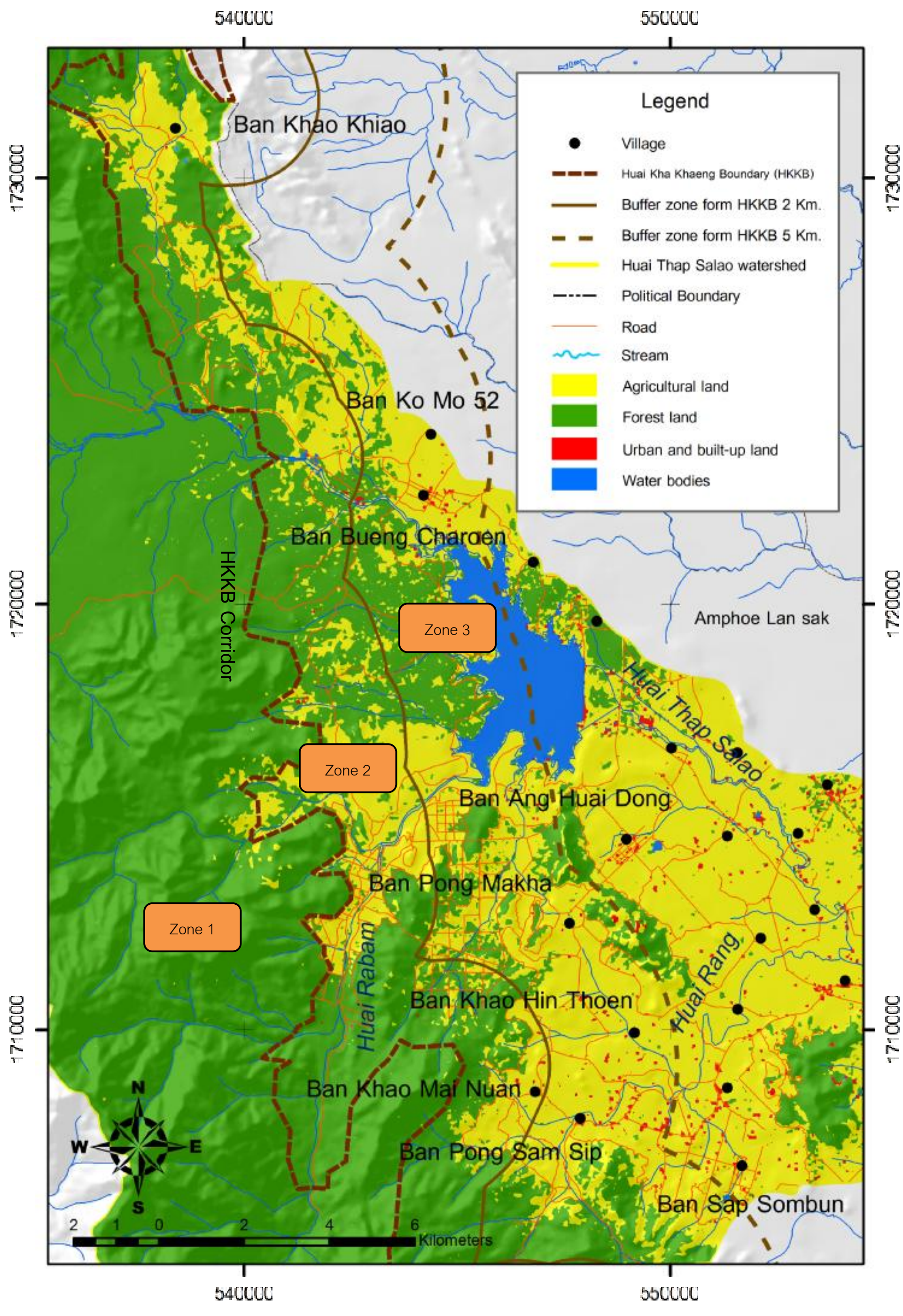


Figure 5-12 Thematic map for the decision-making on land use planning and sustainable development in buffer zone, Huai Thap Salao watershed, Changwat Uthai Thani.

In Figure 5-12, the buffer zone was approximately proposed to be wide 5 km. depending on topographical conditions and the agreements between the surrounding villages and the Royal Forestry Department of Thailand. In the near future, the develop eco-system sustainable management guidelines should be further conducted for the more complex situations. However, this study also primarily proposed three land use zonings (as shown in Figure 5-12) for management of vegetation, wildlife, socio-economic condition and recreation in the study area as follows:

Zone 1 : Preservation area – Huai Kha Khaeng Wildlife Sanctuary

Zone 2 : Conservation and recreation area – buffer zone from the legal boundary of Huai Kha Khaeng Wildlife Sanctuary 2 km. for forest conservation and forest plantation, but do not allow the settlement and deforestation.

Zone 3 : Controlled utilization and development area - buffer zone from *Zone 2* as 2 to 5 km. for commercial plantation and allowed to settlement, but must be strongly regulated by laws and agreements.

Guidelines should be further studied and prepared for each zone with the intention of assisting each protected areas to prepare operational management plans based on the zoning scheme in the future.

REFERENCES

Thai

กฤติกา บุณยชาติพิสุทธิ์. ความสัมพันธ์ระหว่างการใช้ที่ดินบริเวณชายฝั่งกับการเปลี่ยนแปลงของชายฝั่งทะเลจังหวัดเพชรบุรีและจังหวัดประจวบคีรีขันธ์ จากการศึกษาด้วยเทคนิครีโมทเซนซิ่ง, วิทยานิพนธ์ปริญญามหาบัณฑิต, สาขาวิชาวิทยาศาสตร์สภาวะแวดล้อม สหสาขาวิชาวิทยาศาสตร์สภาวะแวดล้อม จุฬาลงกรณ์มหาวิทยาลัย, 2542.

คณะกรรมการวิจัยแห่งชาติ, สำนักงาน. ปัญหาสิ่งแวดล้อมในการทำงานของมนุษย์. กรุงเทพฯ : สำนักงานคณะกรรมการวิจัยแห่งชาติ, 2538.

คมสัน ศีริวงศ์วัฒนา. การประยุกต์แบบจำลอง CLUE-s เพื่อคาดการณ์เปลี่ยนแปลงการใช้ที่ดินและสิ่งปกคลุมดิน ในพื้นที่ลุ่มน้ำแม่หยอด อำเภอแม่แจ่ม จังหวัดเชียงใหม่, วิทยานิพนธ์ปริญญามหาบัณฑิต, ภาควิชาการจัดการลุ่มน้ำและสิ่งแวดล้อม คณะวนศาสตร์ มหาวิทยาลัยเกษตรศาสตร์, 2550.

ทรัพยากรน้ำ, กรม. ศูนย์ป้องกันวิกฤตน้ำ. รายงานสถานการณ์อุทกภัย. [ออนไลน์]. 2549. แหล่งที่มา http://mekhala.dwr.go.th [2553, เมษายน 28]

นิพนธ์ ตั้งธรรม. การจำลองแบบการจัดการลุ่มน้ำและระบบสิ่งแวดล้อม. กรุงเทพฯ : ศูนย์วิจัยป่าไม้ คณะวนศาสตร์ มหาวิทยาลัยเกษตรศาสตร์, 2549.

ประชุมพร นิรัติศยกุล. การประยุกต์ใช้ระบบสารสนเทศภูมิศาสตร์เพื่อการประเมินศักยภาพทรัพยากรน้ำและที่ดิน บริเวณลุ่มน้ำสะแกกรัง ประเทศไทย, วิทยานิพนธ์ปริญญามหาบัณฑิต, สหสาขาวิชาวิทยาศาสตร์สภาวะแวดล้อม บัณฑิตวิทยาลัย จุฬาลงกรณ์มหาวิทยาลัย, 2542.

ป่าไม้, กรม. รายงานประจำปี 2544 กรมป่าไม้ กระทรวงเกษตรและสหกรณ์. กรุงเทพฯ : สไตล์ครีเอทีฟเฮ้าส์, 2545.

สมบัติ อยู่เมือง. การประเมินศักยภาพของตะกอนไหลถล่มและน้ำปนตะกอนท่วมบ่า ในปี 2544 บริเวณพื้นที่น้ำก้อ อำเภอหล่มสัก จังหวัดเพชรบูรณ์ ภาคกลางของประเทศไทย, วิทยานิพนธ์ปริญญาดุษฎีบัณฑิต, สาขาวิชาธรณีวิทยา ภาควิชาธรณีวิทยา คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย, 2548.

สำนักป้องกันภัยธรรมชาติและความเสี่ยงทางการเกษตร. รายงานคาดการณ์พื้นที่เกิดภัยธรรมชาติ. [ออนไลน์]. 2550. แหล่งที่มา http://www.ldd.go.th/web_irw/index.htm [2553, เมษายน 29]

สุที สาดี. แนวทางการป้องกันไฟป่า ป่าชุมชนเขาหินเหล็กไฟ ตำบลระบำ อำเภอลานสัก จังหวัดอุทัยธานี ระยะที่ 1. สำนักงานกองทุนสนับสนุนการวิจัย (สกว.) ฝ่ายวิจัยเพื่อท้องถิ่น, 2550.

English

Adams, J.B., and Gillespie, A.R. Remote Sensing of Landscapes with Spectral Images. Cambridge University, 2006.

Ahmed, K., Mercier, J. R. and Verheem, R. Strategic Environmental Assessment - Concept and Practice. Washington : World Bank, 2005.

Bettinger, P. and Wing, M.G. Geographic Information Systems: Application in Forestry and Natural Resources Management. New York : McGraw-Hill, 2004.

Braimoh, A.K. and Vlek, P.L.G. Modeling land-use change in the Volta Basin of Ghana. Ecology and Development 14, 2004.

Braimoh, A.K. and Vlek, P.L.G. Land Use and Soil Resources. New York : Springer, 2008.

Briassoulis, H. Analysis of Land Use Change: Theoretical and Modeling Approaches [Online]. 2000. Available from: http://www.rri.wvu.edu/WebBook/Briassoulis/contents.htm. [2010, May 30]

Briggs, R. Geographic information system Fundamentals. [Online]. 2010. Available from: http://www.utdallas.edu/~briggs/gisc6381.html [2010, October 29]

Clarke, K. C. Getting started with geographic information systems. London : Prentice Hall, 2001.

Delang, C. O. Deforestation in Northern Thailand : The Result of Hmong Farming Practices or Thai Development Strategies. Society and Natural Resources 15, 2002.

Di Gregorio, A. Land Cover Classification System (LCCS) version 2: Classification Concepts and User Manual. Rome : FAO Environment and Natural Resources Service Series, 2005.

Earth Science Australia. Global Positioning Systems. [Online]. 2010. Available from: http://earthsci.org/education/fieldsk/gps/gps.html [2010, October 29]

EEA. Europe's environment. [Online]. 1998. Available from: http://www.eea.europa.eu/publications [2011, May 30]

Engelsman, W. Simulating land use changes in urbanizing area in Malaysia. Doctoral dissertation, Department of Environmental Sciences Faculty of Environmental Sciences Wageningen University, 2002.

FAO. Terminology for Integrated Resources Planning and Management. Rome, Italy and Nairobi, Kenya : Food and Agriculture Organization/United Nations Environmental Programme, 2003.

FAO. Global Forest Resources Assessment 2005, Rome, Italy, 2006.

Gao, J., Liu, Y. and Chen, Y. Land cover changes during agrarian restructuring in Northeast China. Applied Geography 26 (2006): 312-322.

Garson, G.B. Logistic Regression. [Online]. 2011. Available from: http://faculty.chass.ncsu.edu/garson/PA765/logistic.htm [2011, June 3]

Geoscience Australia. Earth Observation and Satellite Imagery. [Online]. 2009. Available from: http://www.ga.gov.au/remote-sensing/satellites-sensors/landsat [2010, May 16]

Geist, H.J. and Lambin, E.F. Proximate Causes and Underlying Driving Forces of Tropical Deforestation. BioScience 52 (February 2002): 143-150.

Geist, H.J. and Lambin, E.F. What Drives Tropical Deforestation?. Louvain-la-Neuve. Belgium : Ciaco Printshop, 2001.

Geo-Informatics center for Thailand. Introduction to GIS and GIS for everyone. [Online]. 2009. Available from: http://www.gisthai.org/download/ Intro GIS.pdf. [2010, May 30]

Gobin, A., Campling, P. and Feyen, J. Logistic modelling to derive agricultural landuse determinants: a case study from southern Nigeria. Agriculture Ecosystems and Environment 89 (May 2002): 213-228.

Gonzales, C.A.I. Assessing the Land Cover and Land Use Change and Its Impact on Watershed Services in a Tropical Andean Watershed of Peru. Master's Thesis, Department of Biological and Environmental Science University of Jyväskyl, 2009.

Gorr, W. L., and Kurland, K.S. Learning and Using Geographic Information Systems. Canada : Thomson Course Technology, 2008.

Grüner, I., and Gapare, N. Fieldwork Procedures used for LCDB 2" on "Land Cover Database 2 - ArcInfo Shape Format: NZMG Projection. Terralink, Wellington, New Zealand, 2004.

Heathcote, I. W. Integrated Watershed management. 2nded.. New York : Wiley, 2009.

Howard, J.A. Remote Sensing of Forest Resources. Theory and application. London, UK: Champman and Hall, 1991.

IUCN. Financing Protected Areas: Guidelines for Protected Area Managers. IUCN, Gland, Switzerland and Cambridge, UK, 2000.

ITTO. Revised ITTO criteria and indicators for the sustainable management of tropical forests including reporting format. ITTO Policy development, 2005.

Jensen, J.R., and Kiefer, R.W. Remote Sensing of the environment. 2nd edition. Pearson Prentice Hall,Inc, 2007.

Lambin, E.F. Environmental Modelling: Finding Simplicity in Complexity. London, UK : John, W. and Mulligan, M. (eds.), 2004.

Langner, A.J. Monitoring Tropical Forest Degradation and Deforestation in Borneo, Southeast Asia. Doctoral dissertation, GeoBio Center of the Ludwig- Maximilian University of Munich, Germany, 2009.

Lanly, P.J. Deforestation and forest degradation factors. [Online]. 2003. Available from: http://www.fao.org/docrep/article/wfc/xii/ms12a-e.htm [2010, August 24]

Lillesand, T. M., Kiefer, R. W. ,and Chipman, J. W. Remote Sensing and Image Interpretation. Hoboken, N.J : John Wiley & Sons, 2008.

Martin, R.M. Deforestation and forest degradation factors. [Online]. 2008. Available from: http://www.fao.org/docrep/011/i0440e/i0440e02.htm [2010, August 8]

Mengistu, D. A. Remote sensing and gis-based Land use and land cover change detection in the upper Dijo river catchment, Silte zone, Southern Ethiopia. Docteral dissertation, Department of Geography and Environmental Studies Addis Ababa University, 2008.

Mertens, B. and Lambin, E.F. Spatial modelling of deforestation in Southern Cameroon: Spatial disaggregation of diverse deforestation processes. Applied Geography 17 (December 1996): 143-68.

Müller, D. From agricultural expansion to intensification: Rural development and determinants of land-use change in the Central Highlands of Vietnam. Docteral dissertation, Tropical Ecology Support Programme Institute of Rural Development Göttingen University, Germany, 2004.

National Aeronautics and Space Administration. Remote Sensing Tutorial. [Online]. 2009. Available from: http://rst.gsfc.nasa.gov [2010, May 12]

National Aeronautics and Space Administration. Earth Observatory. [Online]. 2010. Available from: http://earthobservatory.nasa.gov [2010, October 16]

Noe, C., 2003. The Dynamics of Land use Changes and their Impacts on the Wildlife Corridor between Mt.Kilimanjaro and Amboseli National Park, Tanzania. Docteral dissertation, Department of geography Dar Es Salaam University, 2003.

Orékan, O. A. V. Simulating Land-Use Change in the Southern Upper Oueme Catchment in Benin, Journals Scientific National CBRST (December 2005).

Orékan, O. A. V. Implementation of local land-use and land-cover changes model for central Benin using socio-economic and satellite data. Doctoral dissertation, Department of Geography University of Bonn, 2007.

Pan, X.Z., and Zhao, Q.G. Measurement of Urbanization process and the paddy soil loss in Yixing city, China between 1949 and 2000. Catena 69 (May 2006): 65-73.

Pontius, R.G. and Schneider, L.C. Land-cover change model validation by an ROC Method for the Ipswich watershed, Massachusetts, USA. Agriculture Ecosystems & Environment 85 (2001): 239-248

Rodenberg, E. Survey and GIS Summit: Introduction to GIS. [Online]. 2006. Available from: http:// proceedings.esri.com/library/userconf/eric_rodenberg_intro.pdf [2010, November 28]

Serneels, S. and Lambin, F.E.Proximate causes of land-use change in Narok District, Kenya: a spatial statistical model. Agriculture Ecosystems and Environment 85 (2001): 65-81.

Skrdla, M. P. Introduction to GIS.,Nebraska, USA : Lincoln, 2005.

Sombat Yumuang. Evaluation of Potential for 2001 debris flood in the vinicity of Namko area, Amphoe Lom Sak, Changwat Phetchabun, Central Thailand. Docteral dissertation, Faculty of Science Chulalongkorn University, 2005.

Sukanda Jotikapukkana. Wildlife, human, and domestic animal use of buffer zone area-Consequences for management strategies, Huai Kha Kaeng Wildlife Sanctuary (Thailand). Master's Thesis, The Swedish Biodiversity Centre, 2007.

SWALIM. Field Survey Manual: Landform – Soil - Soil Erosion - Land Use - Land Cover. Nairobi, Somalia : Somalia Water and Land Information Management, 2007.

Sutten, T., Dassau O.,and Sutton M. A Gentle Introduction to GIS. Eastern Cape : Department of Land Affairs, 2009.

Thapa, R.B. and Murayama, Y. Urban mapping, accuracy,& imageclassification: A comparison of multiple approaches in Tsukuba City, Japan. Applied Geography 29 (October 2009): 135-144.

Trisurat, Y., Alkemade, R., and Verburg, P.H. Projecting Land-Use Change and Its Consequences for Biodiversity in Northern Thailand. Environmental Management. 45 (February 2010): 626–639.

UNEP. Report of the Ad Hoc Technical Expert Group on Forest Biological Diversity. Subsidiary Body for Scientific, Technical and Technological Advice. Seventh Meeting, Montreal, 2001.

UNFCCC. Modalities and procedures for afforestation and reforestation activities under the clean development mechanism in the first commitment period of the Kyoto Protocol. UNFCCC/SBSTA, 2003.

United States Geological Survey. Geographic Information Systems. [Online]. 2007. Available from : http://egsc.usgs.gov/isb/pubs/gis_poster [2010, November 28]

Verburg, P.H., and Veldkamp, A. Projecting land use transitions at forest fringes in the Philippines at two spatial scales. Landscape Ecology 19 (2004): 77-98.

Verburg, P.H. and Veldkamp, A. The role of spatially explicit models in land-use change research: a case study for cropping patterns in China. Agriculture, Ecosystems and Environnement 85 (June 2001): 177-190.

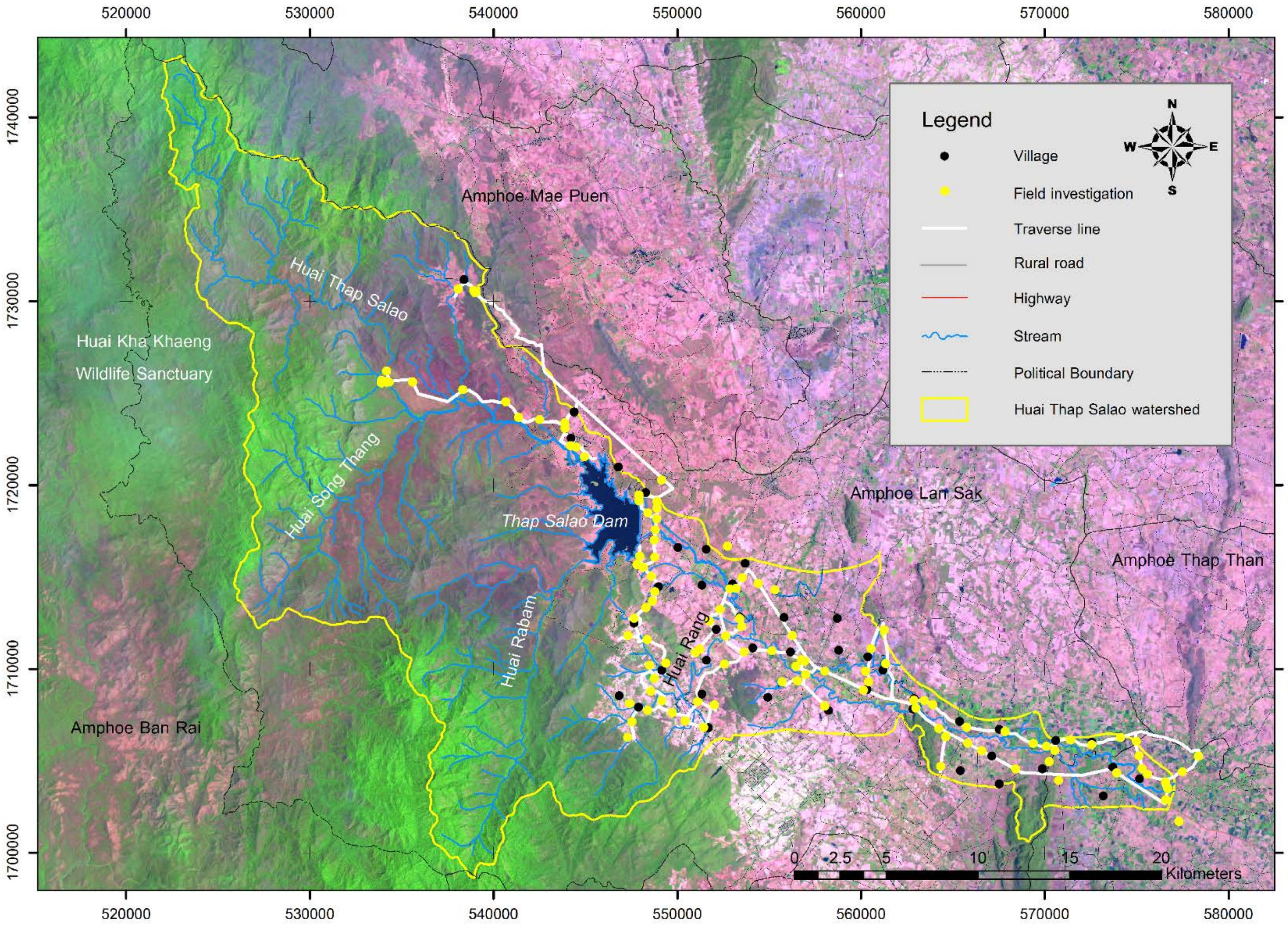
Verburg, P.H., Soepboer, W., Veldkamp, A., Limpiada, R., Espaldon, V. and Mastura, S.S.A. Modeling the Spatial Dynamics of Regional Land Use: The CLUE-s Model. Environmental Management, 30(3) (2002): 391–405.

Wang, G. Integrated Watershed Management : China-Wide Analysis and a case study in the Min river basin,Fujian,China. Docteral dissertation, Faculty of Graduate Studies British Columbia University, 2009.

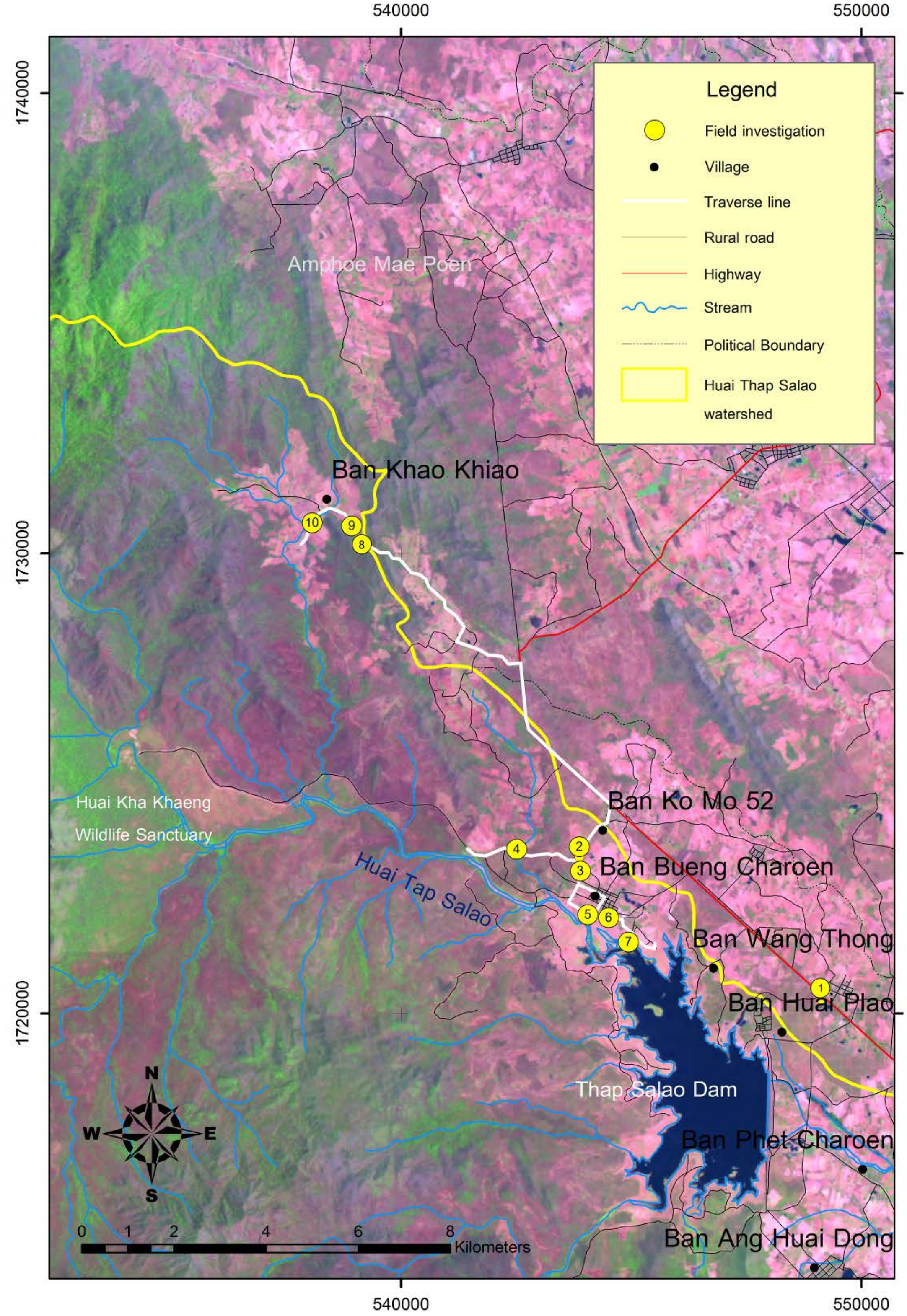
Wang, S.Y. , Liu, J.S. and Ma, T.B. Dynamics and changes in spatial patterns of land use in Yellow River Basin, China. Land Use Policy 27 (April 2010): 313–323.

Zhan, J., Deng, X., Jiang, Q., Shi, N. The application of system Dynamics and CLUE-s model in land use change dynamic simulation: a case study in Taips County, Inner Mongolia of China. System Science,Management Science & System Dynamics (October 2007): 2781-2789.

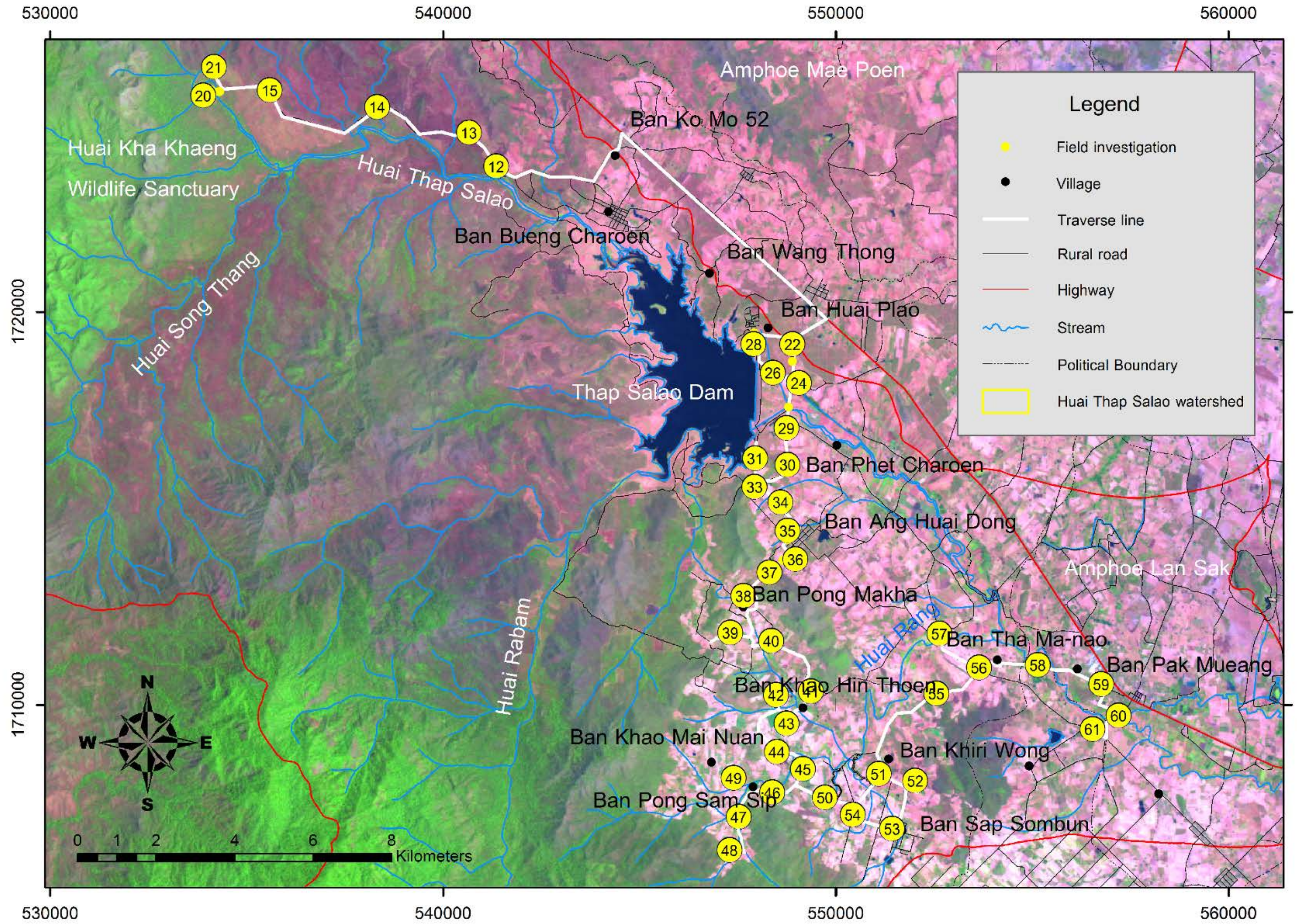
APPENDIX



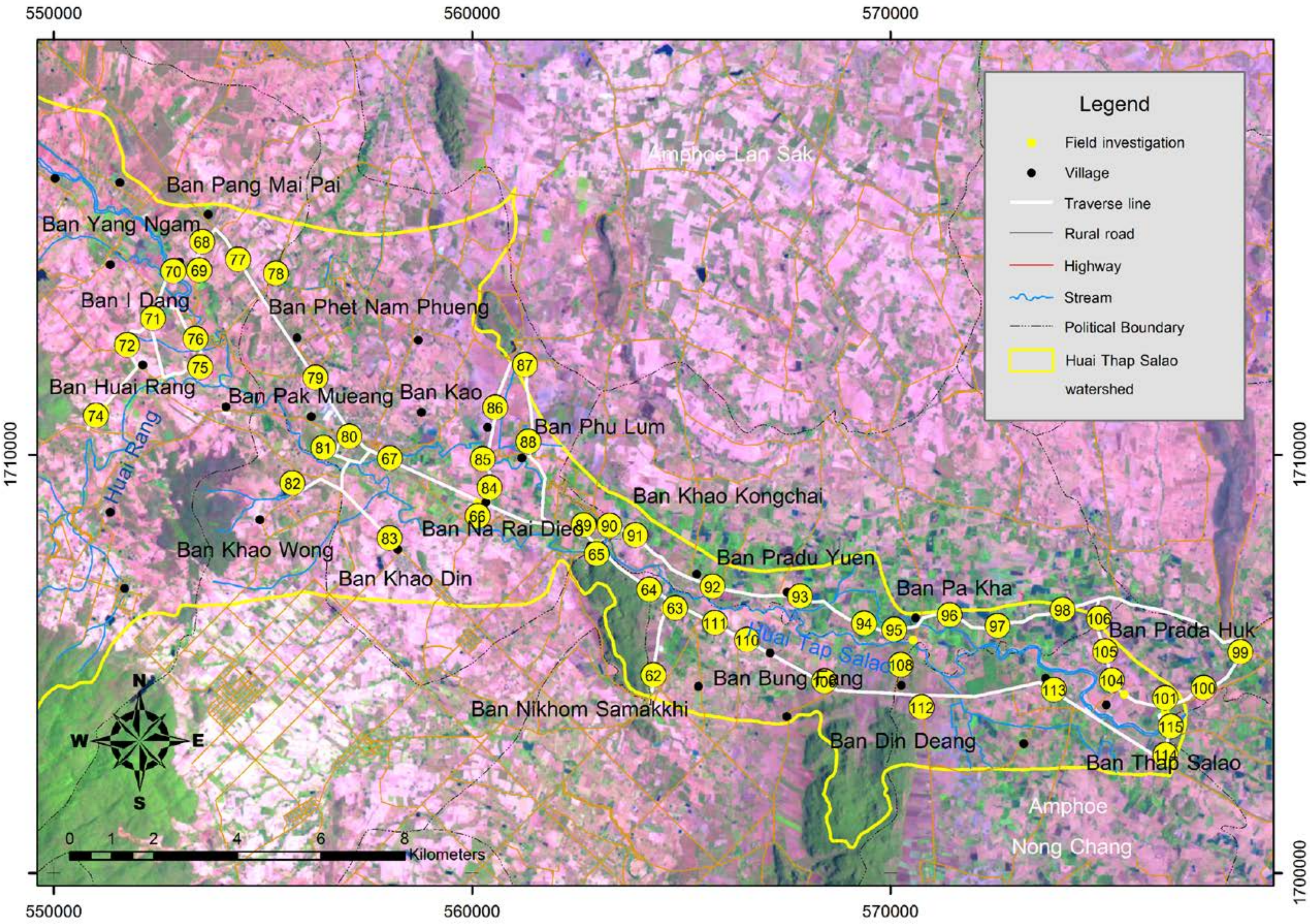
Field investigation located in Landsat 5TM (R=5, G=4, B=3) acquired on 18th-20th March 2011.



Field investigation located in northern of Huai Tap Salao watershed acquired on 18[th] March 2011.



Field investigation located in central of Huai Tap Salao watershed acquired on 19th March 2011.



Field investigation located in southeast of Huai Tap Salao watershed acquired on 20th March 2011.

GIS database illustrating locations of the field investigation

(Sample locations referred to Figure 3-5, 3-6, 3-7 and 3-8)

No.	East	North	Elevation (meter)	Error (meter)	Land use			Location	Description
					Lv.III	Name English	Name Thai		
1	549151	1720275	151		U300	Institutional	สถานที่ราชการ	ที่ทำการองค์การบริหารส่วนตำบลระบำ	ที่ทำการองค์การบริหารส่วนตำบลระบำ อำเภอลานสักจังหวัดอุทัยธานี
2	543874	1723393	176	9	F301	Teak plantation	สวนสัก	บ้านบึงเจริญ	ป่าสัก
3	543895	1723094	175	3	A407	Mango	สวนมะม่วง	บ้านบึงเจริญ	สวนมะม่วง ริมทางเข้าเขตรักษาพันธุ์สัตว์ป่าห้วยขาแข้ง
4	542509	1723569	160	4	A204	Cassava	ไร่มันสำปะหลัง	บ้านบึงเจริญ	ไร่มันสำปะหลัง หมู่บ้านบึงเจริญ
5	544200	1722145	153	5	M200	Wetland	พื้นที่ลุ่ม	บ้านบึงเจริญ	ทุ่งหญ้าเลี้ยงในหน้าแล้ง. ประมงในฤดูน้ำหลากเนื่องจากน้ำท่วม, พื้นที่ป่าชุมชนบริเวณเกาะกลางลำน้ำ
6	544508	1722072	160	3	M200	Wetland	พื้นที่ลุ่ม	อ่างระบำ บ้านบึงเจริญ	ทุ่งทานตะวัน และทุ่งหญ้าเลี้ยงสัตว์
7	544941	1721551	145	3	F300	Forest plantation	สวนป่า	อ่างระบำ บ้านบึงเจริญ	พื้นที่แหล่งน้ำสำหรับทำประมงน้ำจืด, ป่าชุมชนเกาะกลางลำน้ำห้วยทับเสลา
8	538983	1730463	253	4	M00	Miscellaneous land	พื้นที่อื่นๆ	บ้านเขาเขียว	ทางเข้าหมู่14บ้านเขาเขียว, มีการเปิดพื้นที่เพื่อขยายที่ทำกิน
9	538928	1730597	245	4	A204	Cassava	ไร่มันสำปะหลัง	บ้านเขาเขียว	พื้นที่ภายในหมู่บ้านปลูกมันสำปะหลัง ข้าวโพด และร่องรอยยางนา(พรรณไม้เดิมที่ปรากฏในพื้นที่ป่า)
10	538067	1730664	223	9	A204	Cassava	ไร่มันสำปะหลัง	บ้านเขาเขียว	ไร่มันสำปะหลัง สวนกล้วย
11	552731	1716683	156	4	F303	Eucalyptus plantation	สวนยูคาลิปตัส	กม.42 ทางหลวงหมายเลข 3438	สวนยูคาลิปตัส
12	541357	1723680	170	9	F300	Forest plantation	สวนป่า	กม.9 ทางเข้าเขตรักษาพันธุ์สัตว์ป่าห้วยขาแข้ง	ด้านซ้ายของถนนเป็นสวนป่า(ป่าไผ่ที่ชาวบ้านใช้ประโยชน์ได้) ขวาไร่มันสำปะหลัง
13	540664	1724538	172	5	F202	Dry dipterocarp forest	ป่าเต็งรัง	เขตรักษาพันธุ์สัตว์ป่าห้วยขาแข้ง	แนวกันไฟป่า กม.6 เขตสวนป่าปลูก, ไม้พุ่มจำพวกปรง ต้นเสลา
14	538329	1725190	159	6	F202	Dry dipterocarp forest	ป่าเต็งรัง	เขตรักษาพันธุ์สัตว์ป่าห้วยขาแข้ง	แนวกันไฟป่า กม.5 เขตสวนป่าปลูก, ป่าไผ่ และฝายน้ำล้น
15	535591	1725615	193	6	F202	Dry dipterocarp forest	ป่าเต็งรัง	เขตรักษาพันธุ์สัตว์ป่าห้วยขาแข้ง	ป่าเต็งรัง
16	534312	1725606	168	5	U600	Recreation area	สถานที่พักผ่อนหย่อนใจ	เขตรักษาพันธุ์สัตว์ป่าห้วยขาแข้ง	ลานจอดรถ เขตรักษาพันธุ์สัตว์ป่าห้วยขาแข้ง
17	534203	1725599	164	3	U600	Recreation area	สถานที่พักผ่อนหย่อนใจ	เขตรักษาพันธุ์สัตว์ป่าห้วยขาแข้ง	สะพานแขวนข้ามห้วยทับเสลา เขตรักษาพันธุ์สัตว์ป่าห้วยขาแข้ง
18	534106	1725648	173	4	U600	Recreation area	สถานที่พักผ่อนหย่อนใจ	เขตรักษาพันธุ์สัตว์ป่าห้วยขาแข้ง	อนุสรณ์สถาน สืบ นาคะเสถียร
19	533893	1725562	182	5	U600	Recreation area	สถานที่พักผ่อนหย่อนใจ	เขตรักษาพันธุ์สัตว์ป่าห้วยขาแข้ง	บ้านพัก สืบ นาคะเสถียร, ต้นน้ำห้วยทับเสลา
20	533895	1725707	194	5	U600	Recreation area	สถานที่พักผ่อนหย่อนใจ	เขตรักษาพันธุ์สัตว์ป่าห้วยขาแข้ง	จุดชมวิวริมห้วยทับเสลา
21	524134	1726036	206	8	U600	Recreation area	สถานที่พักผ่อนหย่อนใจ	เขตรักษาพันธุ์สัตว์ป่าห้วยขาแข้ง	ลานกางเต็นท์เขตรักษาพันธุ์สัตว์ป่าห้วยขาแข้ง
22	548901	1719113	168	8	F300	Forest plantation	สวนป่า	สวนป่าระบำ	สวนป่าระบำ
23	548900	1718745	161	10	F300	Forest plantation	สวนป่า	สวนป่าทับเสลา-ห้วยคอกควาย	สวนป่าสงวนทับเสลา-ห้วยคอกควาย
24	548883	1718167	146	5	A100	Paddy field	นาข้าว		นาข้าว
25	548801	1717577	146	4	A202	Corn	ไร่ข้าวโพด	สะพานข้ามห้วยทับเสลา	ไร่ข้าวโพด
26	548401	1718506	155	7	F300	Forest plantation	สวนป่า	สวนป่าทับเสลา-ห้วยคอกควาย	สวนป่าปลูกต้นสัก ต้นเสลา
27	547921	1719464	149	5	U300	Institutional	สถานที่ราชการ	สันอ่างเก็บน้ำทับเสลา	หน้ากรมชลประทาน
28	547911	1719154	157	3	M200	Wetland	พื้นที่ลุ่ม	อ่างเก็บน้ำทับเสลา	ทุ่งหญ้าเลี้ยงสัตว์
29	548750	1717017	137	5	A204	Cassava	ไร่มันสำปะหลัง	บ้านเพชรเจริญ	ไร่มันสำปะหลังและนาข้าว(พันธุ์ชัยนาทและสุพรรณบุรี3 ปลูกได้75วันเก็บผลผลิตได้)ทางทิศตะวันตก, ไร่อ้อยด้านตะวันออก

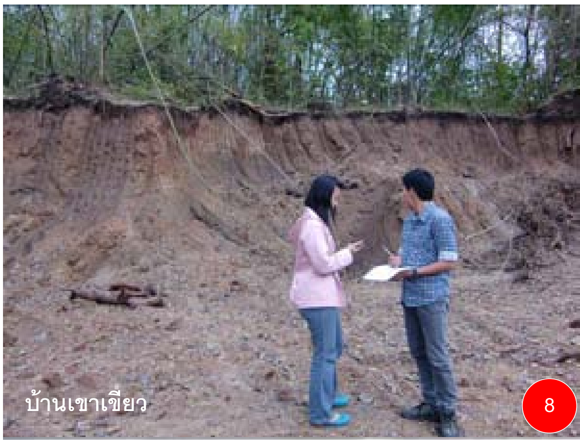
No.	East	North	Elevation (meter)	Error (meter)	Land use			Location	Description
					Lv.III	Name English	Name Thai		
30	548775	1716086	144	7	A204	Cassava	ไร่มันสำปะหลัง	บ้านเพชรเจริญ	ทิศเหนือของหมู่บ้านเป็นป่าชุมชนเพชรเจริญ พรรณไม้จำพวกเสลา ตะแบก ทิศใต้ปลูกมันสำปะหลัง
31	547949	1716132	157	4	U00	Urban and built-up land	พื้นที่อยู่อาศัย	อ่างเก็บน้ำทับเสลา บ้านอ่างห้วยดง	บ้านอ่างห้วยดง
32	547807	1715680	160	10	F300	Forest plantation	สวนป่า	ป่าชุมชนเขาหินเหล็กไฟ	สวนป่าเขาหินเหล็กไฟ พรรณไม้จำพวกเสลา ตะแบก
33	548146	1715524	160	7	F203	Sugarcane	ไร่อ้อย	บ้านอ่างห้วยดง เขาหินเหล็กไฟ	ไร่อ้อย เปิดพื้นที่ถึงเขาหินเหล็กไฟ และไร่มันสำปะหลัง
34	548596	1715041	152	5	A307	Bamboo	สวนไผ่	บ้านอ่างห้วยดง เขาหินเหล็กไฟ	สวนไผ่
35	548777	1714205	163	7	A204	Cassava	ไร่มันสำปะหลัง	บ้านอ่างห้วยดง เขาหินเหล็กไฟ	ไร่มันสำปะหลัง
36	548656	1713681	173	6	A204	Cassava	ไร่มันสำปะหลัง		เส้นทางระหว่างบ้านอ่างห้วยดง-บ้านโป่งมะค่า
37	548293	1713346	200	9	F300	Forest plantation	สวนป่า	ป่าชุมชนโป่งมะค่า	ป่าชุมชนโป่งมะค่า ประกาศปิดป่า 9สิงหาคม2543
38	547653	1712752	188	10	A204	Cassava	ไร่มันสำปะหลัง	บ้านโป่งมะค่า หมู่7	ไร่มันสำปะหลัง
39	547319	1711812	199	8	A204	Cassava	ไร่มันสำปะหลัง	บ้านโป่งมะค่า หมู่7	บ้านโป่งมะค่าบริเวณเขาหินเหล็กไฟ ปลูกไร่มันสำปะหลัง
40	548360	1711607	179	7	A204	Cassava	ไร่มันสำปะหลัง	บ้านโป่งมะค่า หมู่7	เส้นทางระหว่างบ้านโป่งมะค่า-บ้านหินเทิน ไร่มันสำปะหลัง และไร่สับปะรด ด้านป่าชุมชนโป่งมะค่าเป็นป่าเสื่อมโทรม
41	549372	1710316	174	6	A205	Pineapple	ไร่สับปะรด	บ้านเขาหินเทิน	ไร่สับปะรด
42	548483	1710200	182	6	A204	Cassava	ไร่มันสำปะหลัง	บ้านเขาหินเทิน	ไร่มันสำปะหลัง
43	548751	1709484	184	6	A204	Cassava	ไร่มันสำปะหลัง	บ้านเขาหินเทิน	ด้านทิศตะวันตกคือไร่มันสำปะหลัง และต้านทิศตะวันออกคือไร่สับปะรด
44	548570	1708778	177	7	A302	Para rubber	สวนยางพารา	บ้านโป่งสามสิบ หมู่3	สวนยางพารา ติดตีนเขา
45	549165	1708273	175	6	A204	Cassava	ไร่มันสำปะหลัง	บ้านโป่งสามสิบ หมู่3	ไร่มันสำปะหลัง
46	548388	1707749	174	10	A302	Para rubber	สวนยางพารา	บ้านโป่งสามสิบ หมู่3	สวนยางพารา ติดตีนเขา
47	547530	1707129	199	9	A204	Cassava	ไร่มันสำปะหลัง	บ้านโป่งสามสิบ หมู่3	ปลูกมันสำปะหลัง
48	547298	1706279	199	5	F202	Dry dipterocarp forest	ป่าเต็งรัง	บ้านโป่งสามสิบ หมู่3	คลองเสาธง จุดสกัดที่7 ป่าห้วยขาแข้ง 40ปีที่แล้วเคยปลูกมะพร้าว 10ปีที่ผ่านมาปลูกลำไย มะนาว ที่รัฐให้มา
49	547403	1708119	192	6	A204	Cassava	ไร่มันสำปะหลัง	บ้านเขาไม้นวล	ไร่มันสำปะหลัง สับปะรด
50	549724	1707620	170	6	A204	Cassava	ไร่มันสำปะหลัง	เส้นทางระหว่างบ้านโป่งสามสิบ-บ้านปากเหมือง	ไร่มันสำปะหลัง
51	551099	1708220	162	5	A204	Cassava	ไร่มันสำปะหลัง	บ้านคีรีวงษ์(คลองไม้ลาย) หมู่15	ไร่มันสำปะหลัง
52	552025	1708047	176	4	A205	Pineapple	ไร่สับปะรด	บ้านคีรีวงษ์(คลองไม้ลาย) หมู่15	หลังเขาวง ไร่สับปะรด
53	551436	1706824	169	6	A204	Cassava	ไร่มันสำปะหลัง	บ้านทรัพย์สมบูรณ์ หมู่12	ไร่มันสำปะหลัง
54	550434	1707180	181	5	A205	Pineapple	ไร่สับปะรด	บ้านทรัพย์สมบูรณ์ หมู่12	ไร่สับปะรด
55	552565	1710264	144	10	U00	Urban and built-up land	พื้นที่อยู่อาศัย	บ้านทรัพย์สมบูรณ์ หมู่12	
56	553651	1710924	127	5	U00	Urban and built-up land	พื้นที่อยู่อาศัย	บ้านท่ามะนาว หมู่1	ชุมชนบ้านท่ามะนาว
57	552643	1711792	124	5	A100	Paddy field	นาข้าว	บ้านห้วยรัง	สะพานข้ามห้วยรัง บ้านห้วยรัง นาข้าวริมห้วยรัง
58	555147	1710989	116	4	A100	Paddy field	นาข้าว	บ้านท่ามะนาว หมู่1	นาข้าวด้านทิศใต้ บางส่วนเป็นทุ่งเลี้ยงสัตว์และไร่อ้อย
59	556762	1710500	115	3	U00	Urban and built-up land	พื้นที่อยู่อาศัย	บ้านปากเหมือง	ชุมชนบ้านปากเหมือง
60	556981	1709702	112	5	U00	Urban and built-up land	พื้นที่อยู่อาศัย	สะพานข้ามห้วยทับเสลา บ้านปากเหมือง	ชุมชนบ้านปากเหมือง
61	556543	1709360	112	8	A202	Corn	ไร่ข้าวโพด	บ้านเขาวง	ไร่ข้าวโพด
62	564338	1704707	108	5	A204	Cassava	ไร่มันสำปะหลัง	เขาฆ้องชัย	ด้านตะวันตกปลูกมันสำปะหลังติดเขาฆ้องชัย ฝั่งตะวันออกปลูกข้าว

No.	East	North	Elevation (meter)	Error (meter)	Land use			Location	Description
					Lv.III	Name English	Name Thai		
63	564626	1706315	106	4	A202	Corn	ไร่ข้าวโพด	เขาฆ้องชัย	ไร่ข้าวโพด สถานีจ่ายน้ำมันบางจาก สหกรณ์ลานสัก
64	564240	1706757	107	5	U00	Urban and built-up land	พื้นที่อยู่อาศัย	วัดวิเศษนิคมสามัคคี	วัดวิเศษนิคมสามัคคี เขาฆ้องชัย ตำบลทุ่งนางาม
65	562981	1707876	110	3	U00	Urban and built-up land	พื้นที่อยู่อาศัย	บ้านเขาฆ้องชัย	สะพานข้ามห้วยทับเสลา ทางหลวงหมายเลข3438 บ้านเขาฆ้องชัย
66	560136	1708848	111	5	A100	Paddy field	นาข้าว	บ้านนาไร่เดียว	นาข้าว
67	558034	1709893	117	7	U00	Urban and built-up land	พื้นที่อยู่อาศัย	อำเภอลานสัก	ชุมชนลานสัก
68	553548	1714968	139	7	F303	Eucalyptus plantation	สวนยูคาลิปตัส	บ้านยางงาม	สวนยูคาลิปตัส
69	553189	1714390	130	8	F303	Eucalyptus plantation	สวนยูคาลิปตัส	บ้านยางงาม	สวนยูคาลิปตัส, สวนข้าวโพดและมันสำปะหลัง
70	552858	1714365	130	4	A204	Cassava	ไร่มันสำปะหลัง	บ้านยางงาม	สะพานข้ามห้วยทับเสลา บ้านยางงาม-บ้านห้วยรัง
71	552342	1713237	137	6	A202	Corn	ไร่ข้าวโพด	บ้านห้วยรัง	ไร่ข้าวโพดด้านทิศเหนือ ไร่มันสำปะหลังด้านทิศใต้
72	551751	1712602	147	7	A204	Cassava	ไร่มันสำปะหลัง	บ้านห้วยรัง	ไร่มันสำปะหลัง
73	551227	1711080	151	7	A204	Cassava	ไร่มันสำปะหลัง	บ้านปางควาย	ไร่มันสำปะหลัง
74	551010	1710912	144	7	A204	Cassava	ไร่มันสำปะหลัง	บ้านหินเทิน	ไร่มันสำปะหลัง และไร่สับปะรด
75	553502	1712315	128	4	A204	Cassava	ไร่มันสำปะหลัง	บ้านอีด่าง	ไร่มันสำปะหลัง
76	553392	1712750	124	6	A204	Cassava	ไร่มันสำปะหลัง	บ้านอีด่าง	ไร่มันสำปะหลังด้านทิศใต้ ไร่ข้าวโพดด้านทิศเหนือ
77	554407	1714649	136	6	A202	Corn	ไร่ข้าวโพด	บ้านปางไม้ไผ่	ไร่ข้าวโพด ริมทางหลวงแผ่นดินหมายเลข3438
78	555311	1714310	140	7	A100	Paddy field	นาข้าว	บ้านเพชรน้ำผึ้ง	นาข้าวด้านทิศตะวันออกเฉียงเหนือ ไร่มันสำปะหลังและไร่อ้อยด้านทิศตะวันตกเฉียงใต้
79	556258	1711824	132	4	U00	Urban and built-up land	พื้นที่อยู่อาศัย	บ้านเพชรน้ำผึ้ง	แยกบ้านเพชรน้ำผึ้ง ปลูกต้นสักสองข้างทาง
80	556934	1710418	124	6	U00	Urban and built-up land	พื้นที่อยู่อาศัย	บ้านปากเหมือง	ชุมชนบ้านปากเหมือง
81	556447	1710150	121	8	U00	Urban and built-up land	พื้นที่อยู่อาศัย	บ้านปากเหมือง	วัดปากเหมือง
82	555706	1709297	134	4	W00	Water bodies	พื้นที่แหล่งน้ำ	อ่างเก็บน้ำเขาวง	อ่างเก็บน้ำ
83	558030	1707985	129	5	A204	Cassava	ไร่มันสำปะหลัง	บ้านเขาดิน	ไร่มันสำปะหลังและทุ่งหญ้าเลี้ยงสัตว์
84	560422	1709299	115	3	U00	Urban and built-up land	พื้นที่อยู่อาศัย	อำเภอลานสัก	ถนนหน้าเทศบาลอำเภอลานสัก ปลูกต้นสักสองข้างถนน
85	560257	1709872	108	3	A100	Paddy field	นาข้าว	อำเภอลานสัก	นาข้าวด้านทิศเหนือ พื้นที่ปลูกมันสำปะหลังด้านทิศใต้
86	560555	1711107	114	5	A204	Cassava	ไร่มันสำปะหลัง	บ้านเขาพระพายเรือ	ไร่มันสำปะหลัง สวนมะม่วง
87	561268	1712128	115	7	F203	Sugarcane	ไร่อ้อย	บ้านเขาพระพายเรือ	ไร่อ้อย ต้นยูคาลิปตัสโดยรอบ
88	561350	1710291	113	5	W200	Built-up water resources	แหล่งน้ำที่สร้างขึ้น	บ้านพุหล่ม	อ่างเก็บน้ำบ้านพุหล่ม โครงการสูบน้ำด้วยไฟฟ้า
89	562886	1708296	109	6	F203	Sugarcane	ไร่อ้อย	บ้านวังหน้าศาล หมู่11 ตำบลประดู่ยืน	ไร่อ้อยติดโรงงานมันสำปะหลัง
90	563439	1708284	108	4	W100	Natural water bodies	แหล่งน้ำธรรมชาติ	บ้านวังหน้าศาล หมู่11 ตำบลประดู่ยืน	สะพานข้ามห้วยฆ้องชัย
91	563911	1708058	107	5	A100	Paddy field	นาข้าว	บ้านวังหน้าศาล หมู่11 ตำบลประดู่ยืน	นาข้าว และสวนไผ่ บ้านวังหน้าศาล
92	565755	1706825	102	7	A202	Corn	ไร่ข้าวโพด	บ้านประดู่ยืน	ไร่ข้าวโพดด้านทิศเหนือ ฝั่งตรงข้ามเป็นปั๊มสยามแก๊ส
93	567847	1706592	100	5	A100	Paddy field	นาข้าว	บ้านตะคร้อ	นาข้าว, ข้าวโพด
94	569379	1705946	95	5	A100	Paddy field	นาข้าว	บ้านตะคร้อ	นาข้าว
95	570098	1705799	94	6	U300	Institutional	สถานที่ราชการ	บ้านตะคร้อ	ที่ทำการองค์การบริหารส่วนตำบลประดู่ยืน อำเภอลานสักจังหวัดอุทัยธานี
96	571423	1706144	93	6	U00	Urban and built-up land	พื้นที่อยู่อาศัย	บ้านป่าคา	ทางหลวงชนบท อบ.4003
97	572566	1705889	90	6	U00	Urban and built-up land	พื้นที่อยู่อาศัย	บ้านทัพยายปอน	ชุมชนบ้านทัพยายปอน
98	574122	1706274	87	4	A202	Corn	ไร่ข้าวโพด	บ้านทัพยายปอน	ไร่ข้าวโพด

No.	East	North	Elevation (meter)	Error (meter)	Land use			Location	Description
					Lv.III	Name English	Name Thai		
99	578377	1705263	79	4	U00	Urban and built-up land	พื้นที่อยู่อาศัย	บ้านท่าชะอม	ชุมชนบ้านท่าชะอม
100	577500	1704407	80	6	U00	Urban and built-up land	พื้นที่อยู่อาศัย	บ้านท่าชะอม	
101	576576	1703855	80	4	A202	Corn	ไร่ข้าวโพด	คลองชลประทาน	ไร่ข้าวโพด
102	576692	1703540	80	3	W00	Water bodies	พื้นที่แหล่งน้ำ	ฝายทับเสลา (ฝั่งซ้ายลำน้ำ)	ฝั่งซ้ายลำน้ำทับเสลา เป็นฝายกักเก็บน้ำ โดยกรมชลประทาน
103	575596	1704271	88	5	A204	Cassava	ไร่มันสำปะหลัง	บ้านวังตอยาง	ไร่มันสำปะหลัง
104	575299	1704588	86	5	A100	Paddy field	นาข้าว	บ้านวังตอยาง	นาหว่าน เริ่มทำการเพาะปลูก
105	575139	1705276	88	6	F303	Eucalyptus plantation	สวนยูคาลิปตัส	บ้านวังตอยาง	สวนยูคาลิปตัสด้านทิศตะวันตก และไร่มันสำปะหลังด้านทิศตะวันออก
106	574995	1706066	87	3	M502	Laterite pit abandoned	บ่อลูกรังทิ้งร้าง	บ้านวังตอยาง	บ่อลูกรัง มีการขุดดำดินลูกรังไปก่อสร้าง และเริ่มมีการปรับพื้นที่โดยการปลูกยูคาลิปตัส
107	570551	1705571	91	6	U00	Urban and built-up land	พื้นที่อยู่อาศัย	บ้านป่าคา	สะพานข้ามห้วยทับเสลา บ้านป่าคา-บ้าน(โนน)ดินแดง มีการตักทรายจะห้วยทับเสลาขึ้นมาเพื่อทำการก่อสร้าง
108	570253	1704957	97	4	A201	Mixed field crops	พืชไร่ผสม	บ้าน(โนน)ดินแดง	พื้นที่ปลูกถั่ว สวนมะม่วง และมันสำปะหลัง
109	568424	1704563	94	6	U00	Urban and built-up land	พื้นที่อยู่อาศัย	บ้านบุ่งฝาง	วัดเขาดินแดงบ้านบุ่งฝาง ปลูกต้นสักริมทางหลวงหมายเลข3438
110	566574	1705550	95	6	F203	Sugarcane	ไร่อ้อย	บ้านนิคมสามัคคี	ปลูกไร่อ้อย และมันสำปะหลัง
111	565811	1705959	96	5	A100	Paddy field	นาข้าว	บ้านนิคมสามัคคี	ชุมชนบ้านนิคมสามัคคี ปลูกข้าว
112	570751	1703941	91	4	A204	Cassava	ไร่มันสำปะหลัง	บ้านล่องตะเคียนเตี้ย	เริ่มปลูกมันสำปะหลัง บริเวณเขาปลาร้า
113	573917	1704354	78	5	A100	Paddy field	นาข้าว	บ้านเขากวางทอง	นาข้าว
114	576581	1702886	72	5	U00	Urban and built-up land	พื้นที่อยู่อาศัย	บ้านทับเสลา (ชลประทาน) ตำบลทุ่งโพธิ์ อำเภอหนองฉาง	ชุมชนบ้านชลประทาน ใกล้ฝายทับเสลาฝั่งขวาของลำห้วยทับเสลา
115	576710	1703484	71	4	W00	Water bodies	พื้นที่แหล่งน้ำ	บ้านทับเสลา (ชลประทาน) ตำบลทุ่งโพธิ์ อำเภอหนองฉาง	ฝั่งขวาของลำห้วยทับเสลา ฝายทับเสลา
116	577398	1708072	72	4	A100	Paddy field	นาข้าว	บ้านเขาน้อย ตำบลเขากวางทอง อำเภอหนองฉาง	นาข้าว
117	577305	1701712	73	3	A100	Paddy field	นาข้าว	บ้านเขาน้อย ตำบลเขากวางทอง อำเภอหนองฉาง	นาข้าวติดเขาน้อย ป่าชุมชนเขาน้อย

Photographs illustrating locations of the field investigation

(Sample locations referred to Figure 3-5, 3-6, 3-7 and 3-8)


บ้านเขาเขียว 8

บ้านเขาเขียว 9


บ้านเขาเขียว 9


ป่าเต็งรัง เขตรักษาพันธุ์สัตว์ป่าห้วยขาแข้ง 14


ป่าเต็งรัง เขตรักษาพันธุ์สัตว์ป่าห้วยขาแข้ง 15


ลานจอดรถ เขตรักษาพันธุ์สัตว์ป่าห้วยขาแข้ง 16


เขตรักษาพันธุ์สัตว์ป่าห้วยขาแข้ง 17


บ้านพักสืบ นาคะเสถียร 19

เขตรักษาพันธุ์สัตว์ป่าห้วยขาแข้ง 20

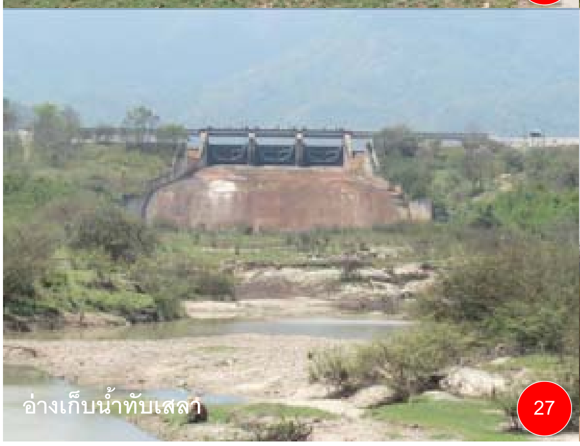
นาข้าว บ้านเพชรเจริญ 24

ป่าชุมชนห้วยทับเสลา-ป่าห้วยคอกควาย 26

ป่าชุมชนห้วยทับเสลา-ป่าห้วยคอกควาย 26

อ่างเก็บน้ำทับเสลา 27

อ่างเก็บน้ำทับเสลา 27



อ่างเก็บน้ำทับเสลา 27

อ่างเก็บน้ำทับเสลา 32


ทางเข้าสวนป่าระบำ 32


ไร่ข้าวโพด บ้านอ่างห้วยดง 33


บ้านอ่างห้วยดง 33


สวนไผ่ บ้านอ่างห้วยดง 34

ไร่ข้าวโพด บ้านโป่งมะค่า 35


ไร่มันสำปะหลังแบบยกร่อง บ้านโป่งมะค่า 36


ไร่ข้าวโพด บ้านโป่งมะค่า 40


ไร่มันสำปะหลังแบบยกร่อง บ้านเขาหินเทิน 41

ไร่สับปะรด บ้านเขาหินเทิน 41

ไร่มันสำปะหลัง บ้านเขาหินเทิน 42

ไร่มันสำปะหลัง บ้านเขาหินเทิน 42

ไร่มันสำปะหลัง บ้านโป่งสามสิบ 45

แนวรอยต่อเขตรักษาพันธุ์สัตว์ป่า บ้านโป่งสามสิบ 48

แนวรอยต่อเขตรักษาพันธุ์สัตว์ป่า บ้านโป่งสามสิบ 48

บ้านเขาไม้นวล 49

บ้านเขาไม้นวล 49


ถนนบ้านโป่งสามสิบ-บ้านปากเหมือง 50

ไร่มันสำปะหลังริมห้วย บ้านทรัพย์สมบูรณ์ 53

ไร่มันสำปะหลังริมห้วย บ้านทรัพย์สมบูรณ์ 53


ไร่ข้าวโพด บ้านคีรีวงษ์ (บ้านคลองไม้ลาย) 51


ทางแยกเข้าบ้านห้วยรัง บ้านท่ามะนาว 56

ลำน้ำห้วยรัง บ้านห้วยรัง 57

ลำน้ำห้วยรัง บ้านห้วยรัง 57


บ้านปากเหมือง 59


สะพานข้ามห้วยทับเสลา อำเภอลานสัก 60


ไร่ข้าวโพด บ้านเขาวง 61

เขาฆ้องชัย 63


เขาฆ้องชัย สหกรณ์อำเภอลานสัก 63


นาข้าว บ้านนาไร่เดียว 64

เขาหินปูน เขาฆ้องชัย 65


ตัวเมืองตำบลลานสัก อำเภอลานสัก 67

ตัวเมืองตำบลลานสัก อำเภอลานสัก 67


ตัวเมืองตำบลลานสัก อำเภอลานสัก 67

สะพานข้ามห้วยทับเสลา บ้านห้วยรัง 70


สะพานข้ามห้วยทับเสลา บ้านห้วยรัง 70


ไร่มันสำปะหลัง บ้านห้วยรัง 72


ไร่มันสำปะหลัง บ้านห้วยรัง 72


ไร่มันสำปะหลัง บ้านปางควาย 73


บ้านอีด่าง 75


สวนสัก บ้านเพชรน้ำผึ้ง 79

อ่างเก็บน้ำเขาวง 82

ทุ่งหญ้าเลี้ยงสัตว์ บ้านเขาดิน 83

นาข้าว ชานเมืองอำเภอลานสัก 85

สวนมะม่วง บ้านเขาพระพายเรือ 86

บ้านวังหน้าศาล 90

บ้านประดู่ยืน 92

นาหว่าน บ้านตะคร้อ 94

ทุ่งนา บ้านตะคร้อ 94


บ้านทับยายปอน 97

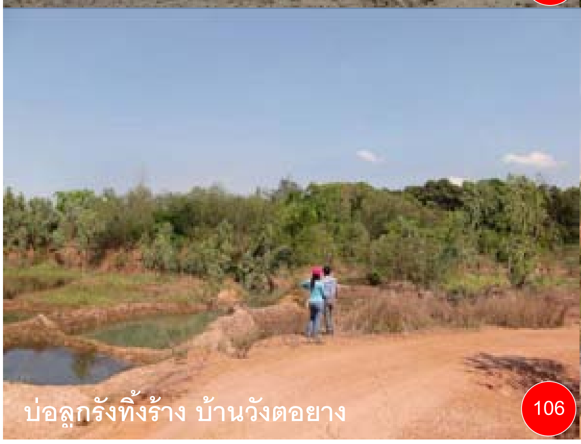

ไร่ข้าวโพด บ้านทับยายปอน 98


ไร่ข้าวโพด ฝายทับเสลา 101


ฝายทับเสลา 102


นาหว่าน บ้านวังตอยาง 104


สวนยูคาลิปตัส บ้านวังตอยาง 105


บ่อลูกรังทิ้งร้าง บ้านวังตอยาง 106


บ่อลูกรังทิ้งร้าง บ้านวังตอยาง 106


บ่อลูกรังทิ้งร้าง บ้านวังตอยาง 106


บ้านป่าคา 107


บ้านป่าคา 107


พืชไร่ผสม บ้านโนนดินแดง 108


บ้านโนนดินแดง 108


บ้านทับเสลา ประตูน้ำทับเสลา 114


บ้านทับเสลา ฝายทับเสลา 115


บ้านทับเสลา ฝายทับเสลา 115

Logistic regression result as inputs in CLUE-s model

Setting of logistic regression results in CLUE-s model

Format	Description
0,1,2,3	Number code for each land use type
β_0	Constant of regression equation for land use type
1, 2, 3, …	Number of explanatory factors in the regression equation for that land use type.
$\beta_1, \beta_2, \beta_{3,...}$	On each line the beta coefficients for the explanatory factors and the number code of the explanatory factors.

Format of logistic regression results in CLUE-s based (alloc1.reg file) in the table above:

alloc1 - Notepad

File Edit Format View Help

```
0
        -2.3420
7
        0.0164 0
        0.0557 1
        -0.0029 2
        -0.0005 3
        0.0007 4
        0.0007 5
```

The beta coefficients for forest land

```
1
        -0.7367
8
        -0.0104 0
        -0.0346 1
        0.0026 2
        0.0005 3
        -0.0011 4
        -0.0005 5
        -0.5606 6
```

The beta coefficients for agricultural land

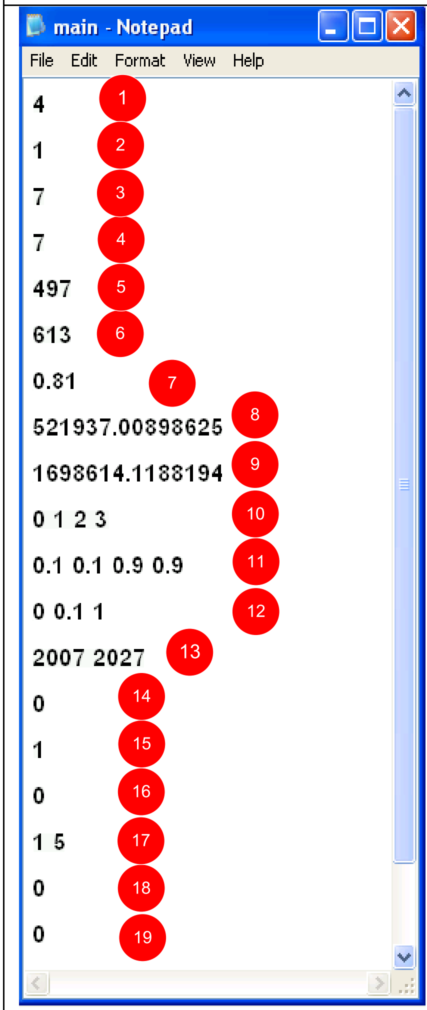
```
2
        8.5390
4
        -0.1523 1
        -0.0082 2
        -0.0002 5
        -0.2418 6
```

The beta coefficients for urban and built-up land

```
3
        -34.2834
6
        -0.0563 0
        -1.0038 1
        0.0316 2
        0.0039 4
        -0.0006 5
        -1.9460 6
```

The beta coefficients for water bodies

Parameter settings for all of variables in the CLUE-s model

Main file	Line	Format	Description
	1	Integer	Number of land use types
	2	Integer	Number of regions
	3	Integer	Maximum number of Independent variables in a regression equation
	4	Integer	Total number of driving factors
	5	Integer	Number of rows
	6	Integer	Number of columns
	7	Float	Cell area (ha) of the grid cells
	8	Float	X-coordinate of the lower left corner
	9	Float	Y-coordinate of the lower left corner
	10	Integer	Number coding of the land use types
	11	Float	Codes for conversion elasticities
	12	Float	Iteration variables for output
	13	Integer	Start and end year of simulation
	14	Integer	Number and coding of explanatory factors that change every year/dynamic driving factors
	15	1, 0, 2 or 2	Output/input file – ArcView (1)
	16	0, 1, or 2	Region specific regression choice, no different regressions for different regions (0)
	17	0, 1, or 2	Initialization of land use history, A random number will be assigned to all pixels to represent the number of years that the current land use is already found at that location according to the standard seed for the random number generator
	18	0, 1, or 2	Neighborhood calculation choice-optional
	19	Integer	Location specific preference addition-optional

Available land use type and driving factor files

File name	Description
Cov1_0.0	Forest land
Cov1_1.0	Agricultural land
Cov1_2.0	Urban and built-up land
Cov1_3.0	Water bodies
Sc1gr0.fil	Elevation
Sc1gr1.fil	Degree of Slope
Sc1gr2.fil	Mean annual precipitation
Sc1gr3.fil	Distance to stream
Sc1gr4.fil	Distance to road
Sc1gr5.fil	Distance to village
Sc1gr6.fil	Soil texture

BIOGRAPHY

Mr. Katawut Waiyasusri was born in Pathumthani, Thailand on January 1, 1986. In 2007 he received a Bachelor of Arts degree in Geography with second class honors from Department of Geography, Faculty of Arts, Silpakorn University. After then he entered the Earth Sciences program, Department of Geology, Faculty of Science, Chulalongkorn University for a Master of Science degree study.