APPLICATIONS OF GEOINFORMATICS TECHNOLOGY TO LAND EVALUATION FOR ENERGY ECONOMIC CROPS IN WESTERN THAILAND

Kanlaya Tienwong

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

Suranaree University of Technology

Academic Year 2008

การประยุกต์เทคโนโลยีภูมิสารสนเทศในการประเมินคุณภาพที่ดินสำหรับพืชเศรษฐกิจที่ให้พลังงาน ในภาคตะวันตก ประเทศไทย

นางสาวกัลยา เทียนวงศ์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
สาขาวิชาภูมิสารสนเทศ
มหาวิทยาลัยเทคโนโลยีสุรนารี
ปีการศึกษา 2551

APPLICATIONS OF GEOINFORMATICS TECHNOLOGY TO LAND EVALUATION FOR ENERGY ECONOMIC CROPS IN WESTERN THAILAND

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

Thesis Examining Committee

____

(Asst. Prof. Dr. Sunya Sarapirome)

Chairperson

____

(Asst. Prof. Dr. Songkot Dasananda)

Member (Thesis Advisor)

____

(Assoc. Prof. Dr. Charlie Navanugraha)

Member (Thesis Co-Advisor)

____

(Assoc. Prof. Dr. Sompong Thammathaworn)

Member

____

(Dr. Suwit Ongsomwang)

Member

____

(Prof. Dr. Pairote Sattayatham)

Vice Rector for Academic Affairs

____

(Assoc. Prof. Dr. Prapan Manyum)

Dean of Institute of Science

กัลยา เทียนวงศ์ : การประยุกต์เทคโนโลยีภูมิสารสนเทศในการประเมินคุณภาพที่ดินสำหรับพืชเศรษฐกิจที่ให้พลังงาน ในภาคตะวันตก ประเทศไทย (APPLICATIONS OF GEOINFORMATICS TECHNOLOGY TO LAND EVALUATION FOR ENERGY ECONOMIC CROPS IN WESTERN THAILAND) อาจารย์ที่ปรึกษา : ผู้ช่วยศาสตราจารย์ ดร.ทรงกต ทศานนท์, 233 หน้า.

วิทยานิพนธ์ฉบับนี้ประกอบไปด้วยรายงานผลการวิจัยใน 4 หัวข้อคือ (1) การวิเคราะห์รูปแบบการเปลี่ยนแปลงที่ตรวจสอบพบและการทำนายรูปแบบการใช้ประโยชน์ที่ดินและสิ่งปกคลุมดิน (LULC) สำหรับจังหวัดกาญจนบุรี ระหว่างปี ค.ศ. 1992-2006 (2) การตรวจสอบปัจจัยขับเคลื่อนซึ่งมีความสัมพันธ์มากที่สุดกับการผันแปรเชิงเวลาของปริมาณพื้นที่เกษตรกรรมใน 4 ช่วงเวลาที่ระบุ (3) พัฒนาแผนที่ความเหมาะสมของที่ดินสำหรับการปลูกอ้อยและมันสำปะหลัง (4) ระบุตำแหน่งที่มีแนวโน้มเหมาะสมสำหรับที่จะตั้งโรงงานเอทานอลแห่งใหม่ในจังหวัด

จากการผันแปรของการใช้ประโยชน์ที่ดินระหว่างปี ค.ศ. 1992-2006 สามารถสรุปอย่างกว้างๆ ได้ว่ารูปแบบการผันแปรของ LULC ที่ตรวจสอบได้ในช่วงเวลาดังกล่าวมีลักษณะดังนี้ (1) การเปลี่ยนแปลงระหว่างกันเป็นอย่างมากของป่าไม้และพื้นที่เกษตรกรรม (โดยเฉพาะพืชการค้า) (2) การผันแปรอย่างสำคัญของรูปแบบ LULC ในพื้นที่เกษตรกรรม (จากคาบเวลาสู่คาบเวลา) (3) การเพิ่มขึ้นอย่างเด่นชัดของพืชพลังงาน (โดยเฉพาะอ้อย) และการลดลงอย่างเด่นชัดของพื้นที่ข้าว (4) การเพิ่มขึ้นอย่างรวดเร็วของพื้นที่เมืองจากการสูญเสียพื้นที่เกษตรกรรม (โดยเฉพาะนาข้าว) สำหรับแผนที่ LULC ในอนาคต (สร้างจากแบบจำลอง Markov and CA-Markov) บ่งชี้ว่าพื้นที่เกษตรกรรมจะลดลงเล็กน้อยขณะที่พื้นที่ป่าไม้เพิ่มขึ้นเล็กน้อยระหว่างปี ค.ศ. 2006 ถึง 2020

ผลการศึกษาจากแบบจำลองสมการถดถอย (multiple regression) เปิดเผยว่า กลุ่มของปัจจัยเหนี่ยวนำที่แตกต่างกันซึ่งมีความสัมพันธ์มากที่สุดกับปริมาณการเปลี่ยนแปลงของพื้นที่เกษตรกรรมที่พบระหว่างช่วงเวลาที่ระบุ (โดยมีระดับความสัมพันธ์ที่ค่อนข้างสูง) โดยทั่วไปปัจจัยทางภูมิอากาศ (โดยเฉพาะอุณหภูมิ) ได้รับการระบุว่าเป็นปัจจัยเหนี่ยวนำที่สำคัญที่สุดในเกือบทุกช่วงเวลาที่พิจารณา

จากการวิเคราะห์ความเหมาะสมของที่ดินพบว่าประมาณ 52.49 และ 45.07 เปอร์เซ็นต์ ของพื้นที่ศึกษาถูกจำแนกเป็นเขตเหมาะสมมากและเหมาะสมปานกลางสำหรับการปลูกอ้อยและมันสำปะหลังตามลำดับ ขณะที่เพียงไม่กี่เปอร์เซ็นต์ของพื้นที่ถูกพบว่าไม่เหมาะสม โดยพื้นที่เหมาะสมที่สุดสำหรับพืชทั้งสองชนิดตั้งอยู่ในด้านตะวันออกและด้านใต้ของจังหวัดเนื่องจากการมีดินที่สมบูรณ์สูงและมีแหล่งน้ำที่ใช้ประโยชน์ได้จำนวนมากตั้งอยู่

จากการวิเคราะห์ความเหมาะสมของตำแหน่งที่ตั้งพบว่า มีห้าตำแหน่งที่อาจเป็นตัวเลือกของโรงงานเอทานอลใหม่ได้ โดยสองตำแหน่งตั้งอยู่ในอำเภอบ่อพลอย หนึ่งตำแหน่งในอำเภอเมืองกาญจนบุรี และอีกสองตำแหน่งตั้งอยู่ในอำเภอท่าม่วง อย่างไรก็ตาม ตัวเลือกของตำแหน่งที่เหมาะสมที่สุดขึ้นอยู่กับสถานการณ์ที่พิจารณาเป็นสำคัญ อิงตามปริมาณพื้นที่เพาะปลูกพืชไร่ซึ่งอยู่ในเขตบริการ 0-50 กม. ตัวเลือกทั้งสองตัวเลือกในอำเภอบ่อพลอยได้รับการวินิจฉัยในเบื้องต้นว่ามีความเหมาะสมมากที่สุดสำหรับการเพาะปลูกอ้อยและมันสำปะหลังที่พบในปี ค.ศ. 2006 เนื่องจากครอบคลุมพื้นที่เพาะปลูกมากที่สุดในเขตบริการดังกล่าว

สาขาวิชาการรับรู้จากระยะไกล ลายมือชื่อนักศึกษา__________________________

ปีการศึกษา 2551 ลายมือชื่ออาจารย์ที่ปรึกษา ___________________

ลายมือชื่ออาจารย์ที่ปรึกษาร่วม ________________

KANLAYA TIENWONG : APPLICATIONS OF GEOINFORMATICS TECHNOLOGY TO LAND EVALUATION FOR ENERGY ECONOMIC CROPS IN WESTERN THAILAND. THESIS ADVISOR : ASST. PROF. SONGKOT DASANANDA, Ph.D. 233 PP.

LAND EVALUATION/ ENERGY CROPS/ LAND USE CHANGE/ MARKOV CHAIN/ CA-MARKOV/ ETHANOL INDUSTRY LOCATION

There are four main works reported in this thesis which are (1) pattern analysis of the observed LULC change and prediction for Kanchanaburi Province during 1992-2006, (2) examination of driving factors that are most related to the temporal changes in amount of agricultural land during the four specified periods, (3) development of land suitability maps for the sugarcane and cassava cultivations, and (4) identification potential suitable locations for new ethanol plant to be situated in the province.

From the land use change analysis during 1992-2006, it can be broadly concluded that the observed LULC change pattern within this specified period were characterized by (1) substantial changes between forest area and agricultural land (cash crops in particular) (2) prominent changes of LULC pattern within agricultural land category (from period to period) (3) notable increase in the amount of energy crops (especially sugar cane) and great loss of paddy fields, and (4) rapid expansion of urban in expense of the agricultural area nearby (especially paddy field). The predicted LULC maps (based on Markov and CA-Markov models) inform that the agricultural land should slightly increase and forest area slightly decreases from 2006 to 2020.

Results from the multiple regression models revealed that the different groups of influencing factors that were related most closely to the amount of agricultural land use change found during each specified period (with fairly high correlation levels achieved). In general, the climatic factors (temperature in particular) were identified as being most important influencing factors in nearly all considered periods.

From land suitability analysis, it was found that about 52.49 and 45.07 percent of the study area were classified as highly or moderately suitable for growing sugarcane and cassava respectively while only a few percent was found unsuitable. Most suitable areas for both crops were located in the eastern and southern parts of the province due to the highly fertile soil and abundant water resources available.

From the site suitability analysis, it was discovered that five locations should be candidates for the new ethanol factory, including two locations in Boploi District, one in Muang Kanchanaburi District, and the other two sites in Thamuang District. However, the choices of most suitable site depend greatly on the scenario considered. Based on amount of crop growing area within 0-50 km service zone, both candidates in Boploi District were initially identified as being the most suitable sites for sugarcane and cassava farming seen in 2006 as they cover the most farming area in that zone.

School of Remote Sensing | Student's Signature___________________

Academic Year 2008 | Advisor's Signature __________________

Co-Advisor's Signature _______________

ACKNOWLEDGEMENTS

First of all, I would like to express my appreciation to my supervisor, Asst. Prof. Dr. Songkot Dasananda for his helpful guidance, kind assistance, and moral support given to me during the period of my study at SUT, and also to my co-supervisor, Assoc. Prof. Dr. Chalie Navanugraha for his valuable guidance and time spending for discussion on many concerned problems. My thesis would never be completed without their helps.

I am very grateful for support and cooperation of my thesis committee, Assoc. Prof. Dr. Sompong Thammathaworn, Asst. Prof. Dr. Sunsa Sarapirom, and Dr. Suwit Ongsomwang. Thanks are also due to the GISTDA, LDD, and DEQP for providing the necessary data, and to all the corresponding experts for their responses to distributed questionnaires. Financial support from the Royal Thai government and personal support from my colleages, Asst. Prof. Charun Sangpoum, Assoc. Prof. Dr.Wichai Srikam, and Asst. Prof. Apisek Pansuwan, who gave me an opportunity to complete my Ph.D. study at SUT, are also appreciated. My sincere thanks are given to Manus Tienwong, Sukhum Phoemee, Pairin Cheenthanom, and Pornchai Tarasawat for their help with the field surveys.

I gratefully express my full appreciations to my dear friends, Dr. Mayureesririn Sririwan, Dr. Nisakorn Prakonchati, Panida Tasee, Wang June, Amornrat Chaiyatum, Nutthapol Junkeaw, Pichai Wongsawat, Sililak Tanang, Somporn Chobtham, Penpraphai Phuthong, and Ratchaneekorn Chatuthai for all their care and help me in everything of studying, and to all my friends from School of Remote Sensing for their kind help and moral support.

Above all, I would like to thank my family for their financial support, great care and long-lasting love. The merit of this thesis, I dedicate to my father, my mother, my elder brother, all former teachers and everyone who have taught me.

Kanlaya Tienwong

CONTENTS

Page

CONTENTS (Continued)

CONTENTS (Continued)

CONTENTS (Continued)

CONTENTS (Continued)

LIST OF TABLES

Table **Page**

LIST OF TABLES (Continued)

Table **Page**

LIST OF TABLES (Continued)

Table **Page**

LIST OF FIGURES

Figure **Page**

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF ABBREVIATIONS

GIS	Geographic Information System
RS	Remote Sensing
Km^2	Square Kilometer
NRD2C	Village Based Socio-Economic Data
ETM+	Enhance Thematic Mapper Plus
TM	Thematic Mapper
MSS	Multispectral Scanner System
CA	Cellular Automata
MC	Markov Chain
CA-Markov	Cellular Automata and Markov Model
FAO	Food and Agriculture Organization of the United Nations
LDD	Land Development Department
MCE	Multi-Criteria Evaluate
AHP	Analytic Hierarchical Process
GPS	Global Position System
DN	Digital Number
IR	Infrared
S1	Highly Suitable
S2	Moderately Suitable
S3	Marginally Suitable
N	Not Suitable

LIST OF ABBREVIATIONS (Continued)

N	Nitrogen
P	Phosphorus
K	Potassium
C.E.C.	Cation Exchange Capacity
B.S.	Base Saturation
MCDA	Multi-Criteria Decision Analysis
MCDM	Multi-Criteria Decision Making
LU	Land Use
LULC	Land Use /Land Cover
LUCC	Land Use /Land Cover Change
UTM	Universal Transverse Mercator
GISTDA	Geo-Informatics and Space Technology Development Agency (Public Organization)
WGS	World Geodetic System
RGB	Red Green Blue
OC	Other Cultivation
SC	Sugarcane
CV	Cassava
ET	Eucalyptus
PA	Pineapple
F	Forest
W	Water bodies

LIST OF ABBREVIATIONS (Continued)

U	Urban and built-up area
RC	Relative Change
DEM	Digital Elevation Model
UTM	Universal Transverse Mercator
CR	Consistency Ratio
Km	Kilometer
X	Independent Variable
Y	Dependent Variable
PA	Procedure’s Accuracy
US	User’s Accuracy

CHAPTER I

INTRODUCTION

1.1 Background

Kanchanaburi is the biggest province in western Thailand which is famous for its abundance of fertile forests, industrial minerals (like gold, gem, and tin) and the energy crop plantation (like cassava and sugarcane). The forest areas cover about 60% of the total area (mostly dry evergreen and mixed deciduous forests) which are home to a wide range of ecosystems and precious natural habitats and the rest of the area is mostly used for agriculture and for being living area.

Like most provinces in Thailand, agriculture is still a crucial component of the land use found where it covers about 30% of the total provincial area, mainly on the flat plain area in the south. As most people still live in the agricultural section but the agricultural land resource is rather limited, therefore, the proper land use strategy for the province is really necessary to assist the sustainable and productive use of land by farmers and reduce great loss of forest area due to the expansion of agricultural land. To develop this strategy effectively, the understanding in dynamic patterns of past and present land use activities within the province is needed and this could be achieved by interpreting multi-temporal satellite images, like Landsat TM, or aerial photographs of the area taken in the interested time period. This kind of work is useful for land use planners; however, it is still rarely implemented in Thailand so far.

Also, knowledge in characteristics of agricultural land use change over time is necessary for the understanding of hidden mechanisms that are responsible for those changes, which can greatly benefit the land use planning of the area.

Moreover, as the consumption of ethanol-mixed gasoline (called gasohol) has been rising dramatically in the last decade especially during the recent oil-price crisis, due to the low-price policy of gasohol implemented by the Thai government, the need for ethanol raw material, like sugarcane and cassava, is also greatly increased. This could provide good opportunity for the local farmers to expand their cultivation of both crops in the near future, if required. And to identify potential area that might be suitable to grow these crops productively, the science of land suitability analysis can be implemented by researchers and results can be used as initial guideline for farmers and the responsible agencies later. In addition, if the new ethanol plant is required for the province (as there is only single factory situates in the province so far), knowledge of the present land use pattern (especially for sugarcane and cassava) can be used in conjunction with experts' opinions to identify the suitable locations for this new plant in order to serve the farmer needs more satisfactorily.

1.2 Research Objectives

The main objectives of this work are as follows (see Figure 1.1 for flowchart):

1.2.1 To analyze patterns of the land use/land cover change in the study area between 1992-2006;

1.2.2 To determine influencing factors of agricultural land use changes found between 1992-1996, 1996-2001, 2001-2006, and 1992-2006;

1.2.3 To evaluate land suitability for sugarcane and cassava cultivations; and

1.2.4 To identify suitable locations for the ethanol plant that uses sugarcane and cassava as raw materials.

1.3 Conceptual Framework

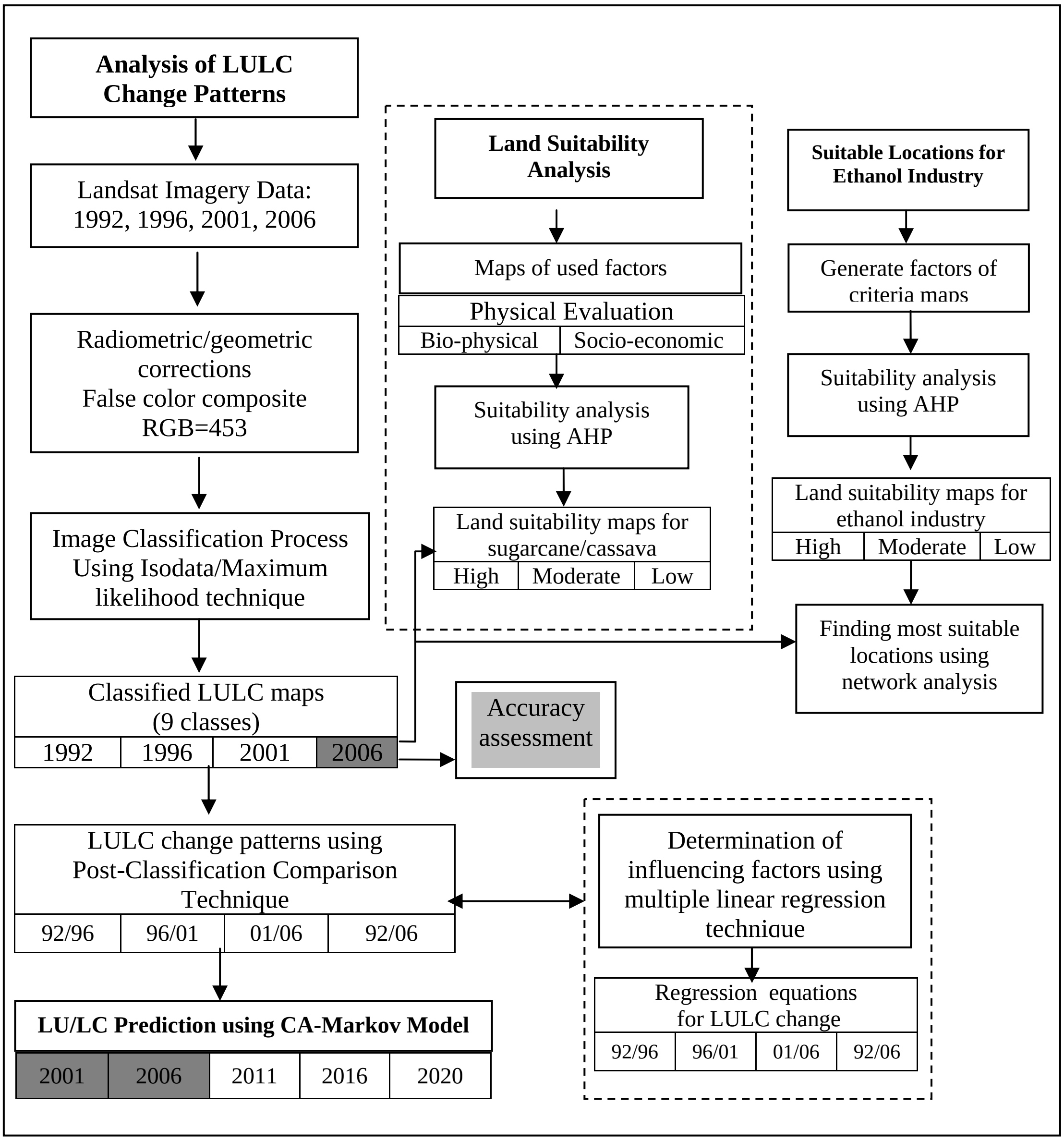


Figure 1.1 Conceptual framework of the whole study

1.4 Scope of the Study

1.4.1 Study area is Kanchanaburi Province, western Thailand (Figure 1.2).

1.4.2 Detail of Landsat imagery used in this study is given in Table 1.1 as below

Table 1.1 Information of Landsat satellite images data

Landsat	Date	Path/Row
	30/01/1993	130/50
Landsat-5 TM	30/01/1993	130/49
	18/11/1992	131/50
	25/01/1997	130/50
Landsat-5 TM	25/01/1997	130/49
	29/11/1996	131/50
Landsat-7 ETM+	30/12/2001	130/50
	30/12/2001	130/49
	07/02/2002	131/50
	03/02/2006	130/50
Landsat-5 TM	03/02/2006	130/49
	22/11/2005	131/50

1.4.3 The village-based socio-economic data (NRD2C) and classified Landsat-TM/ETM+ data (taken in 1992, 1996, 2001, and 2006) are used to analyze general LULC change pattern and multiple regression model is used to determine influencing factors of the observed changes.

1.4.4 LULC patterns for 2001, 2006, 2010, 2011, 2016, and 2020 are creates using Markov chain and CA-Markov models available in Idrisi software.

1.4.5 The total of 9 LULC classes are identified which are forest, sugarcane, cassava, paddy field, eucalyptus, pineapple, other cultivation, urban/built-up area, and water body.

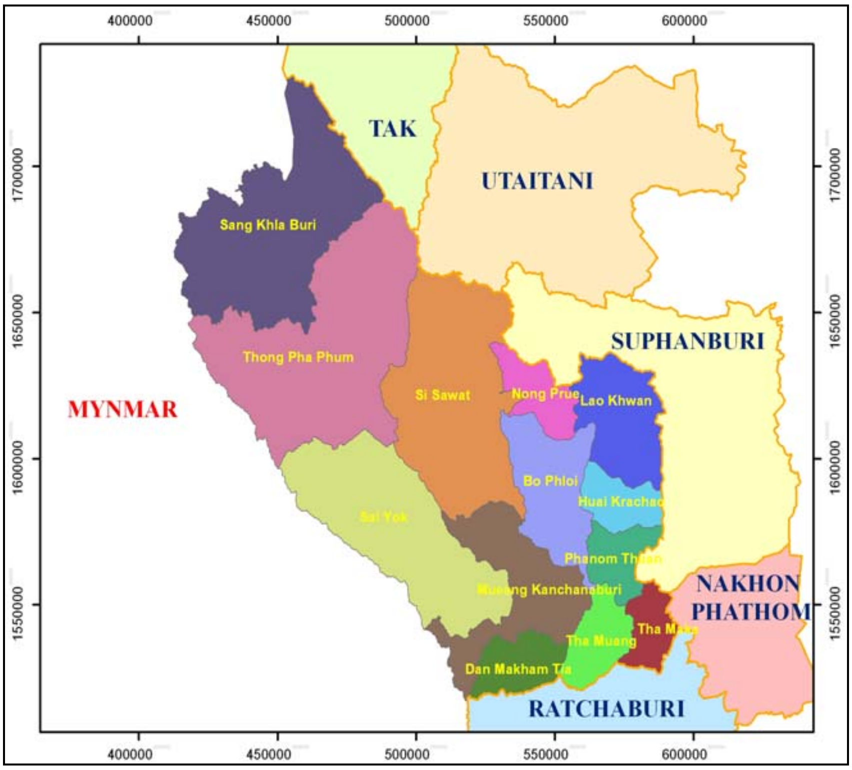


Figure 1.2 Study area and political boundary of Kanchanaburi Province

1.5 Limitation of the Study

1.5.1 Evaluation of suitable area for sugarcane and cassava plantation is done based on criteria guided by FAO in 1976 and Land Development Department in 1996.

1.5.2 Land evaluation of suitable area for energy crops were considered in physical land evaluation.

1.5.3 An analysis of ethanol industry was considered the relation of sugarcane and cassava plantation area, sugar factory specify in Kanchanburi Province.

1.6 Study Area

Kanchanaburi is the Thailand's third largest province and the biggest one in western territory. It is located between latitude 13°45´-15°41´N and longitude 98°10´-99°52´E close to Myanmar border with altitude ranges from about 65 to 1750 m above mean sea level (msl). Its area cover is about 19,380 km^2 (or 12,176,967 rai) with total population of 860,341 (in 2008) distributed within 13 districts: Muang, Tha Muang, Phanom Thuan, Tha Maka, Dan Makham Tia, SaiYok, Thong Pha Phum, Sangkhla Buri, Si Sawat, Bo Phloi, Nong Prue, Huai Krachao, and Lao Khwan (Figure 1.2).

Kanchanaburi is a mountainous province comprising of great mountain ranges in the north and middle (especially in Thong Pha Phum, Sangkhla Buri, Si Sawat, and SaiYok District), while the slow downhill and river plain appear mostly in the south in which agriculture and urban/built-up are located. From land-use and land-cover map, the area ratio of forest and agriculture is 3:1 approximately.

There are three main rivers found in the province which are Khwae Noi (315-km. long), Khwae Yai (386-km long), and Maeklong (130-km long) and two large dams, which are Wachiralongkorn Dam (seen in the upper north) and Srinagarindra Dam (seen in the central part) (Figure 1.3).

Its local climate is monsoonal which is marked by a pronounced rainy season lasting from about May to September and a relatively dry season for the remainder of the year; however, amount of annual rainfall can vary dramatically from year to year. Temperatures are highest in March and April (summer) and lowest in December and January (winter). The annual rainfall is 804.7 mm in 2007 where the temperatures in summer are 20-38°C and 17-30°C in winter (Kanchanaburi Province, 2007).

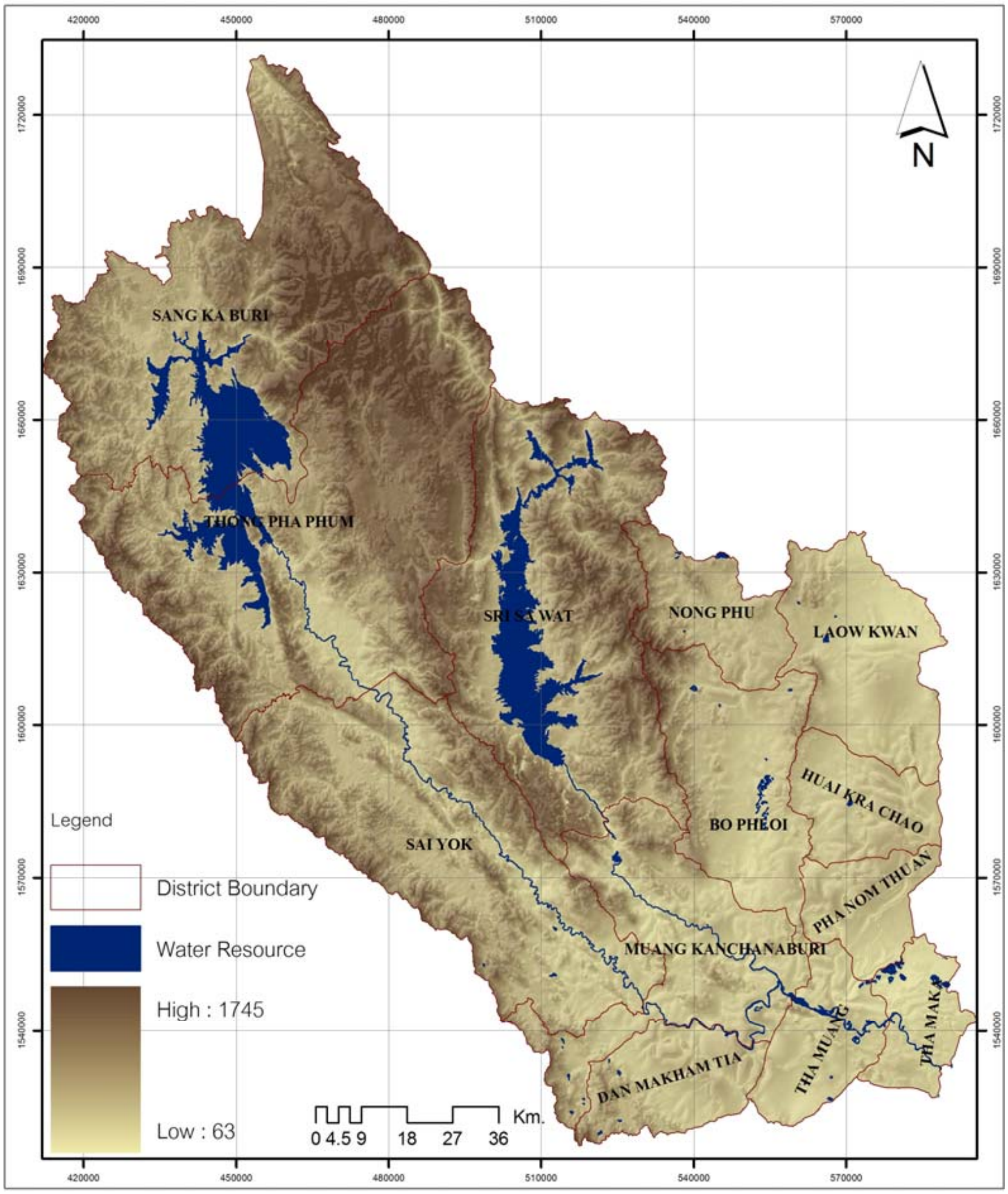


Figure 1.3 Topographic map of Kanchanaburi Province

Kanchanaburi is famous for its abundance of fertile forests, industrial minerals (like gold, gem, and zinc) and the energy crop plantation (like cassava and sugarcane). The forest areas cover about 60% of the total area (mostly dry evergreen and mixed deciduous forests) which are home to a wide range of ecosystems and precious natural habitats. These forests are part of the Western Forest Complex (WEFCOM) which is the largest and most important forest complex in Thailand where at least 9 National

Parks and 6 Wildlife Sanctuaries have been established therein. Among these, two of the largest wildlife sanctuaries, Huai Kha Khaeng and Thung Yai Naresuan, have been designated as World Heritage Sites by UNESCO in 1991 (Emphandhu, 2003; Trisurat, 2003; UNESCO-World Heritage, 2009).

At present, most forests are legally conserved and systematically protected by several agencies of the Thai government in cooperation with the responsible local authorities. However, reports of forest loss still exist from time to time, especially due to the agricultural expansion, shifting cultivation, and illegal logging. And, like most provinces in Thailand, agriculture is a crucial component of the land use found where it covers about 30% of the total area, mainly in the lowlands close to main rivers and water reservoirs in the south. The provincial main economic plants are rice, corn, vegetation, and energy crops, like cassava and sugarcane.

1.7 Expected Results

1.7.1 Knowledge of past and present patterns of LULC in the study area;

1.7.2 Knowledge in trend of LULC changes and their influencing factors;

1.7.3 Land suitability maps for cassava and sugarcane cultivation; and

1.7.4 Knowledge of suitable locations for new ethanol plant.

1.8 References

Department of Provincial Administration. (2009). Statistic of population [On-line]. Available: http://www.dopa.go.th/.html

Kanchanaburi Province. (2007). General information data of Kanchanaburi Province [On-line]. Available: http://www.kanchanaburi.go.th.html

Trisurat, Y. (2003). Ecosystem-based management zones of Western forest complex in Thailand. In **Proceedings of the 5th International Conference on Scientific and Management of Protected Areas Association**. Vancouver: University of Victoria, Canada.

United Nation Environment Programme. (2009). Thungyai-Huai Kha Khaeng wildlife sanctuaries Thailand [On-line]. Available: http://www.unep-cmc.org/sites/wh/pdf/Thungyai-%20HKK.pdf.html

CHAPTER II

ANALYSIS AND PREDICTION OF LAND USE/LAND COVER CHANGE

2.1 Abstract

This study presents pattern analysis of the land use/land cover change (LUCC) found in Kanchanaburi Province during 15-year period from 1992 to 2006 based on land use/land cover (LULC) data derived from the Landsat TM and ETM+ images in 1992, 1996, 2001, and 2006 with the assistance of GIS tools. This knowledge was then used as priori information for the stochastic Markov chain and CA-Markov models to forecast trends of future LUCC in years 2011, 2016, and 2020. Results of the study indicated that LUCC patterns during the proposed period were characterized by (1) substantial changes between forest area and agricultural land (cash crops in particular) (2) prominent changes of LULC pattern within agricultural land category (from period to period) (3) notable increase in the amount of energy crops (especially sugar cane) and great loss of paddy fields, and (4) rapid expansion of urban areas in expense of the agricultural area nearby (especially paddy field). The predicted LULC maps inform that the agricultural land should slightly increase and forest area slightly decreases from 2006 to 2020. This study has shown that the integration of multi-temporal satellite images and predictive stochastic models can provide descriptive understanding of past and present LUCC in Kanchanaburi as well as an insightful outlook to its future LUCC which is useful for the planning of proper land use policy

of the province in the near future.

KEYWORDS: land use/land cover change, LUCC, Markov, CA-Markov model

2.2 Introduction

2.2.1 Typical land use/land cover change patterns

In recent decades, tremendous changes of the land use and land cover (LULC) characteristics have been evidenced globally both due to natural processes like natural disasters, or more significantly, by the human activities (Houghton, 1994; Meyer and Turner, 1996; Lambin et al., 2007). These changes could have profound impact on bio-physical states of the Earth's natural environment and also on the sustainable use of land by human (Matson et al., 1997; Turner et al., 1997). As a result, researches in the field of land use and land cover changes (LUCC) are having great interest at present in both local and global scales, especially in those areas where significant changes normally occur (Turner and Meyer, 1991; Meyer and Turner, 1994).

Two main issues related to LUCC study frequently found in the literature nowadays are urban growth (and its impacts or consequences) (Erna et al., 2001; Weng, 2002; Yang, 2002; Pauleit et al., 2005; Xiao et al., 2006) and the critical degradation of natural environment and ecosystem (e.g., forest loss, air/soil/water pollution, or climate change) as a result from the LUCC (Turner and Corlett, 1996; Luque, 2000; Steininger et al., 2001; Chen et al., 2001; Guatan et al., 2003; Armsworth et al., 2004; Kilic et al., 2004; Echeverria et al., 2006; Kupfer, 2006; Pichancourt et al., 2006; Mutsushita et al., 2006).

In tropical countries, like Thailand, one of the prominent characteristics of LUCC is the decline in forest and woodlands due to land conversion, in particular from agricultural expansion for cash crop production (FAO, 1997; 2003; Barbier and Burgess, 2001). Research conducted by the FAO (2001) suggested that large-scale agriculture is the major cause of deforestation (about 32%), followed by small-scale agriculture (about 26%). Intensification and expansion of the agriculture in shifting cultivation practice comprise about 15% of tropical deforestation. Land expansion occurring in tropical regions is mainly related to structural features of the agricultural sectors of developing economies, such as low agricultural productivity and input use. Poor agricultural intensification and development in turn creates pressure on farmers to convert forest and other marginal lands to crop production. Usually, these structural conditions are influenced, both directly and indirectly, by economic policy (Barbier, 2003). As such, transformations can have significant impacts on rural socio-economy and quality of the natural environment, an understanding of the complex interactions of these changes overtime including their spatial patterns is crucially needed to enable decision makers to formulate better policy in rural development and environmental management.

2.2.2 Roles of remote sensing and GIS in the LUCC study

Normally, most reports found in the LUCC study are associated directly, or indirectly, to the analysis and prediction of LUCC characteristics in some particular area based on knowledge of past LUCC pattern of the area. To identify patterns of LULC change in the past, some remotely-sensed images, like aerial photographs or satellite images recorded on a regular (or timely) basis, could be used as reference sources along with the field survey data (Hall et al., 1988; 1991; Tekle and Hedlund, 2000; Gautam et al., 2000). These changes could be mapped and analyzed more conveniently recently due to the rapid advance and more applicable of the geographic information system (GIS) technology. GIS are computer-based programs which are highly capable in mapping, recording, displaying, and analyzing spatial data and interpreting the relationships among associated data for making inferences (Demers, 2004; Michael et al., 2005). These capabilities make them become a promising tool in LUCC study, especially for the land use planning and LUCC modeling (Serneels and Lambin, 2001; Awasti et al., 2002; Dawn et al., 2003; Li and Yei, 2004; Wu et al., 2006; Quan et al., 2007)

Aerial photographs can provide fine details of the observed area but their production and application are rather time-consuming and costly (even for a small area). Thus, they are not appropriate for the study of LUCC in large areas or with frequent time span. In these situations, satellite images are more preferred due to their wide area coverage in a single scene and their continuous record of the Earth's surface at different temporal and spatial scales. Typically, low-resolution satellite images, like those from the NOAA-AVHRR or Terra-MODIS instruments, are frequently used to examine LUCC characteristics in global or continental scale (Giri et al., 2005; Etter et al., 2006; Hayes et al., 2008; Helldén and Tottrup, 2008; Kong et al., 2009) while the medium-resolution images, like ones from the Landsat-TM/ETM+ or Terra-ASTER, are suitable for the regional- or provincial-scale analysis (Aboel et al., 2004; Chen and Rogan, 2004; Long et al., 2007; Nagayama et al., 2007; Shalaby et al., 2007; Jansen et al., 2008; Paré et al., 2008; Serra et al., 2008). However, fine details of the LULC are more visible and better detected using fine-resolution satellite images, like those of IKONOS or QuickBird satellites, which have spatial resolution close to those of the aerial photographs (Jansen and Cowell, 1999; Alphan, 2003; Hervás et al., 2003; Ozdogan and Woodcock, 2006; Bhattarai and Conway, 2008). Comprehensive review on roles of remote sensing technology in the monitoring and mapping of LUCC is given in Rogan and Chen (2004).

2.2.3 Predictive models for the LUCC study

In order to better facilitate the LUCC assessments, several models had been developed (normally based on different assumptions) to serve this purpose (Veldkamp and Lambin, 2001; Brown et al., 2004; Verburg et al., 2004) where three main objectives of their applications are:

(1) To analyze past and present patterns of LUCC and forecast their trends in the future,

(2) To determine driving factors that influence patterns of the observed LUCC that are typically divided into 2 categories: biophysical and socio-economic factors.

(3) To quantify impacts of the observed LUCC on natural environment and on human beings.

Most researches in the past usually concentrated on the first two objectives; however, researches related to last objective are increasingly seen in recent years due to the growing concern on negative impacts of LUCC to nature and humans (Tang et al., 2005; Genxu et al., 2006; Reidsma et al., 2006).

Knowledge of past LUCC in the area is conventionally required by the LUCC models as a priori condition to forecast trends of future LUCC. These models could be broadly divided into 4 categories, which are (Lambin et al., 2000);

(1) empirical-statistical models, like all the regression-based models,

(2) stochastic models, which are mainly the transition probability models

like Markov model or all the CA-based models,

(3) optimization models, which also take socio-economic factors like farmers' decision into account, and

(4) dynamic (or process-based) models, which simulate LUCC based on the assumed interaction between bio-physical and socio-economic factors that influence the observed changes.

Among these, the empirical-statistical models and stochastic models are found more frequently in the reports related to LULC prediction due to their computational simplicity and their less demand in the reference data, or priori assumptions, for the analysis. However, the stochastic models are superior to the empirical-statistical models in term of geographic information because many of them can provide not only tendency of future change patterns but also the descriptive spatial details of those changes. This latter capability could not obtain directly form the empirical-statistical models. The stochastic models are more convenient to be developed and used at present due to the rapid improvement of GIS technology which makes the processing of spatial data on geographic maps (like topographic maps or thematic maps) more applicable to the less-experienced users. Reports of LUCC based on these models were increasingly seen in recent years, especially those based on applications of the Markov chain (MC) model and Cellular Automata (CA) model; e.g. Lopez et al. (2001), Weng (2002), Luijten (2003), Wu et al. (2006), Azócar et al. (2007).

2.2.4 Research objective

The present work focuses on the analysis and prediction of LUCC pattern in Kanchanaburi Province. Information of the past LUCC was derived from the multi-temporal satellite images taken by TM and ETM+ instruments (onboard Landsat-5 and

Landsat-7 satellites respectively) during the 15-year period of 1992-2006. The prediction was utilized based on the MC and CA-Markov models available on Idrisi software. In Thailand, reports of the model-based LUCC studies are still infrequent, especially in the rural area where agriculture is still the most dominant land use type. Therefore, our work presented here might help us get better understanding in the dynamics of local LUCC which happened in western Thailand in the last decade and we also hope that it might encourage more study of this kind in some other parts of Thailand in the future as well.

2.3 Materials and Methods

2.3.1 Data preparation

Spatial information of past LUCC occurred during years 1992 to 2006 was obtained trough the analysis of multi-date Landsat TM and ETM+ images in 1992 (TM), 1996 (TM), 2001 (ETM+), and 2006 (TM) covering the whole study area, with spatial resolution (or pixel size) of about 25 m. These images were provided by the GISTDA (Geo-informatics and Space Technology Development Agency) and they were mostly recorded during winter period (November-February) because it has less cloud cover and most economic crops are still visible to the instruments.

In the preparation process, the used images had been geometrically corrected first using a set of ground control points (GCP) located by the global positioning system (GPS) during the conducted field surveys based on UTM zone 47 and WGS 84 projection. Then, the RGB-composite images (for each year) were compiled using data from bands 4 (near infrared), 5 (mid-infrared), and 3 (red) of the original satellite images, respectively (RGB = 453) (Figure 2.1). NDVI index used select DN value of training area integrated with field survey point. The images were then automatically classified using ENVI 4.2 software and the corresponding LULC maps were derived (Figure 3.3). Land use and land cover data are commonly recorded in a raster or grid data structure, with each cell (or pixel) having a value that corresponds to a certain given class. The ancillary data, like political map and topographic map (DEM) of the province were provided by the associated government agencies whereas ground-truth information was obtained by field surveys conducted during period 2005-2007.

2.3.2 Methodology

This work has been divided into 3 main steps including: (1) derivation of the LULC map for each chosen year, (2) examination patterns of LULC change during period 1992-2006, and (3) prediction of future LULC pattern for years 2011, 2016, and 2020 based on the Markov chain and CA-Markov models. Some obtained results were also validated to assess the credibility of the techniques used and output obtained (see Figure 2.2 for work flowchart).

2.3.2.1 Derivation of LULC maps

The LULC maps for years 1992, 1996, 2001, and 2006 were synthesized using the composite satellite images prepared for each year. These images were digitally classified using the hybrid classification method where the unsupervised classification (ISODATA clustering algorithm) was performed first to provide prior knowledge of possible LULC states embedded in the classified satellite image. Then, the supervised classification (Maximum Likelihood algorithm) was applied to refine the observed LULC states into fewer dominant classes that would be main components of LULC maps produced.

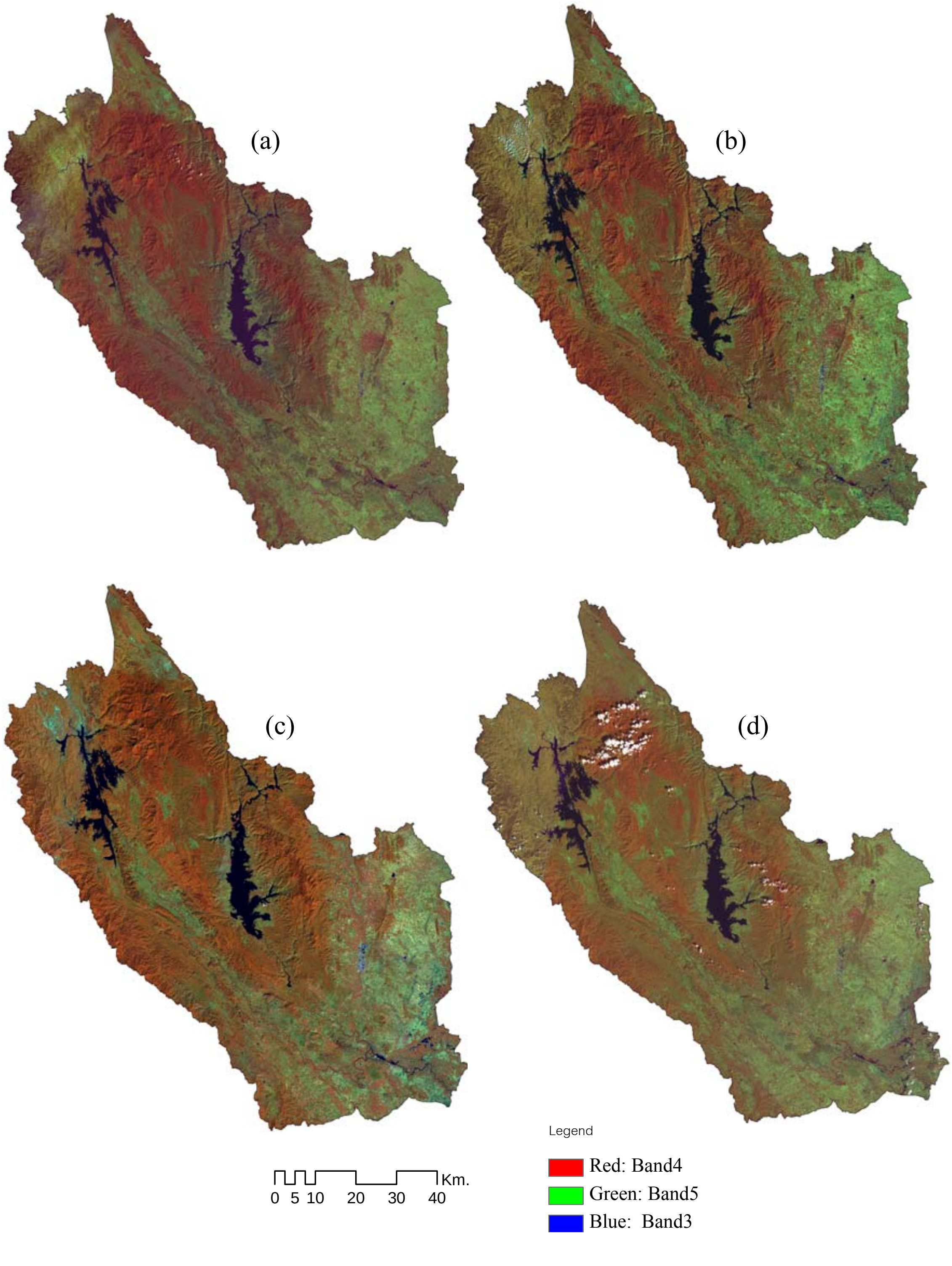


Figure 2.1 Composite images (RGB=453) of Kanchanaburi Province derived from Landsat TM/ETM+ imagery in (a) 1992 (TM), (b) 1996 (TM), (c) 2001 (ETM+), and (d) 2006 (TM).

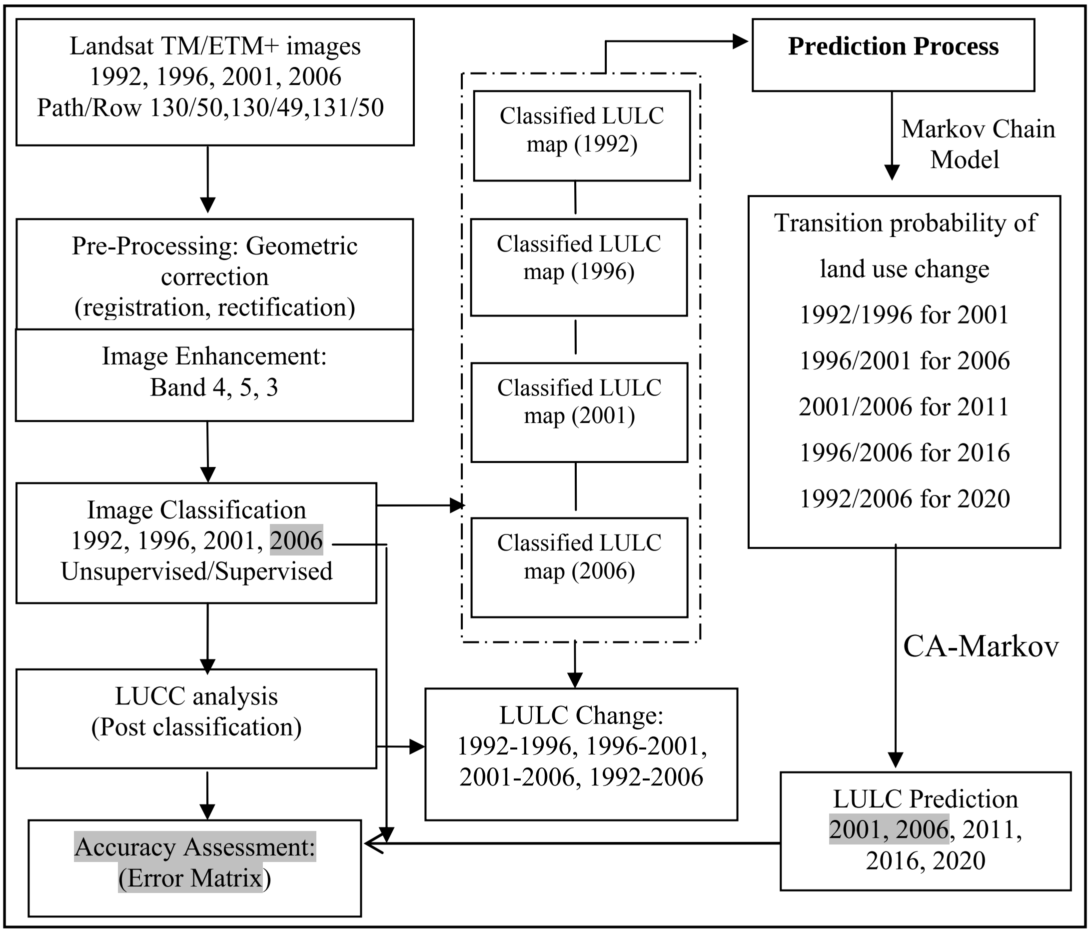


Figure 2.2 Conceptual framework in this study

In this work, the output maps were organized to have 4 main LULC categories which are agricultural land, forest, water body, and urban/built-up area where some notable classes were also identified separately within main categories, for examples, data of rice, cassava, and sugarcane growing areas were separately reported within the agricultural land category. This makes each map have 9 different LULC classes presented altogether which are sugarcane, cassava, paddy field, eucalyptus, pineapple, other cultivation, forest, urban and built-up area, and water body (Figure 2.3 and Table 2.2).

To assess the credibility of the used method and the mapping results obtained, the classified map data for 2006 were compared to the reference data assembled from field surveys and the accuracy assessment was performed in order to find the overall accuracy and Kappa index of the classified result (Stenman, 1997; Jensen, 2005). To achieve this, about 450 sampling points distributed across the entire study area were collected systematically using random stratified sampling approach. The error matrix, derived from classified map and field data, was generated for the assessment and the total accuracy of 94.22% was found with Kappa index at 0.93 (Table 2.1). These results are reasonably satisfied for the classification of the area with highly heterogeneous landscape like this (Dasananda, 2004).

2.3.2.2 LULC change analysis

After the 4 classified LULC maps (for 1992, 1996, 2001, 2006) were obtained, the patterns of LULC changes occurred during these years were identified using post-classification comparison method which compares 2 classified LULC maps (from different dates) and reports any changes (in term of from-to situation) found on a pixel by pixel basis. This method is preferred because data from the two dates are separately classified, thereby minimizing any problems of normalizing for atmospheric and sensor differences between these dates. As a result, the credibility in results of the comparison is principally subject to the accuracy of the individual classification of the used images (Jensen, 2005).

Spatial variations of LULC in four different periods were chosen for the analysis, which are from 1991 to 1996, from 1996 to 2001, from 2001 to 2006, and from 1992 to 2006. For each pair of map dataset, a change matrix was constructed (as seen in Table 2.6 for the 1992/2006 map pair) and locations of class changing (from class to class) were identified and mapped. Therefore, characteristics of past LUCC for each time period could be evaluated throughout the entire area.

2.3.2.3 Prediction of future LUCC

To achieve this objective, patterns of past LUCC found at previous stage were used as prior information for the forecast of future LUCC operated by the Markov chain and CA-Markov models. The LULC maps for years 2011, 2016, and 2020 were simulated and displayed based on the LUCC patterns found from the 2001/2006, 1996/2006, and 1992/2006 map pairs respectively (Figure 3.8). The predicted LULC maps for years 2001 and 2006 were also generated based on the LUCC patterns found from the 1992/1996 and 1996/2001 pair respectively in order to validate capability of the predictive models chosen (Figure 2.7). The entire work processed in this step was carried out using CA-Markov module given in the Idrisi 32 software (Eastman, 2003a; 2003b). In the module, the MC model was applied first to create the class-to-class changing statistics needed by the CA model then future LUCC pattern was derived based on CA algorithm. Brief details of both models are as follows.

Markov chain model

Markov chain (MC) is a mathematical model developed from an original theory proposed by the famous Russian mathematician, Andrey Markov, in 1907 (Markov, 1907; Balzter, 1999). It describes the evolution (or state changing) of a system that has Markov property, which means its next future state (along the evolution line) could be identified based solely on knowledge of its present state (and priori states). These state changes are called transitions and at each step the system may change its state from a current state to other possible state, or still remain in the same state, according to a certain probability distribution. To apply MC model to the LUCC analysis, the study area is normally divided into a set of regular grid cells where the status of each cell evolves over time independently from each other. In this case, it is necessary to assume that the temporal LUCC (for each grid cell) is a stochastic process that having Markov property and different LULC categories are the possible states of the evolution chain.

Most reports about MC application to LUCC analysis usually assume that the model is having discrete time, finite-state, and time stationary. This means that the process is evolving in discrete time-step (e.g., every year) with only limited number of LULC states possible and rules of transitioning from one state to other state at each time-step are time-independent (or not changing with time). Also, only first-order MC is typically applied due to its simple concept and the limitation of software capability. Theoretically, in first-order MC, tendency of change from current state to next state depends on knowledge of the present state only, but for higher-order MC, knowledge about the priori states (apart from the present state) of the system are also taken into account (Meyn and Tweedie, 2005).

According to these assumptions, this state-to-state of LULC changes could be described using the so-called "transition probability matrix", or "Markov matrix", which is accounted for the probability of changing from one state to every other state in a single time-step and normally written as:

$$\mathrm{P} = \begin{bmatrix} P_{11} & P_{12} & \cdots & P_{1n} \\ P_{21} & P_{22} & \cdots & P_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ P_{n1} & P_{n2} & & P_{nn} \end{bmatrix} \tag{2.1}$$

where P_{ij} stands for probability of transition from state i to state j and n is number of all states available. From this perspective, Eq. 2.1 must satisfy these two conditions: (1) $0 \leq P_{ij} \leq 1$ and (2) $\sum_{j=1}^{n} P_{ij} = 1$ (the sum of all elements in each row is 1). Note that, the diagonal components (e.g. P_{11}, P_{22}, P_{33}) represent the probability of remaining in the same state after the transition (no-change situation).

The Markov module in Idrisi32 can be used to generate such a transition probability matrix in which it takes two LULC maps as input and then produces the following output (Eastman, 2003a; 2003b):

(1) A transition probability matrix. This is automatically displayed as well as saved. Transition probabilities indicate the likelihood that a pixel of a given (LULC) class will change to any other class (or remain the same) during the evolution process. This matrix is the result of cross tabulation of the two images adjusted by the proportional error.

(2) A transition areas matrix. This expresses the total area (in number of cells) expected to change over the projected period. It is produced by multiplying each column in the transition probability matrix by the number of cells of corresponding LULC in the later image. In both of these files, the rows represent the older LULC categories and the columns represent the newer categories.

(3) A set of conditional probability maps-one for each LULC class. These maps illustrate the probability that each pixel will belong to the assigned class in the next step. They are called conditional probability maps since this probability is conditional on their current state.

Though, the MC model could forecast total amount of the LULC changing area per category (or classes) given an initial transition probability matrix, it still lacks in spatial knowledge of where the future LUCC should occur geographically. Therefore, to obtain more insightful outlook in the spatial characteristics of the predicted changes, the Cellular Automata (CA) model has been integrated with MC model to provide more spatial dimension to the LUCC forecast.

Cellular Automata and CA-Markov models

Cellular Automata (CA) was initially introduced by John Von Neumann, the Hungarian-born mathematician, in the 1950s to assist his study of self-reproducing system (Von Neumann, 1966; Bandini et al., 2001) but later it has been applied to other several research fields including the LUCC study, like in the SLEUTH model that is widely-use in the study of urban growth prediction (Herold et al., 2003; Rafiee et al., 2009). CA is a discrete, spatial model normally used to describe evolution process of the systems that consist of a regular grid of cells, one of which can be in a finite number of possible states. Each cell could independently vary its state over time (in discrete time-step manner) based solely on its present state and that of its immediate neighbors under some specific rules called "transition rules". Therefore, the fundamental principles of CA model are rather similar to a Markovian process. The only difference is that the transition of each cell depends not only upon its current state, but upon the state of its assigned local neighborhood also.

The crucial advantage of CA over MC is that it can simulate evolution of the systems in two dimensions which significantly benefits for the LUCC prediction. Therefore, when integrated with MC model called CA-Markov model, the model could provide knowledge of the future LUCC scenario in greater details, especially the geographical characteristics of the predicted changes. To achieve this, this method uses an iterative process of LULC allocation to establish the evolution path of each pixel based on the pre-defined transition rules until total areas predicted by the MC model are identified. Number of iteration (n) is determined by the projection time in the future (number of years).

In the process, the model applies distance values to allocate LUCC where filter is integral to the action of CA component. This is a mean filter pool with a Boolean mask filter that is multiplied by the suitability map of land use class considered. By default, the filter size is a 5x5 kernel. Its purpose is to down-weight the suitability of pixels that are distant from existing instances of the LULC type under consideration. The net effect is that to be a likely choice for LULC conversion, the pixel must be both inherently suitable and near to existing areas of that class. Within each time step, the re-weighted suitability maps are run through a multi-objective land allocation (MOLA) process to allocate 1/n of the required land (which is predicted to change from one class to another) and this will continue until the full allocation of land for each LULC class is obtained.

To run the CA module in Idrisi32, the suitability maps for every LULC class are needed along with the LULC map of later date (from a pair of maps used in MC module) that the prediction should be projected from and the associated transition areas matrix. In this case, the transition areas file will determine how much land is allocated to each LULC class over the projected period and the suitability maps determine which pixels will change according to the largest suitability. These maps can be generated in many ways for examples, using deductive approach like multi-criteria evaluation or using an inductive approach like logistic regression (Pontius and

Malanson, 2005). In this work, we used set of conditional probability maps generated by the MC module as the suitability maps for the CA module where accuracy of some predicted LULC maps were also examined to evaluate the validity of the input maps.

2.4 Results and Discussions

Pattern analysis of LUCC is illustrated here based on two types of changes: (1) conversion from one LULC category to another (e.g. from agriculture land to forest), and (2) modification within one category (e.g. from sugarcane to cassava). These two types of change have implications for the methodology used to describe and classify LULC pattern (Jansen and Di Gregorio, 2002). Conversion implies an evident change, whereas modifications are relatively less apparent, therefore, it normally requires a greater level of detail for the classification. The detection of LULC modifications is only possible if enough classes can be identified on the satellite imagery with a high enough accuracy to allow for a shift from one LULC class to a closely related class (Lambin, 1999). Here, 9 LULC classes in 4 main categories were classified (Figure 2.3) and results of the LUCC can be described as follows.

2.4.1 LULC change patterns between 1992-2006

2.4.1.1 General LULC characteristics

Analysis of the LUCC characteristics for the period 1992-2006 was performed based on the classified LULC images for years 1992, 1996, 2001, and 2006 seen in Figure 2.3 where the whole period had been divided into 3 sub-periods: from 1992 to 1996, from 1996 to 2001, and from 2001 to 2006. In broad overview of the area, the most dominant LULC categories found were forest and agricultural land that aggregately covered about 95% of the total provincial area for the whole period at the ratio of 3 (forest) :1 (agricultural land) approximately (Table 2.2). Forest zones were normally found in the upper part of the province whereas the agricultural lands mostly found in the lower part of the south and along the river valleys in the central and the north due to the flat terrain and the fertile soil and water reservoirs available therein.

Paddy, sugarcane and cassava were the most notable economic plantation. Typically, paddy and sugarcane are grown in the flat plain close to main rivers but cassava could be planted further away from the main water bodies as it needs less water and lower quality of soil to survive. Also, the main urban/built-up areas were usually located close to main rivers in the far south or in the boundary of the river plain and they were normally surrounded by agricultural lands.

Table 2.1 Error matrix for the 2006 classified LULC map

		Reference Data											
	Class	OC	CV	ET	F	PA	PF	SC	U	W	Total	EO %	PA %
Classification Data in 2006	OC	48	0	0	1	2	0	4	2	0	57	16	84
	CV	0	47	0	0	0	1	0	0	0	48	2	98
	ET	1	1	48	0	0	1	0	0	0	51	6	94
	F	0	1	0	49	0	0	0	0	1	51	4	96
	PA	0	0	0	0	46	0	0	0	0	46	0	100
	PF	0	0	0	0	0	47	0	1	2	50	6	94
	SC	1	1	2	0	2	1	45	0	0	52	13	87
	U	0	0	0	0	0	0	1	47	0	48	2	98
	W	0	0	0	0	0	0	0	0	47	47	0	100
	Total	50	50	50	50	50	50	50	50	50	450		
	EC (%)	4	6	4	2	8	6	10	6	6			
	CA (%)	96	94	96	98	92	94	90	94	94			

Overall accuracy = (48+47+48+49+46+47+45+47+47)/450 = 0.942 = 94.22 %

Kappa index = 2850+2400+2550+2550+2300+2500+2600+2400+2350

= 22500/202500 = 0.11 = 0.94-0.11/ (1-0.11)

= 0.83/0.89 = 0.93 = 93.26 %

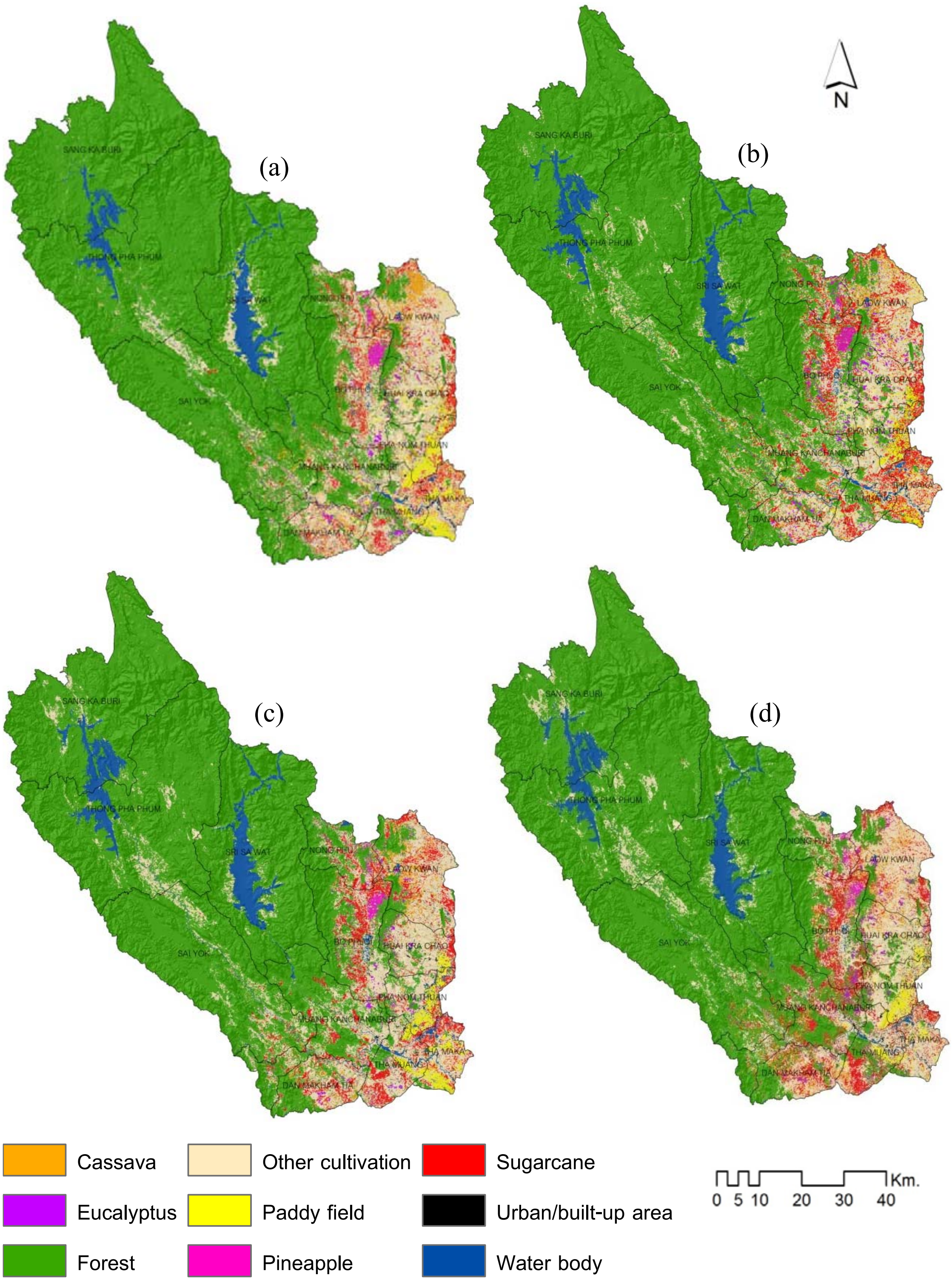


Figure 2.3 Classified LULC maps of Kanchanaburi Province in (a) 1992, (b) 1996, (c) 2001, and (d) 2006

2.4.1.2 Change patterns between categories

Tables 2.2 and 2.3 indicate that, during the 15-year period being considered, LULC pattern of Kanchanaburi Province has experienced considerable changes in their characteristics where about 14.31% of the original area in 1992 were subject to change their LULC categories within the period. The major conversion types are from forest to agricultural land and to water body (about 12.28% and 1.15% of the original forest area respectively) and from agricultural land to forest area and to urban area (about 10.00% and 2.96% of the original agricultural area respectively).

During this period, the total forest area has decreased steadily about 0.39% (of the total area), from 71.97% in 1992 to 71.58% in 2006, whereas the agricultural land has decreased by 0.79%, from 24.21% in 1992 to 23.62% in 2006, or at the average of about 0.05% annually. These data make the relative loss of entire forest area of about 0.54%, or at the average of 0.036% of its original area annually (equivalent to about 5.0 km^2 per year) and the relative loss of agricultural land become 2.41% for the whole period, or 0.16% annually (equivalent to about 7.53 km^2 per year).

During this time, the gross area of urban/built-up has dramatically expanded from 0.3% in 1992 to 0.41% in 2006, or having relative growth of about 36.21% in 15 years, where the additional areas mainly came from the conversion of agricultural land (especially paddy field). However, it should be noticed that only about 25.58% of the original urban area shown in 1992 that still remain unchanged in 2006, but the majority of them had turned into agricultural land (about 66.28%) and some parts into forest land (about 4.65%). This indicates that agricultural land and urban area are still under strong dynamic exchange so far and their definite boundary is still yet to find.

Table 2.2 Allocation for LULC category in 1992, 1996, 2001 and 2006

LULC Type	1992		1996		2001		2006	
	km^2	%	km^2	%	km^2	%	km^2	%
Agriculture (A)	4691	24.21	4533	23.39	4445	22.94	4578	23.62
Forest (F)	13948	71.97	13940	71.93	13930	71.88	13873	71.58
Water body (W)	683	3.52	854	4.41	933	4.82	851	4.39
Urban/built-up (U)	58	0.30	52	0.27	71	0.51	79	0.41
Total area	19380	100	19380	100	19380	100	19380	100

Table 2.3 LULC change matrix between 1992 and 2006 (category level)

LULC 1992	LULC 2006				Total 1992
	A	F	U	W	
Agriculture	3668	917	54	55	4694
Forest	855	12928	154	11	13948
Water body	23	20	640	0	683
Urban	32	8	3	13	56
Total 2006	4578	13873	851	79	19380

Also, the water body had considerably expanded from about 3.52% in 1992 to 4.39% in 2006, or having a relative growth of about 24.6%. Figure 2.5 depicts map of LULC loss/gain areas during 1992-2006 for agricultural land, energy crop (sugarcane and cassava), paddy field and forest and Figure 2.6 displays distribution pattern of some main LUCC features which are from agricultural land to forest and urban/built-up, from forest to agricultural land and urban/built-up and from urban/built-up to agricultural land. It was found that most changes were taken place at low altitudes (especially the urban expansion), along main road network and close to the two main reservoirs in the central and in the north, and close to the existing boundary between forest and agricultural land.

2.4.1.3 Change patterns within the category

Agricultural land

In Tables 2.4 to 2.6, more details of LULC change within each category are illustrated. For agricultural land, plantation area of sugarcane increases from 3.15% in 1992 to 4.76% in 2006, or having relative growth of about 51.05% for the whole period, especially during period 1992-1996 (with relative growth of about 41.8%). In contrast, the relative growing area of cassava had greatly decreased by 38.76% from 1992 to 1996 but it considerably regained by 46.23% from 2001 to 2006. For paddy field, its entire area was relatively shrunk by a significant amount of 43.76% for the whole period (from 2.15% to 1.21% of the total area). This loss mostly contributed to the conversion into some other crops/plants, especially sugarcane, and into urban land and forest. Eucalyptus and pineapple were also other dominant cultivations found but the growing area of eucalyptus varies greatly from period to period while the growing area of pineapple is more stable thought out the entire period.

The substantial increase in amount of the energy crop planting area might be due to rising demand of cassava and sugarcane as raw product by the crop factories as well as ethanol factories in recent years. In contrast, the dramatic reduction in amount of paddy field might be due to the need of farmers to grow more profitable plants instead, especially energy crop. In practice, due to the limitation of usable agricultural land and lack of proper cultivating technology, local farmers normally cultivate cash crops that are believed to be most profitable to them at the time. And, to make their decision; market price, input cost and government policy are three important factors that local farmers normally take into their consideration.

Table 2.4 Allocation for LULC type in 1992, 1996, 2001, and 2006

LULC Class	1992		1996		2001		2006	
	km^2	**%**	**km^2**	**%**	**km^2**	**%**	**km^2**	**%**
Sugarcane (SC)	610	3.15	865	4.46	819	4.22	922	4.76
Cassava (CV)	388	2.00	238	1.23	272	1.40	398	2.05
Paddy field (PF)	416	2.15	321	1.66	250	1.29	234	1.21
Eucalyptus (EU)	228	1.18	227	1.17	158	0.81	151	0.78
Pineapple (PA)	55	0.28	57	0.29	34	0.18	72	0.37
Other cultivations (OC)(1)	2994	15.45	2825	14.58	2913	15.03	2801	14.45
Forest (F)	13948	71.97	13940	71.93	13930	71.88	13873	71.58
Water body (W)(2)	683	3.52	854	4.41	933	4.82	851	4.39
Urban/built-up (U)(3)	58	0.30	52	0.27	71	0.37	79	0.41
Total area	**19380**	**100**	**19380**	**100**	**19380**	**100**	**19380**	**100**

(1) Other cultivations (OC) include all other crop/plants apart from the first five listed crops and bare soil.

(2) Water body includes both natural, like river, and man-made origins, like dam or reservoir

(3) Urban/built up class includes man-made constructions like residential house, village, airport, factory, transportation, infrastructure etc.

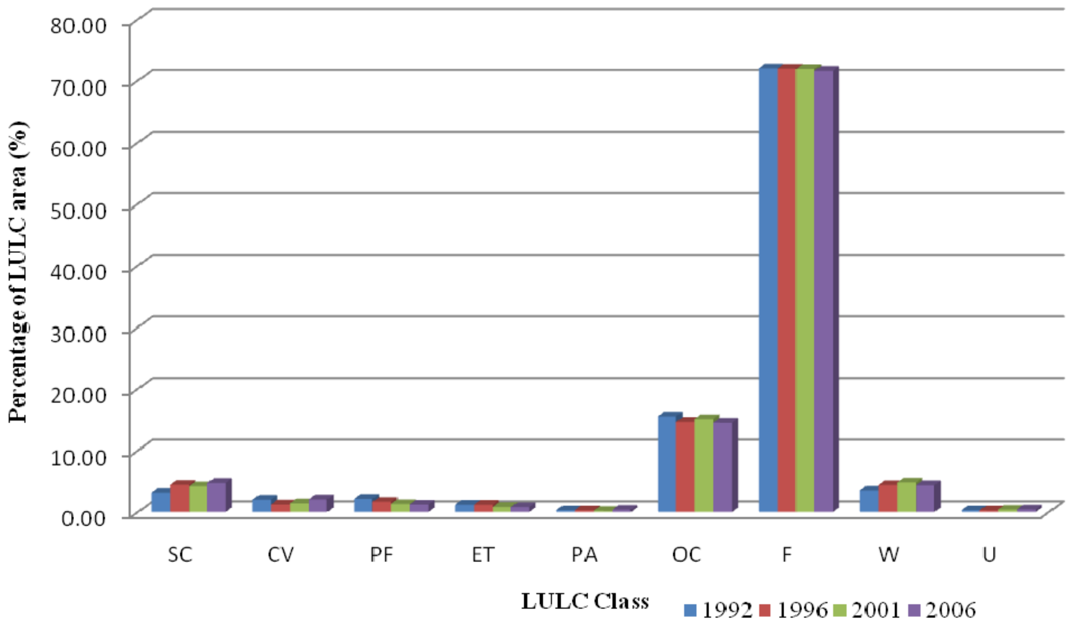


Figure 2.4 Allocation for LULC type in 1992, 1996, 2001, and 2006

Table 2.5 Relative change rate[(1)] and annual change rate[(2)] of main LULC classes in Kanchanaburi during period 1992-2006

Period	Agriculture					Forest	Water	Urban
	SC	CA	PD	OC*[(3)]	Total			
1992-1996	41.80	-38.76	-22.82	-3.37	-23.16	-0.06	-0.01	-9.92
Annual rate	8.36	-7.75	-4.56	-0.67	-4.63	25.18	5.04	-1.98
1996-2001	-5.38	14.60	-22.23	-1.94	-14.95	-0.07	9.24	36.52
Annual rate	-1.08	2.92	-4.45	-0.39	-2.99	-0.01	1.85	7.30
2001-2006	12.58	46.23	-6.31	2.98	55.48	-0.41	-8.81	11.53
Annual rate	2.52	9.25	-1.26	10.50	0.60	-0.08	-1.76	2.31
1992-2006	51.05	2.62	-43.76	-2.43	7.48	-0.54	24.71	37.15
Annual rate	3.65	0.19	-3.13	-0.17	0.53	-0.04	1.76	2.65

[(1)] Relative change rate (%) = [(Second year-First year)/First year] x 100%

[(2)] Annual change rate (%) = Relative change (%)/time interval (year)

[(3)] Other cultivations (OC*) include all other crop/plants apart from the first three listed.

Table 2.6 LULC change matrix between 1992 and 2006 (class level)

LULC Type	LULC Type (2006)									Total 1992
	SC	CV	PF	ET	PA	OA	F	W	U	
SC	222	35	24	6	4	187	117	6	9	610
CV	40	48	3	21	3	160	109	1	2	388
PF	41	4	115	4	1	190	5	7	10	416
ET	32	15	3	31	5	54	87	1	2	229
PA	1	4	0	0	29	13	8	0	0	55
OC	395	202	67	32	16	1365	850	39	28	2995
F	181	89	16	57	15	796	12626	155	14	13948
W	2	0	2	0	0	17	22	639	0	683
U	8	1	4	0	0	18	10	3	13	58
Total 2006	922	398	234	151	72	2801	13873	851	79	19380
Change (km^2)	312	10	-182	-77	17	-194	-76	169	21	

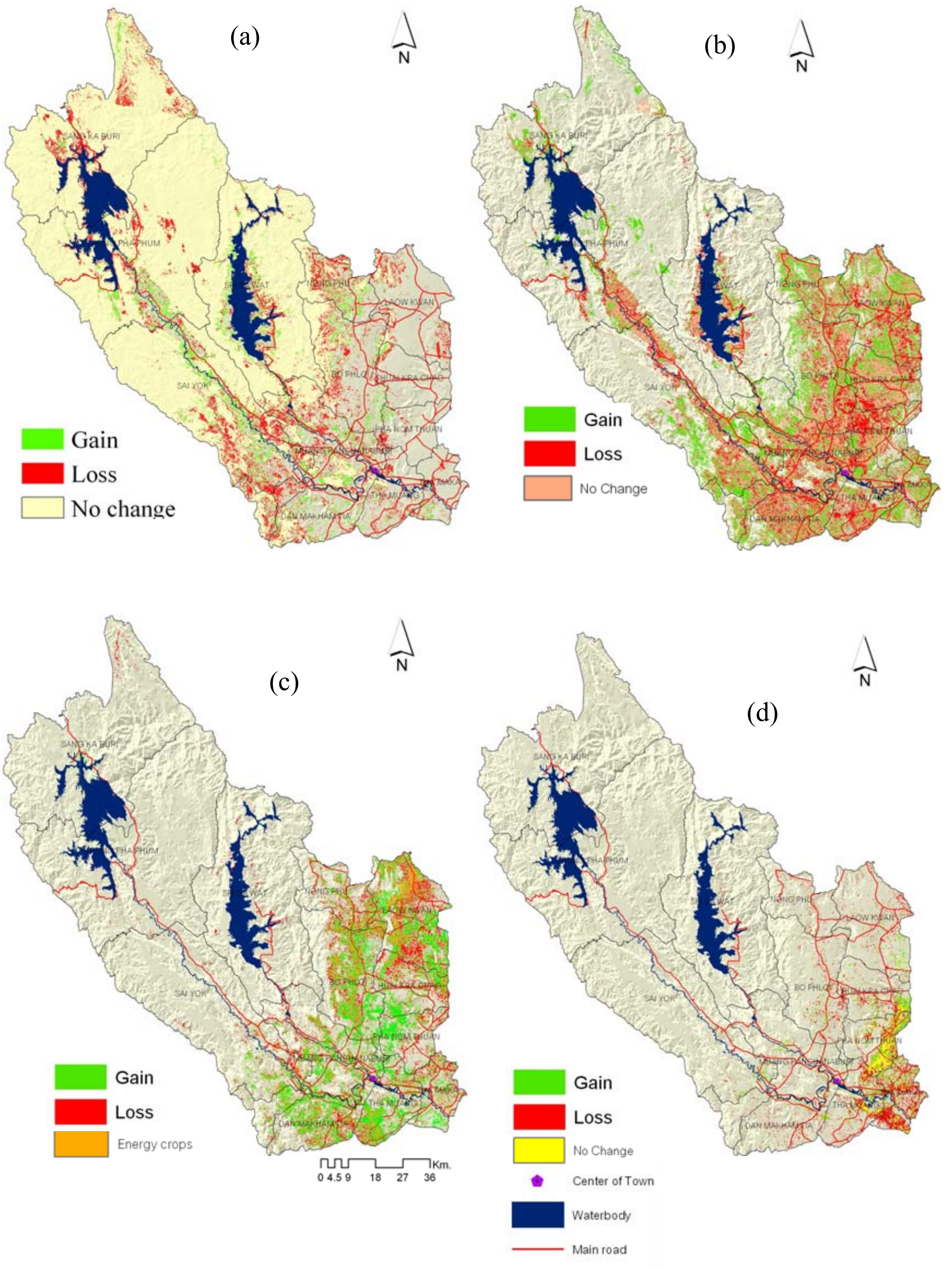


Figure 2.5 LULC loss/gain area during 1992-2006 for (a) forest, (b) agricultural land, (c) energy crop (sugarcane/cassava), (d) paddy field, and (e) urban/built-up area

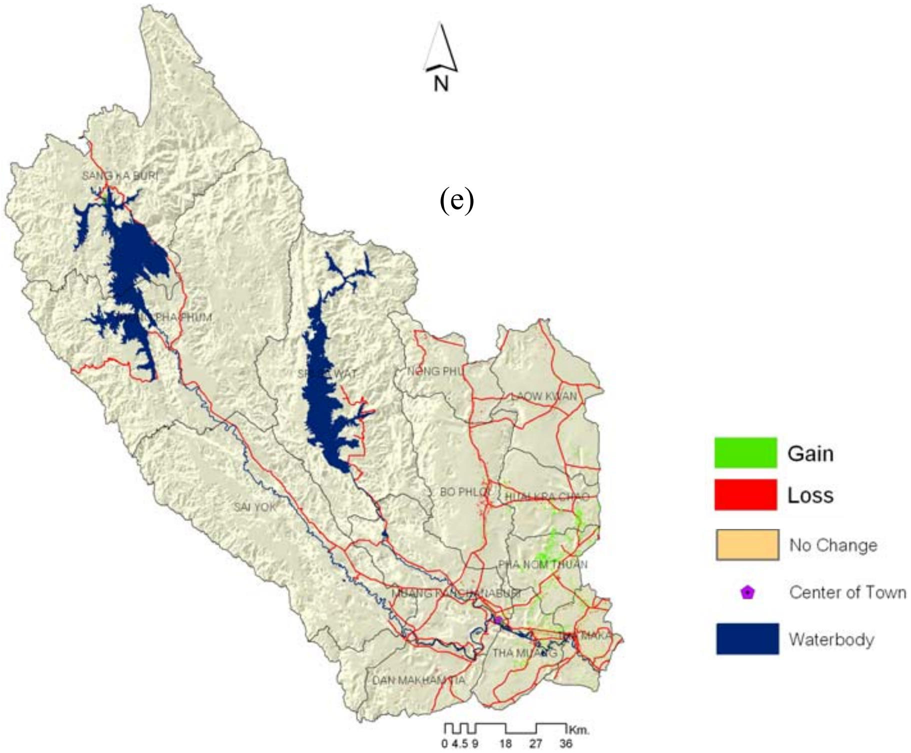


Figure 2.5 (Continued)

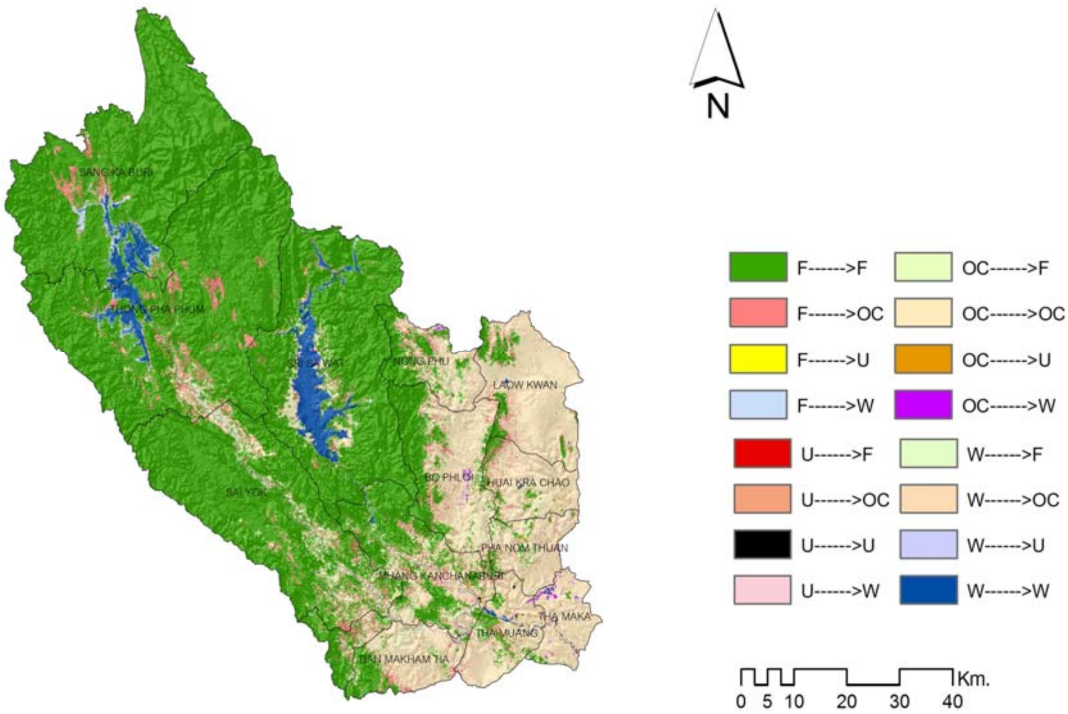


Figure 2.6 LULC change pattern for forest (F), other cultivation (OC), water body (W), and urban/built-up area (U)

2.4.2 LULC prediction using Markov matrices

To apply Markov chain model for the prediction of future LULC pattern, the transition probability matrix, or Markov matrix, must be derived first for chosen pair of LULC maps in the past being used as priori information of change characteristics. Here, the LULC maps for years 2011, 2016, and 2020 were forecasted based on LUCC patterns found from the 2001/2006, 1996/2006, and 1992/2006 LULC map pairs respectively. The used 1992/2006 Markov matrix is shown for example in Table 2.8 and results of the prediction are displayed in Figure 2.8 and Table 2.9 while change matrix between years 2006 and 2020 is described as an example in Table 2.10. These predicted maps inform us that agricultural area should increase slightly by 0.55% from 2006 to 2020 (from 4578 to 4603 km^2) while forest should decrease by 0.115% (from 13873 to 13857 km^2). However, the model predicts urban/built-up area to be 80 km^2 in 2020 which is comparable to the area found in 2006 of 79 km^2. This trend is very unlikely to be realistic as population growth in the 15 years (from 2006) should induce significantly more urban/built-up area. Therefore, this unexpected result may be the deficiency of model that has to pay great attention to.

In addition, the predicted map for years 2001 and 2006 was also generated from the 1996/2001 map pair to examine the validity of the method employed and results are shown in Figure 2.7 and Table 2.7. Predicted areas for most LULC class in 2001 are within ±30% of the classified areas which are still not acceptable for general use. However, the results are better for 2006 with the errors lie within about ±10% of the real value for most classes, which are more acceptable for the use.

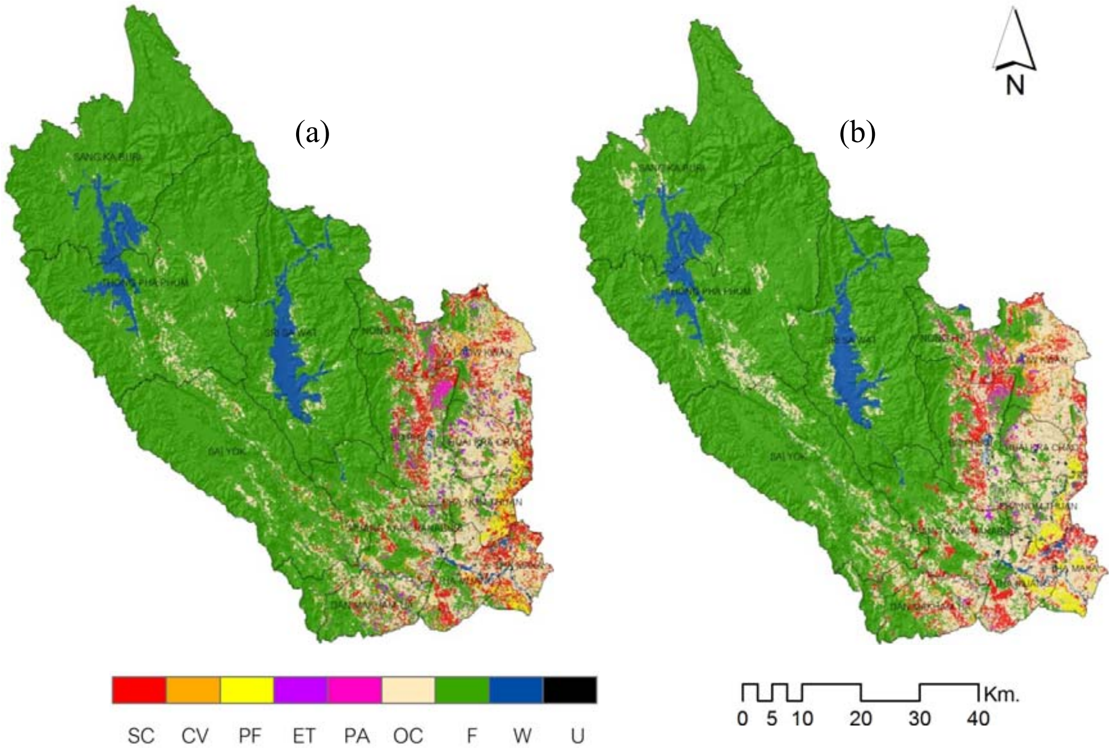


Figure 2.7 Predicted LULC maps for (a) 2001 and (b) 2006

Table 2.7 LULC area coverage in 2001 and 2006 (classified and predicted values)

LULC Class	2001 data					2006 data				
	Classified		Predicted(1)		RC(3)	Classified		Predicted(2)		RC(3)
	km²	%	km²	%	%	km²	%	km²	%	%
SC	819	4.22	856	4.42	4.59	922	4.76	865	4.46	-6.19
CV	272	1.40	246	1.27	-9.78	398	2.05	368	1.90	-7.44
PF	250	1.29	257	1.33	3.01	234	1.21	233	1.20	-0.25
ET	158	0.81	199	1.03	25.95	151	0.78	135	0.69	-10.94
PA	34	0.18	65	0.33	87.50	72	0.37	66	0.34	-8.12
OA	2913	15.03	2752	14.20	-5.51	2801	14.45	2826	14.58	0.90
F	13930	71.88	13986	72.17	0.40	13873	71.58	13898	71.71	0.18
W	933	4.82	944	4.87	1.12	851	4.39	914	4.72	7.37
U	71	0.37	76	0.39	7.27	79	0.41	75	0.39	-4.97
Total	19380	100	19380	100		19380	100	19380	100	

(1) Calculated from the 1992/1996 Markov matrix;

(2) Calculated from the 1996/2001 Markov matrix

(3) RC = [(Predicted area-Classified area)/Classified area] x 100%

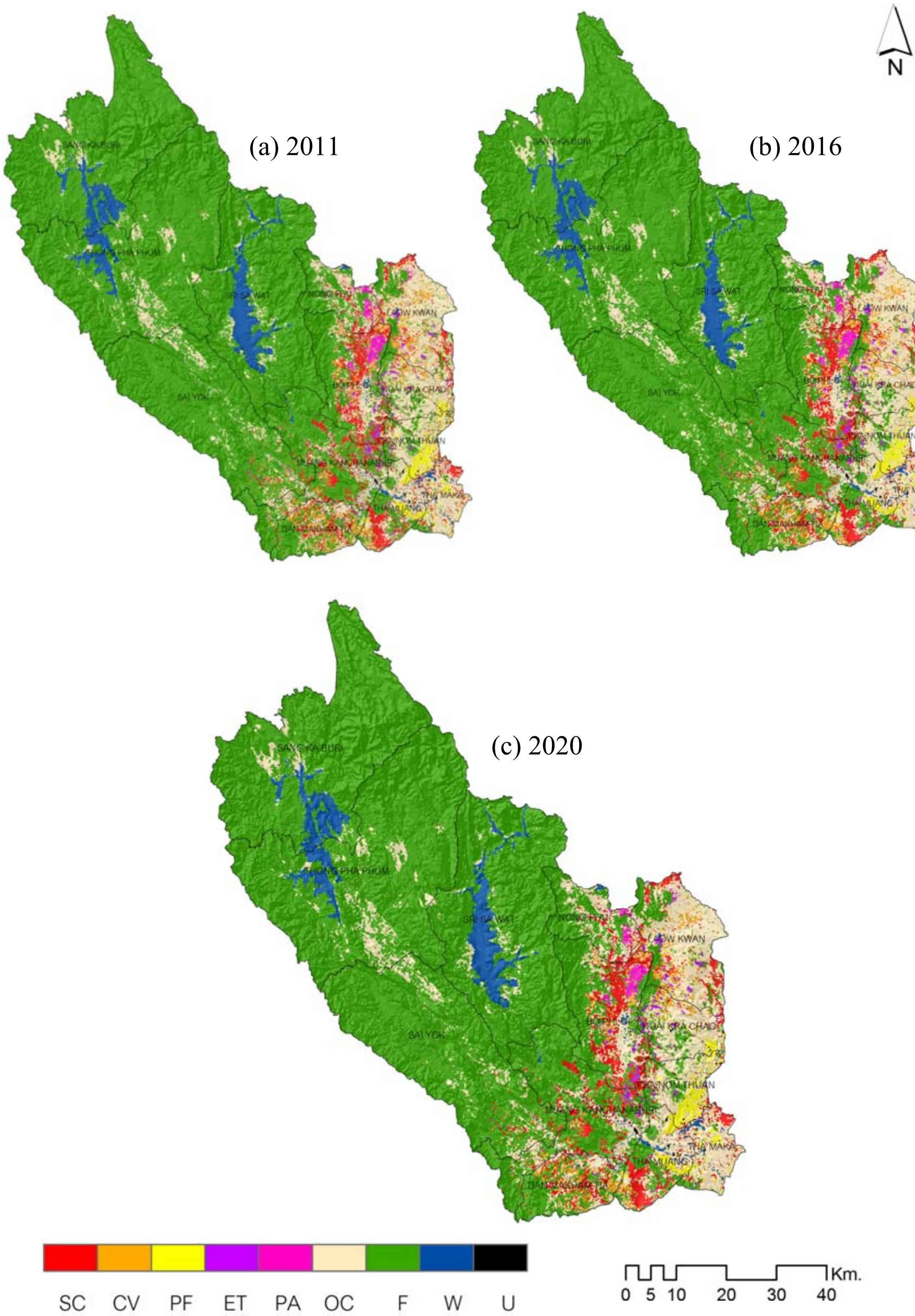


Figure 2.8 Predicted LULC maps for 2011, 2016, and 2020 based on Markov matrices for the 2001/2006, 1996/2006, and 1992/2006 map pairs

Table 2.8 Markov matrix derived from 1992/2006 LULC map pair

LULC Type	Probability of change								
	SC	**CV**	**PF**	**ET**	**PA**	**OC**	**F**	**W**	**U**
SC	0.39	0.01	0.06	0.03	0.00	0.23	0.26	0.01	0.01
CV	0.07	0.12	0.01	0.06	0.01	0.33	0.40	0.00	0.00
PF	0.24	0.00	0.25	0.00	0.00	0.35	0.12	0.01	0.02
ET	0.12	0.02	0.01	0.18	0.02	0.21	0.43	0.00	0.00
PA	0.03	0.01	0.00	0.03	0.47	0.11	0.35	0.00	0.00
OC	0.11	0.04	0.05	0.03	0.00	0.42	0.33	0.02	0.01
F	0.03	0.01	0.01	0.01	0.00	0.13	0.78	0.03	0.00
W	0.01	0.00	0.01	0.00	0.00	0.04	0.13	0.81	0.00
U	0.00	0.01	0.07	0.02	0.00	0.32	0.22	0.07	0.19

Table 2.9 Allocation for LULC category in 2006, 2011, 2016, 2020

LULC Class	2006 (classified)		2011 (predicted)		2016 (predicted)		2020 (predicted)	
	km^2	**%**	**km^2**	**%**	**km^2**	**%**	**km^2**	**%**
SC	922	4.76	788	4.07	790	4.08	804	4.15
CV	398	2.05	383	1.97	386	1.99	326	1.68
PF	234	1.21	212	1.09	214	1.10	217	1.12
ET	151	0.78	153	0.79	152	0.78	166	0.86
PA	72	0.37	106	0.55	98	0.51	94	0.49
OC	2801	14.45	2931	15.12	2930	15.12	2996	15.46
F	13873	71.58	13899	71.72	13892	71.68	13857	71.50
W	851	4.39	837	4.32	838	4.32	840	4.33
U	79	0.41	71	0.37	78	0.40	80	0.41
Total	**19380**	**100**	**19380**	**100**	**19380**	**100**	**19380**	**100**

Table 2.10 LULC change matrix between years 2006 and 2020

2006	LULC 2020									Total 2006
	SC	**CV**	**PF**	**ET**	**PA**	**OC**	**F**	**W**	**U**	
SC	586	31	11	31	5	179	68	8	2	921
CV	26	210	0	7	3	82	67	1	0	397
PF	9	1	164	0	0	46	10	2	2	234
ET	3	3	1	89	4	44	3	0	3	151
PA	1	1	0	0	55	7	7	0	0	72
OC	97	55	26	19	17	2223	342	17	5	2801
F	83	23	7	18	8	370	13292	60	11	13873
W	1	0	1	0	0	31	64	751	2	851
U	0	0	6	1	0	13	4	1	55	80
Total 2020	**806**	**324**	**217**	**166**	**94**	**2996**	**13857**	**840**	**80**	**19380**

2.5 Conclusion

The applications of GIS and remote sensing technologies to monitor, assess, and predict patterns of land use/land cover change have become widespread in recent years. The availability of timely imagery from different sensors is the crucial aid in observing extent and location of LULC both in local and global scale. GIS-based modeling techniques can then subsequently evaluate dynamic pattern of LUCC and identify the socio-economic and biophysical sources that are the driving force of the observed change processes. This knowledge is necessary for the prediction of future LULC in the area as it is needed by the used predictive models as priori information for the evaluation.

The present investigation reports on applications of GIS tools and satellite images to the analysis of LUCC pattern in Kanchanaburi Province, during 15-year period from 1992-2006 and to the prediction of its future LULC for years 2011, 2016, and 2020. From the classification of Landsat-TM and ETM+ images, it was found that the study area was dominated by two LULC categories, agricultural land and forest, that aggregately covered about 95% of the total provincial area for the whole period at the ratio of 3 (forest): 1 (agricultural land) approximately and the main urban/built-up areas were usually located close to main rivers in the far south or in the boundary of the river plain and they were normally surrounded by agricultural lands.

To a large extent, LULC patterns seen in Figures 2.3 and Tables 2.2-2.6 were characterized by (1) substantial changes between forest and agricultural land (cash crops in particular) (2) prominent changes of LULC pattern within agricultural land (from period to period) (3) notable increase in the amount of energy crops (especially sugar cane) and great loss of paddy fields, and (4) rapid expansion of urban areas in expense of the agricultural area nearby (especially paddy field).

Markov chain and CA-Markov models provided data of area prediction and predicted LULC maps in year 2011, 2016, and 2020 (Table 2.9 and Figure 2.8) which inform us that the agricultural land should slightly increase and forest area slightly decrease from 2006 to 2020. However, the forecast of urban/built-up area is still not credible and it is regarded as being deficiency of the used models. To better predict future urban/built up area, some other model is needed.

In general, the MC and CA-Markov models have shown capabilities of descriptive power and simple trend projection of LUCC, regardless of weather or not the trend actually persists. This kind of analysis can serve as an indicator of the direction and magnitude of LULC changes in the future as well as a quantitative description of changes found in the past. However, there are still several limitations of the models in the LUCC applications. For examples, these models are still difficult to accommodate high-order effects (e.g. second-order). Also, the influence of exogenous and endogenous factors to the transitioning process cannot be incorporated into the models explicitly so that the LUCC characteristics can be understood logically. In addition, the assumption of time-independent transition rules is not always true in reality as there are several driving factor involved along each evolution process that could make the rules differ from time to time, especially in the area where rapid changes suddenly occur. Therefore, the models should be used with proper caution and their limitations must be recognized by users on the interpretation of the results.

Knowledge of past and future LUCC pattern for Kanchanaburi Province described in this work is useful for decision makers, such as government agencies or local authorities, in planning more effective and sustainable use of land in the area, and also in the protection of natural resources that are vulnerable to human activities at present and in the future.

2.6 References

Aboel, G.M., Shalaby, A. and Tateishi, R. (2004). Agricultural land monitoring in the Eyptian Nile Delta using Landsat data. **International Journal of Environmental Studies**. 61(6): 651-657.

Alphan, H. (2003). Land-use change and urbanization of Adana, Turkey. **Land Degradation and Development**. 14(6): 575-586.

Armsworth, P., Kendall, B. and Davis, F. (2004). An introduction to biodiversity concepts for environmental economists. **Resource and Energy Economics**. 26(2): 115-136.

Awasthi, K.D., Sitaula, B.K., Singh, B.R. and Baiacharaya, R.M. (2002). Land-use change in Nepalese watershed. **Land Degradation and Development**. 13(6): 495-513.

Azócar, G. et al. (2007). Urbanization patterns and their impacts on social restructuring of urban space in Chilean mid-cities: The case of Los Angles, Central Chile. **Land Use Policy**. 24(1): 199-211.

Balzter, H. (2000). Markov chain models for vegetation dynamics. **Ecological Modelling**. 126(2-3): 139-154.

Bandini, S., Mauri, G. and Simon, C. (2001). Cellular automata: From modeling to applications. **Parallel Computing**. 27(5): 537-538.

Barbier, E.B. and Burgress, J.C. (2001). The economics of tropical deforestation. **Journal of Economic Surveys**. 15(3): 413-33.

Barbier, E.B. (2003). Habitat fishery linkages and mangrove loss in Thailand. **Contemporary Economic Policy**. 21(1): 59-77.

Bhattarai, K. and Conway, D. (2005). Evaluation land use dynamics and forest cover change in Nepal's Bara district (1973-2003). **Remote Sensing of Environment**. 94(1): 123-132.

Brown, D.G., Page, S.E., Riolo, R. and Rael, W. (2004). Agent-based and analytical modeling to evaluate the effectiveness of greenbelt. **Environment Modeling &Software**. 19(12): 1097-1109.

Chen, L., Wang, J., Fu, B. and Qiu, Y. (2001). Land use change in a small catchment of northern Loess Plateau, China. **Agriculture, Ecosystem and Environment**. 86(2): 163-172.

Chen, D.M. and Rogan, J. (2004). Remote sensing technology for mapping and monitoring in the Egyptian Nile Delta using Landsat data. **International Journal of Environmental Studies**. 61(4): 651-657.

Dasananda, S. (2003). **Digital image analysis and interpretation**. Suranaree University of Technology: Thailand.

Eastman, J.R. (2003). **Idrisi Kilimajaro tutorial**. Clark Laboratories, Clark University, Worcester, USA.

Eastman, J.R. (2003b). **IDRISI Kilimanjaro: Guide to gis and image processing**. Clark Laboratories, Clark University, Worcester, USA.

Echeverria, C., Coomes, D., Sala, J., Rey-Benayas, J.L., Lara, A. and Newton, A. (2006). Rapid deforestation and fragmentation of Chilean Temperate Forests. **Biological Conservation**. 130(4): 481-494.

Erna, L., Bocco, G., Mendoza, M. and Duhau, E. (2001). Predicting land-cover and land-use change in the urban fringe: A case in Morelia city, Mexico. **Landscape and Urban Planning**. 55(4): 271-285.

Etter, A., McAlpine, C., Wilson, K., Phinn, S. and Possingham, H. (2006). Regional patterns of agricultural land use deforestation in Colombia. **Agricultural, Systems and Environment**. 114(2-4): 369-386.

FAO. (1997). **State of the world's forests 1997**. United Nations, Food and Agricultural Organization, Rome.

FAO. (2001). **Forest resources assessment (2000)**. Main report. FAO Forestry paper 140. United Nations, Food and Agricultural Organization, Rome.

FAO. (2003). **State of the world's forests 2003**. United Nations, Food and Agricultural Organization, Rome.

Gautam, A.P., Webb, E.L. and Eiumnok, A. (2002). GIS assessment of land use-land cover changes associated with community forestry implementation in middle hills of Nepal. **Mountain Research and Development**. 22(1): 63-69.

Giri, C., Zhu, Z. and Reed, b. (2006). A comparative analysis of the global land cover 2000 and MODIS land cover data sets. **Remote Sensing of Environment**. 94(1): 123-132.

Harvás, J., Rosin, P.L. and Pasuto, A. (2003). Monitoring landslides from optical remotely sensed imagery: the case history of Tessina landslide. **Geomorphology**. 54(1-2): 63-75.

Helldén, U. and Tottrup, C. (2008). Regional desertification: A global synthesis. **Global and Planetary Change**. 64(3-4): 169-176.

Herold, M., Gardner, M.E. and Roberts, D.A. (2003). Spectral resolution requirements for mapping urban areas. **Geoscience and Remote Sensing**. 41(9): 1907-1991.

Houghton, R.A. (1994). The worldwide extent of land-use change. **Bioscience**. 44(5): 305-313.

Jansen, L.J.M. and Gregorio, D.A. (2002). Parametric land cover and land-use classifications as tools for environmental change detection. **Agriculture, Ecosystems & Environment**. 91(1-3): 89-100.

Jensen, J.R. (2005). **Introduction digital image processing: A remote sensing perspective**. USA: Prentice Hall.

Kilic, S., Enrendilek, F., Berberoglu, S. and Demirkesen, A.C. (2004). Environmental monitoring of land-use and land cover changes in a Mediterranean Region of Turkey [On-line]. Available: http://www.isprs.org./congresses/istambul 2004/comm./papers/61.pdf.html

Kong, W., Sun, O.I., Xu, W. and Chen, Y. (2009). Changes in vegetation and landscape patterns with altered river water-flow in arid West China. **Journal of Arid Environments**. 73(7): 306-313.

Kufer, J.A. (2006). National assessments of forest fragmentation in the US. **Global Environment Change**. 6(1): 73-82.

Lambin, E.F. (1999). Monitoring forest degradation in tropical regions by remote sensing: some methodological issues. **Global Ecol Biogeography**. 8(3-4): 191-198.

Lambin, E.F., Rounsevell, M.D.A. and Geist, H.J. (2000). Are agricultural land use models able to predict changes in land use intensity?. **Agricultural, Ecosystems and Environment**. 82(1): 321-331.

Lambin, E.F. and Geist, H. (2007). **Causes of land use and land-cover change** [On-line]. Available: http://www.eoearth.org/article/Causes_of_land-use and land-cover change#Proximate_versus_Underlying_Causes.html

Li, X. and Yeh, A.G. (2004). Analyzing spatial restructuring of land use patterns in a fast growing region using remote sensing and GIS. **Landscape and Urban Planning**. 69(4): 335-354.

Long, H., Tang, G., Li, X. and Heilig, G.K. (2007). Socio-economic driving forces of land-use change in Kunshan, the Yangtze river delta economic area of China. **Journal of Environmental Management**. 83(3): 351-364.

Lopeza, E., Boccoa, G., Mendozan, M. and Duhaub, E. (2001). Predicting land cover and land use change in the urban fringe. A case study in Morelia city, Mexico. **Landscape Urban Plan**. 55(4): 271-285.

Luijten, J.C. (2003). A systematic method for generating land use patterns using stochastic rule and basic landscape characteristic: results for a Colombian hillside watershed. **Agriculture, Ecosystem and Environment**. 95(2-3): 427-441.

Luque, S. (2000). The challenge to manage the biological integrity of nature reserves: a landscape ecology perspective. **International Journal of Remote Sensing**. 21(13): 2613-2643.

Markov, A. (1907). Extension of the limit theorems of probability theory to a sum of variables connected in a china. The Notes of the Imperial Academy of Sciences of St. Petersburg, VIII Series. **Physio-Mathematical College**. XXII No. 9.

Matson, P.A., Parton, W.J., Power, A.G. and Swift, M.J. (1997). Agricultural intensification and ecosystem properties. **Science**. 277(25): 504-509.

Meyer, W.B. and Turner, B.L. (1994). Land-use/land-cover change: Challenges for geographers. **Geojournal**. 39(3): 237-240.

Meyer, W.B. and Turner, B.L. (1996). Land-use/land-cover change: Challenges for geographers. **Geojournal**. 39(3): 237-240.

Meyn, S.P. and Tweedie, R.L. (2005). **Markov chains and stochastic stability** (2rd ed.). Cambridge: Cambridge University.

Nakayama, Y., Yanagi, T., Yamaguchi, S., Nishimura, J. and Mu, G. (2007). Monitoring of environmental change in Dzunger basin by the analysis of multi-temporal satellite data sets. **Advances in Space Research**. 39(1): 52-59.

Ozdogan, M. and Woodcock, C.E. (2006). Resolution dependent errors in remote sensing of cultivated areas. **Remote Sensing of Environment**. 103(2): 203-217.

Pafe, S., Sőderberg, U., Dandewall, M. and Ouadba, J.M. (2008). Land use analysis from spatial and field data capture in southern Burkina Faso, West Africa. **Agriculture, Ecosystems and Environment**. 127(3-4): 277-285.

Pauleit, S., Ennos, R. and Golding, Y. (2005). Modeling the environmental impacts of urban land use and land cover change- a study in Merseyside, UK. **Landscape and Urban Planning**. 71(2-4): 295-310.

Pichancourt, J.B., Burel, F. and Auger, P. (2006). Assessing the effect of habitat fragmentation on population dynamics: An implicit modelling approach. **Ecological Modelling**. 192(3-4): 543-556.

Pontius, R.G. and Malanson, J. (2005). Comparison of the structure and accuracy of two land change models. **International Journal of Geographic information Science**. 19(6): 243-265.

Rafiee, R., Mahiny, A.S., Khorasani, N. and Darvishsefat, A.D. (2009). Simulating urban growth in Mashad City, Iran through the SLEUTH model (UGM). **Cities**. 26(1): 19-26.

Reidsma, P., Tekelenburg, T., Van Den Berge, M. and Alkemade, R. (2006). Impacts of land-use change on biodiversity: an assessment of agricultural biodiversity in the European Union. **Agriculture, Ecosystems and Environment**. 114(1): 86-102.

Rogan, J. and Chen, D.N. (2004). Remote sensing technology for mapping and monitoring land-cover and land-use change. **Progress in Planning**. 61(4): 301-325.

Serneel, S. and Lambin, E.F. (2001). Proximate causes of land-use change in Narok District, Kenya: A spatial statistical mode. **Agriculture, Ecosystems & Environment**. 85(1-3): 65-81.

Serra, P., Pons, X. and Sauri, D. (2008). Land-cover and land-use change in a Mediterranean landscape: A spatial analysis of driving forces integrating biophysical and human factors. **Applied Geography**. 28(3): 189-209.

Shalaby, A. and Tateishi, R. (2007). Remote sensing and GIS for mapping and monitoring land cover and land-use change in the northwestern coastal zone of Egypt. **Applied Geography**. 27(1): 28-41.

Steininger, M., Tucker, C., Ersts, P., Killeen, T., Villlegas, Z. and Hecht, S. (2001). Clearance and fragmentation of tropical deciduous forest in the Tierras Bajas, Santa Cruz, Bolivia. **Conservation Biology** 15(4): 856-866.

Tang, Z., Engel, B.A., Pianowski, B.C. and Lim, K.J. (2005). Forecasting land use change and its environmental impact at a watershed scale. **Journal of Environmental Management**. 76(1): 35-45.

Tekle, K. and Hedlund, L. (2000). Land cover changes between 1958 and 1986 in Kalu district, southern Wello, Ethiopia. **Mountain Research and Development**. 20(1): 212-231.

Turner, I.M. and Corlett, T. (1996). The conversion value of small, isolated fragments of lowland tropical rain forest. **Trend in Ecology and Evolution**. 11: 330-333.

Turner, B.L., David, S., Steven, S., Gunter, F. and Fresco, L.O. (1997). Land use and land cover change. **Earth Science Frontiers**. 4(1): 26-33.

Turner, B.L. and Meyer, W.B. (1991). Land use and land cover in global environment change: consideration study. **International Social Science Journal**. 43(130): 667-669.

Veldkanp, A. and Lambin, E.F. (2001). Predicting land-use change. **Agricultural, Ecosystem & Environment**. 85(1-3): 1-6.

Verburg, P.H. et al. (2004). A method to analyse neighborhood characteristics of land use pattern. **Computer, Environment and Urban Systems**. 28(6): 667-690.

Von Neumann, J. (1966). **Theory of self-reproducing automata**. Illinois: University of Illinois.

Weng, Q. (2002). Land use change analysis in the Zhujiang Delta of China using remote sensing, GIS and stochastic modeling. **Environmental Management**. 64(3): 273-284.

Wu, Q. et al. (2006). Monitoring and predicting land use change in Beijing using remote sensing and GIS. **Landscape and Urban planning**. 78(4): 322-333.

Xiao, X. et al. (2005). Mapping paddy rice agriculture in southern China using multi-temporal MODIS images. **Remote Sensing of Environment**. 95(4): 480-492.

Yang, X. (2002). Satellite monitoring of urban spatial growth in the Atlanta metropolitan area. **Photogrammetric Engineering & Remote Sensing**. 68(7): 725-734.

CHAPTER III

ANALYSIS OF INFLUENCING FACTORS FOR TEMPORAL AGRICULTURAL LAND USE CHANGE

3.1 Abstract

This work aims to determine crucial factors that influence agricultural land use change in Kanchanaburi Province during period of 1992-2006 based on results of the stepwise regression analysis. Several potential factors were included in the regression analysis that can be divided into four broad categories: biophysical, socio-economic, policy, and technology. Information about area coverage of the agricultural land was extracted from the classified LULC maps of the province in years 1992, 1996, 2001, and 2006. These maps were developed from the Landsat TM/ETM+ images taken in those years. The observed agricultural land use changes during the 1992-2006 period and three sub-periods (1992-1996, 1996-2001, 2001-2006) were investigated and the regression results indicated that different groups of initial factors were responsible for producing those changes with fairly high correlation levels achieved. In general, the climatic factors (temperature in particular) were identified as being most important influencing factors of agricultural land use change found in the study area.

KEYWORDS: agricultural land use change, regression analysis

3.2 Introduction

In recent decades, rapid changes of land use/land cover (LULC) characteristics have been evidenced globally both due to the natural processes like natural disasters, or more significantly, by human activities (Houghton, 1994; Meyer and Turner, 1996; Lambin et al., 2007). These changes could have profound impact on the bio-physical states of the earth's natural environment and also on the sustainable use of land by humans (Matson et al., 1997; Turner et al., 1997). As a result, researches in the field of land use and land cover changes (LUCC) are having great interest at present in both local and global scales, especially in the areas where significant changes normally occur (Turner and Meyer, 1991; Meyer and Turner, 1994). Two main issues related to LUCC study frequently found in the literature nowadays are urban growth (and its impacts or consequences) (Erna et al., 2001; Weng, 2002; Yang, 2002; Pauleit et al., 2005; Xiao et al., 2006) and the critical degradation of natural resource and ecosystem (e.g., forest loss, air/soil/water pollution, or climate change) resulting from LUCC (Turner and Corlett, 1996; Luque, 2000; Steininger et al., 2001; Chen et al., 2001; Guatan et al., 2003; Armsworth et al., 2004; Kilic et al., 2004; Echeverria et al., 2006; Kupfer, 2006; Pichancourt et al., 2006; Mutsushita et al., 2006).

One of the main issues related to LUCC study at present is to identify major driving forces behind LULC change pattern observed in the interested area (mostly extracted from set of multi-temporal classified satellite images or aerial photographs). This knowledge is necessary for the understanding of change mechanism undergone in the area and also for the projection on future scenarios of the LULC pattern that are likely to happen (Riebsame et al., 1994). Normally, the important driving factors of LULC changes at any particular area can be divided into 2 broad categories which are

(1) bio-physical parameters, like topography, climate elements, land quality, natural environment, and (2) socio-economic parameters, like population, household income, education, land tenure, labor force, GDP, state policy, infrastructures or agricultural technology. These influencing factors are sometimes considerably remote in space or in time from the observed changes, especially ones involved state's policy changes or macro-economic transformations which are usually difficult to anticipate. This makes the identification of the responsible driving factors for LULC changes discovered in a given area more complicated and the true LUCC mechanism more difficult to assess.

Several studies have achieved a good projection of likely patterns of future LULC changes, based on multivariate models representing the interaction between the natural and cultural landscape variables that are controlling these factors. Such spatial statistical models attempt to identify explicitly causes of the observed LULC changes using multivariate analyses of some possible exogenous contributions to empirically-derived amount of the change (mainly urban growth and agricultural land reduction). Multiple linear regression and logistic regression techniques are generally applied to achieve this purpose as they can derive a statistical equation for making quantitative determinations of the potential driving factors of the interested LULC changes.

For examples, Lopez et al. (2001) used simple linear regression model to find relationship between classified urban area and population growth in Morelia city, Mexico. They found that urban area was increased in linear fashion with population growth in which the correlation level (R^2) of 0.93 was achieved. Xie et al. (2005) also used regression technique (multiple stepwise) to identify influencing factors of paddy field conversions (to other LULC types) in Wuxian City, China during the 1990-2000 period. Results of their work indicated that urban construction, total income of rural economy and agricultural population shift are three strongest factors affecting rapid paddy field conversions. In addition, the farmland protection policy established during that period also had moderate effect on the observed paddy field conversion.

Wu et al. (2006) examined pattern of LULC change during 1986-2001 period in Beijing, China, using LULC maps derived from Landsat-TM satellite images taken in years 1986, 1991, 1996, and 2001. From the temporal variation of urban area found, they applied multiple linear regression technique to identify favor factors influencing this change and concluded that the non-agriculture population, per capita income of urban areas and per capita income of rural areas were most related to the observed change in the area. Bin et al. (2006) also investigate pattern of LULC changes during years 1988-2001 in Xiamen City, China, using multi-temporal Landsat-TM images. In this work, factors influencing observed cropland reduction were also evaluated using linear regression technique. They concluded that this cropland loss was mainly driven by the population growth, present agricultural productions, level of affluence of the farming populations, and production technology. Long et al. (2006) reported that population growth, industrialization, urbanization, and economic reform measures are major driving forces in LULC change of Kunshan City in Jiangsu Province, China.

In Thailand, Wannasai and Shrestha (2008) had investigated roles of the land tenure security and farm household characteristics on land use change found in the Prasae Watershed, eastern Thailand during 1982-2004, using GIS and farm-level data. The study revealed that factors like land tenure security, demand for land registration, and land resource availability are main responsible elements for changes in land use of the studied area. Also, Fox and Vogler (2005) discovered that national land tenure policies and market pressure are two key driving forces that shape land-use systems in mountainous areas of upper-northern Thailand. Recently, Wongsaichue (2006) and Wongsaichue et al. (2006b; 2007; 2008) had examined influences of population and household on the LULC changes found in Nang Rong District, northeastern Thailand, using classified satellite data integrating with social survey data. The analyses were utilized by multiple logistic regression algorithms. Results of the studies indicated that the out-migration events have positive influence on the LULC change because they typically induce less crop cultivation conducted by the household. As a result, decline in household cultivations, in turn, leads to a change in LULC of the parcels. Table 3.1 presents brief details of some interesting works regarding to the relationship between LULC changes and their responsible driving factors.

3.3 Research Objective

Main aim of this study is to identify influencing factors that are responsible for the observed spatial variation of agricultural area in Kanchanaburi Province during periods 1992-1996, 1996-2001, 2001-2006, and 1992-2006 using multiple stepwise regression technique based on integrated data of several input bio-physical and socio-economic factors collected during each defined period. This kind of research is useful to explore complex interactions between the underlain LULC changing processes and their associated bio-physical and socio-economic transformation which is still lack in most researches found in the literature.

Table 3.1 Examples of reports regarding to relationship between LULC changes and their associated driving factors

Report (Method)	Y (Dependent)	X (Independent)
IGBP-Thailand (1997) (Logistic regression)	Temporal change of patch area	Socio-economic: population, crop production, education, Proximities: distance to roads Technology: electricity/TV availability, number of tractors
Serneels/Lambin (2001) (Logistic regression)	Agriculture and rangeland changes (1975-1995)	Bio-physical: altitude, climate, suitability for agriculture Socio-economic: land tenure, population density Proximities: distance to roads, to towns, to city center, to water resources
Müller/Zeller (2002) (Logistic regression)	Agriculture and forest changes (1992-2000)	Bio-physical data: rainfall, soil types, elevation, slope values Socio-economic: ethic minority, population data Proximities: distance to district center, to roads Technology: number of reservoirs Policy: investment from external sources
Tanrivermis (2003) (Linear regression)	Agricultural land use change	Bio-physical: trend of LULC change Socio-economic: market price of agricultural products, population density
McConnell et al. (2004) (Logistic regression)	Conversion of forest to agricultural land (1957-2000)	Bio-physical: elevation, slope, Socio-economic: population density Proximities: distance to village center, to forest
Xie et al. (2005) (Logistic regression)	Paddy field conversion (1990-2000)	Socio-economic: total income of rural economy, urban construction, rural construction, gross domestic product value, agricultural population, agricultural products, non-agricultural population, total tax value, total value of industrial asset
Wongsaichue (2006) (Logistic regression)	Agricultural changes (1994-2000)	Socio-economic: population density, labors number, electricity consumption, land tenure Technology: agricultural machine

3.4 Materials and Methods

According to the purpose of this study described earlier, there are three main working steps to be carried out to achieve this goal which are (1) acquire area data of agricultural land (at Sub-district or Tambon level) in years 1992, 1996, 2001, and 2006 from the classified Landsat-TM images taken during these years. Amount of changes in these data (for each period) are served as an dependent variable in the regression analysis, (2) generate geographic maps of the proposed influencing factors for each period to be used as independent factors in the analysis, (3) finding suitable regression equations for explaining the observed changes of agricultural land in each in relation to the variation of some selected factors based on the correlation coefficient achieved. In step 1, Envi 4.2 and Erdas 9.0 program were applied for operating the 4 class LULC classification while in step 2, ArcGIS 9.2 program was used to produces the required factor maps. And in step 3, the Microsoft Excel and SPSS 15.0 were employed to manipulate the data and run the necessary regression analysis for each defined period. Work flowchart of the whole procedure is presented in Figure 3.1.

3.4.1 Preparation of LULC maps

In order to quantify changes in amount of agricultural area during each defined period, LULC maps of Kanchanaburi in 1992, 1996, 2001, and 2006 were formulated from the classified Landsat-TM images (spatial resolution 25 m) taken in these years. These images were mostly recorded in winter period (November-February) because it has less amount of cloud cover and most economic crops are normally still visible to the instruments. There are five LULC classes identified in each created map which are agricultural land, forest, urban/built-up area, water body and miscellaneous based on the hybrid classification scheme (Isodata/Maximum likelihood) (Figure 3.2). From the maps, amount of agricultural land at each sub-district (or Tambon) can be determined in according with its located boundary and the results are shown in Appendix B (93 of them in total). Variation in amount of the agricultural land during each chosen period is needed as being dependent variable in the regression analysis. Total changes in the area coverage of all LULC types are described in Table 3.3.

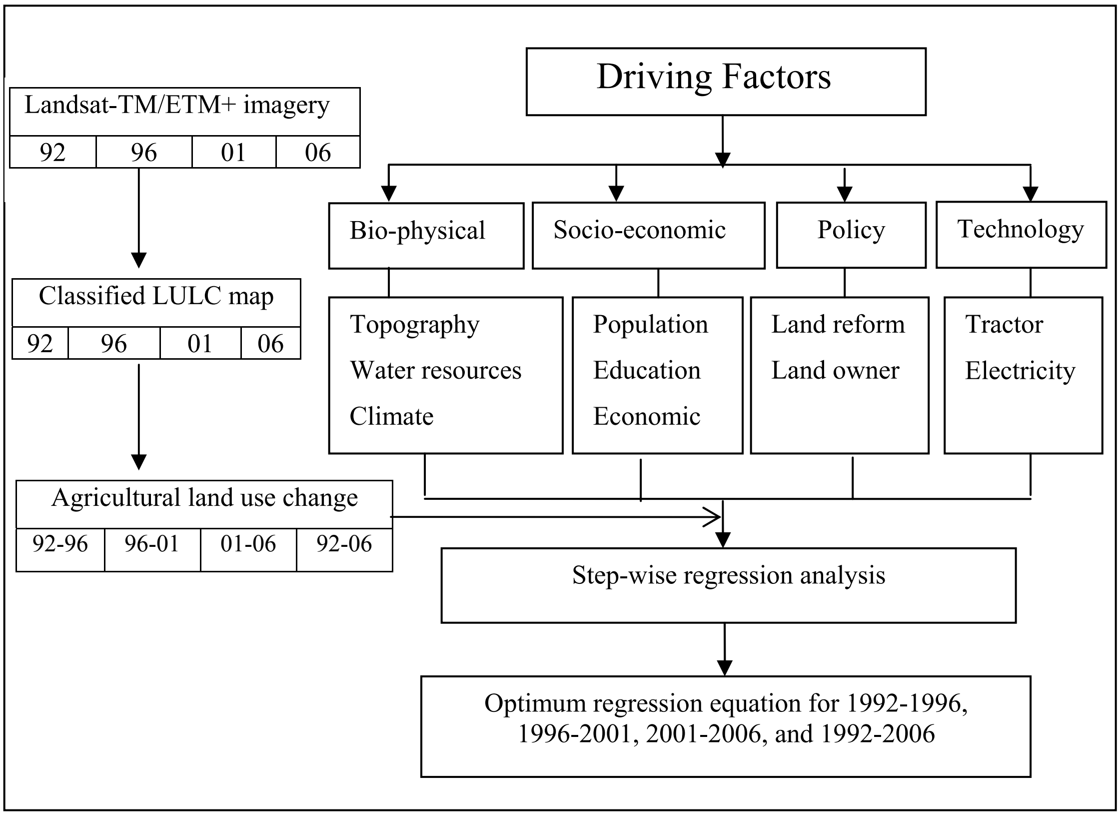


Figure 3.1 Work flowchart of the study

3.4.2 Selection and preparation of the factor maps

In theory, the conversion from other LULC type to agriculture is the result of human decision-making processes where two types of agriculture are present: (1) the large-scale mechanized agriculture (or intensive farming) and (2) the small-holder farming (or household farming) (Sernells and Lambin, 2001). In generally, farm size is key factor that governs farmers' decision where smallholders tend to allocate more land to the consumption crops (to achieve food security) while large holders tend to allocate more land to produce commodity crops for the market.

Expansion of the large-scale agriculture is normally driven by land suitability and economic factors, such as market price and input cost, accessibility to the market (Brush and Turner, 1987). However, expansion of small-scale agriculture is typically driven by different factors, such as changes in demography, especially ones caused by amount of in or out migration and population growth (Entwisle et al., 1998; Vanwey, 2003; Wongsaichue et al., 2007; 2008), land ownership status (Miyacuni, 1999; Mottet et al., 2006; Wannasai and Shrestha, 2008) and socio-economic factors like education and social services (Müller and Zeller, 2002; Bernetti et al., 2006).

As both kinds of the agricultural system are found in the study area, therefore, several factors that may have influences on their area variation were included in the regression analysis. These can be divided into four main categories: (1) bio-physical, (2) socio-economic, (3) agriculture-related policy, and (4) agricultural technology. More detail about type, source and input format of all these factors are listed in Table 3.2. In general, three main sources of the used input data are created LULC maps, GIS-based maps developed from data provided from the responsible agencies, and the socio-economic information extracted from village's status database (NRD2C) collected in 1992, 1996, 2001, and 2006.

Table 3.2 Factors used in the regression analysis (considered at sub-district level)

Dependent Variable	Unit	Input value format(1)	Source
1. Changing amount of agricultural land (ΔA)	rai(2)	relative	LULC map (Landsat TM)
Independent Variables			
1. Biophysical data			
1.1 Water resources data			
1.1.1 number of well (WELL)	number	relative	NRD2C(3)
1.1.2 distance from river (DRIVER)	km.	absolute	LULC map
1.1.3 distance to water body (DWATER)	km.	absolute	
1.2 Topography			
1.2.1 slope (SLP)	degree	absolute	DEM(30m interval)
1.2.1 elevation (ELV)	m	absolute	
1.3 Climate			DEM(30m interval)
1.3.1 mean annual rainfall (RAIN)	mm	relative	
1.3.2 mean annual temperature (TEMP)	^{o}C	relative	
1.3.3 mean annual humidity (HUMID)	percent	relative	Meteorological Department (point interpolation)
2. Socio-economic data			
2.1 Population			
2.1.1 population density (POPD)	number/km^2	relative	NRD2C, DOPA
2.2 Education			
2.2.1 education level (EDU)	number/level	relative	NRD2C
2.3 Economical data			
2.3.1 product price per rai (PPR) (rice/crop)	bath/rai	relative	NRD2C
2.3.2 distance to CBD (DCBD)	km.	absolute	GPS, Field survey
2.3.3 distance from main road (DROAD)	km.	absolute	GIS data based (Road layer)
3. Policy			
3.1 agricultural land reform area (ALRO4-01)	rai	Relative	Land Reform Office
3.2 land ownership (LOWN)	rai	relative	NRD2C
4. Technology			
4.1number of home tractor (ETAN)	number	relative	NRD2C
4.2 number of small tractors (STRACT)	number	relative	NRD2C
4.3 number of big tractors (BTRACT)	number	relative	NRD2C
4.4 electricity availability (household) (ELEC)	number	relative	NRD2C

(1) Relative value for each considered period is used for the dynamic factors and given by relation: value2 (last year) – value1 (first year). But the absolute value is used for the static input factors assumed to be constant through out the entire period.

(2) 1 rai = 1/625 km^2

(3) NRD2C is village's status database assembled every two years nationwide by the Thai government.

Bio-physical data

There were three groups of bio-physical data (nine types in total) used in the analysis: (1) Water resources data (number of wells, distance from river, distance to water body), (2) Topographical data (slope and elevation), and (3) Climatic data (rainfall, temperature, humidity). Water resources (both located underground and on surface) are crucial factors that determine the productivity level of farming in local Thailand, especially for paddy and other water-demanding crops. Therefore, areas situated close to water resources are more likely to be used for agriculture than those situated further away (Wongsaichue, 2006). Geographical data (elevation and slope in particular) are also regarded as key parameters in the analysis of the agricultural land-use change. Normally, crop cultivation is less feasible in highly-elevated land due to limit of land and water resources, difficult to access terrain, and also considerably low temperature all year round (Müller and Zeller, 2002).

Cultivation is also difficult in sloped area due to its steep terrain, structural instability, and possibly high rate of soil erosion; therefore, slope generally inhibits the expansion of agricultural boundary (having negative influence). As a result, it is usually included in most researches that intend to identify influencing factor of the interested agricultural land-use change, especially ones conducted in mountain areas (e.g. Chen et al., 2001; Messing et al., 2003; Zhang et al., 2004; Fu et al., 2006; Mottet et al., 2006; Huang and Kai, 2007; Ningal et al., 2008). Though, slope is typically regarded as being an obstruction to agricultural expansion, however, if the availability of suitable land resources is limited, the expansion of agricultural activity into sloped area is sometimes necessary. In this situation, slope could have positive impact on growth of agricultural land also.

Climate variation (especially in amount of rainfall and temperature) is usually accepted as being critical factor in the study of agricultural land-use change because most productive farming needs specific temperature levels and sufficient amount of rainfall for plants to grow effectively, especially during the growing state. Integration between temperature and rainfall characteristics of the area, one can produce map of the agro-climatic zones that represents the potential agricultural suitability of that area for planting some interested crops, under the rainfall and temperature constraint. An increase in annual amount of rainfall is then, in general, believed to have positive impact on crop cultivation, especially in the rainfed agricultural area where irrigation services are not available (Serneels and Lambin, 2001).

Socio-economic data

There were three groups of socio-economic data (five types in total) included in this analysis: (1) Population (population density), (2) Education (education level), and (3) Economical data (product price per rai, distance to the CBD, distance from main road). Theories explaining agricultural change in association with population density are principally focused around two crucial factors: population pressure and market price incentives (Ali, 2007). According to Boserup (1965), increase in the population density creates the conditions for agricultural intensification that would prevent food shortage. This could result in greater agricultural productivity, rising agricultural standards, and reversal of environmental degradation (Tiffen et al., 1994). However, this conclusion is still much debated and those opposed claim that rapid population growth should lead to the poverty and environmental destruction instead. Specific problems identified include land scarcity, reduction of fertile crop land, deforestation, and production on land unsuited to agriculture (Blaikie and

Brookfield, 1987; Blaikie, 1989; Cleaver and Schreiber, 1992).

In other aspect, Schultz (1964) proposed the commodity demand theory which asserts that growing market price of commodity crops induces farmers to increase the frequency and cultivating area of those crops. More commodity production, in turn, increases farm income which can compensate economic loss incurred from falling market price of consumption crops; improve socio-economic well being of the family; and improve soil quality through crop rotations (Laney, 2002). In reality, most farmers make their decision based on judgment derived from both factors. Therefore, when considering both positive and negative impacts of the population growth and market forces, it becomes apparent that both population growth and market incentives (e.g. input cost, product price, accessibility to market) are great influencing forces behind agricultural intensification and rural development (Verburg et al., 1999; Pfeffer et al., 2005; Wongsaichue et al., 2006; Ali, 2007; Ningal et al., 2008; Wu et al., 2009).

At longer timescale, variation of population density may have a large impact on land use as it can relate directly to the development of household and amount of labor force availability at household level. In several studies (e.g. Wongsaichue, 2006; Wongsaichue et al., 2006; 2007; 2008), it was discovered that land availability and population density (agricultural labor force in particular) are closely related. If land resource is limited for the household, the excess labor forces will be usually pressured to migrate into town to find new available job in a non-agricultural factor. The out-migration events normally have negative influence on the agricultural land-use change because they typically induce less crop cultivation by the household, which in turn, a decline in household cultivations and land use change.

In case of education, it is believed that farmers with better access to education should be expected to use land more intensively and adopt new technologies earlier, thus saving agricultural land to achieve a given income or farm output. As a result, higher education should lead to greater farm productivity and to less demand in land resources by farmers. However, there is also some empirical evidence showing that educated households might engage more in land clearing (Pichon, 1997).

Agriculture-related policy

In general, state policies regarding to the promotion of agricultural activities, e.g. tax rates, interest rates, granting more secure land tenure to farmers, price/cost subsidies, introduction to technology, and initiating more market and credit access, have direct impact on the decision making by farmer and can determine pattern of agricultural land use found in a particular area (Braimoh, 2009).

There were two kinds of the agricultural-related policy examined in this work which are agricultural land reform area, in which farmers are granted right to occupy and use land for agricultural activities, and land ownership. Both factors are regarded as an important determinant in the farmers' decision-making process about land use. It is normally accepted that secured land ownership for responsible farmers leads to more confidence in the investment and efficient use of land resources whereas lack of secured land right potentially lead to expansion of agriculture activity into forested area and the degradation of land resources (Onchan and Feder, 1985; Feder et al., 1986; Miyakuni, 1999; Wannasai and Shrestha, 2008).

Agricultural technology

Technologies developed for agricultural productions like chemicals, fertilizers, plough machine (e.g. tractor), harvesting machines, or irrigating tools are important factors dictating trend of the agricultural land-use change. The role of technology in agricultural change can be described in two ways. Treated exogenously, an improved technology reduces the severity of environmental constraints and induces agricultural growth. Viewed endogenously, it allows more frequent cultivation and increases crop yield (Grigg, 1982; 1992). However, excessive use of the technology may lead to the degradation of natural environment such as soil or water quality (Ali, 2004; 2007). In addition, agricultural technology potentially encourages greater deforestation to serve the need of more fertile agricultural land (Lambin et al., 2003). Also, the introduction of new technology to crop farming system may result in more excessive labor force left in the agricultural section that eventually causes the out-migration consequences.

In this study, four factors related to the agricultural technology in Thailand were included in the analysis, which are number of home tractor (or “Etan”), number of small tractors, number of big tractors, and electricity availability (to household).

3.4.3 Regression analysis

To identify driving factors which should be responsible for observed changes in amount of the agricultural area (at sub-district level) during each period, the multiple linear regression technique was applied to quantify proper relationship between these changes and their associated driving factors. The gained results are described in form of multiple linear regression equation (for each relevant period) as follow:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n \qquad (3.1)$$

where Y is the amount of change in agricultural land (increase/decrease/no-change) at each involved sub-district (dependent variable), X_i is the input value of factor i (in its respective format) used in the analysis (independent variable), β_0 is a constant of the regression and β_i is the regression coefficient of factor i used in the analysis.

In the regression analysis, the stepwise algorithm was used to identify groups of independent variables (driving factors) that are highly correlated (in term of the R^2 value) to spatial variation of considered dependent variable (change in amount of the agricultural land). In this method, the suitable regression equation will be developed step by step where some independent variable is added (or deleted) from the required equation to achieve the greatest R^2 value possible at each step. Main outputs of the analysis (for each specified period) are tables describing sets of chosen variables (or predictors) that give relatively high correlation between dependent and independent parameters used as input data in the analysis along with the regression coefficients for each related independent variables as presented in Appendix B1. Resulted data given in these tables can be used to formulate the suitable regression equation needed for the explanation of agricultural land-use change at each interested period. More complete detail on the use of regression method is given in Wanichbuncha (2003).

In addition, the multi-collinearity, or tolerance statistics, for each used factor was also examined to avoid any problem arising from the highly correlation between selected factors. This tolerance value is defined as $T = 1-R_i^2$ for the regression of that variable on all the other independents, ignoring the dependent. When tolerance is low (e.g. close to zero), this means that the multi-collinearity of that variable with other independents is high and the constant β_0 and regression coefficient β_i will be unstable. (Pongwichai, 2000). As a result, parameters with low tolerance values were excluded from the analysis to make the obtained results more credible.

3.5 Results and Discussion

3.5.1 Assessment of agricultural land use change

To investigate temporal change in amount of agricultural area during period of 1992-2006, the classified LULC maps of Kanchanaburi Province in years 1992, 1996, 2001, and 2006 were produced as displayed in Figure 3.2 in which five LULC classes were identified which are agricultural land, forest, urban/built-up area, water body and miscellaneous. In general, the most dominant LULC categories found were forest and agricultural land that aggregately covered about 95% of the total area at the ratio of 3 (forest) :1 (agricultural land) approximately (Table 3.3) for the whole period. Forests were mostly found in the upper part of the province (mainly mountainous area) where agricultural lands were mostly found in the flat areas of the south and along the river valleys. Main urban/built-up areas were usually situated close to main rivers in the far south and they were normally surrounded by agricultural lands.

Data of the area coverage for all classified LULC types seen in Figure 3.2 are given in Table 3.3 and changes statistics are given in Table 3.4. The data indicate that during this 15-year period, the total forest area has decreased steadily about 0.39% (of the total area), from 71.97% in 1992 to 71.58% in 2006, whereas the agricultural land has decreased by 0.79%, from 24.21% in 1992 to 23.62% in 2006, or at the average of about 0.05% annually. These data make the relative loss of entire forest area of about 0.54%, or at the average of 0.036% of its original area annually, and the relative loss of agricultural land become 2.41% for the whole period, or 0.16% annually.

From the LULC output maps, amount of agricultural land at each sub-district can be determined in according with its identified boundary and the results are shown in Appendix B1 (93 of them in total).

Table 3.3 LULC area allocation in 1992, 1996, 2001, and 2006

LULC Type	1992		1996		2001		2006	
	km^2	%	km^2	%	km^2	%	km^2	%
Agriculture (A)	4691	24.21	4533	23.39	4445	22.94	4578	23.62
Forest (F)	13948	71.97	13940	71.93	13930	71.88	13873	71.58
Water body (W)	683	3.52	854	4.41	933	4.82	851	4.39
Urban/built-up (U)	58	0.30	52	0.27	71	0.51	79	0.41
Total area	19380	100	19380	100	19380	100	19380	100

Table 3.4 Relative change rate[(1)] and annual change rate[(2)] of the main LULC types in Kanchanaburi during period 1992-2006

Period	Agriculture	Forest	Water	Urban
1992-1996	-3.37	-0.06	25.04	-10.34
Annual Rate	-0.67	-0.01	5.01	-2.07
1996-2001	-1.94	-0.07	9.25	36.54
Annual Rate	-0.39	-0.01	1.85	7.31
2001-2006	2.91	-0.41	-8.79	11.27
Annual Rate	0.58	-0.08	-1.76	1.88
1992-2006	-2.41	-0.54	24.60	36.21
Annual Rate	-0.17	-0.04	1.76	2.59

(1) Relative change rate (%) = [(Second year-First year)/First year] x 100%

(2) Annual change rate (%) = Relative change (%)/time interval (year)

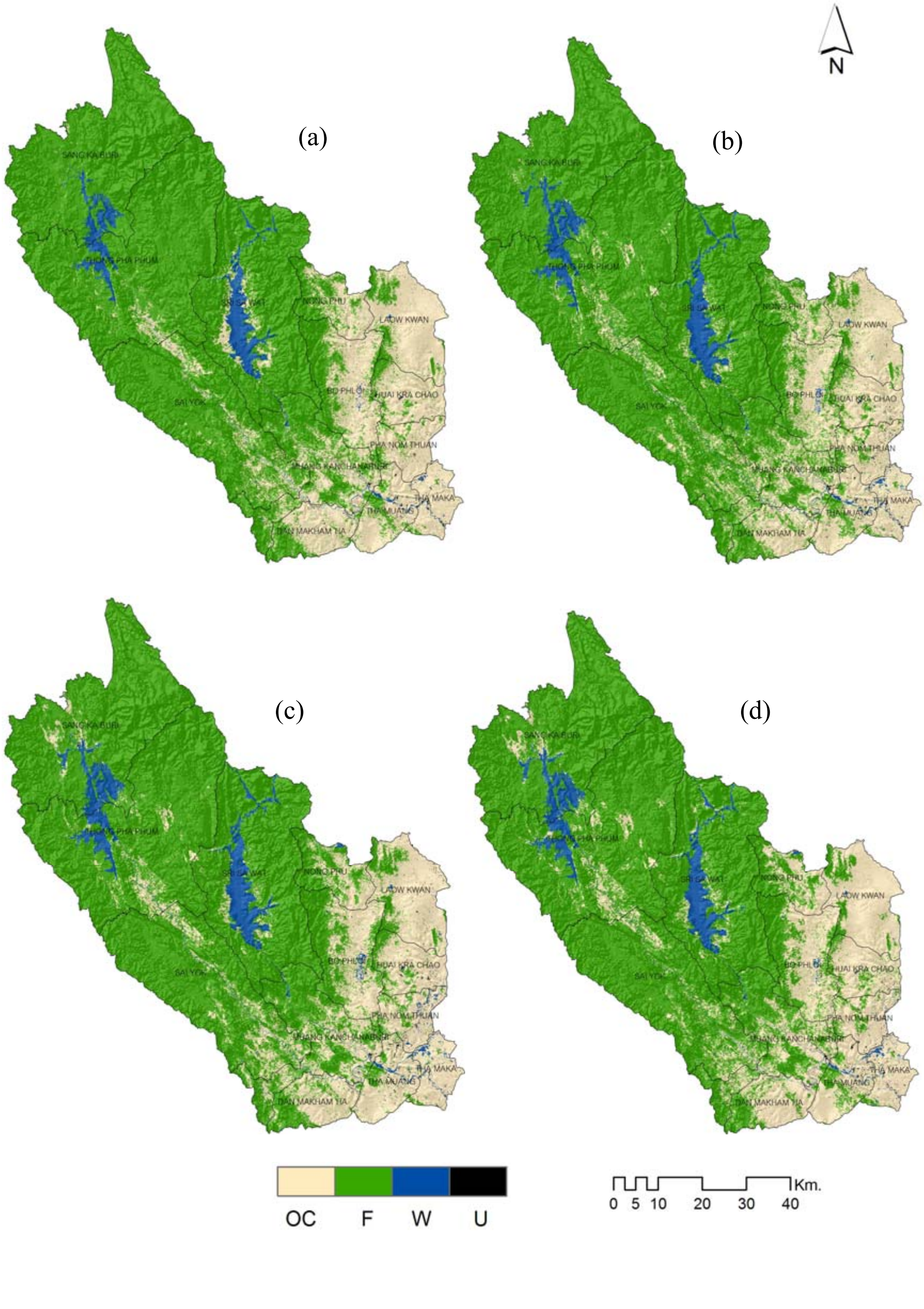


Figure 3.2 Classified LULC maps of Kanchanaburi in (a) 1992, (b) 1996, (c) 2001, and (d) 2006

Table 3.5 Optimum regression equation for each relevant period

Period	Optimum regression equation (using stepwise algorithm)
1992/1996	$\Delta A_{92/96} = 2.631 + 2.119(SLP) - 0.278(POPD) + 0.001(PPR) + 0.092(ELEC)$ **Predictors**: slope, population density, product price, electrical availability
1996/2001	$\Delta A_{96/01} = 74.536 - 2.519(SLP) + 0.094(RAIN) + 345.03(TEMP) - 0.008(DROAD) - 0.004(STRACT)$ **Predictors**: slope, annual rainfall, annual temperature, distance from main road, number of small tractors
2001/2006	$\Delta A_{01/06} = -59.385 - 1.79(SLP) - 0.113(RAIN) + 357.329(TEMP) + 0.225(POPD)$ **Predictors**: slope, annual rainfall, annual temperature, population density
1992/2006	$\Delta A_{92/06} = 89.509 - 0.223(ELV) - 0.11(RAIN) + 353.201(TEMP) - 0.002(DCBD) + 0.089(LOWN)$ **Predictors**: elevation, annual rainfall, annual temperature, distance from city center, land ownership

Table 3.6 Related statistics values for the equations seen in Table 3.5

Period	R^2	Adjusted R^2	Std. error
1992-1996	0.736	0.703	30.55759
1996-2001	0.978	0.976	158.54866
2001-2006	0.985	0.984	129.68499
1992-2006	0.988	0.988	113.08444

Note: See meaning of the statistical parameters shown in the table in Appendix C and all results were achieved at $P < 0.001$ and $\alpha = 0.5$.

3.5.2 Regression analysis

From knowledge about changing area cover of the classified agricultural area (at sub-district level) during each needed period, the regression analysis was operated using the stepwise algorithm (as described in Section 3.4.3) where all the proposed influencing factors (in their respective format for each referred period) were initially input as initial independent variables. As a result, the optimum regression equation associated to the agricultural land-use change for each period (one with highest value of R^2) was identified and results for all chosen periods are given in Tables 3.5 and 3.6 and also in Appendix C for more complete detail.

Table 3.5 indicates that the optimum regression equation for each specified period can establish relationship between dependent variable (ΔA) and its associated independent variables (driving factors) with notably high value of correlation level (with $R^2 > 0.95$ in all cases except in case of the 1992-1996 period). However, factors that are responsible for making these high values of correlation level (as seen in each equation) are significantly different at each considered period. This indicates that the mechanism influencing changes in agricultural land in Kanchanaburi is different for different studied period.

Period 1992-1996

For period 1992-1996, the significant driving factors of the observed changes (identified from the regression equation seen in Table 3.4) are slope, population density, product price, and electrical availability. Based on values of the standardized coefficient for the analysis (given in Appendix C), electrical availability and slope are the two most important driving factors identified in this period.

Among these factors, only population density that has negative influence on the observed change (or oppose to agricultural expansion) but the rest have positive influence (or support agricultural expansion). In general, increasing population means more accommodation, or infrastructure, needed that could result in the expansion of urban/built-up area in expense of the agricultural land located nearby. If this urban expansion outweighs the agricultural expansion then population growth can generate negative impact on agricultural land use. In addition, population growth alone does not guarantee the linear increase of labor force for the agricultural section due to the effect of out-migration phenomena occurring in the area.

As mentioned earlier, sloped area is usually considered as being an obstruction to the agricultural expansion but if the agricultural land resource is limited (e.g. in mountainous region) the expansion of agricultural activity into rather sloped area is sometimes necessary. Regarding to this situation, slope could have positive impact on agricultural expansion also. Typically, household electricity is not related directly to agricultural activity operated by that household, but it normally helps to improve the living standard of local farmers and could indirectly assist some improving farming technology initiated by the farmers like irrigation-related facilities. Strong correlation found between electricity availability and agricultural land use change indicates that the economic development and agricultural modernization had profound influence in the study area at this period (Bin et al., 2006).

About product price, it normally has positive impact on agricultural land use as most farmers tend to grow any crops that could benefit them most (if land quality is supported). If market prices of agricultural product increase, they can initiate notable increase of the agricultural area as a consequence. For Kanchanaburi, its two main economic crops (apart from paddy) are cassava and sugarcane whose growing areas can vary considerably year-by-year in according with the market prices of the crops.

Period 1996-2001

For period 1996-2001, the five significant driving factors being identified are slope, annual rainfall, annual temperature, distance from the main road and number of small tractors but only two climatic factors (temperature and rainfall) that generate positive impact on agricultural land-use change during this period while other factors have negative impact. Temperature and rainfall are also regarded as being the most influencing factors during this period.

Climate variation is usually accepted as key factor in the study of agricultural land-use change because most productive farming needs specific temperature levels and sufficient amount of rainfall to grow plants effectively. Apart from the climatic factors mentioned earlier; slope, distance from the main road and number of small tractors also have impact on the observed changes in negative manner. In general, slope is one of the key geographical factors that determine pattern of LULC changes; as a result, it is normally included in most studies related to this issue especially ones that were conducted in the mountain area like in the upper part of Kanchanaburi.

Distance from main road could be related directly to the accessibility level of any particular parcel of land and it can lead to the greater likelihood of that land to be converted into some other land use type, especially from agriculture to urban/built-up area or from forest to agricultural land. As a result, it has been included in several works as being main causative factor of the observed land use changes, e.g. Verburg et al. (1999); Serneels and Lambin (2001), Müller and Zeller (2002), and Wongsaichue et al. (2008). The negative correlation seen suggests that road closeness potentially induce loss of the agricultural land during this period.

About the small tractors, they are mostly used to support farming activity at small-scale (or household) level not for the large-scale (or intensive) farming like big tractors. Therefore, they can not potentially induce great expansion of the agricultural area like big tractors do. However, the wide-spread used of small tractors may lead to the considerably reduction of labor force needed in the agricultural system. This can have negative impacts on agricultural production by reducing labor force availability and lowering the demand of new farming land that can eventually lead to the decrease in amount of active agricultural land instead. From the study of Wongsaichue et al. (2008) in Nangrong District, northeast Thailand, they had discovered that number of agricultural machine in a household does not have much impact on the agricultural land-use change observed in their study area. Also, in this study, the number of small tractors has provided some negative impact on agricultural land use in Kanchanaburi Province during this considered period.

Period 2001-2006

For this period, the four identified responsible driving factors are slope, annual rainfall, annual temperature, and population density. Like the 1996-2001 period, only temperature data that has significantly high influence on agricultural land-use change while other factors have relatively small influence. However, unlike in the 1992-1996 period, population density in this period has positive impact on the changing amount of agricultural land. This indicates the higher demand in agricultural land as a result of the population growth (or due to population pressure).

Period 1992-2006

From Tables 3.3 and 3.4, during this 15-year period, the agricultural land has increased about 16.6% from its original value in 1992 and the identified influencing factors for this considerably gain are elevation, annual rainfall, annual temperature, distance from city center, and land ownership. Among these, the most important ones are annual temperature and distance from city center whereas only temperature and land ownership that have positive influences on the expanding of agricultural land. This means farmers tend to do more farming if their land ownership is secured.

Distance to city center is important for the analysis because it informs level of accessibility to potential market of agricultural products and to political center of the study area. Therefore, it is typically regarded as being crucial explanatory variable for the understanding of land-use change process in many researches, e.g., Verburg et al. (1999), Serneels and Lambin (2001), Müller and Zeller (2002), Wongsaichue et al. (2008), and Braimoh (2009). In general, agriculture is less attractive for land situated closer to city center due to higher price of land rent, or land value, and greater chance to use it for other activities that are more profitable (mostly for commercial purposes). As a result, proximity of land location to the city center is key variable normally used to determine likelihood of the agricultural land use change. The further distance from city center implies the less chance of the land to have agricultural land-use change.

3.6 Conclusion

The main objective of this work is to identify associated parameters which are responsible for the observed agricultural land-use change in Kanchanaburi Province during the 1992-2006 periods. In the analysis, several potential factors were taken into account for the variation in amount of agricultural land during this 15-year time span (Table 3.2). Based on the classified LULC maps and data for years 1992, 1996, 2001, and 2006 derived from the corresponding Landsat-TM data (Figure 3.2 and Tables 3.3 and 3.4), we found that area coverage of the agricultural land has been continuously increased by about 16.54% during this studied period (mostly on the expense of close forest land). Output results given by the stepwise regression technique (Table 3.5 and 3.6) indicate different group of driving factors which are responsible for the observed changes in the amount of agricultural land (at sub-district level) during each specified sub-period (1992-1996, 1996-2001, 2001-2006) and the whole period (1992-2006).

In general, climatic factors (temperature and rainfall) were being identified as the most dominant influencing factors of the changes. Other bio-physical parameters like elevation and slope; socio-economic parameters like population density, product price, distance to CBD, and distance from main road; policy-related parameter like land ownership; and agricultural technologies like electrical availability and number of small tractors, are also having some influence (through relatively small) (Table 3.5 and appendix B). Results of the study indicate that long-term variation (of agricultural land use area) during the whole 15-year period (1992-2006) was influenced mainly by elevation, annual rainfall, annual temperature, distance from CBD and land ownership characteristics of the study area.

The stepwise regression technique may be proved in this study to be capable of identifying driving factors that influence observed agricultural land-use change in Kanchanaburi during each specified period regarding to its high correlation level (R^2) obtained (Table 3.6). The output results allow us to better understand which spatial determinants prevail to explain the spatial distribution of different changes in amount of agricultural land. However, it is still difficult to distinguish between correlation and causality. For example, slope and population density have been shown to have both negative and positive influence on the observed changes (for different period) but it is difficult to tell that which mechanism links both parameters to agricultural expansion in each situation. To remedy this deficiency, different LUCC models (process-based in particular) are thus required to give more information about the actual mechanisms that are responsible for the observed land-use changes found in our study.

3.7 References

Ali, A.M.S. (2004). Technological change in agriculture and land degradation in Bangladesh: a case study. **Land Degradation and Development**. 15(3): 283-298.

Armsworth, P., Kendall, B. and Davis, F. (2004). An introduction to biodiversity concepts for environmental economists. **Resource and Energy Economics**. 26:115-136.

Barredo, J.I., Kasanko, M., McCormick, N. and Lavalle, C. (2002). Modelling dynamic spatial processes: simulation of urban future scenarios through cellular automata. **Landscape and Urban Planning**. 64(3): 145-160.

Bin, Q., Fei, C.J., Lie, H.Q., Romkens, M.J.M., Qi, X.Q., Feng, S.F. and Cheng, B.C. (2006). Spatial-temporal pattern and driving forces of land use change in Xiemen. **Pedosphere**. 16(4): 447- 488.

Blaikie, P.M. and Brookfield, H. (1987). **Land degradation and society**. London: Methuen.

Blaikie, P.M. (1989). Explanation and policy in land degradation and rehabilitation for developing countries. **Land Degradation and Development**. 1(1): 23-37.

Boserup, E. (1965). **The conditions of agricultural growth: the economics of Agrarian change under population pressure**. New York: Aldine.

Braimoh, A.K. (2009). Agricultural land-use change during economic reforms in Ghana. **Land Use Policy**. 26(3): 763-771.

Brush, S.B. and Turner, B.L. (1987). **The nature of farming systems and views of their change**. Comparative Farming System. New York: Guilford.

Chen, L., Wang, J.W., Fu, B. and Qiu, Y. (2001). Land-use change in small catchment of northern Loess Plateau, China. **Agriculture, Ecosystems and Environment**. 86(2): 163-172.

Cleaver, K.M. and Schreiber, G.A. (1992). **The population, agriculture and environment nexus in Sub-Saharan Africa**. Agriculture and Rural Development Series Number 1. The World Bank, Technician Department, Africa Region: Washington DC.

Echeverria, C., Coomes, D., Sala, J., Rey-Benayas, J.L., Lara, A. and Newton, A. (2006). Rapid deforestation and fragmentation of Chilean temperate forests. **Biological Conservation**. 130(4): 481-494.

Entwisle, B. (1998). **Land-use/land-cover and population dynamics, Nang Rong, Thailand**. People and Pixels: Linking remote sensing and social science. National Research Council, Washington, D.C: National Academy.

Erna, L., Bocco, G., Mendoza, M. and Duhau, E. (2001). Predicting land-cover and land-use change in the urban fringe: A case in Morelia city, Mexico. **Landscape and Urban Planning**. 55(4)10: 271-285.

Feder, G., Onchan, T., Chalamwong, Y. and Hongladarom, C. (1986). **Land ownership security, farm productivity, and land policies in rural Thailand**. The Collaborative Project of the World Bank. Kasetsart University and Thammasat University.

Fox, J. and Vogler, J.B. (2005). Land-use and land-cover change in Montane Mainland Southeast Asia. **Environmental Management**. 36(3): 394-403.

Fu, B.J. et al. (2006). Temporal change in land use and its relationship to slope degree and soil type in a small catchment on the Loss Plateau of China. **Catena**. 65 (1): 41-48.

Guatam, A.P., Webb, E.L., Shivakoti, G.P. and Zoebish, M.A. (2003). Land use dynamics and landscape change pattern in a mountain watershed in Nepal. **Agriculture, Ecosystems and Environment**. 99: 83-96.

Houghton, R.A. (1994). The worldwide extent of land-use change. **Bioscience**. 44(5): 305-313.

Iacopo, B., Chiara, F. and Ginevra V.L. (2006). Land use change and the multi functional role of agriculture: a spatial prediction model in an Italian rural area. **International Journal of Agricultural Resources, Governance and Ecology**. 5(2-3): 145-161.

IGBP-Thailand. (1997). **Land use and land cover change project Thailand case study**. International Geosphere Biosphere Programme-Thailand.

Kilic, S. Evrendilek, F., Berberoglu, S. and Demirkesend, A.C. (2004). Environmental monitoring of land-use and land-cover changes in Amik plain, Turkey [On-line]. Available: http://www.isprs.org/congresses/istanbul2004/comm7/ papers/61.pdf.html

Kupfer, J.A. (2006). National assessment of forest fragmentation in the US. **Global Environmental Change**. 16: 73-82.

Lambin, E.F., Geist, H.J. and Lepers, E. (2003). Dynamics of land-use and land cover change in Tropical regions. **Annual Review of Environment and Resources**. 28: 205-241.

Lambin, E.F. and Geist, H. (2007). **Causes of land use and land-cover change** [On-line]. Available: http://www.eoearth.org/article/Causes_of_land-use_and _land-cover_change#Proximate_versus_Underlying_Causes.html

Laney, R. (2002). Disaggregating indiced intensification for land-change analysis: a case study from Madagascar. **Annals of the Association of American Geographers**. 92(4): 702-726.

Long, H., Tang, G., Li, X. and Heilig, G.K. (2006). Socio-economic driving forces of land use change in Kunshan, the Yangtze river delta economic area of China. **Environmental Management**. 83(3): 351-364.

Luque, S.S. (2000). Evaluating temporal changes using multi-spectral scanner and thematic mapper data on the landscape of a natural reserve: the New Jersey Pine Barrens, a case study. **International Journal of Remote Sensing**. 21(13-14): 2589-2611.

Matson, P.A., Parton, W.J., Power, A.G. and Swift, M.J. (1997). Agricultural intensification and ecosystem properties. **Science**. 277(25): 504-509.

McConnell, W.J., Sweeney, S.P. and Mulley, B. (2004). Physical and social access to land: spatio-temporal patterns of agricultural expansion in Madagascar. **Agriculture, Ecosystems and Environment**. 101(1-2): 171-184.

Messing, I., Fagerström, H.M., Chen, L. and Fu, B. (2003). Criteria for land suitability evaluation in a small catchment on the Loess Plateau in China. **Catena**. 54 (1-2): 215-234.

Meyer, W.B. and Turner, B.L. (1994). **Change in land use and land cover: A global perspective**. Cambridge: Cambridge University.

Meyer, W.B. and Turner, B.L. (1996). Land-use/land-cover change: Challenges for geographers. **Geojournal**. 39(3): 237-240.

Miyakuni, K. (1999). Changes of land tenure and the introduction of tree cash crops by shifting cultivators: The case of paluan muruts in Sabah, Malasia. **Journal of Forest Research**. 4(2): 67-74.

Mottet, A., Ladet, S., Coqué, N. and Gibon, A. (2006). Agricultural land-use change and its drivers in mountain landscapes: A case study in the Pyrenees. **Agriculture, Ecosystems & Environment**. 114(2-4): 296-310.

Muller, D. and Zeller, M. (2002). Land use dynamics in the central highlands of Vietnam: a spatial model combining village survey data with satellite imagery Interpretation. **Agricultural Economics**. 27(3): 333-354.

Ningal, T., Hartemink, A.E. and Bregt, A.K. (2008). Land use change and population growth in the Morobe province of Papua New Guinea 1975 and 2000. **Journal of Environment Management**. 87(1): 117-124.

Onchan, T. and Feder, G. (1985). **Land tenure security and farm investment in Thailand discussion paper No.7**. Center for Applied Economics Research, Kasetsart University.

Pauleit, S., Ennos, R. and Golding, Y. (2005). Modeling the environmental impacts of urban land use and land cover change a study in Merseyside, UK. **Landscape and Urban Planning**. 71(2-4): 295-310.

Pfeffer. M.J., Schlelhad, J.W., De Gloria, S.D. and Gomez, J. (2005). Population, conservation, and land use change in Honduras. **Agriculture, Ecosystems and Environment**. 110(1-2): 14-28.

Pichancourt, J.B., Burel, F. and Auger, P. (2006). Assessing the effect of habitat fragmentation on population dynamics: an implicit modeling approach. **Ecological Modeling**. 192: 543-556.

Pichó, F.J. (1997). Colonist land allocation decisions, land uses and deforestation in the Ecuadorian Amazon frontier. **Economic Development Cultural and Change**. 35(3): 707-744.

Pichon, F.J. (1997). Settler households and land-use patterns in the Amazon frontier: farm-level evidence from Ecuador. **World Develop**. 25: 67-91.

Pongwichai, S. (2000). **An analysis data in statistic by computer**. Bangkok: Chulalongkorn of University.

Riebsame, W.E., Meyer, W.B. and Turner B.L. (1994). Modeling land use and cover as part of global environmental change. **Climatic Change**. 28: 45-64.

Ronald, R. (1998). **Linking remote sensing and social science: The need and the challenges**. People and pixels: Linking remote sensing and social science. National Research Council, Washington, D.C: National Academy.

Schultz, T. (1964). **Transforming traditional agriculture**. New Haven: Yale University.

Serneels, S. and Lambin, E.F. (2001). Proximate causes of land use change in Narok District, Kenya: a spatial statistical model. **Agriculture, Ecosystems and Environment**. 85(1-3): 65-81.

Shajaat Ali, A.M. (2007). Population pressure, agricultural intensification and changes in rural systems in Bangladesh. **Geoforum**. 38(4): 720-738.

Steininger, M.K., Tucker, C.J., Townshend, J.R.G., Killeen, T.J., Desch, A., Bell V. and Ersts, P. (2001). Tropical deforestation in the Bolivian Amazon 2001. **Environmental Conservation**. 28: 127-134.

Tanrivermis, H. (2003). Agricultural land use change and sustainable use of land resources in the Mediterranean region of Turkey. **Journal of Arid Environment**. 54: 553-564.

Tiffen, M., Mortimore, M. and Gichuki, F. (1994). **Less erosion: environmental recovery in Kenya**. New York: Wiley and Sons.

Turner, B.L. and Meyer, W.B. (1991). Land use and land cover in global environment change: consideration study. **International Social Science Journal**. 43(130): 667-669.

Turner I.M. and Corlett, R.T. (1996). The conservation value of small, isolated fragments of lowland tropical rain forest. **Trends in Ecology & Evolution**. 11(8): 330-333.

Turner, B.L., David, S., Steven, S., Gunter, F. and Fresco, L.O. (1997). Land use and land cover change. **Earth Science Frontiers**. 4(1): 26-33.

Vanwey, L.K. (2003). Land ownership as a determinant of temporary migration in Nang Rong, Thailand. **European Journal of Population**. 19(2): 121-145.

Verburg, P.H., Veldkamp, T. and Bouma, J. (1999). Land use change under conditions of high population pressure: the case of Java. **Global Environmental Change**. 9(4): 303-312.

Wannasai, N. and Shrestha, R.P. (2008). Role of land tenure security and farm household characteristics on land use change in the Prasae watershed, Thailand. **Land Use Policy**. 25(2): 214-224.

Wanicnbuncha, K. (2003). **Using SPSS for windows in data analysis**. Bangkok: Chulalongkorn of university.

Weng, Q. (2002). Land use change analysis in the Zhujiang Delta of China using remote sensing, GIS and stochastic modeling. **Environmental Management**. 64(3): 273-284.

Wongsaichue, T. (2006). **Household production resources, population dynamics and land use/land cover change in rural northeast village, Thailand**. Ph.D. Dissertation, Mahidol University.

Wongsaichue, T., Sawangdee, Y. and Rindfuss, R. (2006). Influences of population dynamics on agricultural land use in rural northeastern Thailand: a case study in Nang Rong district. **Journal of Population and Social studies**. 15(1): 45-63.

Wongsaichue, T., Sawangdee, Y. and Rindfuss, R. (2007). Influences of population dynamics on agricultural land use in rural northeastern Thailand: A case study in Nang Rong district. **Journal of Population and Social Studies**. 15(2): 45-63.

Wongsaichue, T., Sawangdee, Y. and Rindfuss, R. (2008). Land use/land cover change in agricultural villages of Northeastern Thailand. **Kasetsart Journal (Social Sciences)**. 29(1): 93-103.

Wu, Q. et al. (2006). Monitoring and predicting land use change in Beijing using remote sensing and GIS. **Landscape and Urban Planning**. 78(4): 322-333.

Wu, J.X., Eiao, H.S., Wang, H., Yang, L.Z. and Eillis, E.C. (2009). Agricultural landscape in China's Yangtze delta1942-2002: A case study. **Agriculture, Ecosystems and Environment**. 129(4): 524-533.

Xiao, X.S., Boles, S., Frolking, C., Li, J.Y., Babu, W.S. and Moore, B. (2006). Mapping paddy rice agriculture in South and Southeast Asia using multi-temporal MODIS images. **Remote Sensing of Environment**. 100: 95-113.

Xie, Y. et al. (2005). Socio-economic driving force of arable land conversion: A case study of Wuxian city, China. **Global Environmental Change**. 15(3): 238-252.

Yang, X. (2002). Satellite monitoring of urban spatial growth in the Atlanta metropolitan area. **Photogrammetric Engineering & Remote Sensing**. 68(7): 725-734.

Zhang, Q.J. et al. (2004). Dynamics and driving factors of agricultural landscape in the semiarid hilly area of the Loess Plateau, China. **Agriculture, Ecosystems and Environment**. 103(3): 535-543.

CHAPTER IV

LAND SUITABILITY ASSESSMENT FOR SUGARCANE AND CASSAVA CULTIVATION

4.1 Abstract

The main objective of this study is to evaluate land suitability for cultivating important energy economic crops, which are sugarcane and cassava, in Kanchanaburi Province, western Thailand. To achieve this goal, the Multi-Criteria Decision Making (MCDM) integrated with 1976 FAO Framework for crop plantation were used to assess suitable areas for growing the crops. Several biological and economical factors involved in the analysis were selected based on the FAO Framework description and experts' opinions, and their data were kept and displayed as individual and combined GIS layers for the use. Each factor had been given weight and score, which represent its relative importance in the suitability analysis by using the Analytic Hierarchical Process (AHP) method which is one of the widely used techniques of MCDM. Land suitability map for each selected crop were produced based on the linear combination in factor weight and class weight (rating) of each factor involved and presented as suitability classes according to FAO standard. It was found that about 52.49% (for sugarcane) and 45.07% (for cassava) of the study area is highly suitable or moderately suitable and only a few percent that is not suitable for growing the interested crops. Typically, most suitable areas for both crops locate in the eastern and lower part of the province due to the highly fertile soil and abundance of the water resources available therein. Comparing to land use map derived from Landsat-TM image, it was also found that most parts of the suitable area were located in the existing agricultural land (but being used for other crops/plants) and the forest area, which is typically not allowed for any agricultural use.

KEYWORDS: land suitability area, land evaluation, energy crops, MCDM, AHP

4.2 Introduction

It is obvious that energy crisis has spread all over the world as the price of petroleum is dramatically increased in recent years. One possible solution to ease this problem is to find some renewable energy to substitute petroleum such as ethanol. Ethanol is renewable liquid energy obtained by biomass of agricultural raw materials (Sriroth et al., 2003). Typically, two of the most popular crops for producing ethanol are sugarcane and cassava because of their price and availability (Nutsombun, 2006). As a result, the Thai government has recently issued new policy in order to increase production of these crops to meet growing demand in the energy market. Therefore, to serve this purpose, finding suitable areas for cultivating these two crops efficiently is necessary and it is the main objective of this study.

The land evaluation method is the systematic assessment of land potential to find out the most suitable area for cultivating some specific crops. Theoretically, the potential of land suitability for agricultural use is usually determined by an evaluation process of the climate, soil quality, water resources, topographical and environmental components under criteria given and the understanding of local biophysical restraints (Ceballos-Silva and Lopez-Blanco, 2003). At present, this process could be performed efficiently and conveniently by using the Multi-Criteria Decision Making (MCDM) integrated with Geographic Information System (GIS), which is an essential tool in storage, management, an analysis of spatial and non-spatial data.

In the process, data of all used factors (for each crop) will be kept, displayed and managed as individual or combined GIS layers which make them convenient to be analyzed together spatially. Each factor (or criterion) will be given specific weight, which represents its relative importance in the suitability evaluation, by using some MCDM techniques like the Multi-criteria Evaluation (MCE) or Analytic Hierarchical Process (AHP). Each criteria weight could be multiplied with its associated criteria suitability rating (or score) for each land mapping unit and results (from all factors) could be summed up to give suitability score for each land unit of the final suitability map later using GIS overlay technique.

For examples, Ceballos-Silva and Lopez-Blanco (2003) used MCE approach to delineate suitable areas for growing maize and potato in Toluca, Central Mexico. Relevant criteria for the crops and suitability levels were defined according to FAO standards, and criteria maps were created based on the MCE algorithm to obtain the suitability map for each chosen crop. Also, Prakash (2003) had studied land suitability for rice in Dehradum district, India. The used parameters for evaluation included: soil quality, climate, irrigation area, and some socio-economic components (e.g. market and infrastructure). In the study, AHP technique was integrated with fuzzy logic to determine suitable area for the crop. Recently, Thapa and Murayama (2007) had used AHP technique to evaluate land suitability for peri-urban agriculture in Hanoi City. The obtained results indicated that this technique can be very useful in helping policy makers doing rapid assessment of land suitability for agricultural purpose.

In Thailand, Boonyanuphap, Wattanachaiyingcharoen, and Sakura (2004) had assessed suitable area for banana plantation in Phitsanulok Province, Thailand using several factors combined. After that, the classified suitable area obtained was overlaid with current land use/land cover map to find new possible sites for banana plantation in that province. Based on the FAO guidelines for land evaluation and the GIS-based processing model, Paiboonsak and Mongkolsawat (2007) found that approximately 11% and 20% of total area in northern Thailand are highly and moderately suitable for sugarcane plantation respectively whereas the unsuitable area covers about 43%. Suitable area for rice in the Nampong watershed was assessed in Mongkolsawat et al. (1997) using water availability, soil quality (nutrient availability), soil salinity and topography as key factors. They found that only 7% of the area was highly suitable for the crop and about 29% was moderately suitable while the unsuitable area covered about 18% of the studied area. Based mainly on water availability, soil quality and topography, Charuppat and Mongkolsawat (2003) had examined land suitability for eight economic crops (rice, sugarcane, maize, cassava, rubber, mango, tamarind, and pasture) in Lam Phra Phloeng Watershed, northeastern Thailand. They found that maize, mango, tamarind, and pasture are the most suitable plants for the watershed while sugarcane, cassava, and rubber are only moderately and marginally suitable and rice is only marginally suitable. The study also revealed that more than one-half of Lam Phra Phloeng watershed area is marginally suitable.

4.3 Research Objective

The study aims to evaluate land suitability for cultivating two economic crops (sugarcane and cassava) in Kanchanaburi Province based on AHP technique and GIS-based processing model.

4.4 Materials and Methods

4.4.1 Data sources

Data used in this study were assembled from a variety of sources (Table 4.1). The primary data were collected through the field surveys (for gathering LULC data) and expert interviews through distributed questionnaires (for identifying prior factors of sugarcane/cassava plantation). Also, Lansat-5 TM image in 2006 was employed for the land use/land cover (LULC) classification along with GPS data, digital map, and statistical data (Figure 4.1).

Regarding to the acquired information, nine important factors (in form of nine GIS-based layers) were incorporated for sugarcane's land suitability evaluation (Table 4.2), and ten factors for cassava's evaluation (Table 4.3). These selected factors could be divided into two main categories: physical and socio-economic sections. In the first section, the maps were separated into 4 sub-categories: (1) topography (slope), (2) climate (annual rainfall, temperature), (3) soil potential, and (4) water supply (distance from water body, stream or rivers, irrigation zone). In the second section, there were two sub-categories involved: (1) distance from the main road, and (2) distance from sugar factory, or distance from cassava chip point/modifying factory.

Data of each used factor at a specific location in the study area was classified into four suitability classes (in according with the crop growth requirement) which are (1) high suitability: S1; (2) moderate suitability: S2; (3) marginal suitability: S3; and (4) non-suitability: N, as seen in Figures 4.4 (for sugarcane) and 4.5 (for cassava). The classifying criteria being used were followed FAO guidelines and literature review.

Moreover, some restricted areas including conservation area, fertile forest area and watershed class A area (boundary as defined by the responsible agencies) were primarily masked during the evaluation process as it is unlikely to employ these areas for any agricultural use as needed due to their legal protection.

4.4.2 Methods

There were three crucial steps to produce land suitability map for each chosen crop which are (1) finding suitable factors to be used in the analysis, (2) assigning factor weight and class weight (rating) to the parameters involved, and (3) formulation of land suitability map for each interested crop. However, there are another two more steps to complete the work's objective which are (1) derivation of LULC map in 2006 and (2) comparison between the obtained suitability maps and derived LU/LC map. Details of each processing step are as follows (Figure 4.2).

4.4.2.1 Determination of factors involved

Land evaluating process for each studied crop was done based on ten chosen factors which can be divided into 2 main categories: bio-physical and socio-economic section (as discussed in Section 4.4.1 and listed in Figure 4.1 and Tables 4.2 and 4.3). These factors were selected according to the 1976 FAO framework and professional opinions given by 20 experts in this field through questionnaires distributed. More details can be seen in Appendix H.

Table 4.1 List of used land evaluation factors and their original sources

Data	Scale	Source
Boundary map	1:50,000	Department of Environmental Quality Promotion
Soil series map[1]		
-oxygen available: soil drainage -water retention: soil texture - nutrient availability: N,P, K, pH - nutrient retention: C.E.C., B.S.	1:50,000	Department of Land Development
Water supply		
- stream, river - water body - irrigation zone	1:50,000	Department of Environmental Quality Promotion, Department of Land Development
Topography : Dem, Slope		Department of Environmental Quality Promotion
- contour line	1:50,000	
- Spot height	1:50,000	
Road	1:50,000	Department of Rural Road
Point of sugar industry Point of cassava chip , Point of modification cassava (mill, starch), point of cassava pellet factory		Department of Land Development and field surveys
Climate data		Meteorological Department
Annual rainfall data in 1976-2006 (IDW method) Annual temperature data in 1976-2006 (SPLINE method)		Produced using interpolation method (data from 96 stations)
Watershed classes A	1:50,000	Department of Environmental Quality Promotion
LU 2007/Forest area	1:50,000	Department of Land Development
LULC 2006	1:50,000	Interpreted from Landsat-5 TM image in 2006

(1) More detail of soil quality classification is given in Appendix C4-1, 2

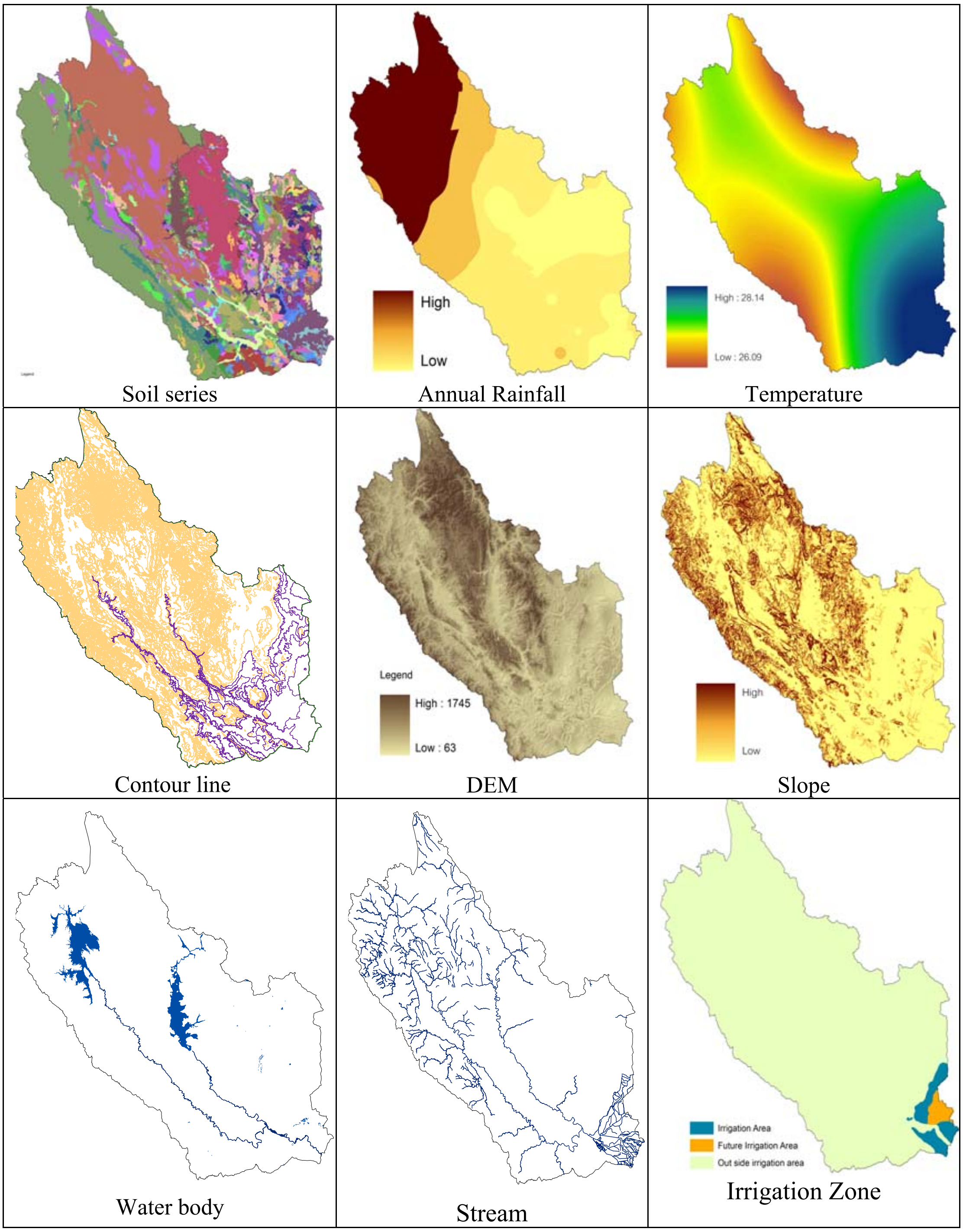


Figure 4.1 GIS-based data layers for use in analysis of suitable area for energy economic crops

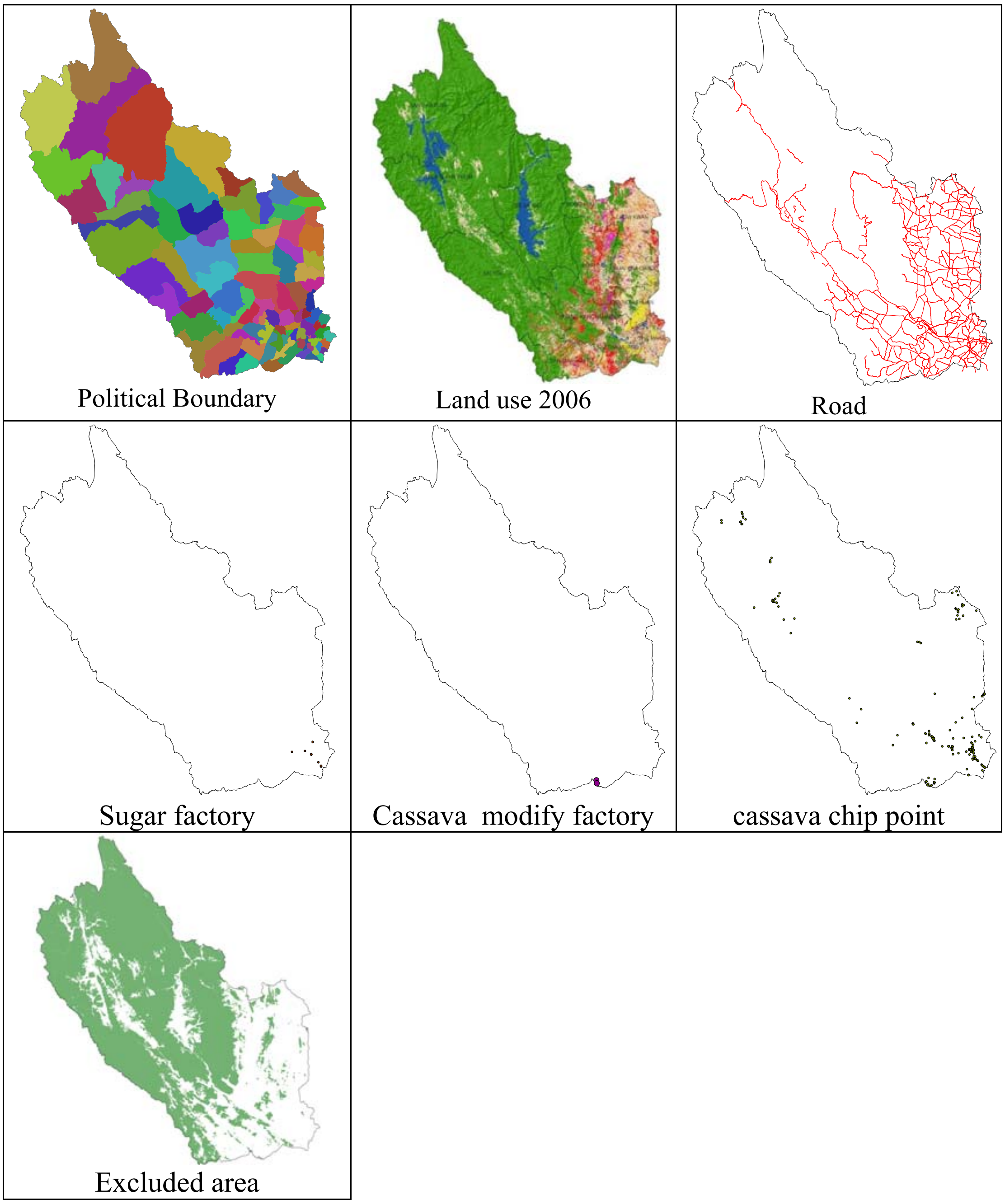


Figure 4.1 (Continued)

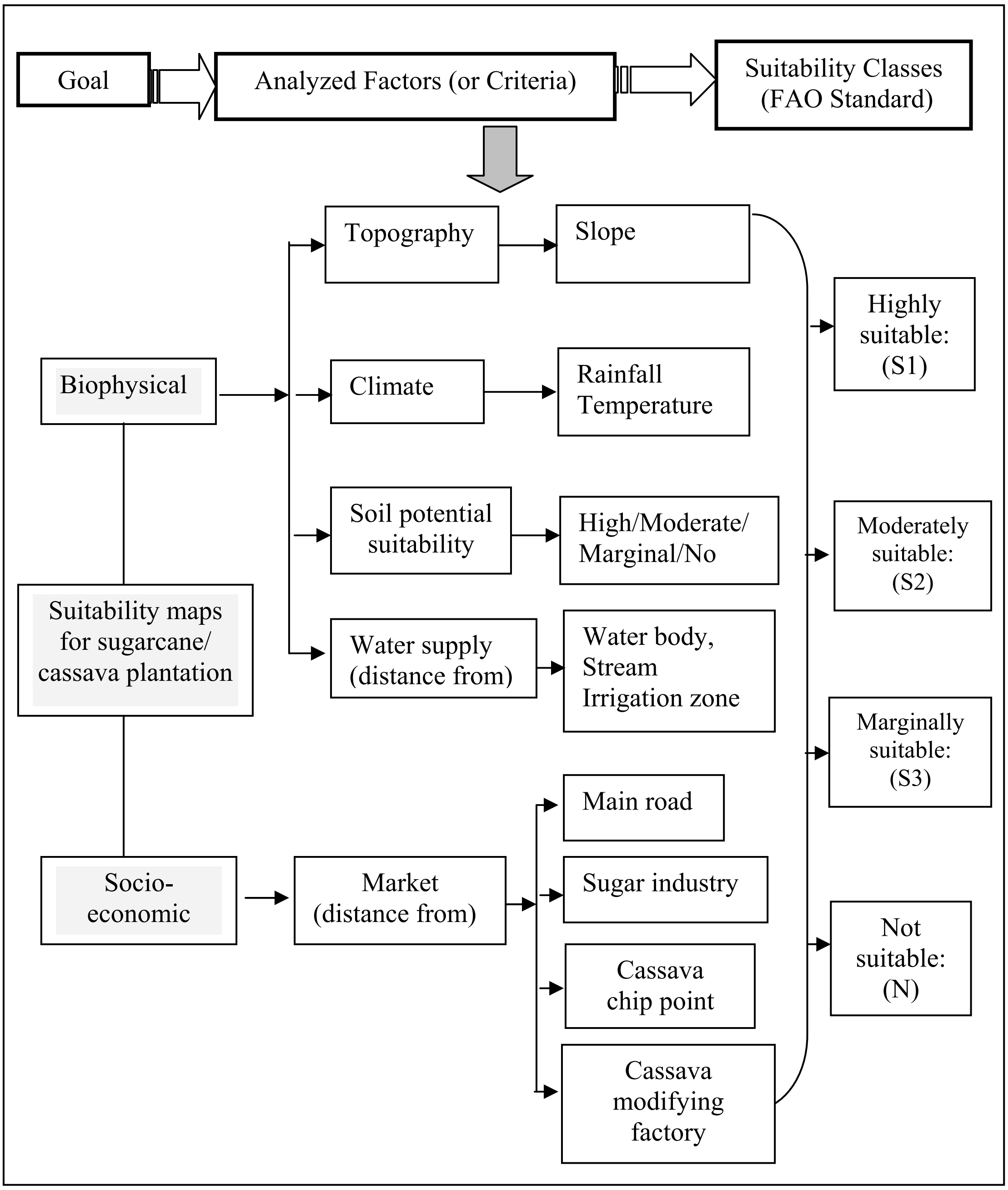


Figure 4.2 Hierarchical process of land evaluation analysis for sugarcane and cassava

Table 4.2 Land suitability classification criteria for sugarcane

Crop Requirement			Factor Suitability Rating				**Reference**
Land quality	Diagnostic factor	Unit	High (S1)	Moderate (S2)	Marginal (S3)	Not suit (N)	
1. Bio-physical							
1.1 Topography	Slope	class	0-12%	12-20%	20-35%	> 35%	Srifuk and Tunsiri (1996)
1.2 Climate	Average annual rainfall	mm.	1600-2500	1200-1600 2500-3000	900-1200 3000-4000	<900 >4000	
	Average annual temperature	° C	24-27	28-31, 19-23	32-35, 18-15	>35,<15	
1.3 Soil potential	Soil potential	class	Highly suitable	Moderately suitable	Marginally suitable	Not suitable	FAO, An analysis
1.4 Water supply	Stream	meter	<500	500-1000	1000-1500	>1500	Wattanachaiyingjaroen (2003)
	Water body	meter	<500	500-1000	1000-1500	>1500	
	Irrigation zone	km.	Inside	Outside 0-1 km.	Outside 1-5 km.	Outside >5 km.	Ministry of Science, Technology and Environment
2. Socio-economic	Distance from road	km.	< 1	1-5	5-10	>10	Wattanachaiyingjaroen (2003)
	Distance from sugar Factory	km.	<50	50-75	75-100	>100	Questionnaire

Table 4.3 Land suitability classification criteria for cassava

Crop Requirement			Factor Suitability Rating				Reference
Land quality	Diagnostic factor	Unit	High (S1)	Moderate (S2)	Marginal (S3)	Not suit (N)	
1. Bio-physical data							
1.1Topography	Slope	class	0-12%	12-20%	20-35%	>35%	
1.2 Climate	Average annual rainfall	mm.	1200-1500	1500-2500 900-1200	2500-4000 500-900	<500 >4000	Srifuk and Tunsiri, (1996)
	Average annual temperature	°C	25-29	30-32 14-24	33-35 10-13	>35 <10	
1.3 Soil potential	Soil potential	class	Highly suitable	Moderately suitable	Marginally Suitable	Not Suitable	FAO, An analysis
1.4 Water supply	Stream	meter	<500	500-1000	1000-1500	>1500	Wattanachaiyingjaroen (2003)
	water body	meter	<500	500-1000	1000-1500	>1500	
	Irrigation zone	km.	Inside	Outside 0-1 km.	Outside 1-5 km.	Outside >5 km.	Ministry of science, Technology and Environment
2. Socio-economic data	Distance from road	km.	< 1	1-5	5-10	>10	Wattanachaiyingjaroen (2003)
	Distance from cassava factory	km.	<50	50-75	75-100	>100	Questionnaire
	Distance from cassava chip point	km.	<50	50-75	75-100	>100	

4.4.2.2 Determination of factor weight and class weight (rating)

In order to produce land suitability map, actual factor weight and class weight (or rating) for parameters involved in the study are needed. These were determined systematically based on the Analytic Hierarchical Process (AHP) which is one of the most well-known and widely-used MCDM methods. The method evaluates relative significance of all parameters by assigning weigh for each of them in the hierarchical order, and in the last level of the hierarchy, the suitability weight (rating) for each class of the used factors will be given. Typically, the priority of each factor involved in the AHP analysis is determined based principally on the suggestions from experts in the field instead of prioritizing factors using lots of accurate land data (Mu, 2006). This makes the outcome from AHP method rather subjective depending on the expert opinions used in the evaluation.

AHP has been developed by Saaty (1977; 1990) and become a widely used multi-criteria evaluation method later on. It assists the decision-makers in simplifying the decision problem by creating a hierarchy of decision criteria with different number of factors taken into account in each step. The method is usually implemented using the pair-wise comparison technique that simplifies preference ratings among decision criteria. In most study, expert opinions were used to calculate the relative importance of the involved factors (or criteria).

The first step of the analysis was creating questionnaires where experts were asked to determine the relative importance of each given factor when compared to one another. Results of the comparison (for each factors pair) were described in term of integer values from 1 to 9 where higher number means the chosen factor is considered more important in greater degree than other factor being compared with

(Table 4.4). The overall results were recorded in form of a pairwise comparison matrix where the relative weight (and rating) for each factors can be derived later on using technique described in Saaty (1990). Apart from this, description of the factor and class weights derivation using AHP technique was also discussed in several published reports, for examples, Prakash (2003), Ma et al. (2005), Mu (2006), Duc (2006), and Hossain et al. (2007). In addition, critical review of the uses and limitations of AHP was mentioned in Qureshi and Harrison (2007).

Table 4.4 Preference scale for pairwise comparison in AHP technique (Saaty, 1990)

Scales	**Degree of preferences**	**Explanation**
1	Equally	Two activities contribute equally to the objective.
3	Moderately	Experience and judgment slightly to moderately favor one activity over another.
5	Strongly	Experience and judgment strongly or essentially favor one activity over another.
7	Very strongly	An activity is strongly favored over another and its dominance is showed in practice.
9	Extremely	The evidence of favoring one activity over another is of the highest degree possible of an affirmation.
2, 4, 6, 8	Intermediate values	Used to represent compromises between the preferences in weights 1, 3, 5, 7, and 9.
Reciprocals	Opposites	Used for inverse comparison.

The obtained factor weights and class weights in this study are presented in Table 4.5 (for sugarcane) and Table 4.6 (for cassava) respectively. Note that, factor weights at each hierarchical level need to be summed up to 1 (for each category/sub-category defined). However, to find proper class weights, data of each used parameter were classified into 4 suitability classes (S1, S2, S3, N) and their suitability scores were presented in the standardized format ranking from 0 (least suitable) to 1 (most suitable) as described in Prakash (2003).

However, to ensure the credibility of the output weights, the consistency ratio index (CR) for each crop was also calculated. This value indicates probability that the derived weights were randomly assigned. Saaty (1980) suggests that if CR is smaller than 0.10 then degree of consistency is fairly acceptable. But if it is larger than 0.10 then there are inconsistencies in the evaluation process, and AHP method may not yield meaningful results. More details of the CR calculation were given in Ma et al. (2005) and Hossain et al. (2007).

The AHP weights were calculated using Microsoft Excel. A consistency ratio (CR) was also calculated and found to be 0.06 (for sugarcane) and 0.01 (for cassava), which is acceptable to be used in the suitability analysis as mentioned earlier. In this study, ArcGIS 9.2 program had been used in the suitability map producing process.

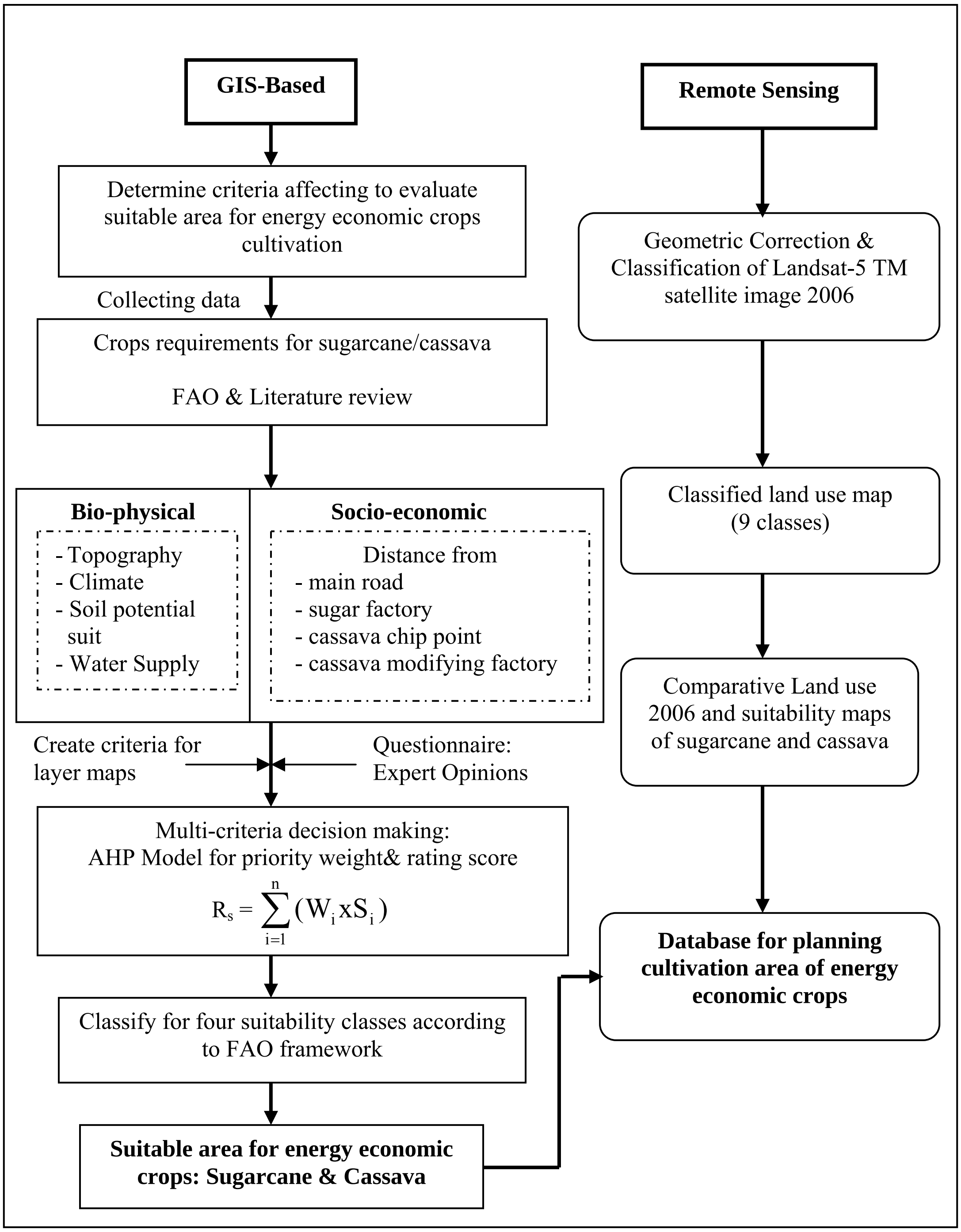


Figure 4.3 Analysis process of land suitability for cultivating energy economic crops

Calculation detail of factor weight and class weight

We present here example of the calculation of factor weight and class weight performed in this work.

Step I Development of the pairwise comparison matrix

Factor	Topography	Climate	Soil potential	Water supply
Topography	1.00	1.78	0.92	1.74
Climate	0.56	1.00	1.60	2.94
Soil potential	1.09	0.63	1.00	2.34
Water supply	0.57	0.34	0.43	1.00
Total	3.22	3.75	3.95	8.02

Step II Computation of the factor weights

Factor	Topography	Climate	Soil potential	Water supply	SUM	Weight
Topography	0.31	0.47	0.23	0.22	1.24	0.31
Climate	0.17	0.27	0.41	0.37	1.21	0.30
Soil potential	0.34	0.17	0.25	0.29	1.05	0.26
Water supply	0.18	0.09	0.11	0.12	0.50	0.13
Total	1	1	1	1		1

Step III Estimation of the consistency ratio

Factor	Topography	Climate	Soil potential	Water supply	SUM	Consistency vector
Topography	0.31	0.53	0.24	0.22	1.31	4.24
Climate	0.17	0.30	0.42	0.37	1.26	4.17
Soil potential	0.34	0.19	0.26	0.29	1.08	4.12
Water supply	0.18	0.10	0.11	0.13	0.52	4.13
						16.66

Compute value for lamda (λ) = consistency vector / n = 16.66-4 = 4.16

Compute consistency index (CI) = (λ- n)/(n-1) = (4.16-4)/(4-1) = 0.05

Calculate the consistency ratio (CR) = CI/RI = 0.05/0.90 = 0.05

CR < 0.1 indicates that level of consistency in the pairwise comparison is acceptable.

Calculation detail of factor rate

For example of slope factor as table below;

Step I Development of the pairwise comparison matrix

Slope	S1	S2	S3	N
S1	1	5.2	6.95	8.65
S2	0.19	1	4	6.25
S3	0.14	0.25	1	3.55
N	0.12	0.16	0.28	1

Step II Computation of the factor rate

Slope	S1	S2	S3	N	SUM	Weight	Rate
S1	0.69	0.79	0.57	0.45	2.49	0.62	1.00
S2	0.13	0.15	0.33	0.32	0.93	0.23	0.38
S3	0.10	0.04	0.08	0.18	0.40	0.10	0.16
N	0.08	0.02	0.02	0.05	0.18	0.05	0.07
	1	1	1				

Linear scale transformation method used to convert weights into standardized criteria score (Malczewski, 1999). Then, the maximum score used to standardize as equation:

$$X'_{ij} = \frac{X_{ij}}{X_{j^{\max}}} \tag{4.1}$$

where X'_{ij} is the standardize score for the i*th* object j th attribute

X_{ij} is the raw score (weight)

$X_{j^{\max}}$ is the maximum score for j *th* attribute

The value of standardized scores can range from o to 1.

Table 4.5 Factor weight and class weight (rating) from AHP method (for sugarcane)

Layer 1		**Layer 2**		**Layer 3**		**Total**	**Layer 4**	
Factor	Weight	Factor	Weight	Factor	Weight	Weight	Class	Rating
Bio-physical	0.792	Topography	0.31	Slope	1	0.245	S1	1
							S2	0.375
							S3	0.160
							N	0.073
		Climate	0.30	Rainfall	0.849	0.202	S1	1
							S2	0.524
							S3	0.256
							N	0.102
				Temperature	0.151	0.036	S1	1
							S2	0.526
							S3	0.275
							N	0.118
		Soil potential	0.26	Soil potential	1	0.206	S1	1
							S2	0.464
							S3	0.201
							N	0.088
		Water supply	0.13	Distance from river/ stream	0.362	0.037	S1	1
							S2	0.432
							S3	0.203
							N	0.084
				Distance from water body	0.306	0.032	S1	1
							S2	0.445
							S3	0.261
							N	0.080
				Irrigation zone	0.332	0.034	S1	1
							S2	0.335
							S3	0.161
							N	0.073
Socio-economic	0.208	Market	1	Distance from main road	0.670	0.139	S1	1
							S2	0.503
							S3	0.237
							N	0.090
				Distance from sugar factory	0.330	0.069	S1	1
							S2	0.503
							S3	0.234
							N	0.090

Table 4.6 Factor weight and class weight (rating) from AHP method (for cassava)

Layer 1		Layer 2		Layer 3		Total	Layer 4	
Factor	Weight	Factor	Weight	Factor	Weight	Weight	Class	Rating
Bio-physical	0.708	Topography	0.392	Slope	1	0.278	S1	1
							S2	0.420
							S3	0.207
							N	0.089
		Climate	0.241	Rainfall	0.845	0.144	S1	1
							S2	0.465
							S3	0.224
							N	0.422
				Temperature	0.155	0.026	S1	1
							S2	0.497
							S3	0.245
							N	0.099
		Soil potential	0.281	Soil potential	1	0.199	S1	1
							S2	0.597
							S3	0.154
							N	0.098
		Water supply	0.086	Distance from river/ stream	0.483	0.029	S1	1
							S2	0.491
							S3	0.249
							N	0.107
				Distance from water body	0.341	0.021	S1	1
							S2	0.463
							S3	0.232
							N	0.114
				Irrigation zone	0.176	0.011	S1	1
							S2	0.430
							S3	0.231
							N	0.102
Socio-economic	0.292	Market	1	Distance from main road	0.519	0.152	S1	1
							S2	0.481
							S3	0.244
							N	0.097
				Distance from cassava ship point	0.323	0.094	S1	1
							S2	0.425
							S3	0.222
							N	0.089
				Distance from modify cassava factories	0.158	0.046	S1	1
							S2	0.442
							S3	0.225
							N	0.089

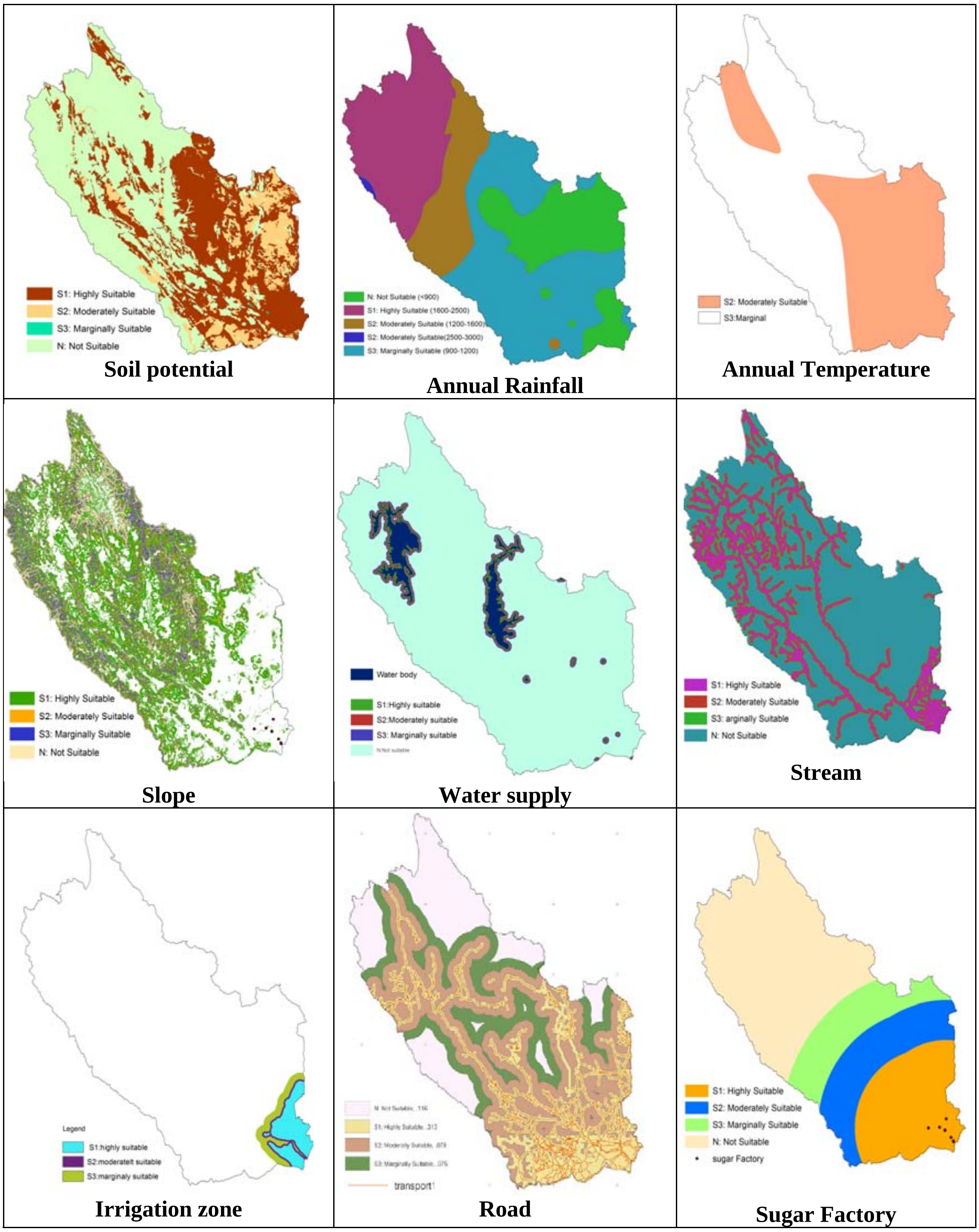


Figure 4.4 Criteria map for analysis of suitable area for sugarcane plantation

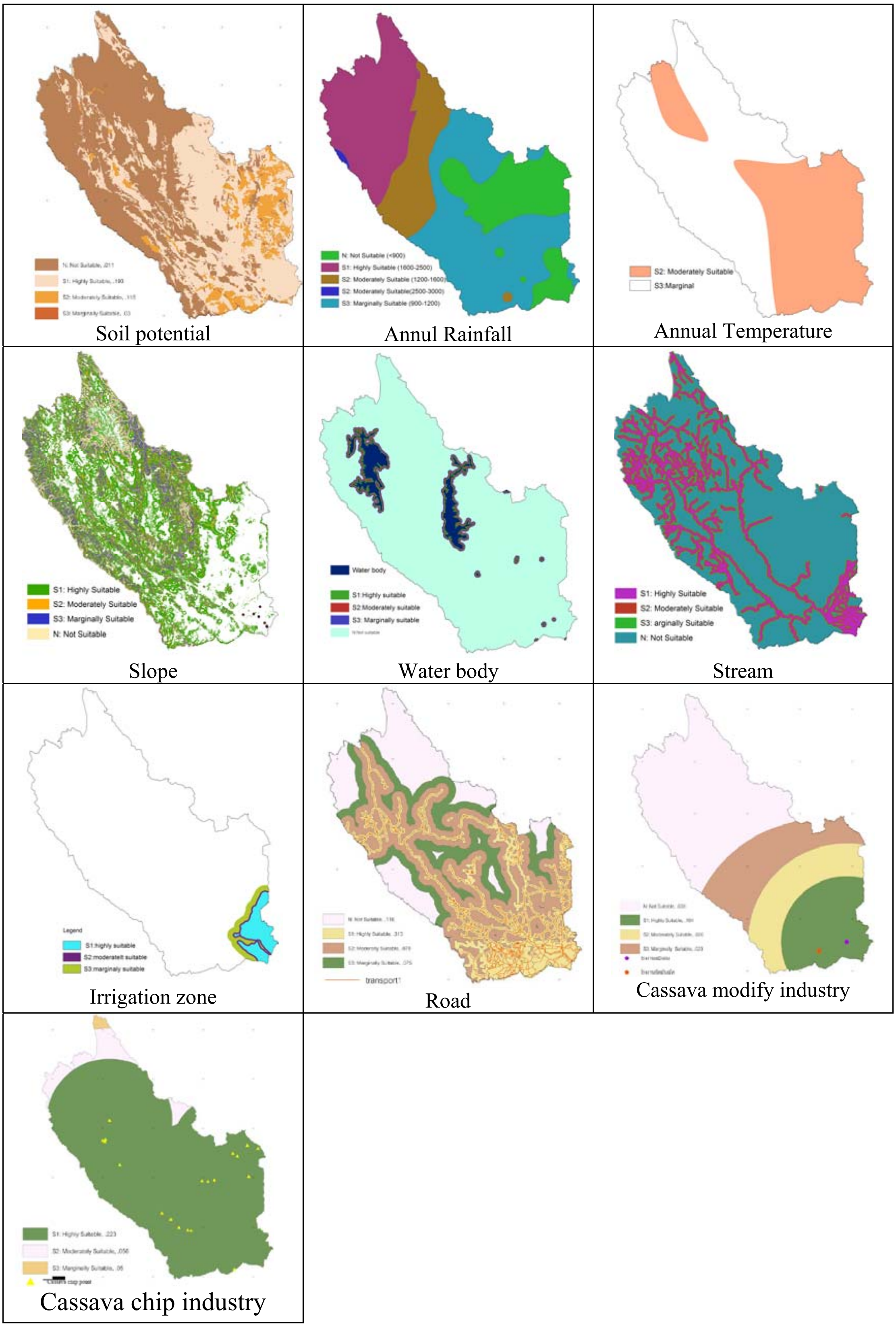


Figure 4.5 Criteria map for analysis of suitable area for cassava plantation

4.4.2.3 Land suitability assessment

After the needed factor and class weights were derived (ass seen in Tables 4.5 and 4.6), land suitability maps could be produced using GIS overlay method available in ArcGIS 9.2 program where spatial data of the used factors were processed together as a set of GIS layers (with 9 and 10 layers for sugarcane and cassava respectively). The total suitability score for each defined land unit (i.e. each raster cell on the map) was simply calculated from the linear combination of known suitability score for each factor. These scores were derived by multiplying each class weight with all associated factor weights found in each level of the hierarchy, or the class weight multiplies with the total factor weight shown in Tables 4.5 and 4.6. Therefore, the calculation of total suitability score could be written as

$$S_i = \sum_{i=1}^{n} (W_i \times R_i), \qquad (4.2)$$

where S_i represents the total suitability score (for each land unit), n represents the number of factors involved in the analysis (9 for sugarcane and 10 for cassava) where W_i is the multiplication of all associated weights in the hierarchy of *i*th factor (or the total weight seen in Tables 4.5 and 4.6) and R_i represents the class weight (or rating) given for specific class of the *i*th factor found on the assessed land unit, respectively (Dansagoonpon, 2006; Liu, 2007).

The total suitability scores (for each land unit) had values range between 0 and 1 and they were assembled to create land suitability map for each selected crop as seen in Figures 4.6 for sugarcane and 4.7 for cassava. These maps had been organized to present 4 suitability classes according to FAO guidelines as follows:

Table 4.7 Defined score ranges for land suitability classification

Suitability class	Suitability score range
Highly suitable area (S1)	0.8-1.0
Moderately suitable area (S2)	0.4-0.8
Marginally suitable area (S3)	0.2-0.4
Not suitable area (N)	0.0-0.2

Note that in this study, the restricted areas including conservation area, fertile forest area and watershed class A area (boundary as defined by responsible agencies) were not included in the analysis as it is very unlikely to use them for any agricultural activities as needed due to imposed legal protection.

4.4.2.4 Land use/land cover classification

In addition, land use/land cover (LULC) map in year 2006 was derived from Landsat-5 TM image (taken on 3rd February 2006 and using 453-RGB combination) where the supervised classification was done using maximum likelihood technique. The 9 land use classes were presented in the map including urban and built-up area, water body, other cultivation, paddy field, sugarcane, cassava, pineapple, eucalyptus, and forest. When overlaid with the suitability map, the result could indicate areas where sugarcane and cassava could be cultivated more in the future.

4.4.2.5 Comparison between suitability map and LU/LC map

Finally, the output suitability map for each selected crop was cross-examined with the 2006 classified LU/LC map derived from the previous step to find potential areas where the crops might be cultivated more apart from the existing growing area found in the classified LU/LC map, e.g., the agricultural area being used for growing other crops/plants or the degrade forest areas close to the existing agricultural land.

4.5 Results and Discussion

4.5.1 Classified land suitability maps

The classified suitability maps for sugarcane and cassava are shown in Figure 4.6 and 4.7 respectively and the corresponding data of area cover for each suitability class are seen in Table 4.7. From these maps, it was found that most suitable areas for these crops are located in the eastern and lower part of the province due to the fairly fertile soil and abundance of water resources situated therein. However, in theory, the highly suitable area for planting cassava can be found more easily than for sugarcane because, as a drought resistant crop, it can grow in the dry area and sandy soil (while sugarcane needs more water and better quality of soil to grow effectively). Normally, sugarcane's suitable areas can be found in plain areas close to main water resources, such as big rivers or reservoirs, while cassava can be planted in the more up-hill area further away from the main rivers.

In total, about 52.49 and 45.07 percent of the total area were classified as highly and moderately suitable areas for growing sugarcane respectively while for cassava, they are about 2.46 and 5.57 percent respectively. It is interesting that only a few percent of the total area was classified as not suitable for growing both crops.

In addition, the land suitability analysis for both crops at district level was also assessed and the results are shown in Tables 4.9 (for sugarcane) and 4.10 (for cassava). These data inform us that the three highest percentages of highly suitable area for sugarcane are 19.14%, 17.47%, and 11.93% in Sai Yok, Muang, and Dan Ma Kham Tia Districts respectively and three highest percentages for cassava are 18.74%, 16.49%, and 11.91% in Boploi, Muang, and Sai Yok Districts respectively.

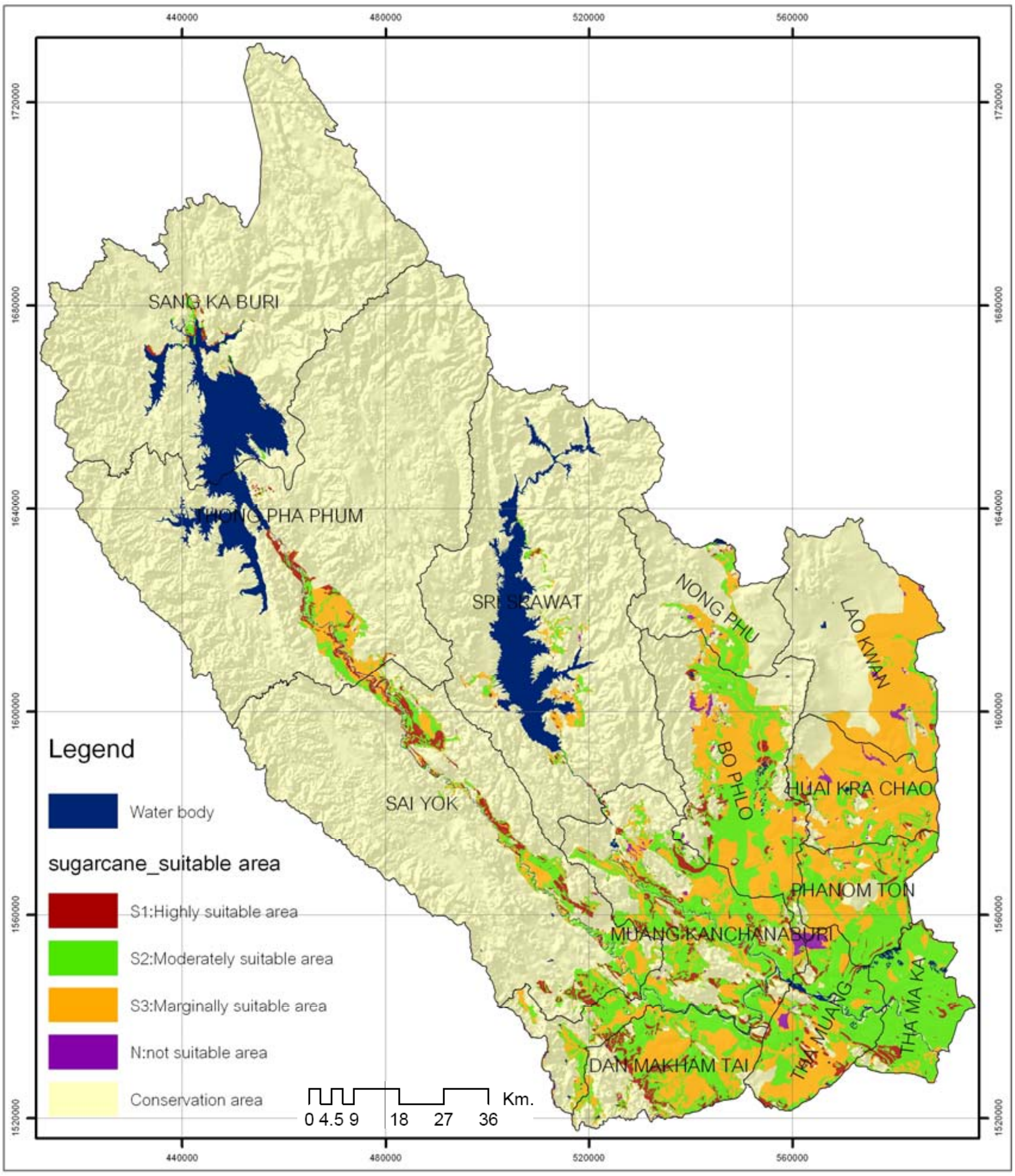


Figure 4.6 Classified land suitability map for sugarcane in Kanchanaburi Province

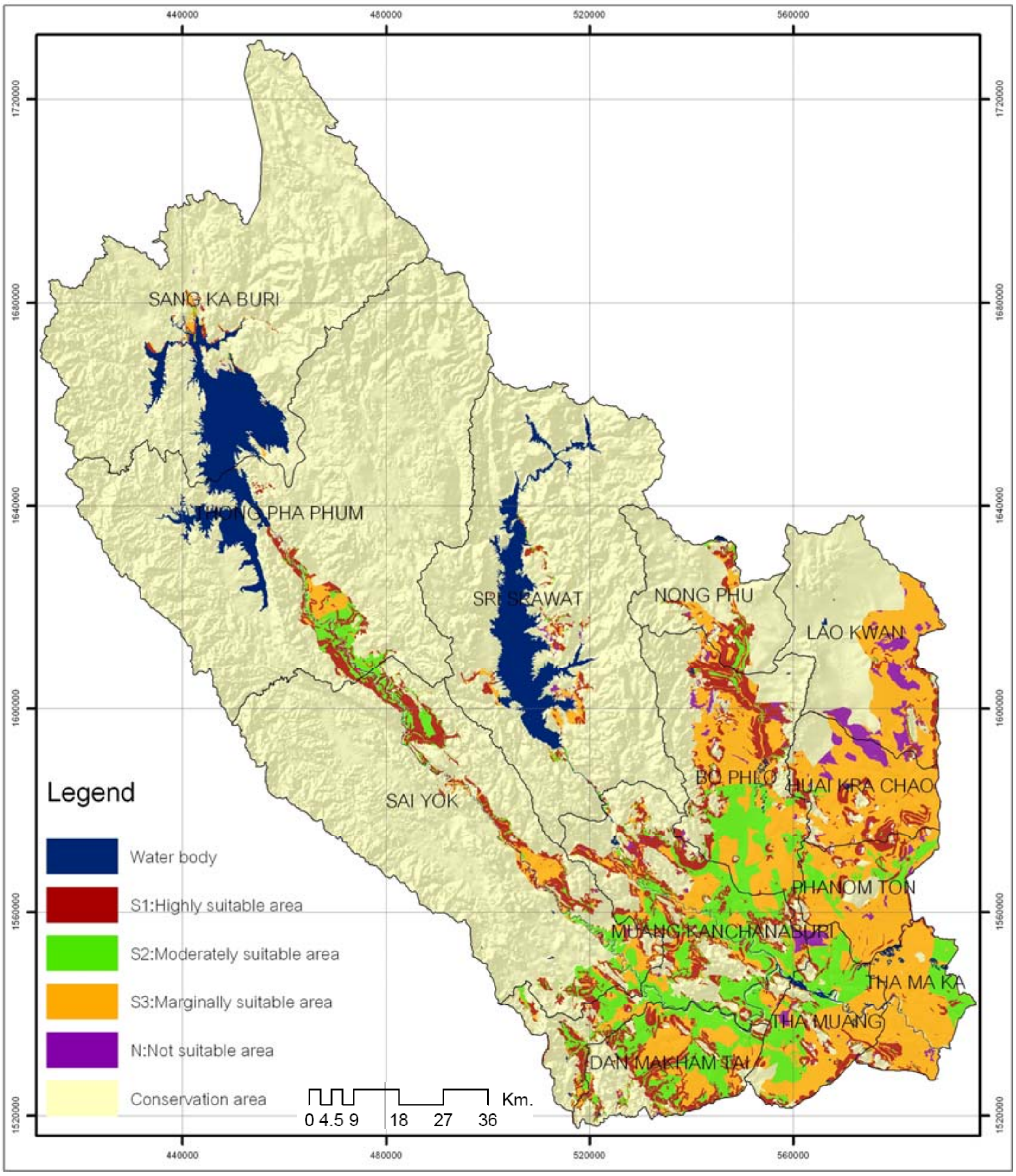


Figure 4.7 Classified land suitability map for cassava in Kanchanaburi Province

To determine the average suitability for each district, the weighted-linear combination method was used where the average score was calculated as follows:

$$DS = \sum_{i=1}^{4} (P_i \times W_i) \tag{4.3}$$

where DS (between 0-3) is the average suitability score for the interested district, P_i is proportion of the suitability class i in that district and W_i is proposed class weight given as 3, 2, 1, and 0 for S1, S2, S3, and N class respectively. Results of DS outcome are shown in Tables 4.9 (for sugarcane) and 4.10 (for cassava) respectively. It can be seen that most suitable districts for sugarcane growing is Tha Ma Ka District (DS = 1.97) and least suitable is Lao Kwan District (DS = 1.05) but for cassava, most suitable district is Sai Yok District (DS = 2.21) and least suitable one is Lao Kwan District (DS = 0.94).

It is worth mentioning here that, as described earlier, this work focused mainly on producing land suitability map based on the crucial bio-physical factors needed by each chosen crop and some proximity causes related to the crop marketing. It was not aimed to perform intense socio-economic analysis in the required process; therefore, most socio-economic factors involved in the crop production system such as market prices, management systems, input cost and benefit of the production, were omitted in this report. Though, the factors are also crucial elements in farmers' decision making but they were not included in the study as their values are rather uncertain and it is normally difficult to quantify their impacts on crop production in general.

Table 4.8 Area coverage on classified land suitability map for sugarcane and cassava

Suitability class	Score range	Area coverage			
		Sugarcane		Cassava	
		Km^2	%	Km^2	%
Highly suitable (S1)	0.8-1.0	284.08	6.87	889.89	21.52
Moderately suitable (S2)	0.4-0.8	1886.36	45.62	973.77	23.55
Marginally suitable (S3)	0.2-0.4	1863.08	45.05	2041.09	49.36
Not suitable (N)	0.0-0.2	101.66	2.46	230.44	5.57
Total area		**4135.18**	**100**	**4135.18**	**100**

Table 4.9 Classified suitable area for sugarcane cultivation at district level

District	S1 (W=3)		S2 (W=2)		S3 (W=1)		N (W=0)		DS
	Km^2	%	Km^2	%	Km^2	%	Km^2	%	
Bo Phloi	26.51	9.33	291.69	15.46	307.25	16.49	17.42	17.14	1.51
Dan Ma Kham Tia	33.90	11.93	156.25	8.28	130.17	6.99	1.53	1.51	1.69
Huai Kra Chao	6.99	2.46	94.01	4.98	353.41	18.97	15.99	15.73	1.20
Lao Kwan	0.92	0.32	29.62	1.57	354.29	19.02	11.96	11.77	1.05
Muang	49.62	17.47	287.97	15.27	147.33	7.91	15.63	15.37	1.74
Nong Phu	0.68	0.24	47.87	2.54	36.36	1.95	4.02	3.96	1.51
Pha Nom Tuan	12.72	4.48	196.69	10.43	165.27	8.87	2.19	2.16	1.58
Sai Yok	54.37	19.14	105.63	5.60	65.50	3.52	3.40	3.35	1.92
Sang Ka Buri	17.06	6.00	21.53	1.14	5.19	0.28	0.01	0.01	1.71
Sri Sa Wat	6.66	2.34	55.57	2.95	74.03	3.97	18.17	17.87	1.33
Tha Ma Ka	16.95	5.97	299.79	15.89	25.02	1.34	0.39	0.39	1.97
Tha Muang	28.24	9.94	249.00	13.20	127.67	6.85	9.76	9.60	1.71
Thong Pha Phum	29.46	10.37	50.73	2.69	71.59	3.84	1.17	1.15	1.71
Total	284.08	100	1886.36	100	1863.08	100	101.66	100	

Table 4.10 Classified suitable area for cassava cultivation at district level

District	S1 (W=3)		S2 (W=2)		S3 (W=1)		N (W=0)		DS
	Km^2	%	Km^2	%	Km^2	%	Km^2	%	
Bo Phloi	166.76	18.74	163.54	16.79	299.38	14.67	23.42	10.17	1.73
Dan Ma Kham Tia	91.44	10.28	129.83	13.33	104.96	5.14	1.54	0.67	1.95
Huai Kra Chao	72.86	8.19	6.51	0.67	356.77	17.48	44.23	19.19	1.22
Lao Kwan	27.61	3.10	3.54	0.36	283.45	13.89	81.62	35.42	0.94
Muang	146.72	16.49	215.56	22.14	84.40	4.14	15.35	6.66	2.07
Nong Phu	39.85	4.48	12.91	1.33	32.87	1.61	3.48	1.51	2.00
Pha Nom Tuan	41.72	4.69	63.18	6.49	268.20	13.14	9.78	4.24	1.36
Sai Yok	105.99	11.91	68.70	7.06	51.10	2.50	3.10	1.35	2.21
Sang Ka Buri	19.02	2.14	5.72	0.59	15.92	0.78	3.38	1.47	1.92
Sri Sa Wat	55.07	6.19	18.79	1.93	52.84	2.59	23.69	10.28	1.70
Tha Ma Ka	19.90	2.24	60.50	6.21	263.32	12.90	4.43	1.92	1.28
Tha Muang	43.76	4.92	163.66	16.81	199.36	9.77	16.09	6.98	1.56
Thong Pha Phum	59.19	6.65	61.32	6.30	28.51	1.40	0.34	0.15	2.20
Total	889.89	100	973.77	100	2041.09	100	230.44	100	

4.5.2 Classified LU/LC map using Landsat-TM image

The classified LULC map for year 2006 (with 9 classes displayed) developed from Landsat-TM image is shown in Figure 4.8 and its LULC area data is given in Table 4.10. From accuracy assessment process, it was found that the overall accuracy of the classified result was 94.22% and the Kappa index was 93.26% respectively (see for detail in Table 2.1).

From Table 4.11, it can be seen that, from the total area of 19,380 km^2 in Kanchanaburi Province, about 71.58% (or 13873 km^2) was classified as forest area while another 23.62% (or 4578 km^2) was employed for various agricultural uses, e.g. planting rice, sugarcane, cassava, and other crops/trees. In contrast, less than 1% was classified as urban/built-up area.

Table 4.11 LULC area coverage of Kanchanaburi Province in 2006

LULC Class	2006	
	Km^2	%
Sugarcane (SC)	922	4.76
Cassava (CV)	398	2.05
Paddy field (PF)	234	1.21
Eucalyptus (EU)	151	0.78
Pineapple (PA)	72	0.37
Other cultivations (OC)(1)	2801	14.45
Forest (F)	13873	71.58
Water body (W)	851	4.39
Urban/built-up (U)	79	0.41
Total area	19380	100.00

(1) Other cultivations include all other plants apart from the first five listed crops.

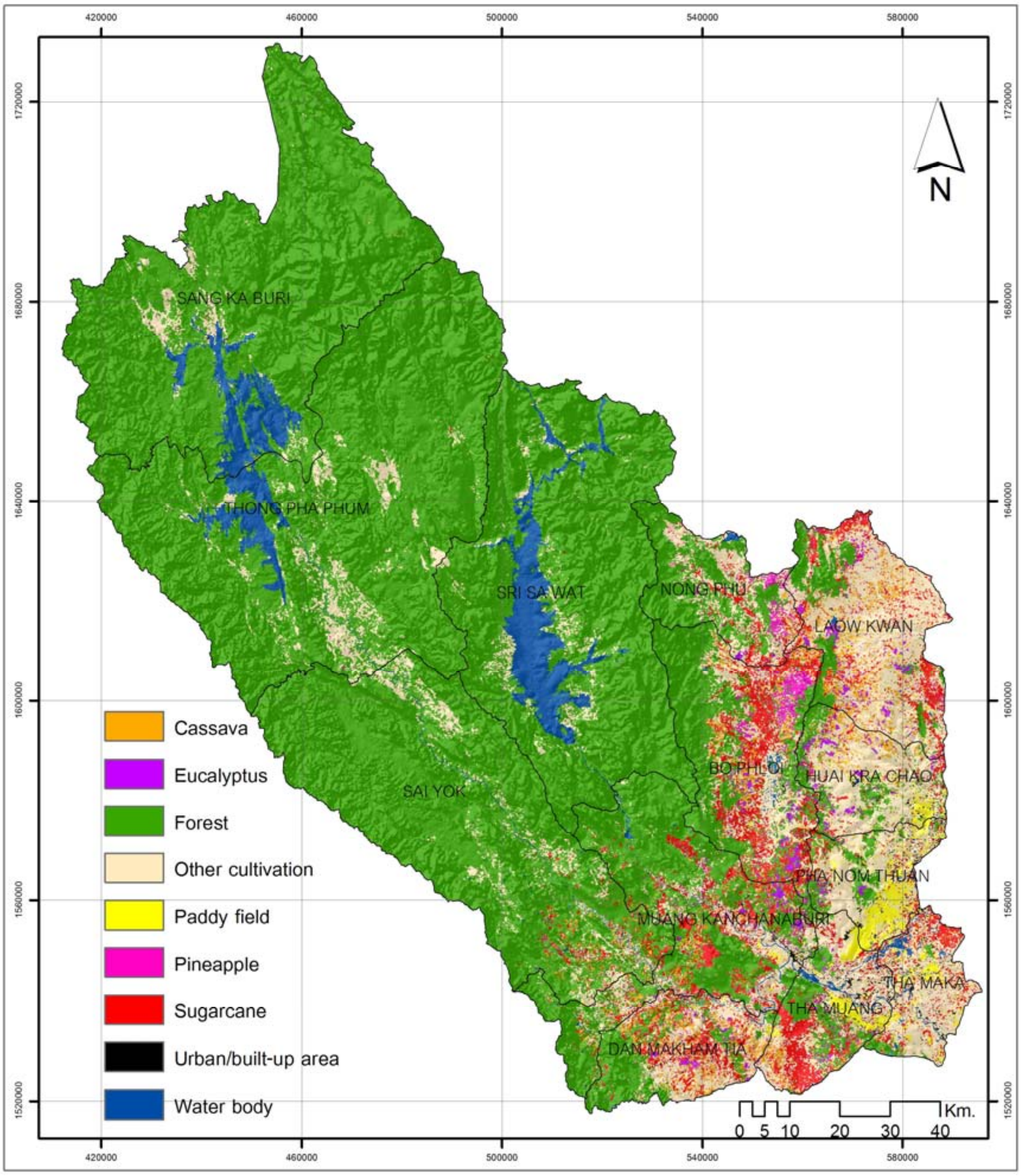


Figure 4.8 Classified LULC map of Kanchanaburi in 2006 (from Landsat-TM image)

4.5.3 Comparison between suitability map and LU/LC map

To find potential new areas for growing sugarcane and cassava, the suitability maps for both crops (Figure 4.6 and 4.7) had been cross-examined with

LU/LC map in 2006 (Figure 4.8). Results of the comparison were reported in Tables 4.12 (for sugarcane) and 4.13 (for cassava) respectively. The data indicated that, for both crops, the highly/moderately suitable areas have fallen upon two LU/LC features which are forest area (dry evergreen forest and mixed deciduous forest in particular) apart from the restricted area marked from the study, and the area which is currently employed for agricultural use already, especially for growing some crops/trees.

Considering plantation area of sugarcane and cassava in particular, it could be seen that the present growing areas for both crops are still relatively small compared to the potential suitable area found in the analysis (highly/moderately suitable areas in particular). Therefore, in theory, it is still highly possible to expand growing area for these interested crops by converting the existing agricultural areas which are using for other crops/trees (like paddy fields) to cultivate these two energy crops instead.

Also, the government might consider about providing some degraded lands (outside the conservation zone) for local farmers as being land resource for growing these demanded crops. If these suggestions are done efficiently, significant increase in amount of sugarcane and cassava production can be possibly achieved as government has required.

Table 4.12 Comparison between classified LULC map and land suitability map for sugarcane plantation

Suitability Class		Cassava	Eucalyptus	Pineapple	Paddy field	Sugarcane	Other cultivation	Urban	Water body	Total
S1	km^2	14.68	9.35	0.29	18.84	72.52	137.22	5.30	22.41	284.08
	%	5.17	3.29	0.10	6.63	25.53	48.30	1.87	7.89	100
S2	km^2	98.69	68.22	7.44	239.44	569.02	760.90	61.31	53.23	1886.36
	%	5.23	3.62	0.39	12.69	30.16	40.34	3.25	2.82	100
S3	km^2	189.37	124.08	17.86	102.99	507.95	845.72	28.26	36.39	1863.08
	%	10.16	6.66	0.96	5.53	27.26	45.39	1.52	1.95	100
N	km^2	6.98	4.82	0.90	3.09	19.78	52.00	2.27	11.22	101.66
	%	6.87	4.74	0.88	3.04	19.45	51.15	2.23	11.03	100
Total	km^2	309.71	206.46	26.49	364.37	1169.26	1795.83	97.14	123.24	4135.18
	%	7.49	4.99	0.64	8.81	28.28	43.43	2.35	2.98	100

Table 4.13 Comparison between classified LULC map and land suitability map for cassava plantation

Suitability Class		Cassava	Eucalyptus	Pineapple	Paddy field	Sugarcane	Other cultivation	Urban	Water body	Total
S1	km^2	75.59	40.38	0.67	41.59	205.76	474.34	12.07	32.25	889.89
	%	8.49	4.54	0.08	4.67	23.12	53.30	1.36	3.62	100
S2	km^2	84.36	45.00	0.17	61.44	353.20	368.65	22.77	28.77	973.77
	%	8.66	4.62	0.02	6.31	36.27	37.86	2.34	2.95	100
S3	km^2	219.41	105.95	0.68	251.66	519.01	821.77	58.08	39.87	2041.09
	%	10.75	5.19	0.03	12.33	25.43	40.26	2.85	1.95	100
N	km^2	28.26	15.07	0.18	9.65	47.15	105.69	4.14	18.99	230.44
	%	12.26	6.54	0.08	4.19	20.46	45.86	1.80	8.24	100
Total	km^2	407.61	206.39	1.70	364.35	1125.11	1770.45	97.07	119.88	4135.18
	%	9.86	4.99	0.04	8.81	27.21	42.81	2.35	2.90	100

4.6 Conclusion

This work assessed potential suitable area for cultivating two important energy crops (sugarcane and cassava) in Kanchanaburi Province. The analysis was performed using AHP technique integrated with GIS-based processing program.

The AHP method was applied to determine relative importance of all selected factors for each studied crop, which were divided into 2 main categories: biophysical and socio-economic sections. Results of the study were found, based on professional opinions of 20 experts in the field and literature review, and then described in terms of factor weight and class weight (rating) for all the factors involved in each hierarchical layer established.

The land suitability map for each crop has been created, based on the linear combination of each used factor's suitability score (calculated by Eq. 4.1) as discussed in detail in Section 4.4.2.3. The output map was then classified to present 4 suitability classes called as S1, S2, S3, and N according to FAO standard as seen in Figures 4.6 (for sugarcane) and 4.7 (for cassava).

It was found that about 52.49 percent (for sugarcane) and 45.07 percent (for cassava) of the total examined area were classified as highly or moderately suitable to grow these crops and only few percent being classified as not suitable for them (Table 4.8). Typically, most suitable areas (for both crops) are found in the eastern and lower parts of the province due to better soil quality and more abundance of water resources situated therein. At district level according to the proposed district suitability score in Eq. 4.3, Tha Ma Ka and Sai Yok were found to be most suitable places for growing sugarcane while Sai Yok and Thong Pha Phum were most suitable for growing cassava and, in general, Sai Yok and Muang district were most suitable for cultivating both crops (Tables 4.9 and 4.10).

To find potential new cultivating areas for both crops, the obtained suitability maps were cross-examined with the 2006 LU/LC map was derived from Landsat-TM image in which 9 LU/LC classes were identified (Figure 4.8). A comparison between LU/LC map and suitability maps for both crops indicated that most parts of classified suitable area were located in the existing agricultural land (that is being used for other crops/plants) and in the forest land, which is typically not allowed for any agricultural uses due to legal protection.

Therefore, it is still highly possible to expand growing area for these interested crops by converting existing agricultural areas still using for other crops/plants (like paddy fields) to cultivate these two energy crops instead. Also, the government might consider providing some degraded lands (outside the conservation zone) for local farmers as being land resource for growing these two crops.

4.7 References

Boonyanuphap, J., Det, W. and Kasutoshi, S. (2004). GIS-based land suitability assessment for Musa (ABB group) plantation. **Journal of Applied Horticulture**. 6(1): 3-10.

Ceballos-Silva, A. and Lopez-Blanco, J. (2003). Delineation of suitable areas for crops using a multi-criteria evaluation approach and land use/cover mapping : A case study in Central Mexico. **Agricultural System**. 77(2): 117-136.

Charuppat, T. and Mongkolsawat, C. (2003). Land evaluation for economic crops of Lam Phra Phloeng watershed in Thailand using GIS modeling. **Asian Journal of Geoinformatics**. 3(3): 89-98.

Dansagoonpon, S. (2006). **Crop substitution modeling using remote sensing and gis**. Ph.D. Dissertation, Asian Institute of Technology, Thailand.

Due, T.T. (2006). Using gis and AHP technique for land use suitability analysis. evaluation [On-line]. Available: http://wgrass.media.osaka-cu.ac.jp/gisideas 06/viewpaper.php.html

Food and Agriculture Organization of the United Nations (FAO). (1976). **A framework for land evaluation**. Soil Bulletin No.32.Rome: FAO.

Food and Agriculture Organization of the United Nations (FAO). (1983). **Guidelines: land evaluation for rainfed agriculture**. Soil Resource Management and Conservation Service Land and Water Resource Development Division. Soil Bulletin No.52.Rome: FAO.

Hossain, M., Chowdhury, S.R., Das, N.G. and Rahaman, M.M. (2007). Multi-criteria evaluation approach to GIS-based land suitability classification for tilapia farming in Bangladesh. **Journal Aquaculture International**. 15(6): 425-443.

Liu, Y., LV, X., Qin, X., Guo, H., Yu, Y., Wang, J. and Mao, G. (2007). An integrated GIS-based analysis system for land use management of lake areas in urban fringe. **Landscape and Urban Planning**. 82(4): 233-246.

Ma, J., Scott, N.R., DeGloria, S.D. and Lembo, A.J. (2005). Siting analysis of farm-based centralized anaerobic digester systems for distributed generation using GIS. **Biomass and Bioenery**. 28(6): 591-600.

Malczewski, J. (1999). **GIS and multicriteria decision analysis**. USA: John wiley & sons.

Ministry of Science, Technology and Environment. (2001). Drought information system [On-line]. Available: http://www.negistda.kku.ac.th/drought/ed_ method.htm

Mongkolsawat, C., Kuptawutinan P. and Thirangoon, C. P. (2007). A physical evaluation of land suitability for rice: A methodological study using gis [On-line]. Available: http://www.gisdevelopment.net/aars/acrs/1997/ts11/ts11004pf.htm

Mu, Y. (2006). **Developing a suitability index for residential land use: A case study in Dianchi drainage area**. M.S. thesis. University of Waterloo. Canada.

Nutsombul, N. (2005). Ethanol: a new chooses energy**. Journal of Industry**. 48: 42-44.

Prakash, T.N. (2003). **Land suitability for agricultural crops: A case fuzzy multicriteria decision making approach.** M.S.thesis, International institute for Geo-information science and earth observation enschede, Netherlands.

Qureshi, M.E. and Harrison, S.R. (2003). Application of the analytic hierarchy process to riparian revegetation policy options. **Small-Scale Forest economics, Management and Policy**. 2(3): 441-458.

Thapa, R.B. and Murayama,Y. (2007). Land evaluation for peri-urban agriculture using analytical hierarchical process and geographic information system techniques: A case study of Hanoi. **Land Use Policy**. 25(2): 225-239.

Trifuk, K. and Tunsiri, B. (1996). **Qualitative land evaluation for economic crops. Land development department**. Ministry of agriculture and cooperatives. Thailand.

Wattanachaiyingcharoen, D. and Boonyanuphap, J. (2003). **Production management of Musa (ABB group) “Kluai Nam Wa” for export and agro-industry using GIS**. The National Science and Technology Development Agency (NSTDA). Thailand.

Saaty, T.L. (1977). A scaling method for priorities in hierarchical structure. **Journal of Mathermatical Psychology**. (15): 234-281.

Saaty, T.L. (1980). **The analytic hierarchy process**. New York: McGraw-Hill.

Saaty, T.L. (1990). **Multi criteria decision making: The analytic hierarchy process**. RWS Publication, Ellsowrth Avenue, USA.

Sriroth, K., Piyachomkwan, K., Termvejsayanon, N. and Burannares, I. (2003). **A study of directions for the development of ethanol industry in Thailand**. The office of the National Ethanol Committee, Ministry of Industry. Thailand.

CHAPTER V

SUITABLE LOCATION DETERMINATION

FOR ETHANOL INDUSTRY

5.1 Abstract

The main objective of this work is to identify suitable locations of new ethanol plant for Kanchanaburi Province, western Thailand, by using the integrated AHP/GIS technique and the service zoning system based on road net work analysis. Five groups of influencing factors, which are topography (elevation), proximity to raw material (sugarcane and cassava), proximity to market, amount of water supply, and proximity to labor resource or administrative center, were included in the AHP's site suitability analysis and the suitability map was obtained as a result. Based on two criteria given to the network analysis, five possible candidates for being new site of the plant were identified where three of them located close to the main river in the south. The service areas of these candidate sites were also determined using the proximity-based zoning system and data of sugarcane and cassava planting areas in 2006 and land suitability maps of both crops for Kanchanaburi. By considering only within the 0-50 km service zone of each candidate, the most suitable location of the plant can be identified under different scenarios considered which are for sugarcane farming, for cassava farming, for highly and moderately suitable land of sugarcane and of cassava respectively.

KEYWORDS: suitable location, ethanol industry, network analysis, service area, AHP, sugarcane, cassava

5.2 Introduction

Ethanol is a widely-used renewable liquid energy produced from the organic materials and is important both as a strategic biofuel and also a cleaner alternative fuel compared to the commonly-used fossil energy (Sriroth et al., 2003; Zhan et al., 2005). At present, it becomes principal element used as a petrol substitute where it can be blended with gasoline in varying quantities, normally from 5 and 10% (called E5 and E10 respectively) or up to 100% (pure ethanol called E100) (BFP, 2009). Ethanol is biodegradable, low in toxicity and causes little environmental impact from its burning (which mainly produces carbon dioxide and water). It is also high octane fuel that has replaced lead as an octane enhancer in the commercial petrol and by blending with the gasoline, this mixed fuel can be oxygenated (or having more oxygen) so it burns more completely and reduces polluting emissions.

Generally, ethanol can be mass-produced by the fermentation process of sugar or by hydration of ethylene from petroleum. However, current interest focuses mainly on the bio-ethanol produced from sugars, starches, and cellulose materials from a wild variety of crops. Sugars (e.g. from sugarcane, sugar beets, molasses, and fruits) can be converted into ethanol directly. Starches (e.g. from corn, rice, cassava, potatoes, and root crops) must first be hydrolyzed to fermentable sugars by action of enzymes from malt or molds. Cellulose (e.g. from wood, agricultural residues, waste sulfite liquor from pulse, and paper mills) must also be converted into sugars first, generally by the action of mineral acids. Once sugars are formed, enzymes from microorganisms can readily ferment them to ethanol (Lin and Tanaka, 2006).

In Thailand, the interest of ethanol-mixed gasoline (called gasohol) has been rising dramatically in the last decade, especially during the recent oil-price crisis, due to the low-price policy of gasohol implemented by the Thai government in order to reduce oil imports and carbon emissions significantly in the near future. The Ministry of Energy (MOEN) targeted gasohol sale to reach eight million litters/day by the end of 2007 and 20 million/day by the end of 2011 by expanding more gasohol stations throughout Thailand, particularly in small-scale petrol stations, which normally have limited access to gasohol supplies (USDA, 2007; APEC Biofuels, 2008).

Almost 90% of ethanol produced in Thailand at present is from cane molasses and the remaining 10% is from cassava. However, the proportion is expected to shift over time in favor of the cassava as sugarcane is also needed for producing sugar for household consumption and for the use in some food industries. Cassava production was about 22.5 million tons in 2006, and it is expected to grow when the new cassava-based ethanol plants start operating. Ethanol production in Thailand was about 322.19 million liters in 2008 from twelve operating plants (ten sugarcane-based, one cassava-based, and the other one for both) with twelve more plants are still under construction (one sugarcane-based, nine cassava-based, and the other two for both) (DEDE, 2008).

As the sugarcane and cassava cultivating area in Kanchanaburi Province are substantially expanding in the last decade (Table 3.3) but only single ethanol factory exists in the province so far (belongs to the Ethanol Industry Company) (Figure 5.4). Therefore, the establishment of new ethanol plant in the province should be planned to cope with growing area of the energy crops found in the area and this work will give some suggestion about the potential candidate locations to house this new plant based on the integrated AHP/GIS method for site suitability selection and under several scenarios introduced.

Applications of Integrated AHP/GIS models to site selection analysis

Facility location selection is a decisive decision as it means large investments of capital and long-term strategic commitments for any business. Normally, this kind of decision is primarily driven by consideration of a number of factors such as access to the labor markets, access to raw materials, access to customer markets, access to needed services, environmental and bio-physical constraints, and regional incentives which reduce costs. The relative importance of these factors in the decision-making process depends on the type of industry. For example, for the labor-intensive industry, this may be largely driven by access to low-cost labor market, but for capital intensive industries, this may be driven by the relative costs of attaining inbound raw materials and of delivering outbound finished products (Noon et al., 2002).

From its concept mentioned earlier, location suitability analysis is inherently a multi-criteria problem in which several related factors must be taken into the decision-making process. To identify the potential candidate locations, these selected factors are systematically combined (in term of their given suitability scale or factors weight) using some chosen multi-criteria decision making (MCDM) methods. Several MCDM methods have been applied to the site selection analysis so far and the most popular one found in literature is the analytic hierarchy process (AHP) developed by Saaty (1977; 1980). AHP assists the decision-makers in simplifying the decision problem by creating a hierarchy of decision criteria with different number of chosen factors taken into account at each step (or hierarchical level). The method is usually implemented using the pair-wise comparison technique that simplifies preference ratings among decision criteria. In most studies, expert opinions are used to calculate the relative importance of the involved factors (or criteria) (see more detail in Section 5.4.2.2)

Most AHP-based researches found in recent years usually use it in corporation with the geographic information system (GIS) tools to investigate suitable sites under various purposes. In general, GIS are the computer-based programs which are highly capable of assembling, storing, mapping, analyzing, and displaying geographic data and interpreting the relationships among them for making inferences. These qualities make them become a promising tool in the site selection study as they enable the spatially explicit evaluation of site suitability and the assignment of various measures (of suitability) to the specific sites or geographic area. The combination also allows area allocation at the specific geographic locations. Hence, the integrated model combines spatial capabilities of GIS with the analytical power of the multi-criteria analyses from which it permits both analytical planning and optimization of land use decisions at different levels, namely; (1) site suitability assessments based on different factors and specific land uses; (2) generation of suitability indices based on the combinations of different factors (i.e. composite index/measure of site suitability); and (3) generation of an optimal land use strategy that simultaneously considers the individual site suitability, and the optimal allocation to the most suitable land use (i.e. mix of land uses that yields the "highest" overall cumulative suitability score).

Integrated AHP/GIS models have been applied in several recent works related to suitable site selection with fairly satisfied results. For examples, Tseng et al. (2001) used for artificial reef development location selection, Pérez et al. (2003) used for integrating and developing marine fish cages within the tourism industry in Tenerife, Huang and Wang (2006) used for the suitability analysis of nuclear waste disposal site in Canada, Sener et al. (2006) and Banar et al. (2007) used in landfill site selection, Hossain et al. (2007) used for land suitability classification of tilapia farming in

Bangladesh, Dey and Ramcharan (2008) used in site selection for limestone quarry expansion in Barbados and Hossain et al. (2009) used for urban aquaculture development in Bangladesh.

5.3 Research Objective

The main objective of this work is to identify suitable locations of new ethanol plant for Kanchanaburi Province by using the integrated AHP/GIS technique for site suitability selection and the service zoning system based on road net work analysis. Results of this work will give some suggestion about the potential candidate locations to house this new plant under several scenarios given.

Application of the integrated AHP/GIS method for site selection in Thailand is still rare, hence, this work might be giving good example of how to use this technique properly to handle other site selecting problems, or land suitability analysis, normally experienced in the country.

5.4 Materials and Method

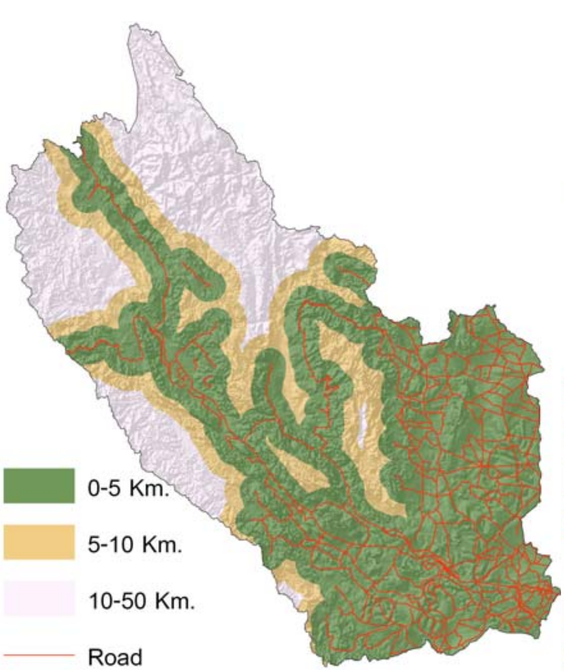
5.4.1 Data preparation

To evaluate the potential candidates for being new location for ethanol plant in the province, several influencing factors were included in the decision making process employed (AHP). These can be separated into five broad categories: (1) Topography-elevation, (2) Proximity to raw material-distances from sugar factory and cassava chip point, (3) Proximity to market-distance to main road, (4) Amount of the water supply-distance from available water resource, and (5) Proximity to the labor resource and the administrative center (regarded as being social environmental factors) distance to community, distance to provincial public offices.

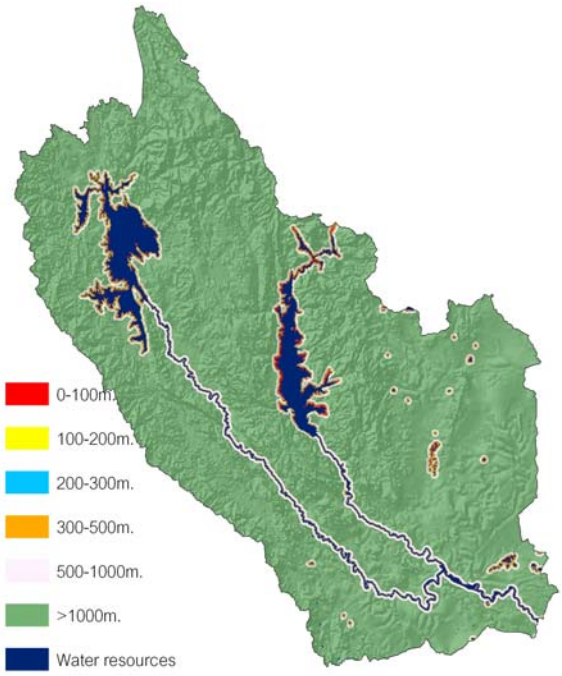
These data were originally provided from the responsible agencies (mostly the Department of Environmental Quality Promotion) and then reorganized to be kept and displayed as GIS-based vector map at scale 1:50,000 (Table 5.1 and Figure 5.1) using the ArcGIS 9.2 software. For elevation, five levels of altitude above the mean sea level (msl) have been identified for the use in the weight-evaluating process while for the proximity-based factors, a number of distance-based buffer zones have been assigned to serve this purpose (as described in Table 5.2).

Table 5.1 Information of data used and their original sources

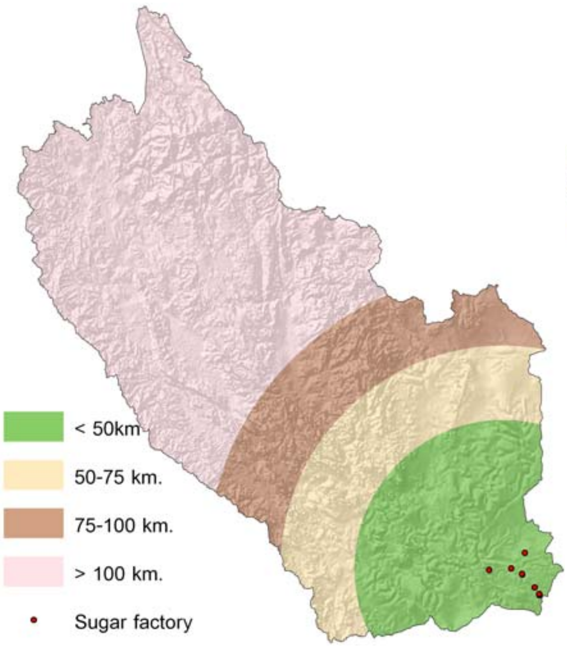
Data category	Scale	Source
Topography Elevation (DEM)	1:50,000	Department of Environmental Quality promotion (DEQP)
Raw material Point of sugar industry, cassava chip, starch factory, pellet factory	1:50,000	Department of Land Development and field survey
Market Road map	1:50,000	Department of Rural Road
Water supply Stream, river, reservoir	1:50,000	Department of Environmental Quality Promotion (DEQP)
Social Environment	1:50,000	Department of Environmental Quality Promotion (DEQP)
Political boundary, points of school, temple, village, public office	1:50,000	Department of Environmental Quality Promotion (DEQP)



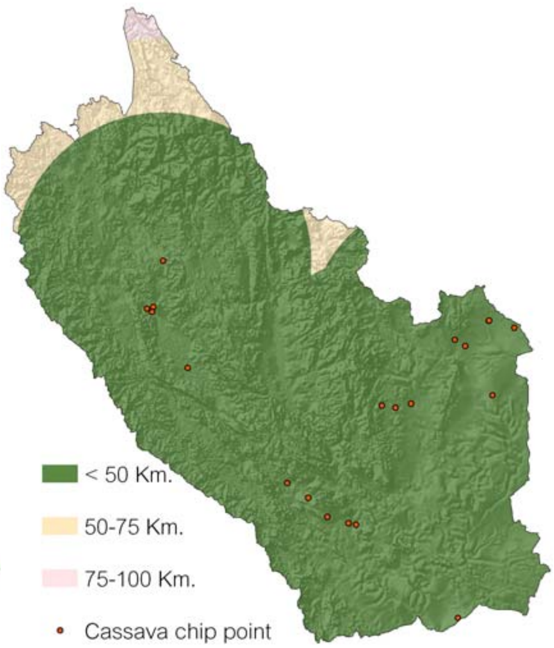
(a) Distance from road



(b) Distance from water resources

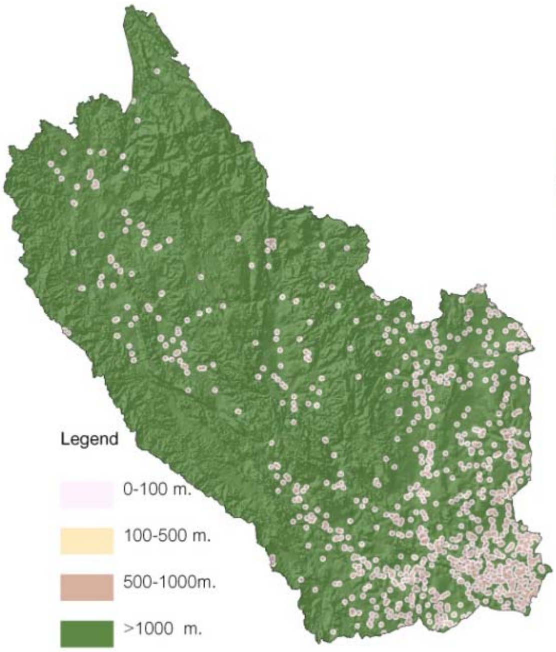


(c) Distance from Sugarcane factory

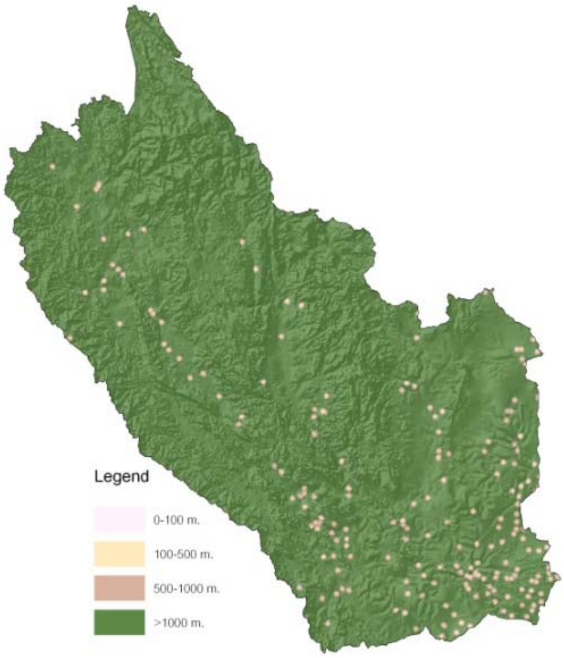


(d) Distance from cassava chip point

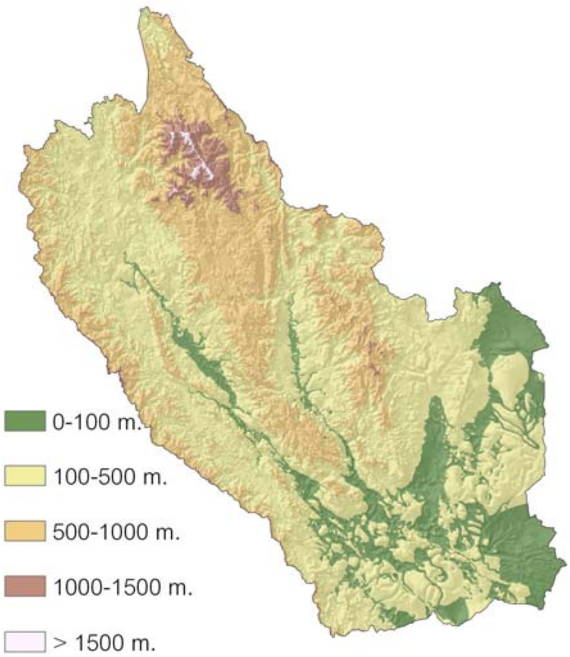
Figure 5.1 Maps of the input data for the AHP-based decision-making analysis



(e) Distance from community



(f) Distance from public places



(g) Elevation

(h) Excuded Area

Figure 5.1 (Continued)

5.4.2 Methodology

To fulfill the purpose of this study described earlier, three main working steps had been planned and utilized which are (1) determining the factor weights and class weights for all the involved factors using AHP method based on opinions given by the associated experts through the returned questionnaires, (2) formulating suitability map to locate potential candidate points for possible new ethanol factory in the province, (3) identifying proximity-based service areas of each candidate point and their relative suitability scale based on the LULC maps and land suitability maps of sugarcane and cassava in the study area obtained from Chapters III and V respectively. Flowchart of the work is shown in Figure 5.2 and brief details of its main steps are as follows.

5.4.2.1 Determination of factor weights and class weight through AHP method

In this step, the relative importance scores for all the introduced factors when being compared to one another were assembled, first based on the judgment provided by the 17 corresponding experts through the returned questionnaires (see list of these experts and details of the questionnaire in Appendices N respectively). Then, these opinions were re-evaluated to create pair-wise comparison matrix needed by the AHP method (as seen for example in Appendix K). The factor and class weights of all the parameters were then evaluated using AHP technique and results are reported in Table 5.2 (more comprehensive detail of the AHP method is given in Section 5.4.2.2 and in Ma et al. (2005) and Bascetin (2007)). The consistency ratio (CR) of this study is found to be 0.06, which is less than 0.1, therefore, the obtained weights are acceptable as valid information for further use based on criteria proposed by Saaty (1980).

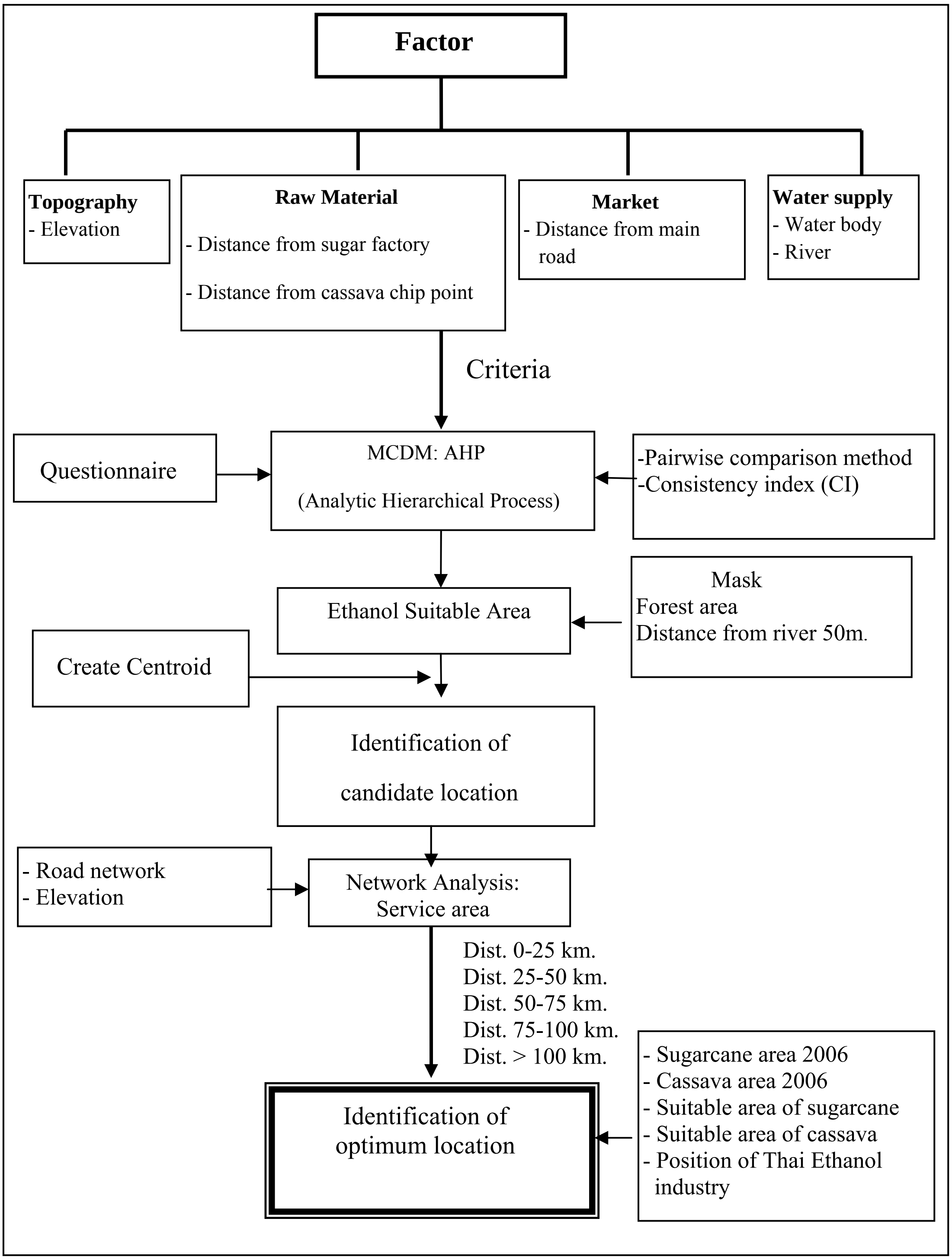


Figure 5.2 Flowchart of the study

From the factor weights and class weights (or rating) presented in Table 5.2, it can be primarily concluded that topography (elevation) and proximity to raw material are considered the two most important prior factors in the decision-making of suitable site for new ethanol plant (score 0.27 and 0.21 respectively). Broad conclusion is that, it should be placed in the low area (e.g. less than 500 msl) close to its raw material resources (especially sugarcane), also close to main roads (e.g. less than 10 km away) and water body (e.g. within the 500 m distance) but should not stand too close or too far from the community (e.g. within 500-1000 m radius), and it is not necessary to be located close to the administrative center (public offices). And, it was later found that, for 5 nominated candidate points, three of them are located close to main river in the south and the other two are also located close to large water body (Figure 5.3).

Table 5.2 Factor weights and class weights (or rating) derived form the AHP method

Factor	Class	Weight I	Weight II	Total Weight	Rating	SUM
1. Topography		0.27				
1.1 Elevation	0-100 m.		1	0.27	5.7	1.54
	>100-500 m.				6.13	1.66
	>500-1000 m.				4.81	1.30
	>1000-1500 m.				3.88	1.05
	>1500 m.				2.5	0.68
2. Raw Material		0.21				
2.1 Distance from sugar factory	<50 km.		0.76	0.16	6.38	1.03
	>50-75 km.				6.56	1.06
	>75-100 km.				5.44	0.88
	>100 km.				3.31	0.54
2.2Distancefrom cassava chip point	<50 km.		0.24	0.05	6.31	0.33
	>50-75 km.				6.25	0.33
	>75-100 km.				4.81	0.25
	>100 km.				3.44	0.10
3.Proximity		0.18				
3.1 Distance from road	<0-5 km		1	0.18	6.63	1.18
	>5-10 km.				6.44	1.14
	>10-50 km.				4.75	0.84
	>50-100 km.				5.19	0.92
	>100 km.				3.38	0.60
4. Water Supply		0.18				
4.1 Distance from water body	100-200 m.		1	0.18	5.81	1.05
	>200-300 m.				6.00	1.08
	>300-500 m.				4.94	0.89
	>500-1000 m.				4.50	0.81
	>1000 m.				2.94	0.53

Table 5.2 (Continued)

Factor	Class	Weight I	Weight II	Total Weight	Rating	SUM
5. Social Environment						
5.1 Distance from community	0-100 m.	0.16	0.73	0.12	3.44	0.41
	>100-500 m.				4.94	0.58
	> 500-1000 m.				5.75	0.68
	>1000 m.				5.25	0.62
5.2 Distance from public places	0-100 m.		0.27	0.04	3.38	0.15
	>100-500 m.				4.69	0.20
	> 500-1000 m.				6.06	0.26
	>1000 m.				7.44	0.32
SUM		**1.00**		**1.00**		

5.4.2.2 Derivation of location suitability map and identification of candidate points

After the all the needed weights were obtained, the total site suitability level for each land unit is derived and presented in term the location suitability index (LSI) using the following equation;

$$LSI = \sum_{i=1}^{n} (W_i \times R_i) \tag{5.1}$$

where W_i is the assigned weight for factor i (or total weight in Table 5.2) and R_i is its given class weight (for that land unit), n is number of factors used (here n = 7).

From Eq. 5.1, it was found that the minimum and maximum values for LSI are 0.14 and 1.66 respectively, with average value of 0.9 and a standard deviation of 0.41. The LSI value represents the relative suitability level of that land unit for being new ethanol plant according to the criteria given in AHP method. Therefore, the higher the index, the more suitable the land is. To create required land suitability map, these calculated LSI values were divided into 3 levels (based on the equal interval algorithm available in the ArcGIS 9.2 software) which are highly suitable (HS), moderately suitable (MDS), and marginally suitable (MGS).

Table 5.3 Defined LSI score ranges for location suitability classification

Suitability class	Suitability score range	Area coverage (km^2)
Highly suitable area (HS)	3.84-4.38	316.18
Moderately suitable area (MDS)	3.29-3.84	5,786.45
Marginally suitable area (MGS)	2.74-3.29	272.93
Excluded area	-	13,004

The produced suitability map is shown in Figure 5.3 where class range of the LSI values and its area coverage are described in Table 5.3. Note that, some restricted areas, including conservation area, forest area, watershed class A and 50 m distance from river, were masked out and labeled as not-suitable area (NS) in the output map as they are unlikely to be used for the desired purpose.

From the derived suitability map, the candidate points for being new ethanol plant were identified in according to two given basic criteria: (1) they must be located at (or close to) center of the classified highly suitable areas, (2) they must have at least 300-500 rai of land available within the location for housing plant's facilities. Based on these criteria, there were five suitable points eventually identified (Figure 5.4).

5.4.2.3 Service-area suitability analysis of the candidate points

To quantify the suitability level of each candidate point individually, maps of the potential service area of each selected point were created and cross-examined with the LULC maps and land suitability maps invented for sugarcane and cassava in the study area taken from Chapter V. Service area suitability for the sole existing ethanol plant in Kanchanaburi at present was also evaluated (Figure 5.3).

Table 5.4 Positions of five candidate points and the existing ethanol industry

Candidate	Position Coordinates	Location
1	X: 563583, Y: 1544720	Tambon Thalao in Thamuang District
2	X: 568844, Y: 1541910.	Tambon Thalao in Thamuang District
3	X: 558937, Y: 1547040	Tambon Koh Sumlong in Muang District
4	X: 554039, Y: 1588480	Boploi Sub-district in Boploi District
5	X: 553846, Y: 1588300	Boploi Sub-district in Boploi District
Existing	X: 587103, Y: 1534672	Thamai Sub-district, Thamaka District

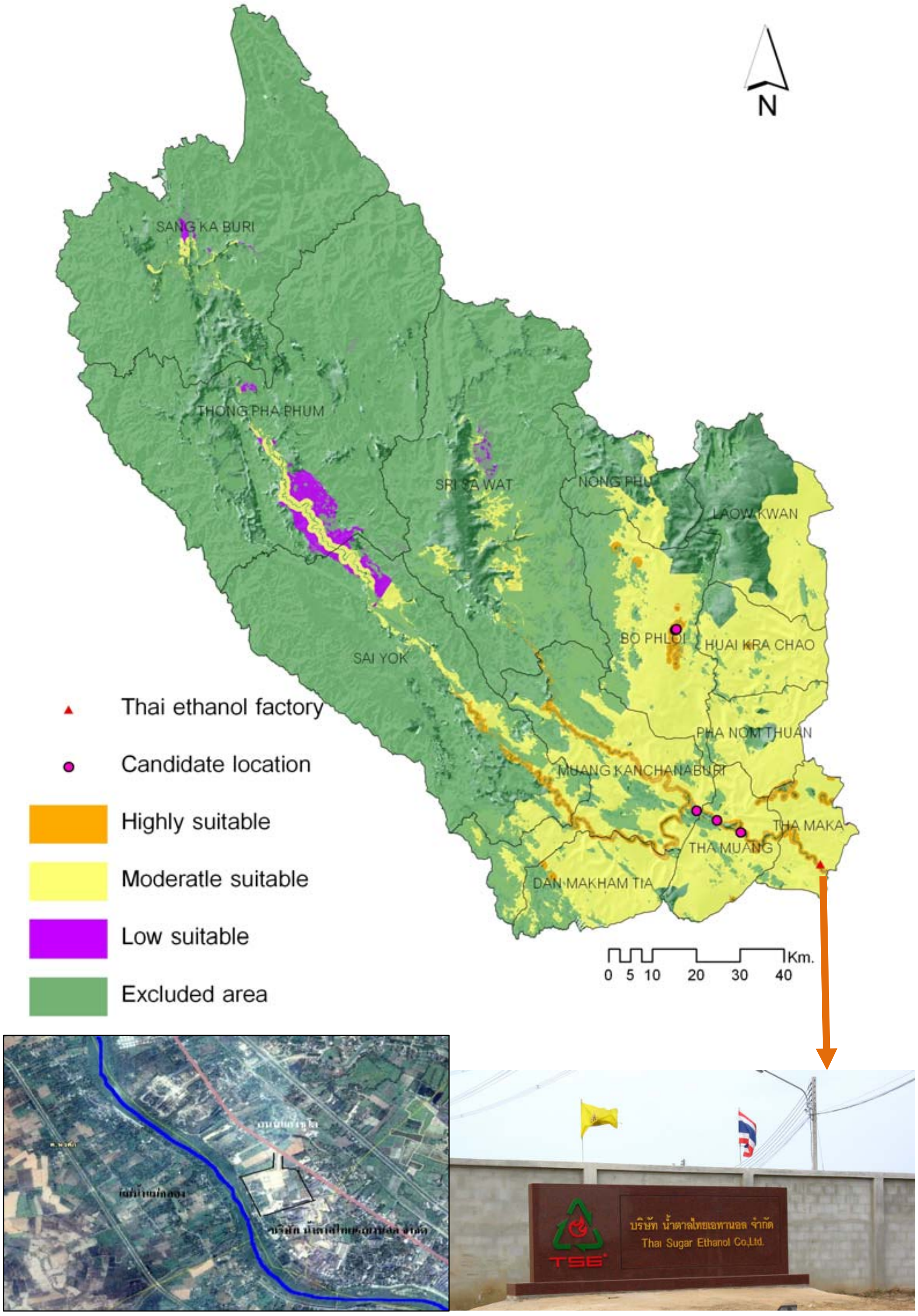


Figure 5.3 Suitability map for new ethanol plant site in Kanchanaburi developed based on AHP method where five candidate points were identified (red dots) but two sites in Bo Phloi District are situated close to each other and cannot be distinguished on map. Red triangle in the bottom represents site of the existing plant.

5.5 Results and Discussion

5.5.1 Location suitability map and potential candidate point

Form the knowledge of LSI values for the area (derived from Eq. 5.1), the site suitability map can be developed in which three suitability classes were shown, which are, highly suitable (HS), moderately suitable (MDS), and marginally suitable (MGS) (Figure 5.3). Some excluded areas were also displayed in the map. From Table 5.3, it can be seen that the proportion of area coverage for these four groups of data (HS, MDS, MGS, excluded) on the map are 1.63%, 29.86%, 1.41%, and 67.10% respectively.

From the information about spatial distribution of the high suitability areas on the map and two specific criteria for choosing candidate points mentioned earlier in Section 5.4.2.2, eventually five potential candidate locations were determined as seen in Figure 5.3. Position and location of these chosen points and the now existing plant are shown in Table 5.4. It is obvious that three of them are located in the south close to main river (candidate number 3-5) and the other two in Thamuang District are also located close to big reservoir situated near by.

5.5.2 Service area zoning for the candidate points

To quantify the suitability level of each candidate point individually, maps of the potential service area of each selected point were created and cross-examined with the LULC maps and land suitability maps invented for sugarcane and cassava in the study area taken from Chapter IV (Figure 5.6-5.7). The potential service areas for each candidate point and the existing one were classified into five distance-based zones which are 0-25 km, 25-50 km, 50-75 km, 75-100 km, and greater than 100 km. And three scenarios of service area zoning were examined for each chosen location which are for (1) cassava and sugarcane plantations in 2006, (2) classified suitability area for sugarcane cultivation, and (3) classified suitability area for cassava cultivation in the study area (as displayed in Figures 5.4-5.9). The distance-based criteria are measured along existing road network (for the delivery of raw material to the chosen site) using the transportation network analysis available in the ArcGIS 9.2 software. Data of area allocation for the zoning system of each considered scenario are given in Tables 5.5 and 5.6 (for sugarcane and cassava plantations in 2006 respectively), and Tables 5.7 and 5.8 (for combined highly/moderately suitable areas for sugarcane and cassava in the study area respectively (more results of the analysis are given in Appendix L, M).

Relationship between service zoning and crop cultivating area

According to Kanchanasutham (2005), the suitability level for transporting distance (from the crop truck-loading place to the ethanol plant) could be defined as highly suitable (0-50 km), moderately suitable (51-100 km), and marginally suitable or unsuitable (more than 100 km). As a result, if focus only within the first 50 km of the classified service area for each chosen location points seen in Figures 5.4 to 5.9, along with data in Tables 5.5 and 5.6, it was found that this 50 km zone covers about 599.92, 615.78, 654.52, 672.72, 670.62, and 378.35 km^2 of sugarcane planting area in 2006 for candidates 1 to 5 and the existing one respectively, but for cassava planting area, these are 311.19, 215.95, 124.51, 349.23, 334.96, and 274.05 km^2 respectively. Based on amount of these derived data, candidate points 4, 5, and 3 should be the most suitable locations to build new ethanol plant to serve sugarcane farming and candidate points 4, 5, and 1 are the most suitable for cassava farming respectively. All points are in favor of sugarcane to cassava especially locations 4 and 5.

Note that, as candidates 4 and 5 (which are most preferred candidates for both crops) are situated very close to each other, therefore, their area covers for each service zone are very resemble, and as a consequence, they could be examined interchangeably or counted as being just one preferred choice. In addition, the existing plant has served relatively small area of sugarcane and cassava farming in the study area compared to most suitable locations addressed earlier (points 4, 5, 1 and 4, 5, 1 respectively).

Relationship between service zoning and suitable areas for crops

When superimpose the service area map (e.g. Figures 5.6a, 5.7a) onto the land suitability maps derive for sugarcane and cassava in Chapter IV (Figures 4.6 and 4.7), the relationship between these two maps can be investigated and the overlapping areas among their specific classes are described in Appendix L. However, if consider only the overlapping between the service classes and only the combined highly/moderately suitable (S1+S2) areas of the suitability map, the results could be achieved as seen in Tables 5.7 (for sugarcane) and 5.8 (for cassava).

Also, if focus only within the first 50 km of the classified service area for each chosen candidate points seen in Figures 5.4 to 5.9, along with data in Tables 5.7, 5.8 and M-2, it was seen that this 50 km criteria covers about 1279.40, 1296.21, 1454.06, 964.76, 957.34 km^2 of sugarcane's suitable area (S1+S2) for candidates 1 to 5 and the existing one respectively, but for the cassava's suitable area, these are 350.37, 705.40, 1166.85, 907.74, 944.90 km^2 respectively. Based on amount of these derived data, candidate points 3, 2, and 1 should be the most suitable locations to build new plant to serve potential sugarcane farming and candidate points 3, 4, and 5 are most suitable for potential cassava farming respectively. It is obvious that all points are in favor of sugarcane to cassava especially locations 3. Note that the existing plant has served just relatively small area of potential sugarcane and cassava farming in the study area compared to the most suitable locations addressed earlier (points 3, 2, 1 and 3, 4, 5 respectively).

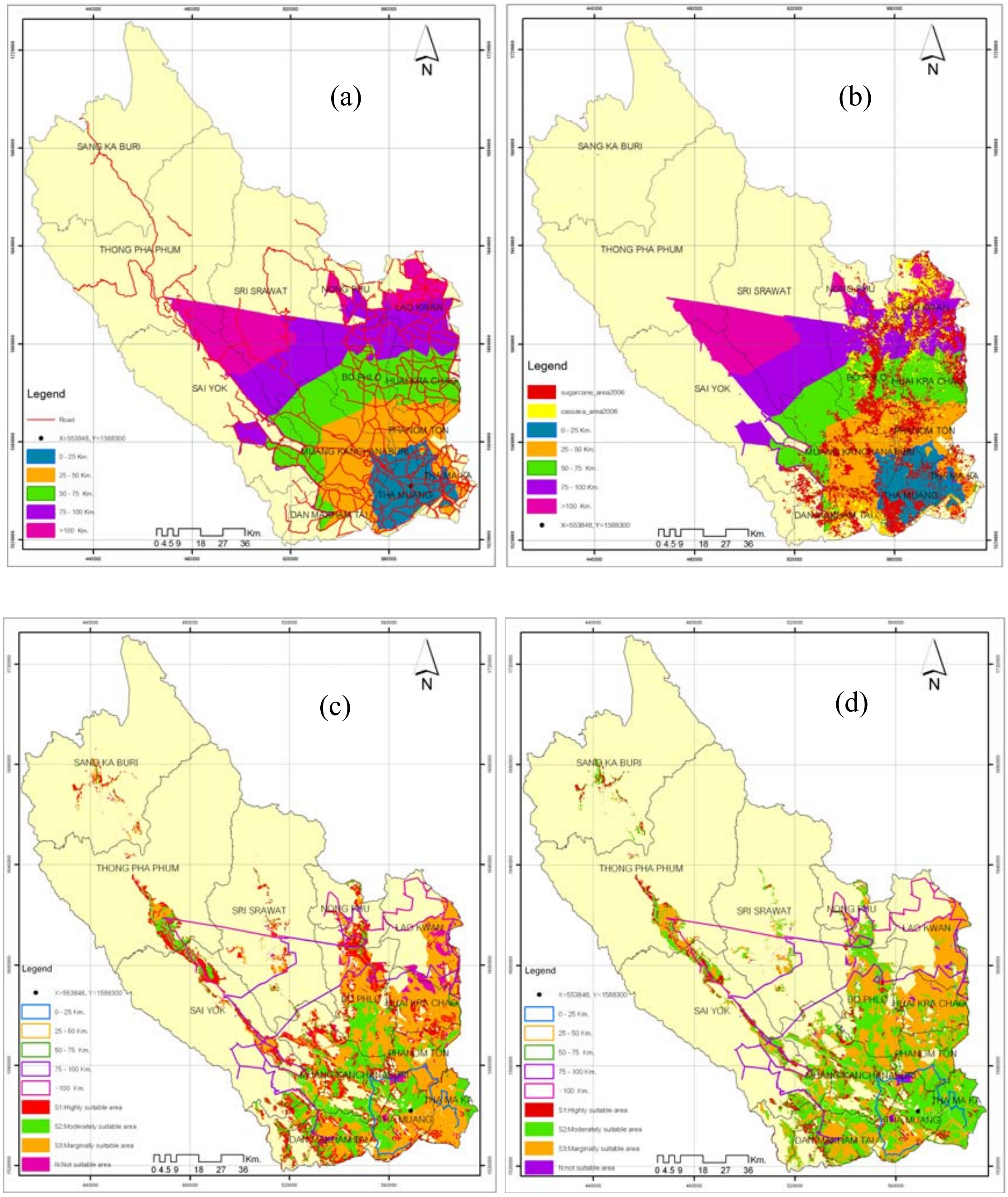
Suitable locations based on the comparative capability index (CCI)

To make more comprehensive evaluation on capability of each candidate point to serve their entire service area, new index called comparative capability index (CCI) is proposed. It was calculated using a weighted-linear combination method:

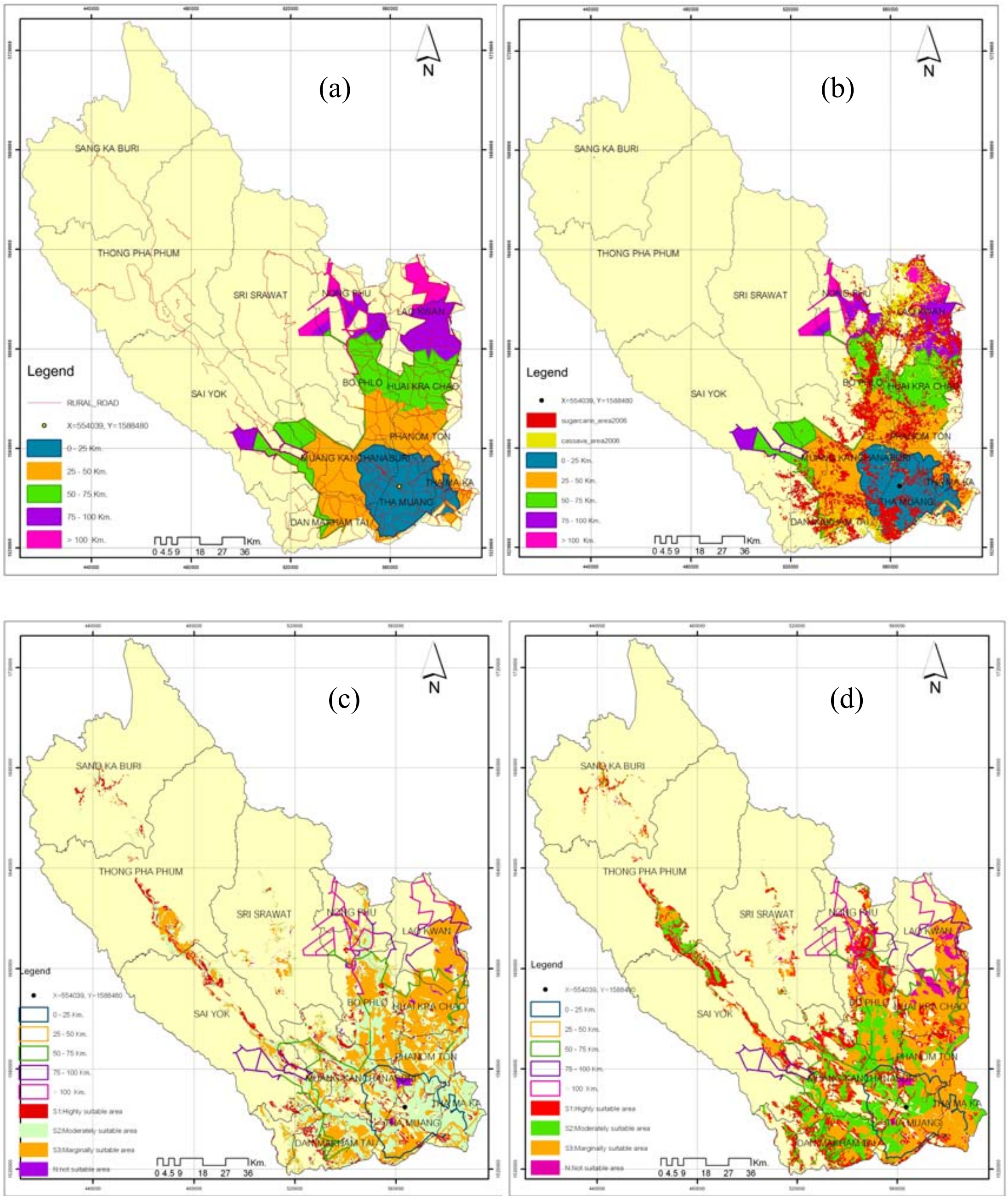
$$CCI = \sum_{i=1}^{5} (P_i \times W_i) \,, \quad (5.2)$$

where CCI (between 0-5) is the average capability score for the interested candidate, P_i is proportion of the area coverage (of crop planting or potential crop planting lands) in the service zone i for that candidate and W_i is proposed zoning weight given as 5, 4, 3, 2, 1 for the 0-25, 25-50, 50-75, 75-100, and >100 km zones respectively. Results of CCI outcome are given in Tables 5.4 and 5.5 (for sugarcane and cassava plantation in 2006 respectively) and in Tables 5.6 and 5.7 (for potential sugarcane and cassava plantation land according to the used land suitability maps, respectively).

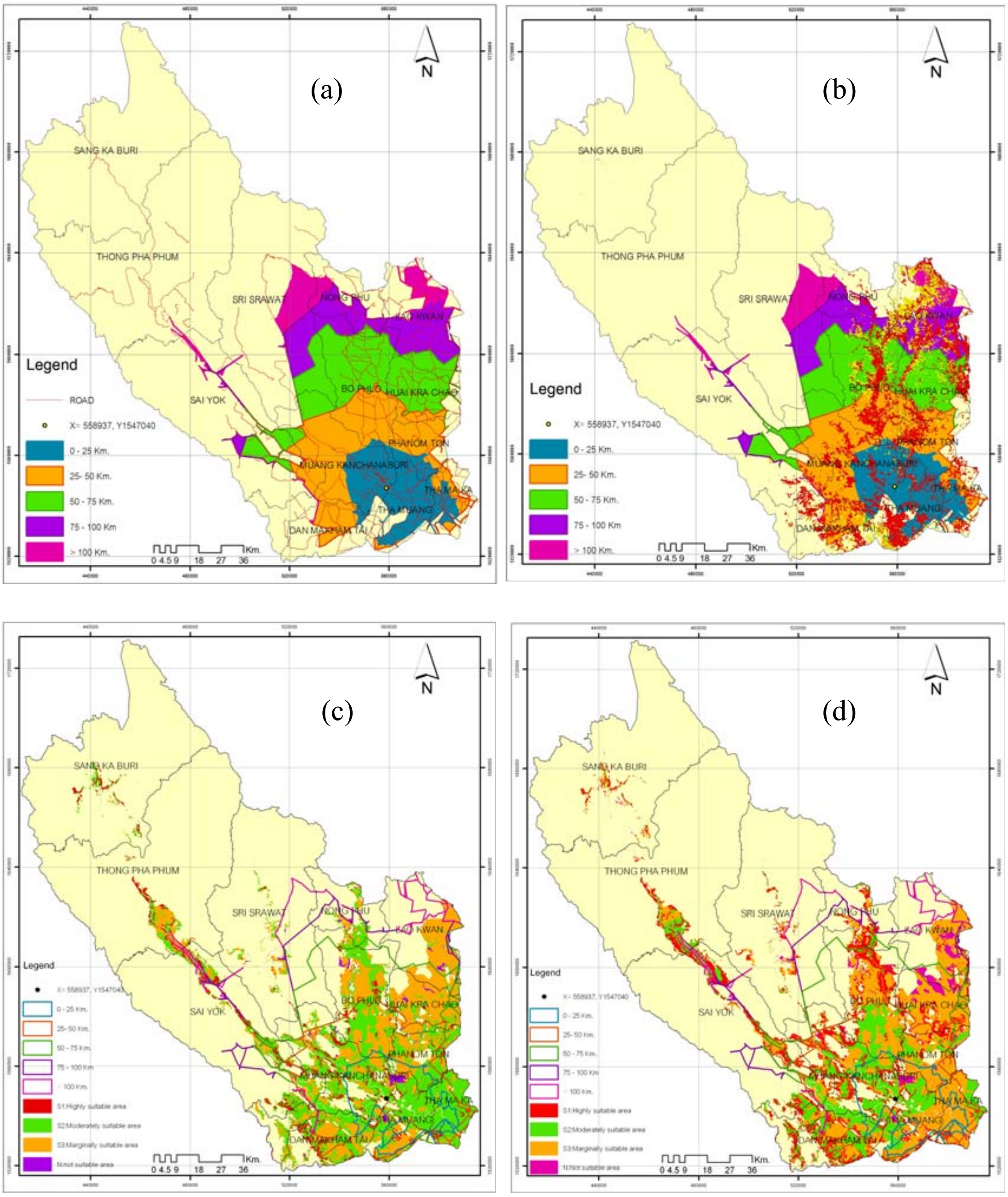
It can be concluded from these CCI data that most capable candidates for the sugarcane farming in 2006 are numbers 3, 4, 5 with CSI scores of 3.80, 3.76, 3.75 respectively and least capable is number I (CCI = 2.67) but for cassava farming, most capable candidates are number 2, 5, 4 with CCI 3.08, 2.75, 2.44 respectively and least capable one is number 3 (CCI = 2.07). And for the potential sugarcane planting land are numbers 2, 3, 1 with CCI scores of 4.18, 4.07, 3.74 respectively and least capable is number 5 (CCI = 3.61) but for potential cassava planting land, most capable candidates are numbers 3, 2, 4 with CCI = 3.84, 3.78, 3.75 respectively and least capable one is number 1 (CCI = 3.42).



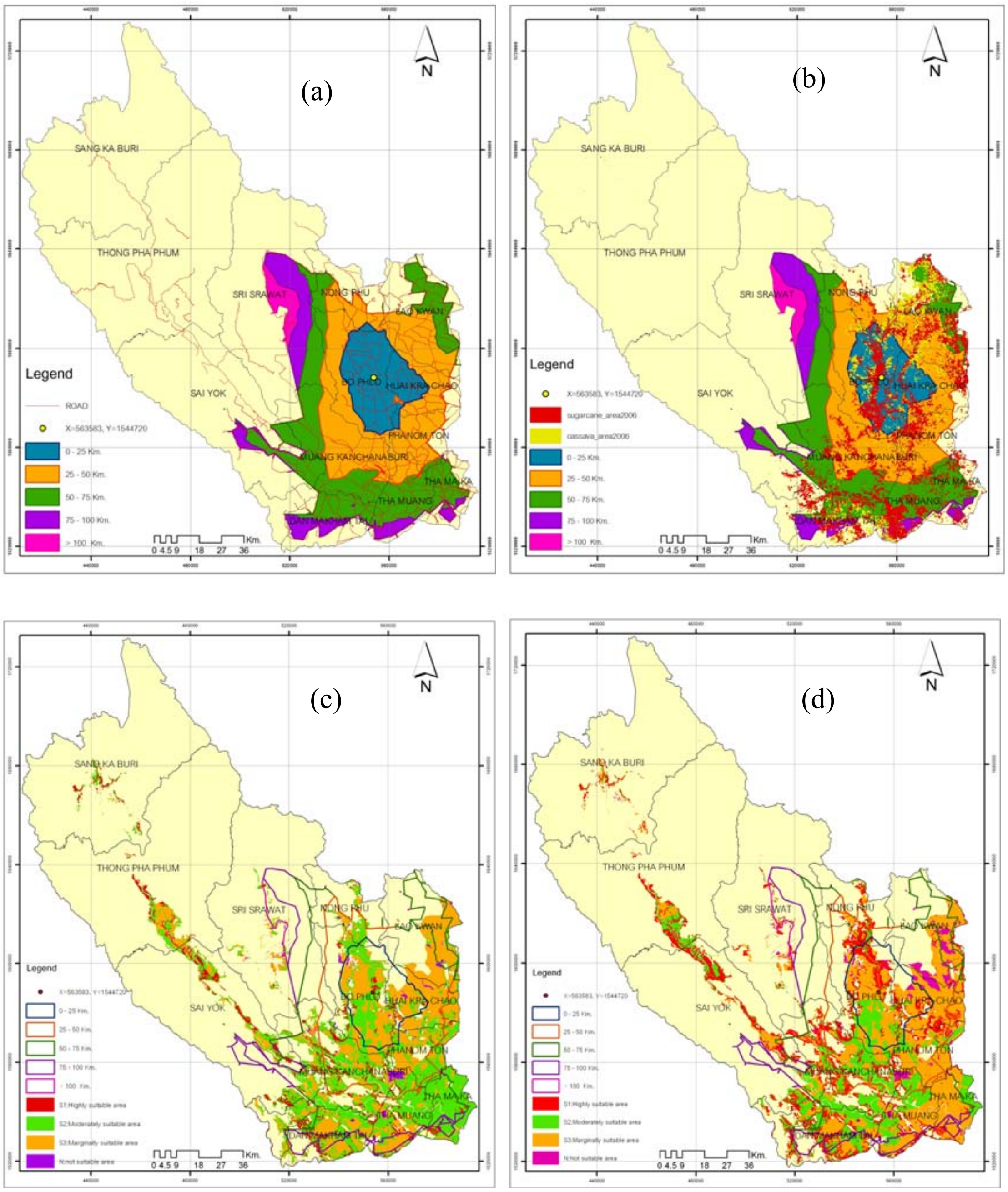
Figures 5.4 (a) service area zoning for candidate 1 (b) service zoning with sugarcane and cassava cultivating area observed in 2006 (c) service zoning with land suitability map of sugarcane (d) service zoning with suitability map of cassava



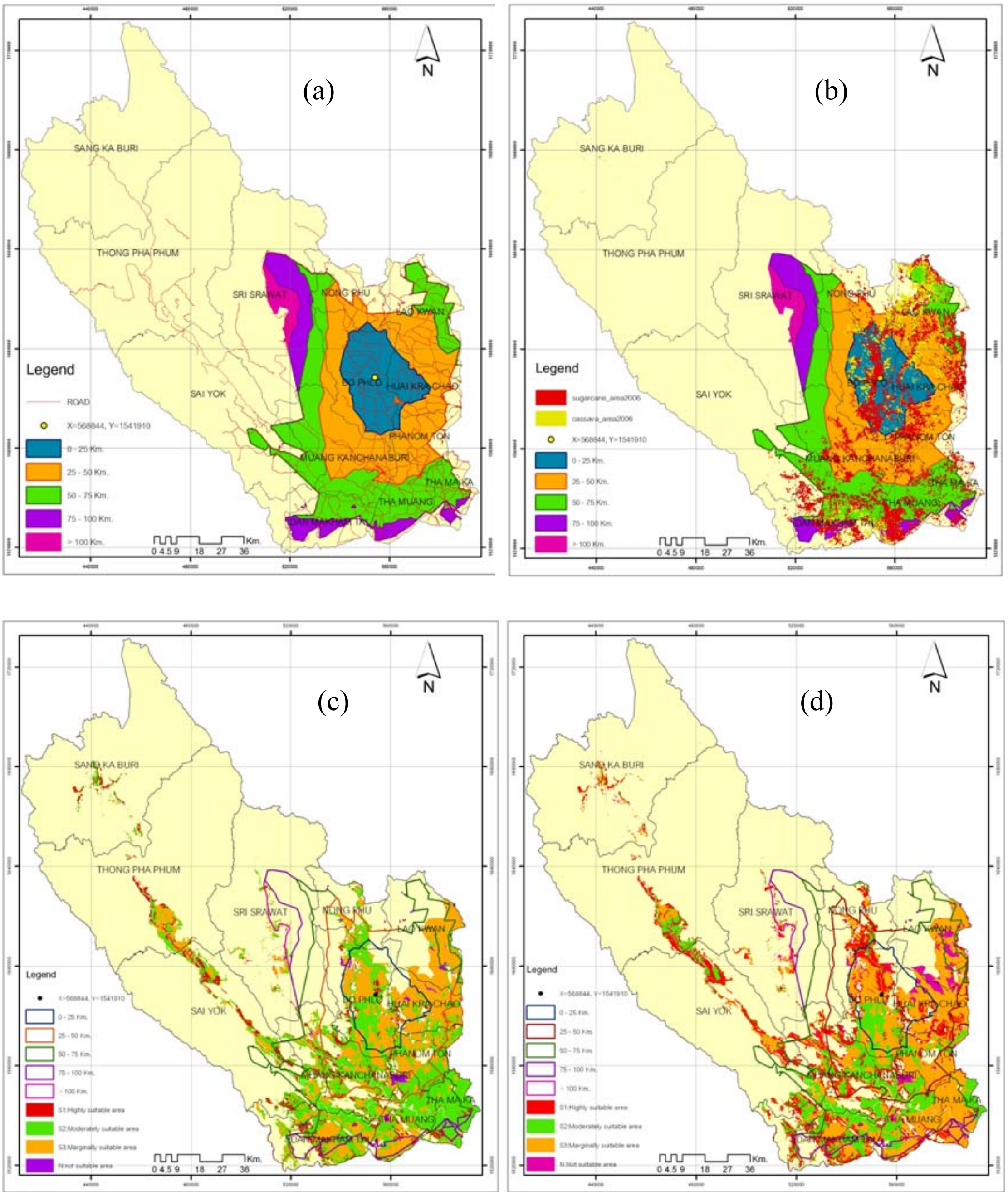
Figures 5.5 (a) service area zoning for candidate 2 (b) service zoning with sugarcane and cassava cultivating area observed in 2006 (c) service zoning with land suitability map of sugarcane (d) service zoning with suitability map of cassava



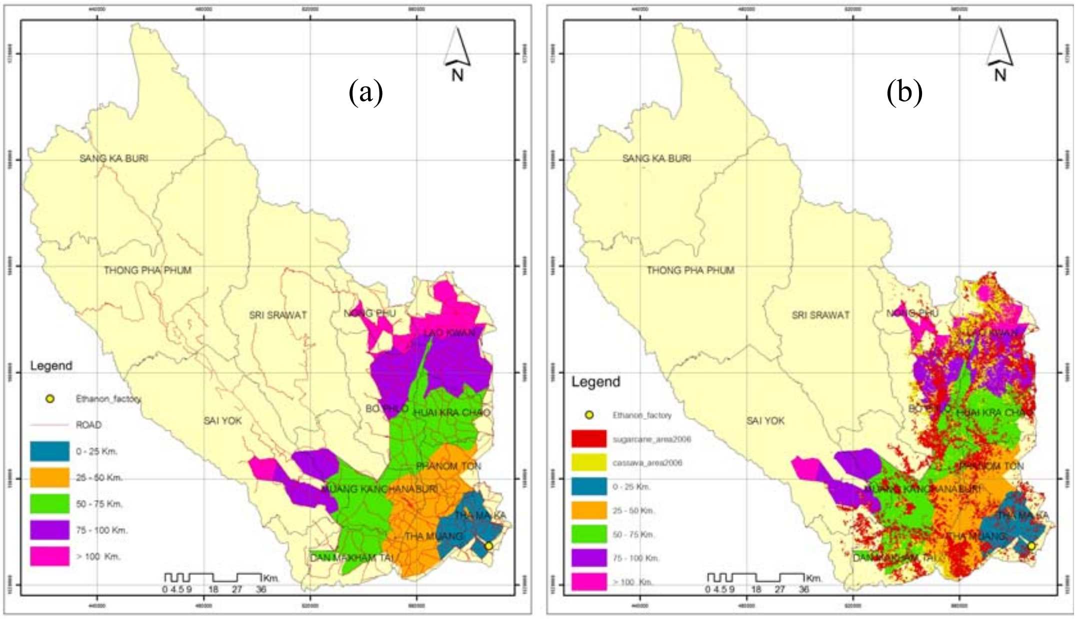
Figures 5.6 (a) service area zoning for candidate 3 (b) service zoning with sugarcane and cassava cultivating area observed in 2006 (c) service zoning with land suitability map of sugarcane (d) service zoning with suitability map of cassava



Figures 5.7 (a) service area zoning for candidate 4 (b) service zoning with sugarcane and cassava cultivating area observed in 2006 (c) service zoning with land suitability map of sugarcane (d) service zoning with suitability map of cassava



Figures 5.8 (a) service area zoning for candidate 5 (b) service zoning with sugarcane and cassava cultivating area observed in 2006 (c) service zoning with land suitability map of sugarcane (d) service zoning with suitability map of cassava



Figures 5.9 Location and service area of Thai sugar ethanol of industry (a) service area zoning (b) service zoning with sugarcane and cassava cultivating area in 2006

Table 5.5 Area cover of the classified service zones for sugarcane plantation in 2006 and the comparative capability index (CCI) of each candidate location

Candidate	Distance on road network (km)					Total area (km^2)	CCI
	0-25	**25-50**	**50-75**	**75-100**	**> 100**		
1	204.13	395.79	325.70	789.99	541.22	2256.83	2.67
	9.04	17.54	14.43	35.00	23.98	100%	
2	245.70	370.08	191.47	161.15	109.64	1078.04	3.45
	22.79	34.33	17.76	14.95	10.17	100%	
3	213.10	441.42	201.11	163.72	17.38	1036.73	3.80
	20.56	42.58	19.40	15.79	1.68	100%	
4	249.76	422.96	377.98	71.63	0.02	1122.35	3.76
	22.25	37.69	33.68	6.38	0.00	100%	
5	249.30	421.32	376.01	73.52	0.12	1120.27	3.75
	22.25	37.61	33.56	6.56	0.01	100%	
Existing plant	76.57	301.78	370.14	274.84	49.52	1071.85	3.08
	7.14	28.16	34.53	25.64	4.62	100%	

Table 5.6 Area cover of the classified service zones for the cassava plantation in 2006 and the comparative capability index (CCI) of each candidate location

Candidate	Distance on road network (km)					Total area (km^2)	CCI
	0-25	25-50	50-75	75-100	> 100		
1	121.21	189.98	108.73	674.29	607.86	1702.07	2.14
	7.12	11.16	6.39	39.62	35.71	100%	
2	0.00	215.95	77.28	75.12	54.14	422.49	3.08
	0.00	51.11	18.29	17.78	12.81	100%	
3	20.62	103.89	328.69	327.19	508.59	1288.98	2.07
	1.60	8.06	25.50	25.38	39.46	100%	
4	106.58	242.65	321.05	390.71	187.09	1248.08	2.44
	8.54	19.44	25.72	31.30	14.99	100%	
5	107.32	227.64	466.47	418.41	186.57	1406.41	2.75
	7.63	16.19	33.17	29.75	13.27	100%	
Existing plant	226.07	47.98	110.53	146.44	123.38	654.4	3.16
	34.55	7.33	16.89	22.38	18.85	100%	

Table 5.7 Allocation of the classified service zones for sugarcane's suitability area (S1+S2) and the comparative capability index (CCI) of each candidate location

Candidate	Distance on road network (km)					Total area (km^2)	CCI
	0-25	25-50	50-75	75-100	> 100		
1	511.03	768.37	486.09	130.19	95.94	1991.62	3.74
	25.66	38.58	24.41	6.54	4.82	100%	
2	596.87	699.34	247.02	29.79	1.86	1574.88	4.18
	37.90	44.41	15.69	1.89	0.12	100%	
3	615.64	838.42	292.48	3.47	62.84	1812.85	4.07
	33.96	46.25	16.13	0.19	3.47	100%	
4	315.73	649.03	810.26	96.82	11.36	1883.2	3.62
	16.766	34.464	43.026	5.141	0.603	100%	
5	315.28	642.06	809.76	100.50	11.56	1879.16	3.61
	16.78	34.17	43.09	5.35	0.62	100%	

Table 5.8 Allocation of the classified service zones for cassava's suitability area (S1+S2) and the comparative capability index (CCI) of each candidate location

Candidate	Distance on road network (km)					Total area (km^2)	CCI
	0-25	**25-50**	**50-75**	**75-100**	**> 100**		
1	222.52	127.85	63.29	50.08	135.34	599.08	3.42
	37.14	21.34	10.56	8.36	22.59	100%	
2	108.05	597.35	216.84	47.85	3.51	973.6	3.78
	11.10	61.35	22.27	4.91	0.36	100%	
3	415.25	751.60	219.17	74.96	97.36	1558.34	3.84
	26.65	48.23	14.06	4.81	6.25	100%	
4	294.04	613.70	572.17	79.09	12.96	1571.96	3.75
	18.71	39.04	36.40	5.03	0.82	18.71	
5	293.80	651.10	605.11	80.89	13.42	1644.32	3.69
	17.87	39.60	36.80	4.92	0.82	100%	

5.6 Conclusion

This work identified potential new locations for ethanol plant factory located in Kanchanaburi Province using integrated AHP/GIS technique and the service zoning system based on road net work analysis. From the calculated factor and class weights from the pair-wise comparison matrix, it can be primarily concluded that topography (elevation) and proximity to raw material are considered the two most important prior factors in the decision-making of suitable site for new ethanol plant. Broad conclusion is that, it should be placed in the low area close to its raw material resources, close to main roads (e.g. less than 10km away) and water body (e.g. within the 500m distance) but should not locate too close or too far from the community (e.g. within 500-1000m radius), and not necessary to be located close to the administrative center (public offices).

Eventually, five candidate points were identified, two in Thamuang District, one in Muang District, and the other two in Boploi District. Among these, three of them are located close to main river in the south of the province and the other two (in Bo Ploi District) are situated close to large water reservoir also.

The service area zoning of each candidate point was also examined using the proximity-based zoning system and data of sugarcane and cassava planting areas in 2006 and land suitability maps of both crops for Kanchanaburi. By considering only within the 0-50 km service zone of each candidate, the most suitable location of the plant can be identified under different scenarios considered which are for sugarcane farming, for cassava farming, for highly and moderately suitable land of sugarcane and of cassava respectively. Based on amount of these derived data, candidate points 4, 5, and 3 should be the most suitable locations to build new ethanol plant to serve sugarcane farming and candidate points 4, 5, and 1 are the most suitable for cassava farming respectively. It was apparent that all candidate points are in favor of sugarcane to cassava especially locations 4 and 5.

In addition the comparative capability index (CCI) was proposed (calculated by Eq. 5.2) and the results indicated that most capable candidates for the sugarcane farming in 2006 are candidates 3, 4, 5 respectively and least capable is candidate 1 but for cassava farming, most capable are candidates 2, 5, 4 with and least capable is candidate 3 (Tables 5.4 and 5.5). And for the potential sugarcane planting land are candidates 3, 2, 1 and least capable is candidate 5, but for potential cassava land, most capable are candidates 3, 5, 4 and least capable is candidate 1.

5.7 References

APEC Biofuels. (2007). Thailand bio-fluels annual 2007. Global agriculture information network [On-line]. Available: http://www.biofuels.apec.org/ me_thailand. html

Banar, M., Kose, B.M., Ozkan, A. and Acar, I.P. (2007). Choosing a municipal land fill site by analytic network process. **Environmental Geology**. 52(4): 747-751.

Bascetin, A. (2007). A decision support system using analytical hierarchy process (AHP) for the optimal environmental reclamation of an open-pit mine. **Original Article**. 52: 663-672.

Chomchalaow, N. (2005). Energy crop. **Journal of Crop Growing in Thailand**. 1(4): 40-41.

Ciancarella, L., Geremei, F., Valpreda, E., Secondini, P. and Tropelocationa, M. (2009). GIS and industrial location: A prototypic application in a South American developing country [On-line]. Available: http://www.downloads2. esri.com/campus/uploads/library/pdfs/5972.pdf.html

Dey, P.K. and Ramcharan, E.K. (2008). Analytic hierarchy process helps select site for limestone quarry expansion in Barbodos. **Journal of Environment Management**. 88(4): 1384-1395.

Energy Policy and Planning Office. (2007). **The situation of energy in 2007 and trend 2008**. Ministry of Energy, Thailand.

Giap, D.H., Yi, Y. and Yakupitiyage, A. (2005). GIS for land evaluation for shrimp farming in Hiphong of Vietnam. **Ocean and Coastal Management**. 48: 51-63.

Graham, R.L., English, B.C. and Noon, C.E. (2000). A geographic information system- based modeling system for evaluating the cost of delivered energy crop feedstock. **Biomass and Bioenergy**. 18(4): 309-329.

Haddad, M.A. and Anderson, P.F. (2008). A gis methodology to identify potential corn stover collection locations [On-line]. Available: http://www.science direct.com.html

Harouff, S.E., Grushecky, S.T. and Spong, B.D. (2008). West Virginia forest industry transportation network analysis using GIS [On-line]. Available: http://www.treesearch.fs.fed.us/pubs/14029.html

Hossain, M.S., Rahman, S., Chowdhury, S.R., Das, N.G. and Rahaman, M.M. (2007). Multi-criteria evaluation approach to GIS-based land suitability classification for tilapia farming in Bangladesh. **Aquaculture International**. 15: 425-443.

Hossain, M.S., Chowdhury, S.R., Das, N.G., Sharifuzzaman, S.M. and Sultana, A. (2009). Intergration of GIS and multicriteria decision analysis for urban aquaculture development in Bangladesh. **Landscape and Urban Planning**. 90(3-4): 119-133.

Huang, L.X., Sheng, G. and Wang, L. (2006). GIS-based hierarchy process for the suitability analysis of Nuclear waste disposal site. **Environmental Informatics Archives**. 4: 289-296.

Kanchanasutham, S. (2005). **To define economic of agro zone for a goods of agriculture**. Bangkok: Sukothaithammatirath of University.

Lin, Y. and Tanaka, S. (2006). Ethanol fermentation from biomass resources: current state and prospects. **Applied Microbiology and Biotechnology**. 69(6): 627-642.

Ma, J., Scott, N.R., DeGloria, S.D. and Lembo, A.J. (2005). Siting analysis of farm-based centralized anaerobic digester systems for distributed generation using GIS. **Biomass and Bioenergy**. 28(6): 591-600.

Noon, C.E., Zhan, F.B. and Graham, R.L. (2002). GIS-based analysis of marginal price variation with an application in the identification of candidate ethanol conversion plant locations. **Network and Spatial Economics**. 2(15): 79-93.

Nutsombul, N. (2005). Ethanol: a new chooses energy. **Journal of Industry**. Department of Industry Promotion. 48(November- December): 42-44.

Pérez, O.M., Telfer, T.C. and Ross, L.G. (2003). Use of GIS-based models for integrating and developing marine fish cages within the tourism industry in Teneńfe (Canary Island). **Coastal Management**. 31(4): 355-366.

Ruiz Puente, M.R., Diego, I.F., Santa Maria, J.O., Perez, H. and Arroyabe, F.D. (2007). The development of a new methodology based on GIS and fuzzy to locate sustainable industrial area [On-line]. Available: http://www.people. plan.aau.dk/~enc/AGILE2007/PDF/8_PDF.pdf.html

Sener, B., Súzen Lütfi, M. and Doyuran, V. (2006). Landfill site selection by using geographic information system. [On-line]. Available: http://www.people. plan.aau.dk/~enc/AGILE2007/PDF/8_PDF.pdf

Sriroth, K., Piyachomkwan, K., Termvejsayanon, N. and Burannares, I. (2003). **A study of directions for the development of ethanol industry in Thailand**. The office of the National Ethanol Committee, Ministry of Industry, Thailand.

Tseng, C., Chen, S., Huang, C. and Liu, C. (2001). GIS-assisted site selection for artificial reefs. **Fisheries Science**. 67(6): 1015-1022.

Zhan, F.B., Chen, X., Noon, C.E. and Wu, G. (2005). A gis-enabled comparison of fixed and discriminatory pricing strategies for potential swithgrass to ethanol conversion facilities in Alabama. **Biomass and Bioenergy**. 28: 295-306.

CHAPTER VI

CONCLUSION AND RECOMMENDATION

There are four main works reported in this thesis which are (1) pattern analysis of the observed LULC change and prediction for Kanchanaburi Province during 1992-2006 (Chapter II), (2) Examination of driving factors that are most related to the changes in the amount of agricultural land during the specified periods (Chapter III), (3) development of land suitability maps for both sugarcane and cassava cultivations (Chapter IV), and (4) identification potential suitable locations for new ethanol plant (Chapter V). From results obtained from each work, the overall conclusion and some recommendations can be presented as follows.

6.1 Conclusion

6.1.1. Analysis and prediction of land use/land cover change

In this work, GIS tools and satellite images had been applied to the analysis of LUCC pattern in Kanchanaburi Province during 15-year period from 1992 to 2006 and to predict its future LULC for years 2011, 2016, and 2020. From the classification of Landsat-TM and ETM+ images, it was found that the area was dominated by two LULC categories, agricultural land and forest, that aggregately covered about 95% of the total provincial area for the whole period at the ratio of 3 (forest): 1 (agricultural land) approximately and the main urban/built-up areas were usually located close to main rivers in the far south or in the boundary of the river plain and they were normally surrounded by agricultural lands.

Results of the study indicated that LUCC patterns during the proposed period were characterized by (1) substantial changes between forest area and agricultural land (cash crops in particular) (2) prominent changes of LULC pattern within agricultural land category (from period to period), (3) notable increase in the amount of energy crops (especially sugar cane) and great loss of paddy fields, and (4) rapid expansion of urban areas in expense of the agricultural area nearby (especially paddy field). The predicted LULC maps (based on Markov chain and CA-Markov models) inform that the agricultural land should slightly increase and forest area slightly decreases from 2006 to 2020. However, the forecast of urban/built-up area is still not credible and it is regarded as being deficiency of the used models. To better predict future urban/built up area, some other model is needed.

In general, the MC and CA-Markov models have shown capabilities of descriptive power and simple trend projection of LUCC, regardless of weather or not the trend actually persists. This kind of analysis can serve as an indicator of the direction and magnitude of the LULC changes in near future as well as a quantitative description of changes found in the past.

However, there are still several limitations of the used models in the LUCC applications. For examples, these models are still difficult to accommodate high-order effects (e.g. second-order). Also, the influence of exogenous and endogenous factors to the transitioning process cannot be incorporated into the models explicitly so that the LUCC characteristics can be understood logically. In addition, the assumption of time-independent transition rules is not always true in reality as there are several driving factor involved along each evolution process that could make the rules differ from time to time, especially in the area where rapid changes suddenly occur. Therefore, the models should be used with proper caution and their limitations must be beared in mind of users on the interpretation of the obtained results.

6.1.2 Analysis of driving factors for the agricultural land use change

The main objective of this work was to identify associated parameters which are responsible for the observed agricultural land-use change in Kanchanaburi Province during the 1992-2006 period. In the analysis, several potential factors were taken into account for the variation in amount of agricultural land during this 15-year time span. Based on the classified LULC maps for years 1992, 1996, 2001, and 2006 derived from the corresponding Landsat-TM data, it was found that area coverage of the agricultural land has been decreased by about 0.79% during this studied period. Output results given by the stepwise regression technique indicate different group of driving factors which are responsible for the observed changes in the amount of agricultural land (at sub-district level) during each specified sub-period (1992-1996, 1996-2001, 2001-2006) and the whole period (1992-2006).

In general, climatic factors (temperature and rainfall) were being identified as the most dominant influencing factors of the changes. Other bio-physical parameters like elevation and slope; socio-economic parameters like population density, product price, distance to CBD, and distance from main road; policy-related parameter like land ownership; and agricultural technologies like electrical availability and number of small tractors, are also having some influence (through relatively small). Results of the study indicate that long-term variation (of agricultural land use area) during the 1992-2006 was influenced mainly by elevation, annual rainfall, annual temperature, distance from CBD and land ownership characteristics of the study area. The stepwise regression technique may be proved in this study to be capable of identifying driving factors that influence observed agricultural land-use change in Kanchanaburi during each specified period regarding to its high correlation level (R^2) obtained. The results allow us to better understand which spatial determinants prevail to explain the spatial distribution of different changes in amount of agricultural land. However, it is still difficult to distinguish between the correlation and causality. For example, slope and population density have been shown to have both negative and positive influence on the observed changes (for different period) but it is difficult to tell that which mechanism links both parameters to agricultural expansion in each situation. To remedy this deficiency, different LUCC models (process-based in particular) are thus required to give more information about the actual mechanisms that are responsible for the observed land-use changes found in our study.

6.1.3 Land suitability assessment for sugarcane and cassava cultivation

This work assessed potential suitable area for cultivating two important energy crops (sugarcane and cassava) in Kanchanaburi Province. The analysis was performed using AHP technique integrated with GIS-based processing program.

The AHP method was applied to determine relative importance of all selected factors for each studied crop, which were divided into 2 main categories: biophysical and socio-economic sections. Results of the study were found, based on professional opinions of 20 experts in the field and literature review, and then described in terms of factor weight and class weight (rating) for all the factors involved in each hierarchical layer established.

The land suitability map for each crop has been created, based on the linear combination of each used factor's suitability score (calculated by Eq. 4.1) as discussed in detail in Section 4.4.2.3. The output map was then classified to present 4 suitability classes called as S1, S2, S3, and N according to FAO standard (Table 4.6) as seen in Figures 4.6 (for sugarcane) and 4.7 (for cassava).

It was found that about 52.49 percent (for sugarcane) and 45.07 percent (for cassava) of the total examined area were classified as highly or moderately suitable to grow these crops and only few percent being classified as not suitable for them. Typically, most suitable areas (for both crops) are found in the eastern and lower parts of the province due to better soil quality and more abundance of water resources situated therein. At district level, Tha Ma Ka and Sai Yok were found to be most suitable places for growing sugarcane while Sai Yok and Thong Pha Phum were most suitable for growing cassava and, in general, Sai Yok and Muang District were most suitable for cultivating both crops.

To find potential new cultivating areas for both crops, the obtained suitability maps were cross-examined with the 2006 LU/LC map was derived from Landsat-TM image in which 9 LU/LC classes were identified. A comparison between LU/LC map and suitability maps for both crops indicated that most parts of classified suitable area were located in the existing agricultural land (that is being used for other crops/plants) and in the forest land, which is typically not allowed for any agricultural uses due to legal protection.

Therefore, it is still highly possible to expand growing area for these interested crops by converting existing agricultural areas still using for other crops/plants (like paddy fields) to cultivate these two energy crops instead. Also, the government might consider providing some degraded forest areas (outside the conservation zone) for local farmers as being land resource for growing these two crops.

6.1.4 Suitable location determination for ethanol industry

This work identified potential new locations for ethanol plant factory located in Kanchanaburi Province using integrated AHP/GIS technique and the service zoning system based on road net work analysis. From the calculated factor and class weights from the pair-wise comparison matrix, it can be primarily concluded that topography (elevation) and proximity to raw material are considered the two most important prior factors in the decision-making of suitable site for new ethanol plant. Broad conclusion is that, it should be placed in the low area (e.g. less than 500 msl) close to its raw material resources, close to main roads (e.g. less than 10 km away) and water body (e.g. within the 500 m distance) but should not locate too close or too far from the community (e.g. within 500-1000 m radius), and not necessary to be located close to the administrative center (public offices).

Eventually, five candidate points were identified, two in Thamuang District, one in Muang District, and the other two in Boploi District. Among these, three of them are located close to main river in the south of the province and the other two (in Boploi District) are situated close to large water reservoir also.

The service area zoning of each candidate point was also examined using the proximity-based zoning system and data of sugarcane and cassava planting areas in 2006 and land suitability maps of both crops for Kanchanaburi. By considering only within the 0-50 km service zone of each candidate, the most suitable location of the plant can be identified under different scenarios considered which are for sugarcane farming, for cassava farming, for highly and moderately suitable land of sugarcane and of cassava respectively. Based on amount of these derived data, candidate points 4, 5, and 3 should be the most suitable locations to build new ethanol plant to serve sugarcane farming and candidate points 4, 5, and 1 are the most suitable for cassava farming respectively. It was seen that all candidate points are in favor of sugarcane to cassava especially locations 2 and 3.

In addition, the comparative capability index (CCI) was proposed and results indicated that most capable candidates for sugarcane farming in 2006 are candidates 3, 4, 5 respectively and least capable is candidate 1 but for cassava farming, most capable are candidates 2, 5, 4 with and least capable is candidate 3.

It is also worth noting here that one critical limit of the site analysis described here is that, it considered only the cultivating areas and service areas that are located in Kanchanaburi Province only which may be not realistic as the service area of the plant can be expanded cross boundary into some other neighbor provinces also. Therefore, if the more realistic results are needed, the planting areas and service areas should not be limited by the provincial boundary and crop data of the neighbor provinces should be included in the study also.

6.2 Recommendation

Many objectives were taken into account dealing with evaluating the land use, examining the agricultural land use change, predicting agricultural land use change in the future, and finding out the ethanol industry location in Kanchanaburi Province.

The possibly expected suggestions could be made as follows:

1. The application of CA-Markov should be applied to investigate land use change in the other provinces in Thailand.

2. From this work, it was discovered that the CA-Markov could be suitably applicable to small areas. For any other research work, testing in small area e.g. sub-

district, district, and small province should be additionally organized. Moreover, in small area, it can be easily to make an analysis with higher accuracy occurred.

3. High resolution satellite images (e.g. IKONOS or Quickbird) are suggested to be used with CA-Markov model in future research to yield more efficient results.

4. Interval between LULC date, e.g. longer than five years or 10 years apart, and over four time periods are strongly recommended to examine the continuous changes of the LULC patterns.

5. There are several models to be used in the prediction of LULC changes, e.g. SLUETH, CLUE, and these can be applied to the further study if needed.

6. The reliability and validity of the secondary data used in this kind of work should also be examined to gain more confidence the output products.

8. In practice, the economic factors such as market price, management system, or input cost are also important factors in farmers' decision making. Therefore, they should be taken into the consideration for more complete studies.

9. More factors might be added in the process of finding the suitable locations for ethanol factory e.g. land price, product price, distance to oil refinery etc. Also, the ethanol industries in Thailand should be studied more, and the government should support sugar industries to build their own ethanol plants in order to save the budgets.

10. Land evaluation for other energy economic crops, e.g., maize or corn which are capable of producing ethanol, should be further investigated.

APPENDICES

APPENDIX A

LAND USE/LAND COVER CHANGE

Table A-1 LULC change matrix between 1992 and 1996 (class level)

LULC Type	LULC Type (1996)									
	SC	CV	PF	ET	PA	OA	F	W	U	1992
SC	284	7	33	15	1	123	138	4	5	610
CV	27	55	4	21	3	125	149	1	2	388
PF	92	2	124	2	0	137	49	4	6	416
ET	27	4	3	47	5	47	95	0	0	228
PA	1	0	0	1	31	4	17	0	0	55
OA	279	115	120	79	9	1470	863	44	15	2994
F	148	54	33	61	8	895	12597	145	8	13948
W	1	0	1	0	0	7	21	652	0	683
U	6	0	4	1	0	17	11	4	15	58
Total 1996	865	238	321	227	57	2826	13940	854	52	19380
Change (Km^2)	254	-150	-95	-1	2	-169	-8	172	-6	

Table A-2 LULC change matrix between 1996 and 2001 (class level)

LULC Type	LULC Type (2001)									
	SC	CV	PF	ET	PA	OA	F	W	U	1996
SC	425	23	58	15	2	**218**	111	8	5	865
CV	16	49	0	6	1	104	61	1	0	238
PF	39	3	98	2	0	122	39	10	8	321
ET	10	8	1	31	1	86	90	1	0	227
PA	2	2	0	4	18	8	23	0	0	57
OA	175	114	69	35	5	1691	673	32	32	2825
F	144	72	18	64	9	645	12873	105	11	13940
W	1	0	1	0	0	20	54	775	2	854
U	6	0	4	1	0	20	7	2	12	52
Total 2001	819	272	250	158	34	2913	13930	933	70	19380
Change (Km^2)	-46	35	-71	-69	-23	88	-10	79	18	

Table A-3 LULC change matrix between 2001 and 2006 (class level)

LULC Type	LULC Type (2006)									
	SC	CV	PF	ET	PA	OA	F	W	U	2001
SC	354	53	27	23	3	231	114	3	11	819
CV	19	69	1	4	2	134	42	0	0	272
PF	17	1	130	0	0	78	15	3	6	250
ET	17	8	2	34	4	38	54	0	1	158
PA	1	1	0	1	20	8	3	0	0	34
OA	350	164	54	49	13	1435	798	15	34	2913
F	154	100	4	39	29	799	12748	48	10	13930
W	6	1	9	0	0	48	88	781	2	933
U	4	0	8	1	0	31	12	1	15	71
Total 2006	921	398	234	151	72	2801	13873	851	78	19380
Change (Km^2)	103	126	-16	-7	38	-111	-57	-83	8	

Table A-4 Markov matrix derived from 1992/1996 LULC map pair

LULC Type	Probability of change in 2001								
	SC	CV	PF	ET	PA	OA	F	W	U
SC	0.39	0.01	0.06	0.03	0.00	0.23	0.26	0.01	0.01
CV	0.07	0.12	0.01	0.06	0.01	0.33	0.40	0.00	0.00
PF	0.24	0.00	0.25	0.00	0.00	0.35	0.12	0.01	0.02
ET	0.12	0.02	0.01	0.18	0.02	0.21	0.43	0.00	0.00
PA	0.03	0.01	0.00	0.03	0.47	0.11	0.35	0.00	0.00
OA	0.11	0.04	0.05	0.03	0.00	0.42	0.33	0.02	0.01
F	0.03	0.01	0.01	0.01	0.00	0.13	0.78	0.03	0.00
W	0.01	0.00	0.01	0.00	0.00	0.04	0.13	0.81	0.00
U	0.00	0.01	0.07	0.02	0.00	0.32	0.22	0.07	0.19

Table A-5 Markov matrix derived from 1996/2001 LULC map pair

LULC	Probability of change in 2006								
Type	SC	CV	PF	ET	PA	OA	F	W	U
SC	0.42	0.03	0.08	0.02	0.00	0.29	0.15	0.01	0.00
CV	0.07	0.18	0.00	0.03	0.00	0.45	0.27	0.00	0.00
PF	0.13	0.01	0.26	0.01	0.00	0.40	0.13	0.03	0.03
ET	0.05	0.04	0.00	0.11	0.00	0.39	0.40	0.00	0.00
PA	0.04	0.03	0.00	0.08	0.27	0.16	0.43	0.00	0.00
OA	0.08	0.05	0.03	0.02	0.00	0.48	0.31	0.01	0.01
F	0.03	0.01	0.00	0.01	0.00	0.15	0.77	0.02	0.00
W	0.00	0.00	0.00	0.00	0.00	0.06	0.16	0.77	0.00
U	0.12	0.01	0.08	0.01	0.00	0.41	0.14	0.05	0.17

Table A-6 Markov matrix derived from 2001/2006 LULC map pair

LULC	Probability of change in 2011								
Type	SC	CV	PF	ET	PA	OA	DEF	W	U
SC	0.37	0.07	0.04	0.03	0.00	0.32	0.15	0.00	0.01
CV	0.08	0.22	0.00	0.02	0.01	0.52	0.16	0.00	0.00
PF	0.07	0.00	0.38	0.00	0.00	0.45	0.05	0.01	0.03
ET	0.11	0.05	0.02	0.18	0.03	0.25	0.36	0.00	0.01
PA	0.05	0.05	0.00	0.02	0.51	0.28	0.09	0.00	0.00
OA	0.11	0.06	0.03	0.03	0.01	0.43	0.31	0.01	0.01
DEF	0.03	0.02	0.00	0.01	0.01	0.14	0.78	0.01	0.00
W	0.01	0.00	0.02	0.00	0.00	0.09	0.16	0.71	0.00
U	0.06	0.00	0.11	0.01	0.00	0.49	0.17	0.02	0.15

Table A-7 Markov matrix derived from 1996/2006 LULC map pair

LULC	Probability of change in 2016								
Type	SC	CV	PF	ET	PA	OA	F	W	U
SC	0.29	0.07	0.06	0.03	0.00	0.35	0.16	0.01	0.02
CV	0.09	0.14	0.01	0.03	0.01	0.46	0.26	0.00	0.00
PF	0.12	0.02	0.19	0.01	0.00	0.49	0.13	0.01	0.02
ET	0.09	0.07	0.01	0.15	0.01	0.26	0.39	0.00	0.00
PA	0.03	0.06	0.01	0.04	0.42	0.31	0.13	0.00	0.00
OA	0.12	0.07	0.03	0.03	0.01	0.42	0.31	0.01	0.01
F	0.03	0.02	0.00	0.01	0.00	0.14	0.77	0.01	0.00
W	0.01	0.00	0.01	0.00	0.00	0.08	0.15	0.74	0.00
U	0.13	0.01	0.11	0.02	0.00	0.33	0.17	0.04	0.20

Table A-8 Markov matrix derived from 1992/2006 LULC map pair

LULC	Probability of change in 2020								
Type	SC	CV	PF	ET	PA	OA	DEF	W	U
SC	0.29	0.06	0.04	0.03	0.01	0.33	0.21	0.01	0.02
CV	0.10	0.10	0.01	0.06	0.01	0.42	0.30	0.00	0.01
PF	0.10	0.01	0.24	0.01	0.00	0.48	0.12	0.02	0.03
ET	0.14	0.07	0.01	0.12	0.02	0.24	0.39	0.00	0.01
PA	0.03	0.07	0.00	0.03	0.44	0.27	0.16	0.00	0.00
OA	0.13	0.08	0.03	0.03	0.01	0.39	0.32	0.01	0.01
DEF	0.03	0.02	0.00	0.01	0.00	0.14	0.77	0.03	0.00
W	0.01	0.00	0.01	0.00	0.00	0.08	0.10	0.80	0.00
U	0.13	0.03	0.07	0.03	0.00	0.34	0.18	0.07	0.16

Table A-9 Error matrix of prediction model in 2001 based on land use 1992and 1996

Classification data in 1992

class	1	2	3	4	5	6	7	8	9	Total	EO (%)	PA (%)
1	110302	0	0	0	0	52	5292	186	3	115835	4.78	95.22
2	1	30179	0	11	0	6064	288	0	1	36544	17.42	82.58
3	46	0	40022	0	0	2	332	0	30	40432	1.01	98.99
4	1656	358	0	29873	0	5123	674	0	16	37700	20.76	79.24
5	0	262	0	715	7878	201	21	0	0	9077	13.21	86.79
6	6573	2114	4345	972	71	350664	133994	7329	205	506267	30.74	69.26
7	1207	107	166	105	0	882	1737263	0	25	1739755	0.14	99.86
8	0	0	0	0	0	20	4005	210833	91	214949	1.91	98.09
9	0	0	2	0	0	0	9	0	6424	6435	0.17	99.83
Total	119785	33020	44535	31676	7949	363008	1881878	218348	6795	2706994		
EC (%)	7.92	8.60	10.13	5.69	0.89	3.40	7.68	3.44	5.46			
CA (%)	92.08	91.40	89.87	94.31	99.11	96.60	92.32	96.56	94.54			

Overall accuracy = (110302+30179+4002+29873+7878+350664+1737263+ 210833+6424) / 2706994 = 0.93 = 93%

Kappa coefficient = (0.93-0.48)/(1-0.48) = 0.45/0.52 = 0.87 = 87%

Table A-10 Error matrix of prediction model in 2006 based on land use 1996 and 2001

Reference Data

Classification data in 1992

class	1	2	3	4	5	6	7	8	9	Total	EO (%)	PA (%)
1	100651	2	36	0	0	69	3811	142	4	104715	3.88	96.12
2	457	29086	0	157	0	3325	451	0	0	33476	13.11	86.89
3	2265	0	25387	0	0	1323	33	0	145	29153	12.92	87.08
4	433	189	0	15959	21	927	3537	0	16	21082	24.30	75.70
5	39	118	0	17	4701	239	138	0	0	5252	10.49	89.51
6	9672	8310	8778	3762	38	390377	204733	14904	1487	642061	39.20	60.80
7	23	94	93	68	0	81	1740039	0	20	1740418	0.02	99.98
8	0	1	148	0	0	38	1415	114355	90	116047	1.46	98.54
9	0	0	171	0	0	7026	12	0	7581	14790	48.74	51.26
Total	113540	37800	34613	19963	4760	403405	1954169	129401	9343	2706994		
EC (%)	11.35	23.05	26.65	20.06	1.24	3.23	10.96	11.63	18.86			
CA (%)	88.65	76.95	73.35	79.94	98.76	96.77	89.04	88.37	81.14			

Overall accuracy = (100651+29086+25387+15959+4701+390377+1740039 +114355+7581)/ 2706994 = 0.90 = 90%

Kappa coefficient = (0.9-0.5)/(1-0.5) = 0.80 = 80%

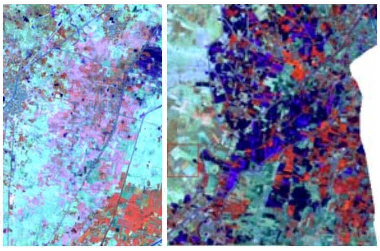
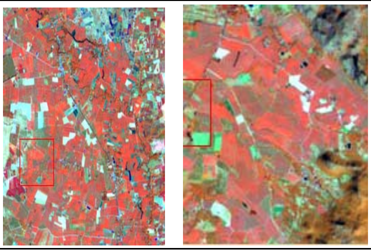
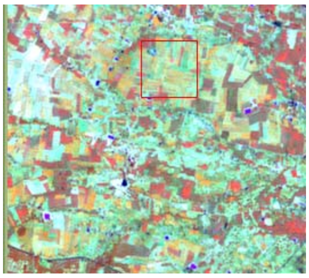
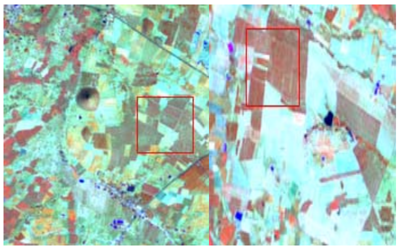
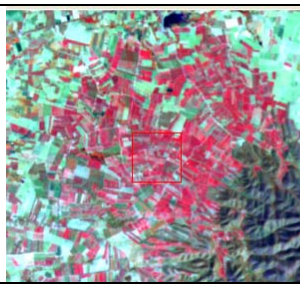
LULC	Feature	Landsat image Band 453 (RGB)
Paddy Field		
Sugarcane		
cassava		
Eucalyptus		
Pineapple		

Figure A-1 Characteristics of satellite image and LULC pattern

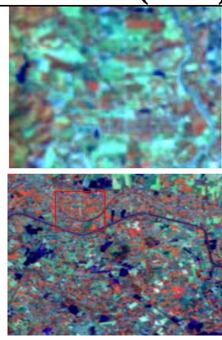
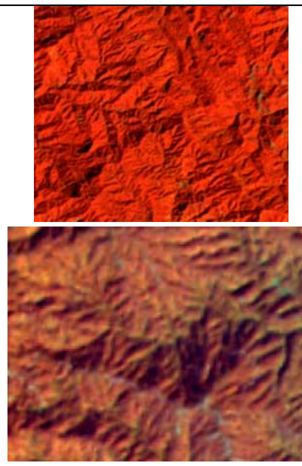
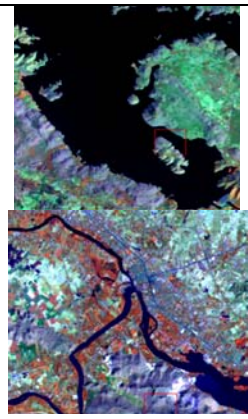
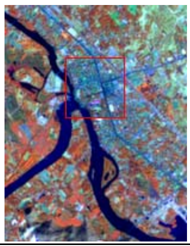
LULC	**Feature**	**Landsat image Band 453 (RGB)**
Other agricultural land (Perennial /Orchards/Horticulture etc.)		
Forest		
Water Bodies		
Urban and Buil-up Area		

Figure A-1 (Continued)

APPENDIX B

DATA OF AGRICULTURAL LAND USE CHANGE

Table B-1 Data of agricultural land change at sub district (or Tambon) level

Sub District	Area coverage (rai)				Sub District	Area coverage (rai)			
	1992-1996	1996-2001	2001-2006	1992 2006		1992-1996	1996-2001	2001-2006	1992 2006
Aulok Sri Min	27.27	7.14	13.33	54.55	Nong Roung	-38.24	33.33	-32.14	-44.12
Ban Kao	-22.55	56.33	-44.94	-33.33	Nong Sarai	50.00	-33.33	100.00	100.00
Ban Mai	75.00	-46.43	100.00	87.50	Nong Son	20.00	116.67	-84.62	-60.00
Bo Phlo	55.41	-0.82	-56.61	-33.12	Nong Tak Ya	0.00	-33.33	-50.00	-66.67
Bong Ti	-47.33	56.52	35.65	11.83	Nong Ya	6.36	-33.33	16.67	-17.27
Cha Lae	25.00	118.42	-25.06	104.61	Pak Plak	-4.55	40.48	27.12	70.45
Chong Dan	29.55	6.14	34.71	85.23	Panomton	172.73	40.00	-33.33	154.55
Chong Sadao	-13.62	18.61	38.83	42.23	Phang Thu	50.00	-5.88	-66.67	-52.94
Chorakha Phuak	-17.56	37.04	-32.43	-23.66	Phong Tuk	50.00	-33.33	-50.00	-50.00
Dan Mae Chaleap	-1.36	20.27	19.71	42.03	Phran Than	100.00	-81.25	266.67	37.50
Dan Makham Tia	-24.05	46.67	-38.64	-31.65	Pilok	22.89	196.15	-62.54	36.32
Don Cha-Am	50.00	-50.00	500.00	350.00	Plang Pha	186.43	-14.47	13.95	179.15
Don Chadi	50.00	0.00	33.33	100.00	Rang Sali	15.38	-13.33	-42.31	-42.31
Don Khamin	-58.06	15.38	0.00	-51.61	Rang Wai	30.00	38.46	-22.22	40.00
Don Saleap	70.00	11.76	-15.79	60.00	Sa Long Rua	-80.95	75.00	14.29	-61.90
Hin Dat	82.46	-42.79	15.97	21.05	Sahakhon Nikom	73.42	20.44	-30.30	45.57
Huai Kha Yeng	-32.05	56.03	-40.91	-37.35	Sai Yok	-0.29	234.20	-70.25	-0.87
Khang Sian	-46.67	-54.17	0.00	-75.56	San To	-44.44	30.00	-69.23	-77.78
Khao Chop	-76.32	610.00	-22.85	29.74	Sanam Yhae	-75.00	-33.33	350.00	-25.00
Khao Noi	-7.41	-18.00	-48.78	-61.11	Sing	-41.80	-9.86	-15.63	-55.74
Khao Samsip Hap	26.09	0.00	-58.62	-47.83	Somdat Charaen	-47.45	-8.96	118.03	4.31
Kho Samrong	-7.84	-25.53	5.71	-27.45	Sri Mong Khon	-46.64	129.83	-49.18	-37.67
Kok Tha Bong	44.44	7.69	-85.71	-77.78	Tha Kanun	13.39	10.42	7.23	34.25
Kron Do	35.71	-15.79	-25.00	-14.29	Tha Kham-En	-27.66	-11.76	53.33	-2.13
Lai Wo	221.22	-60.88	53.25	92.58	Tha Kradan	-16.01	52.19	24.85	59.58
Lao Kwan	-9.09	30.00	-23.08	-9.09	Tha Lo	-28.00	-11.11	118.75	40.00
Lat Ya	-43.86	43.75	-47.83	-57.89	Tha Mai	-64.29	100.00	-70.00	-78.57

Table B1-1 (Continued)

Sub District	Area (rai)				Sub District	Area (rai)			
	1992-1996	1996-2001	2001-2006	1992 2006		1992-1996	1996-2001	2001-2006	1992 2006
Lin Tin	50.82	7.61	-18.69	31.97	Tha Maka	80.95	-76.32	133.33	0.00
Lum Rung	37.50	25.45	-55.07	-22.50	Tha Makham	-70.00	216.67	-47.37	-50.00
Lum Sum	-22.82	71.74	-49.11	-32.55	Tha Muang	-10.00	77.78	81.25	190.00
Mae Kra Bung	-12.68	33.87	-22.09	-8.92	Tha Rua	-20.00	75.00	-85.71	-80.00
Muang Chum	57.14	9.09	-8.33	57.14	Tha Sao	5.73	12.27	16.08	37.79
Na Sun	-47.80	72.96	0.59	-9.19	Tha Ta Khro	85.71	-30.77	22.22	57.14
Nng Bua	-19.67	-26.53	-22.22	-54.10	Thung Kra Pum	3.85	-40.74	37.50	-15.38
Nong Fai	74.81	-7.42	-42.92	-7.63	Thung Samo	100.00	0.00	-50.00	0.00
Nong Khao	-40.00	-53.33	185.71	-20.00	Thung Thong	66.67	0.00	280.00	533.33
Nong Krang	33.33	-37.50	-40.00	-50.00	Wai Nieo	-50.00	0.00	-50.00	-75.00
Nong Kum	16.67	15.18	-31.01	-7.29	Wang Dong	5.50	11.40	-48.54	-39.52
Nong Lan	-14.29	-41.67	-14.29	-57.14	Wang Kanai	-18.18	-44.44	640.00	236.36
Nong Lu	7.79	102.21	-42.77	24.75	Wang Kra Choe	-58.17	165.49	-8.09	2.06
Nong Pat	-65.82	114.81	27.59	-6.33	Wnag Phi	41.18	-4.17	-28.99	-3.92
Nong Pha Du	-40.91	65.38	-72.09	-72.73	Wang Sala	5.00	-42.86	233.33	100.00
Nong Phi	-25.00	-20.00	-50.00	-70.00	Wang Yan	36.67	-20.73	-49.23	-45.00
Nong Phu	-16.31	-14.41	84.16	31.91	Wong Kok Kaeo	64.71	91.07	-45.79	70.59
Nong Pling	-64.00	155.56	-19.57	-26.00	Wong Pla Lai	28.85	11.94	-32.00	-1.92
Nong Ri	60.48	-42.54	207.14	183.23	Yang Muang	125.00	-44.44	-60.00	-50.00

APPENDIX C

STATISTICAL DATA FROM THE REGRESSION ANALYSIS

Table C-1 Regression analysis for the 1992-1996 period

Model	R	R^2	Adjusted R^2	Standard Error of the Estimate
1	0.629[(a)]	0.396	0.379	44.16133
2	0.703[(b)]	0.494	0.464	41.02229
3	0.805[(c)]	0.649	0.617	34.68948
4	0.858[(d)]	0.736	0.703	30.55759

[(a)] Predictors: constant, electrical availability
[(b)] Predictors: constant, electrical availability, slope
[(c)] Predictors: constant, electrical availability, slope, population density
[(d)] Predictors: constant, electrical availability, slope, population density, crop price

Model	Independent variables	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta	B	Std. Error
1	constant	28.884	9.830		2.938	0.006
	electrical	0.077	0.016	0.629	4.792	0.000
2	constant	12.536	11.141		1.125	0.268
	electrical	0.088	0.016	0.721	5.671	0.000
	slope	1.298	0.507	0.326	2.562	0.015
3	constant	26.919	10.148		2.653	0.012
	electrical	0.092	0.013	0.756	7.005	0.000
	slope	1.779	0.447	0.446	3.984	0.000
	population	-0.334	0.088	-0.410	-3.814	0.001
4	constant	2.631	11.659		0.226	0.823
	electrical	0.092	0.012	0.752	7.914	0.000
	slope	2.119	0.407	0.532	5.204	0.000
	population	-0.278	0.079	-0.342	-3.520	0.001
	crop price	00.001	0.000	0.320	3.245	0.003

Note: Dependent variable - agricultural area

Table C-2 Regression analysis for the 1996-2001 period

Model	R	R^2	Adjusted R^2	Standard Error of the Estimate
1	0.983[(a)]	0.966	0.966	191.58637
2	0.985[(b)]	0.971	0.970	178.80987
3	0.987[(c)]	0.974	0.973	169.13114
4	0.988[(d)]	0.976	0.975	163.26662
5	0.989[(e)]	0.978	0.976	158.54866

[(a)] Predictors: constant, annual temperature
[(b)] Predictors: constant, annual temperature, slope
[(c)] Predictors: constant, annual temperature, slope, annual rainfall
[(d)] Predictors: constant, annual temperature, slope, annual rainfall, distance from road
[(e)] Predictors: constant, temperature, slope, rainfall, distance from road, small tractor

Model	Independent variables	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta	B	Std. Error
1	constant	17.354	19.982		.868	0.387
	annual temperature	344.731	6.779	0.983	50.852	0.000
2	constant	51.389	20.685		2.484	0.015
	annual temperature	347.037	6.356	0.989	54.600	0.000
	slope	-3.055	0.803	-0.069	-3.804	0.000
3	constant	59.362	19.705		3.013	0.003
	annual temperature	344.470	6.059	0.982	56.852	0.000
	slope	-2.697	0.767	-0.061	-3.517	0.001
	annual rainfall	0.092	0.027	0.059	3.405	0.001
4	constant	71.487	19.529		3.661	0.000
	annual temperature	344.921	5.851	0.983	58.948	0.000
	slope	-2.717	0.740	-0.061	-3.669	0.000
	annual rainfall	0.089	0.026	0.057	3.398	0.001
	distance from road	-0.008	0.003	-0.045	-2.740	0.007
5	constant	74.536	19.004		3.922	0.000
	annual temperature	345.030	5.682	0.984	60.720	0.000
	slope	-2.519	0.723	-0.057	-3.483	0.001
	annual rainfall	0.094	0.025	0.061	3.711	0.000
	distance from road	-0.008	0.003	-0.046	-2.879	0.005
	small tractor	-0.004	0.002	-0.041	-2.513	0.014

Note: Dependent variable - agricultural area

Table C-3 Regression analysis for the 2001-2006 period

Model	R	R^2	Adjusted R^2	Standard Error of the Estimate
1	0.990[(a)]	0.979	0.979	149.93142
2	0.991[(b)]	0.983	0.982	136.93766
3	0.992[(c)]	0.984	0.984	132.36385
4	0.992[(d)]	0.985	0.984	129.68499

[(a)] Predictors: constant, annual temperature
[(b)] Predictors: constant, annual temperature, annual rainfall
[(c)] Predictors: constant, annual temperature, annual rainfall, slope
[(d)] Predictors: constant, annual temperature, annual rainfall, slope, population density

Model	Independent variables	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta	B	Std. Error
1	constant	-113.045	15.972		-7.078	0.000
	annual temperature	354.497	5.419	0.990	65.421	0.000
2	constant	-46.023	21.169		-2.174	0.032
	annual temperature	358.395	5.029	1.000	71.268	0.000
	annual rainfall	-0.140	0.032	-0.061	-4.369	0.000
3	constant	-38.881	20.631		-1.885	0.063
	annual temperature	357.828	4.865	0.999	73.545	0.000
	annual rainfall	-0.115	0.032	-0.051	-3.575	0.001
	slope	-1.670	0.617	-0.038	-2.707	0.008
4	constant	-59.385	22.310		-2.662	0.009
	annual temperature	357.329	4.772	0.997	74.873	0.000
	annual rainfall	-0.113	0.032	-0.049	-3.567	0.001
	slope	-1.790	0.607	-0.040	-2.950	0.004
	population density	0.225	0.103	0.029	2.171	0.033

Note: Dependent variable - agricultural area

Table C-4 Regression analysis for the 1992-1996 period

Model	**R**	**R^2**	**Adjusted R^2**	**Standard Error of the Estimate**
1	0.987[(a)]	0.975	0.974	162.82870
2	0.991[(b)]	0.983	0.982	134.63535
3	0.993[(c)]	0.986	0.985	124.01342
4	0.994[(d)]	0.987	0.987	117.85815
5	0.994[(e)]	0.988	0.988	113.08444

[(a)] Predictors: constant, annual temperature
[(b)] Predictors: constant, annual temperature, distance from CBD
[(c)] Predictors: constant, annual temperature, distance from CBD, elevation
[(d)] Predictors: constant, annual temperature, distance from CBD, elevation, rainfall
[(e)] Predictors: constant, temp., distance from CBD, elevation, rainfall, land ownership

Model	Independent variables	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta	B	Std. Error
1	constant	-120.920	17.414		-6.944	0.000
	annual temperature	347.842	5.881	0.987	59.143	0.000
2	constant	65.706	31.865		2.062	0.042
	annual temperature	351.215	4.890	0.997	71.822	0.000
	distance from CBD	-0.003	0.000	-0.091	-6.565	0.000
3	constant	96.755	30.298		3.193	0.002
	annual temperature	351.252	4.504	0.997	77.982	0.000
	distance from CBD	-0.002	0.000	-0.066	-4.701	0.000
	elevation	-0.272	0.066	-0.058	-4.132	0.000
4	constant	112.494	29.199		3.853	0.000
	annual temperature	352.899	4.311	1.002	81.866	0.000
	distance from CBD	-0.002	0.000	-0.062	-4.622	0.000
	elevation	-0.215	0.065	-0.046	-3.294	0.001
	annual rainfall	-0.096	0.030	-0.042	-3.246	0.002
5	constant	89.509	29.094		3.077	0.003
	annual temperature	353.201	4.137	1.002	85.368	0.000
	distance from CBD	-0.002	0.000	-0.061	-4.723	0.000
	elevation	-0.223	0.063	-0.048	-3.570	0.001
	annual rainfall	-0.110	0.029	-0.048	-3.830	0.000
	land ownership	0.089	0.030	0.035	2.930	0.004

Note: Dependent variable - agricultural area

APPENDIX D

EXPLANTION OF REGRESSION

(1) "R^2" (or the coefficient of determination) is the proportion (or percent) of variance in the dependent variable that can be predicted (or explained) from the used independent variables of the regression method,

(2) "Adjusted R^2" is more corrected value of the correlation level (R^2) when the correlation by chance in the regression process was reduced.

(3) "Standard Error of the Estimate" is the standard deviation of error term in the regression representing by square root of the Mean Square Residual (or Error).

(4) The "t-statistic" is used to test the significance for each of the independent variables used in the regression model. The t-test evaluates the null hypothesis that the unstandardized regression coefficient for the chosen predictor is zero when all other predictors' coefficients are fixed to zero. For example, a significance value of 0.000 indicating that the null hypothesis mentioned earlier can be rejected.

(5) The standardized regression coefficients are the coefficient that would be obtained if the independent (predictors) and dependent variables were standardized prior to the analysis. Since all of predictors are standardized (or in z-score form), they are measured in the same units which are useful for comparing size of the coefficients across variables. Since the variables are measured in standard units, a one unit change corresponds to a one standard deviation change.

APPENDIX E

CHARACTERISTICS OF ENERGY ECONOMIC CROPS: SUGARCANE AND CASSAVA

Characteristics of Sugarcane Cultivation

According to FAO (1986), sugarcane was originated in Asia, probably in New Guinea. Most of the rainfed and irrigated commercial sugarcane is grown between 35° N and S of the equator. The crop flourishes under a long, warm growing season with a high incidence of radiation and adequate, followed by a day, sunny and fairly cool but frost-free ripening and harvesting period.

The duration of each different growth stage is displayed in Figure 2.7. It may slightly vary depending on crop types and the environment conditions. The principal growth stages of sugarcane can be seen in Table 2.3 (FAO, 1986; Kuyper, 1952). The optimum growth is achieved with mean daily temperatures between 22 and 30°C and the optimum temperature for sprouting of stem cutting is 32 to 38°C.

The crop's flowering is controlled by day length, but it is also influenced by water and nitrogen supply, Flowering has a progressive deleterious effect on sucrose content. Flowering, therefore, is normally prevented or non- flowering. Sugarcane does not require any special types of soil. The optimum soil pH is about 6.5, but it can be grown in soil with pH range 5 to 8.5. Sugarcane contains high nitrogen and potassium needs and relatively low phosphate requirement. In general, for a yield of

100 ton/ha cane, it needs 100-200 kg/ha N, 20-90 kg/ha P, and 125-160 kg/ha K, but the rates are sometimes higher (Department of Agriculture, 2002).

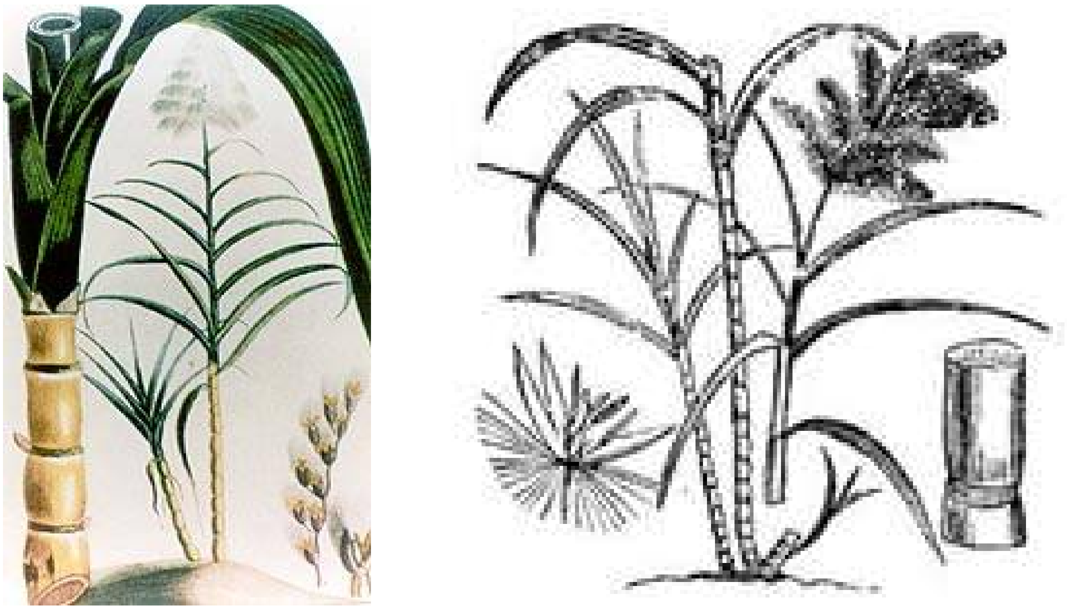


Figure E-1 Feature of sugarcane, (Nadem, 2009)

Development stage of sugarcane

Development stage	Days
Planting to 0.25 full canopy	30-60
0.25 to 0.50 full canopy	30-40
0.50 to 0.75 full canopy	15-25
0.75 to full canopy	45-55
Peak use	180-330
Early senescence	30-150
Ripening	30-60

Characteristics of Cassava Cultivation

Cassava is woody shrub of the Euphorbiaceae (spurge family) native to South America that is extensively cultivated as an annual crop in the tropical and subtropical regions where its edible starchy is major source of carbohydrates. Common names of cassava are manioc, sagu, yuca (Spanish), and tapioca. The scientific name is Manihot esculenta (see Figure 2.8 for its feature).

Cassava is the third largest source of the carbohydrates for human food in the world, with Africa as the largest center of production (Fauquet and Fargette, 1990). It originated in western and southern Mexico, part of Guatemala and the northeast of Brazil. It is evidence that it was grown 5,000 years ago in Columbia, 4000 years ago in Peru, and 2000 years ago in Mexico. It was brought to Africa by the Portuguese and was encouraged as a famine food and reserved during locust attacks. Cassava is the most important root crop of the lowland tropics.

Ecology and Agronomy

The crop normally contains 5 to 10 tuberous roots which are induced by short photoperiod. Its leaves are palmate and it is cross pollinated (Figure 2.8).

Figure E-2 Feature of Cassava (Kohler, 1987)

A lowland tropical crop cannot withstand cold or frost; however, it can stand prolonged drought and survive in shedding leaves. It can be grown on sandy, poor soils. Moreover, it is grown best as well with 150 inches of rainfall. Yield is sensitive to drought or available supply water. It requires short days to tuberize. The vegetative propagated are done by stem cuttings (8 inches long) and it is ready to be harvested at 10 to 18 months to produce 3 to 11 tons roots/acre. Tender leaves are edible and good for livestock feed. Cassava can be divided into two broad types: short season and long season. The first can mature in 6 months and could be harvested within 9–11 months while the second harvested at 3 to 4 years of age. The long season types tend to be the bitter cassava. The average global yield of cassava is about 10 ton/ha (or 4 ton/acre), and good commercial yield is about 30–50 ton/acre, but the potential yield might be about 40 to 90 ton/acre possible.

APPENDIX F

LAND EVALUATION

Concept of Land Evaluation

Land evaluation is defined by International Land Development Consultants (1981) as the term used to describe the process of collating and interpreting basic inventories of soil, vegetation, climate and other aspects of land in order to identify and compare land use alternatives. Then, land evaluation and socio-economic analysis provide the foundation for land use planning. They may refer to present conditions of the land; land potentials that will materialize as a result of the implementation of land improvement measures, or involve a comparison of both situations.

Typically, decision to make use of land depends on various factors since land varies greatly within itself. The most important one is soil quality but it also includes other physical environment elements which can influence the nature and usefulness of land also e.g. water, vegetation and climate. Broadly speaking, the land evaluation is a technique to access various land suitability for the selected alternative land use types including physical, social, economic, and environmental aspects which are associated with the change in land use. The assessment of land evaluation is based on a matching of qualities of the different land units in specific areas with the requirements of actual or potential interesting land use types, e.g. for growing some specific crops.

APPENDIX G

LAND SUITABILITY CLASSIFICATION

Land suitability classification generally refers to the fitness of a given type of land for a defined use either in present condition or after improvement. It is a process of appraisal and grouping of specific type of land in terms of their absolute or relative suitability for a specified kind of use (FAO, 1976). For suitability assessment, firstly specific requirement of the crop needs to be known or alternatively what soil and site attributes adversely influence the crop. Secondly, the land is identified and delineated which has the desirable attributes but without the undesirable ones. However, it seems impossible to include all physical and socio-economic needs for a comprehensive land evaluation purpose.

There are two main types of suitability classification recognized according to FAO Framework (1976): qualitative and quantitative type. Qualitative classifications are general appraisal that represents the relative suitability in qualitative terms only based on the physical properties of land. There are 25 factors proposed by the FAO Framework (1976) to be included in the land evaluation process but in Thailand, only 13 of them are considered which are radiation regime, temperature regime, moisture availability, nutrient availability, nutrient retention capacity, rooting conditions, flood hazard, excess of salts, soil toxicities, soil workability, potential for mechanization, and erosion hazard (Srifuk and Tunsiri, 1996).

However, in this thesis, only 7 critical factors are being considered including oxygen available (soil drainage), nutrient retention (nitrogen, phosphorus, potassium, pH), root available (C.E.C., B.S.), water retention (texture), erosion hazard (slope), temperature regime (temperature), and moisture availability (rainfall). The suitability criteria for both crops studied here are shown in Tables 2.4 and 2.5 respectively.

Table G-1 Land quality requirement of sugarcane

Crop Requirement			Factor Suitability Rating			
Land quality	**Diagnostic factor**	**Unit**	**High (S1)**	**Moderate (S2)**	**Marginal (S3)**	**Not suit (N)**
Temperature (t)	Mean temp. in growing period	° C	24-27	28-31, 19-23	32-35, 18-15	>35,< 15
Moisture Availability (m)	Ann. rainfall	mm.	1600-2500	1200-1600 2500-3000	900-1200 3000-4000	<900 >4000
Oxygen Availability (O)	Soil drainage	class	5,6	3,4	2	1
Nutrient Availability(s)	N (total)	%	>0.2	0.2-0.1	<0.1	
	P	ppm	>25	6-25	<6	
	K	ppm	>60	30-60	<30	
	Organic matter	%	2.5	1.5-2.5	<1.5	
	Nutrient status	Class	VH,H,M	L	VL	
	Reaction	pH	5.6-7.3	7.4-7.8 4.5-5.5	7.9-8.4 4.0-4.5	>8.4 <4
Nutrient Retention (n)	C.E.C.	Meq/100g	>15	5-15	<5	
	B.S.	%	>75	35-75	<35	
Rooting Condition (r)	Effective soil depth	cm.	>100	50-100	25-50	<25
	Water table depth	cm.	>160	50-100	25-50	<25
	Root penetration	class	<25, 25-50	50-100	100-150	
Flood Hazard (f)	Frequency	Yrs./time	10 yrs/1	6-9yrs/1	3-5 yrs/1	1-2 yrs/1
Excess of salts (s)	EC. Of saturation	mmho/cm.	<2.5	2.5-9	9-11	>11
Soil Toxicities (z)	Depth of jarosite	cm.	>100	50-100	<50	
Soil Workability (k)	Workability class	class	1,2	3	4	
Potential for mechanization (w)	Slope	class	0-2%, 2-5%,5-12%	12-20 %	20-35 %	>35%
	Rock out crop	class	1	2	3	4
	Stoniness	class	1	2	3	4
Erosion Hazard (e)	Slope	class	0-2%, 2-5%,	5-12%	12-20 %	>20%
	Soil loss	Ton/rai/yrs	<2	2-4	4-12	>12

Source: Tunsiri and Srifuk (1996)

Table G-2 Land quality requirement of cassava

Crop Requirement			Factor Suitability Rating			
Land quality	**Diagnostic factor**	**Unit**	**High (S1)**	**Moderate (S2)**	**Marginal (S3)**	**Not suit (N)**
Temperature (t)	Mean temp. in growing period	° C	25-29	30-32, 24-14	33-35, 13-10	>35,<10
Moisture Availability (m)	Ann. rainfall	mm.	1200-1500	1500-2500 900-1200	2500-4000 500-900	>4000 <500
Oxygen Availability (O)	Soil drainage	class	5,6	4	-	1,2,3
Nutrient Availability(s)	N (total)	%	>0.1	<0.1		
	P	ppm	>10	<10		
	K	ppm	>30	<30		
	Organic matter	%	>1	<1		
	Nutrient status	Class	VH,H,M	L , VL		
	Reaction	pH	6.1-7.3	7.4-7.8 5.1-6.0	7.9-8.4 4.0-5.0	>8.4 <4.0
Nutrient Retention (n)	C.E.C.	Meq/100g	>10	<10		
	B.S.	%	>35	<35		
Rooting Condition (r)	Effective soil depth	cm.	>100	50-100	25-50	<25
	Water table depth	cm.	>160	50-100	25-50	<25
	Root penetration	class	<25	25-50	50-100	100-150
Flood Hazard (f)	Frequency	Yrs./time	10 yrs/1	6-9yrs/1	3-5 yrs/1	1-2 yrs/1
Excess of salts (s)	EC. Of saturation	mmho/cm.	<2	2-4	4-8	>8
Soil Toxicities (z)	Depth of jarosite	cm.	>100			
Soil Workability (k)	Workability class	class	1	2	3	4
Potential for mechanization (w)	Slope	class	0-2%, 2-5%,5-12%	12-20 %	20-35 %	>35%
	Rock out crop	class	1	2	3	4
	Stoniness	class	1	2	3	4
Erosion Hazard (e)	Slope	class	0-2%, 2-5%,	5-12%	12-20 %	>20%
	Soil loss	Ton/rai/yrs	<2	2-4	4-12	>12

Source: Tunsiri and Srifuk (1996)

APPENDIX H

LIST OF ASSOCIATED EXPERTS FOR LAND SUITABILITY ANALYSIS

Table H-1 List for sugarcane analysis

ชื่อ-สกุล	ตำแหน่ง	สถานที่ปฏิบัติงาน
1. รศ.ดร. ชาลี นาวานุเคราะห์	อาจารย์ระดับ 9	คณะสิ่งแวดล้อมและการจัดการทรัพยากรธรรมชาติ ม.มหิดล
2. อ.ดร.จรัณธร บุญญานุภาพ	อาจารย์ระดับ 6	คณะเกษตรศาสตร์ ทรัพยากรธรรมชาติและสิ่งแวดล้อม ม.นเรศวร
3. นายภูมิ ยั่งยืนยง	ผอ.สน.เกษตรจังหวัดกาญจนบุรี (8ว.)	สำนักงานเกษตรจังหวัดกาญจนบุรี
4. นายสมเจตน์ สวัสดิ์มงคล	นักวิชาการส่งเสริมการเกษตร (7ว.)	
5. นายมนตรี เชื้อใจ	นักวิชาการส่งเสริมการเกษตร (7ว.)	
6. นายคำรณ ไทรฟัก	ผู้เชี่ยวชาญด้านการวางแผนการที่ดิน (8ว.)	สำนักผู้เชี่ยวชาญ กรมพัฒนาที่ดิน
7. นายวุฒิชาติ สิริช่วยชู	ผู้เชี่ยวชาญด้านการสำรวจและจำแนกที่ดิน (8ว.)	
8. นายไพฑูรย์ คดีธรรม	ผอ.สำนักบริหารและพัฒนาการใช้ที่ดิน	กรมพัฒนาที่ดิน
9. นายสมศักดิ์ ปีติธีรภาพ	นักวิชาการเกษตร (8ว.)	ส่วนจัดการพื้นที่ทิ้งร้าง สำนักบริหารและพัฒนาการใช้ที่ดิน กรมพัฒนาที่ดิน
10. นางสาวพิมพ์พร พรหมมินทร์	นักวิชาการเกษตร (6ว.)	ส่วนวางแผนการใช้ที่ดิน 1 สำนักสำรวจดินและวางแผนการใช้ที่ดิน
11. นางกุลวดี สุทธาวาส	นักสำรวจดิน (8ว.)	สำนักงานพัฒนาที่ดินเขต 10 กลุ่มวางแผนการใช้ที่ดิน กรมพัฒนาที่ดิน
12. นายไพฑูรย์ พุทธาศรี	เจ้าหน้าที่บริหารงานเกษตร (8ว.)	สถานีพัฒนาที่ดินกาญจนบุรี สำนักงานพัฒนาที่ดินเขต 10
13. นายชนะ กะรีรัตน์	ผอ. สำนักพัฒนาวัตถุดิบ (8ว.)	สำนักพัฒนาวัตถุดิบ สำนักงานคณะกรรมการอ้อยและน้ำตาลทราย
14. นายรณยุทธ์ สัตยานิคม	นักวิทยาศาสตร์ (7ว.)	ศูนย์ส่งเสริมอุตสาหกรรมอ้อยและน้ำตาลทรายเขต 1
15. นายจิรวัฒน์ เทอดพิทักษ์พงษ์	นักวิทยาศาสตร์ (7ว.)	สถานีทดลองและขยายพันธุ์อ้อยพิจิตร
16. นายวัฒนะ วัฒนานนท์	ผู้เชี่ยวชาญเฉพาะด้านพืชไร่ (9ว.)	สำนักผู้เชี่ยวชาญ กรมวิชาการเกษตร
17. นายประพันธ์ ประเสริฐศักดิ์	นักวิชาการเกษตร (7ว.)	สถาบันวิจัยพืชไร่ กรมวิชาการเกษตร
18. ดร. ธงชัย ตั้งเปรมศรี	นักวิชาการเกษตร (8ว.)	ศูนย์วิจัยพืชไร่สุพรรณบุรี สน.วิจัย
19. ดร.วันทนา ตั้งเปรมศรี	นักวิชาการเกษตร (8ว.)	และพัฒนาการเกษตรเขตที่ 5
20. รศ.ดร.จุฑารัตน์ อรรถจารุสิทธิ์	อาจารย์ สาขาวิชาเทคโนโลยีการผลิตพืช	สำนักวิชาเทคโนโลยีการเกษตร มหาวิทยาลัยเทคโนโลยีสุรนารี

Table H-2 List for cassava analysis

ชื่อ-สกุล	ตำแหน่ง	สถานที่ปฏิบัติงาน
1. รศ.ดร. ชาลี นาวานุเคราะห์	อาจารย์ระดับ 9	คณะสิ่งแวดล้อมและการจัดการทรัพยากรธรรมชาติ ม.มหิดล
2. อ.ดร.จรัณธร บุญญานุภาพ	อาจารย์ระดับ 6	คณะเกษตรศาสตร์ ทรัพยากรธรรมชาติและสิ่งแวดล้อม ม.นเรศวร
3. ผศ.ดร.เรณู ขำเลิศ	อาจารย์ สาขาวิชาเทคโนโลยีผลิตพืช	สำนักวิชาเทคโนโลยีการเกษตร
4. ดร.อัศจรรย์ สุขธำรง	อาจารย์พิเศษ สาขาวิชาเทคโนโลยีผลิตพืช	มหาวิทยาลัยเทคโนโลยีสุรนารี
5. ผศ.ดร.สมชาติ อู่อ้น	อาจารย์ ภาควิชาภูมิศาสตร์	คณะอักษรศาสตร์ ม.ศิลปากร
6. อ.ดร.สุวิทย์ อ๋องสมหวัง	อาจารย์ สาขาวิชาการรับรู้จากระยะไกล	สำนักวิชาวิทยาศาสตร์ ม.เทคโนโลยีสุรนารี
7. นายกิตตินันท์ วรอนุวัฒนกุล	นักสำรวจดิน (7ว.)	ส่วนวางแผนการใช้ที่ดินสำนักสำรวจดินและวางแผนการใช้ที่ดิน กรมพัฒนาที่ดิน
8. นายดนัย ศุภาหาร	นักวิชาการเกษตร (8ว.)	ศูนย์วิจัยพืชไร่ระยอง สำนักวิจัยและ
9. ดร.อัจฉรา ลิ่มศิลา	นักวิชาการเกษตร (8ว.)	พัฒนาการเกษตร เขตที่ 6 กรมวิชาการ
10. ดร.โอภาษ บุญเส็ง	นักวิชาการเกษตร (8ว.)	เกษตร
11. นายไพฑูรย์ พุทธาศรี	เจ้าหน้าที่บริหารงานเกษตร (8ว.)	สถานีพัฒนาที่ดินกาญจนบุรี สำนักงานพัฒนาที่ดินเขต 10
12. นายคำรณ ไทรฟัก	ผู้เชี่ยวชาญด้านการวางแผนการที่ดิน (8ว.)	สำนักผู้เชี่ยวชาญ กรมพัฒนาที่ดิน
13. นายวุฒิชาติ สิริช่วยชู	ผู้เชี่ยวชาญด้านการสำรวจและจำแนกที่ดิน (8ว.)	
14. นายไพฑูรย์ คดีธรรม	ผอ.สำนักบริหารและพัฒนาการใช้ที่ดิน	กรมพัฒนาที่ดิน
15. นายสมศักดิ์ ทองศรี	นักวิชาการเกษตร (8ว.)	กลุ่มวิชาการเกษตร สถาบันวิจัยพืชไร่ กรมวิชาการเกษตร
16. นางกุลวดี สุทธาวาส	นักสำรวจดิน (8ว.)	สำนักงานพัฒนาที่ดินเขต 10 กลุ่มวางแผนการใช้ที่ดิน กรมพัฒนาที่ดิน
17. นายวัฒนะ วัฒนานนท์	ผู้เชี่ยวชาญเฉพาะด้านพืชไร่ (9ว.)	สำนักผู้เชี่ยวชาญ กรมวิชาการเกษตร
18. นายมนตรี เชื้อใจ	นักวิชาการส่งเสริมการเกษตร (7ว.)	สำนักงานเกษตรจังหวัดกาญจนบุรี
19. นายไกวัล กล้าแข็ง	นักวิชาการเกษตร (7ว.)	กลุ่มพืชเส้นใยและพืชหัว ส่วนส่งเสริม
20. นางวิลาวัลย์ วงษ์เกษม	นักวิชาการเกษตร (7ว.)	การผลิตพืชไร่ สำนักส่งเสริมและจัดการสินค้าเกษตร กรมส่งเสริมการเกษตร

APPENDIX I

SOIL SUITABILITY CLASSIFICATION

Table I-1 Classification criteria in soil suitability for sugarcane

Crop Requirement			Factor Suitability Rating			
Land quality	**Diagnostic factor**	**Unit**	**High (S1:1.0)**	**Moderate (S2: 0.8)**	**Marginal (S3: 0.5)**	**Not suit (N: 0.2)**
Oxygen availability	Soil drainage	Class	well, excessively	moderately well	-	Very poorly, poorly, Somewhat poorly
Nutrient availability	Nitrogen (N)	%N	>0.1	<0.1		
Index	Phosphorus(P)	ppm	>10	<10		
(NAI=NxPxK)	Potassium(K)	ppm	>30	<30		
	pH	pH	6.1-7.3	7.4-7.8	7.9-8.4	>8.4
				5.1-6.0	4.0-5.0	<4.0
Nutrient retention capacity	C.E.C	Meg/100 gm soil	>10	<10		
	B.S.	% BS	>35	<35		
Water retention	Soil texture	-	L,Si,SiL, SCL,CL	SiCL,SL, LS	SiC,S	C,G,SC, AC

Source: Land Development Department (LDD), 1996

Table I-2 Classification criteria in soil suitability for cassava

Crop Requirement			Factor Suitability Rating			
Land quality	**Diagnostic factor**	**Unit**	**High (S1:1.0)**	**Moderate (S2: 0.8)**	**Marginal (S3: 0.5)**	**Not suit (N: 0.2)**
Oxygen availability	Soil drainage	Class	well, excessively	Somewhat poorly, moderately well	poorly	Very poorly
Nutrient availability	Nitrogen (N)	%N	>0.2	0.2-0.1	<0.1	
Index	Phosphorus	ppm	>25	6-25	<6	
(NAI=NxPxK)	(P)	ppm	>60	30-60	<30	
	Potassium(K)	pH	5.6-7.3	7.4-7.8	7.9-8.4	>8.4
	pH			4.5-5.5	4.0-4.5	<4
Nutrient retention capacity	C.E.C	Meg/100 gm soil	>15	5-15	<5	
	B.S.	% BS	>75	35-75	<35	
Water retention	Soil texture	-	L,scl,Si, SiL,CL,Sl	LS	SiC	S,G,SC,C, AC

Source: Land Development Department (LDD), 1996

Table I-3 List of classified soil series in Kanchnaburi Province

Soil series	Great Soil Group Classification	Area		Soil series	Great Soil Group Classification	Area	
		km²	%			km²	%
Wang Chomphu	Chromusterts	18.03	0.29	Takhli	Haplustolls	203.43	3.24
Hup Kapong	Dystropepts	312.74	4.98	Chumsaeng	Tropaquepts	119.02	1.90
Yang Talat				Saraburi			
Chatturat				Lat Ya			
Hin Son				Phon Ngam			
Kamphaeng Saen	Haplustalfs	319.00	5.08	Phu Sana	Haplustults	365.48	5.82
Li				Sakon			
Muak Lek				Tha Yang			
Pranburi							
Wang Saphung							
Chiang Rai				Dong Yang En			
Manorom				Loei			
Nakhon Pathom series	Paleaquults	302.30	4.81	Sikhiu	Paleustalfs	1974.99	31.45
Pak Tho series				Thap Khwang			
Renu series				Wang Hai			
Roi Et series							
Ban Chong				Lop Buri	Pellusterts	13.42	0.21
Chiang Khan				Phon Phisai	Plinthustults	14.21	0.23
Dan Sai				Nam Phong	Quartzipsamments	394.09	6.27
Hang Chat Kabin Buri				Doembang Lampang	Tropaqualfs	159.19	2.53
Korat				Nakhon Phanom			
Mae Rim	Paleustults	1930.95	30.74	Chumsaeng	Tropaquepts	119.02	1.90
Mae Taen				Saraburi			
Pak Chong				Tha Muang	Ustifluvents	15.84	0.25
San Pa Tong				Chuntuk	Ustipsamments	137.99	2.20
Satuk Sung Noen							
Warin							
Yasothon							

Total area = 6,280.70 km^2

Source: Adapted from Soil Survey Laboratory (1994), and Kheoruenromne (2006)

APPENDIX J

DISTRIBUTED QUESTIONAIRE TO CONTACTS EXPERTS

ตัวอย่างแบบสอบถามผู้เชี่ยวชาญพืชพลังงาน
แบบสอบถามผู้เชี่ยวชาญเรื่อง
การประยุกต์เทคโนโลยีภูมิสารสนเทศในการประเมินคุณภาพที่ดินสำหรับพืชเศรษฐกิจที่ให้พลังงานในภาคตะวันตกของประเทศไทย

เรียน ท่านผู้ตอบแบบสอบถาม

เนื่องจากข้าพเจ้า นางสาวกัลยา เทียนวงศ์ นักศึกษาระดับปริญญาเอก สาขาการรับรู้จากระยะไกล สำนักวิชาวิทยาศาสตร์ มหาวิทยาลัยเทคโนโลยีสุรนารี กำลังทำวิทยานิพนธ์เรื่อง การประยุกต์เทคโนโลยีภูมิสารสนเทศในการประเมินคุณภาพที่ดินสำหรับพืชเศรษฐกิจที่ให้พลังงานในภาคตะวันตก ซึ่งจากแบบสอบถามนี้มีวัตถุประสงค์เพื่อต้องการหาพื้นที่ที่มีความเหมาะสมกับการปลูกอ้อยและมันสำปะหลังในจังหวัดกาญจนบุรีเพื่อจะส่งเสริมการปลูกให้สนับสนุนกับการเป็นแหล่งวัตถุดิบให้กับโรงงานผลิตเอทานอลและอุตสาหกรรมอื่น ๆ ที่เกี่ยวข้อง โดยใช้เทคโนโลยีทางด้านภูมิสารสนเทศ (Geoinformatics)

ในการศึกษาครั้งนี้มีความจำเป็นที่ต้องให้ผู้เชี่ยวชาญและผู้มีประสบการณ์ด้านสาขาเกษตรเป็นผู้ให้ค่าน้ำหนัก (Weight) ของคะแนนความสำคัญ และค่าคะแนนระดับ(Rating) ความเหมาะสมของช่วงของปัจจัยที่เกี่ยวข้องกับการปลูกพืชเศรษฐกิจ (อ้อย, มันสำปะหลัง) ในพื้นที่ของจังหวัดกาญจนบุรี เพื่อให้ผลลัพธ์ของการวิเคราะห์ข้อมูลมีความถูกต้องตามหลักวิชาการ ข้าพเจ้าจึงขอความอนุเคราะห์จากท่านเป็นผู้เชี่ยวชาญตอบแบบสอบถามให้ค่าน้ำหนักและค่าระดับกับปัจจัยที่กำหนดให้ในครั้งนี้ด้วย

จึงเรียนมาเพื่อขอความอนุเคราะห์ในการตอบแบบสอบถามดังกล่าว เพื่อประโยชน์ในการศึกษาวิจัยครั้งนี้ด้วย จักเป็นพระคุณยิ่ง

ขอขอบพระคุณอย่างสูง
กัลยา เทียนวงศ์
ผู้ศึกษาวิจัย

แบบสอบถามชุดที่ 1 (พื้นที่ที่เหมาะสมกับการปลูกอ้อย)

การให้ค่าน้ำหนักสำหรับผู้เชี่ยวชาญในแต่ละสาขาที่เกี่ยวข้องเพื่อประกอบการศึกษาวิจัย

เรื่อง

การประยุกต์เทคโนโลยีภูมิสารสนเทศในการประเมินคุณภาพที่ดินสำหรับพืชเศรษฐกิจที่ให้พลังงานในภาคตะวันตกของประเทศไทย

จัดทำโดย

นางสาวกัลยา เทียนวงศ์

สาขาวิชาการรับรู้จากระยะไกล
สำนักวิชาวิทยาศาสตร์ มหาวิทยาลัยเทคโนโลยีสุรนารี

ข้อมูลผู้ตอบแบบสอบถาม

ชื่อ-นามสกุล.. ตำแหน่ง ....ระดับ ....

สถานที่ปฏิบัติงาน ....

คำชี้แจง แบบสอบถามชุดนี้มีความต้องการข้อมูลทั้งค่าคะแนนความสำคัญของค่าน้ำหนัก (Weighting Score) และค่าคะแนน (Rating score) ความเหมาะสมของช่วงของปัจจัย ที่จะนำไปในการวิเคราะห์โดยใช้เทคนิคกระบวนการลำดับชั้นเชิงวิเคราะห์ Analytical Hierarchical Process (AHP) เป็นหนึ่งในวิธีการตัดสินใจแบบหลายเกณฑ์ (Multi-Criteria Decision Method) ได้นำมาประยุกต์กับการหาพื้นที่ที่เหมาะสมกับการปลูกพืชเศรษฐกิจที่ให้พลังงาน (อ้อย) ในจังหวัดกาญจนบุรี โดยในการตอบแบบสอบถามนี้ผู้เชี่ยวชาญจะต้องให้ความสำคัญของปัจจัยแต่ละตัวที่ใช้พิจารณาโดยเปรียบเทียบความสำคัญของปัจจัยแต่ละตัวเป็นคู่ๆ ไป จนครบทุกปัจจัย

ในแบบสอบถามชุดนี้ประกอบไปด้วย 4 ตอนด้วยกัน คือ

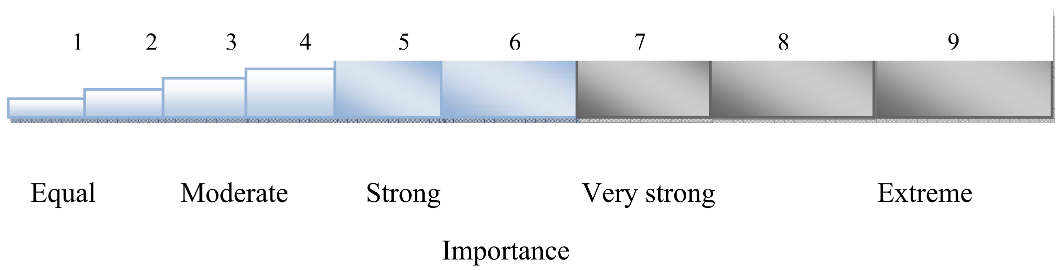
1. การให้ค่าน้ำหนัก (Weighting Score) ของกลุ่มปัจจัยหลักที่มีผลกับการหาพื้นที่ที่เหมาะสมกับการปลูกอ้อยจำนวน 4 กลุ่มประกอบด้วย ปัจจัยด้านชีวกายภาพ (Biophysical): (ภูมิประเทศ, ภูมิอากาศ, ศักยภาพของที่ดินตามความเหมาะสมของ FAO, ระยะห่างจากแหล่งน้ำ) กับปัจจัยด้านเศรษฐสังคม (Socio-economic)

2. การให้ค่าน้ำหนัก (Weighting Score) ของปัจจัยในกลุ่มปัจจัยหลักที่มีผลกับการหาพื้นที่ที่เหมาะสมกับการปลูกอ้อย ประกอบด้วย ปัจจัยด้าน**ชีวกายภาพ: ปัจจัยด้านภูมิประเทศ** (ความลาดชัน, ความสูงของพื้นที่), **ปัจจัยด้านภูมิอากาศ** (อุณหภูมิ, ปริมาณน้ำฝนเฉลี่ยรายปี), **ปัจจัยด้านศักยภาพของที่ดินตามความเหมาะสมของ FAO** (ความเป็นประโยชน์ของออกซิเจนต่อรากพืช, ความเป็นประโยชน์ของธาตุอาหาร, ความจุในการดูดยึดธาตุอาหาร,ความจุในการอุ้มน้ำ, การหยั่งลึกของราก), **ปัจจัยด้านระยะห่างจากแหล่งน้ำ** (ระยะห่างจากเส้นทางน้ำ, แหล่งน้ำผิวดิน,เขตชลประทาน) และ**ปัจจัยด้านเศรษฐสังคม** (ระยะห่างจากถนน, โรงงานน้ำตาล, แหล่งรับซื้อผลผลิตทางการเกษตร)

3. การให้ค่าน้ำหนัก (Weighting Score) ของปัจจัยย่อยในข้อที่ 2 ซึ่งเป็นปัจจัยที่ใช้ในการวินิจฉัยคุณภาพดินที่มีผลกับการหาพื้นที่ที่เหมาะสมกับการปลูกอ้อยโดยยึดตามหลักของ FAO และจากการทบทวนงานวิจัยที่เกี่ยวข้อง

4. การให้ค่าคะแนน (Rating Score) ความเหมาะสมของปัจจัยที่ใช้วินิจฉัยความเหมาะสมของพื้นที่สำหรับปลูกอ้อย

ค่าคะแนนที่ผู้เชี่ยวชาญต้องพิจารณาค่าน้ำหนักและค่าคะแนนของความสำคัญ ตั้งแต่ 1 – 9 ดังนี้



ตัวอย่างการตอบแบบสอบถาม

จากแบบสอบถามที่แสดงไว้เป็นตัวอย่างนี้ ผู้ตอบแบบสอบถามจะต้องพิจารณาให้ค่า

ค่าความสำคัญ	ความหมาย	คำอธิบาย
1	มีความสำคัญเท่ากัน (Equal Importance)	ปัจจัยทั้งสองที่กำลังพิจารณาเปรียบเทียบมีความสำคัญเท่าเทียมกัน (Two activities contribute equally to the objective)
3	มีความสำคัญมากกว่าพอประมาณ (Moderate Importance)	ปัจจัยที่กำลังพิจารณาเปรียบเทียบ มีความสำคัญมากกว่าปัจจัยตัวหนึ่งพอประมาณ (Experience and judgements slightly favour one activity over another)
5	มีความสำคัญมากกว่าอย่างเด่นชัด (Strong Importance)	ปัจจัยที่กำลังพิจารณาเปรียบเทียบมีความสำคัญมากกว่าปัจจัยอีกตัวหนึ่งอย่างเด่นชัด (Experience and judgements strongly favour one activity over another)
7	มีความสำคัญมากกว่าอย่างเด่นชัดมาก (Very strong or demonstrated importance)	ปัจจัยที่กำลังพิจารณาเปรียบเทียบ มีความสำคัญมากกว่าปัจจัยอีกตัวหนึ่งอย่างเด่นชัดมาก (An activity is favoured very strongly over another and dominance is demonstrated in practice)
9	มีความสำคัญมากกว่าอย่างยิ่ง (Extreme Importance)	ค่าความสำคัญสูงสุดที่จะเป็นไปได้ ในการพิจารณาเปรียบเทียบปัจจัยทั้งสอง (The evidence favouring one activity over another is of the highest possible order of affirmation)
2, 4, 6, 8	เป็นค่าความสำคัญระหว่างกลางของค่าที่กล่าวไว้ข้างต้น	ค่าความสำคัญในการเปรียบเทียบปัจจัย ถูกพิจารณาว่าควรเป็นค่าระหว่างกลางของค่าที่กล่าวไว้ข้างต้น

ความสำคัญของปัจจัยเมื่อเปรียบเทียบกับปัจจัยตัวอื่นในแต่ละแถวของตาราง ตัวอย่างเช่น การพิจารณาให้ค่าความสำคัญของปัจจัยในแถวแรกของตาราง ท่านจะต้องพิจารณาดูว่าปัจจัย A1 มีความสำคัญมากกว่าปัจจัย A2 มากน้อยเพียงใด

ถ้าท่านคิดว่าปัจจัย A1 มีความสำคัญมากกว่าปัจจัย A2 อย่างเด่นชัดมาก ท่านก็ให้ค่าความสำคัญเป็น 7 ในคอลัมน์ของช่อง มากกว่า ในตารางแบบสอบถามหรือ

ถ้าท่านคิดว่าปัจจัย A1 มีความสำคัญน้อยกว่าปัจจัย A3 อย่างพอประมาณ ท่านก็ให้ค่าความสำคัญเป็น 3 ในคอลัมน์ของช่อง น้อยกว่า ในตารางแบบสอบถาม

ถ้าท่านคิดว่าปัจจัย A2 มีความสำคัญน้อยกว่าปัจจัย A3 อย่างยิ่ง ท่านก็ให้ค่าความสำคัญเป็น 9 ในคอลัมน์ของช่องน้อยกว่า ในตารางแบบสอบถาม

ปัจจัย	การเปรียบเทียบค่าคะแนนมาตรฐานปัจจัย																	ปัจจัย
	มากกว่า								เท่ากัน	น้อยกว่า								
A1	9	8	⑦	6	5	4	3	2	1	2	3	4	5	6	7	8	9	A2
A1	9	8	7	6	5	4	3	2	1	2	③	4	5	6	7	8	9	A3
A2	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	⑨	A3

คำอธิบายปัจจัยสำหรับพิจารณาการให้ค่าน้ำหนัก (Weighting Score) และค่าคะแนน (Rating)

ปัจจัย	คำอธิบาย
1. ปัจจัยด้านชีวกายภาพ (Biophysical) **1.1 ปัจจัยด้านภูมิประเทศ** (Topography)	**1. ความลาดชัน (Slope)** ความลาดชันเป็นปัจจัยที่แสดงถึงความต่างระดับ ความซับซ้อนของพื้นที่และทิศด้านลาดซึ่งมีผลต่อการเลือกพื้นที่ในการปลูกพืช โดยระบุเป็นเปอร์เซ็นต์ ของความลาดชันที่มีความสัมพันธ์กับระดับความเหมาะสมเพื่อการปลูกอ้อย
	2. ความสูงพื้นที่ (Elevation) ความสูงของพื้นที่ วัดจากระดับทะเลปานกลาง จะมีความสัมพันธ์กับสภาพภูมิอากาศ เช่น ปริมาณน้ำฝน และอุณหภูมิเป็นต้น
1.2 ปัจจัยด้านภูมิอากาศ (Climate)	**1. ปริมาณน้ำฝนเฉลี่ยรายปี (Mean Annual Rainfall)** ซึ่งมีความสัมพันธ์กับความถี่ของการกระจายของฝน ทำให้สามารถประมาณการณ์ของปริมาณน้ำฝนที่จะเพียงพอกับการปลูกพืชในช่วงการเพาะปลูก รวมทั้งประเมินโอกาสของความเสี่ยงที่จะเกิดความแห้งแล้งในพื้นที่ได้
	2. อุณหภูมิเฉลี่ยรายปี (Mean Annual Temperature) ซึ่งจะมีผลต่อพืชในช่วงของการเจริญ โดยเฉพาะมีอิทธิพลต่อการงอก การออกดอก และมีส่วนสัมพันธ์กับขบวนการสังเคราะห์แสงที่จะส่งผลกระทบต่อการเจริญ เติบโตของพืช
1.3 ศักยภาพของที่ดินตามความเหมาะสมของระบบFAO(Soil Potential of FAO Framework)	เป็นเกณฑ์ที่ FAO ได้กำหนดชั้นความเหมาะสมของคุณภาพที่ดิน (Land Quality) ที่ใช้การประเมินคุณสมบัติของที่ดินที่จะมีผลต่อการเจริญเติบโตและผลผลิตของพืช ในการนี้ได้พิจารณากลุ่มคุณลักษณะที่ดินที่มีข้อจำกัดรุนแรงที่สุดตามที่ FAO Framework กำหนด ซึ่งมีปัจจัยที่ใช้ในการศึกษาคือ ความเป็นประโยชน์ต่อรากพืช (การระบายน้ำ) ความเป็นประโยชน์ของธาตุอาหาร (N,P,K,pH) ความจุในการดูดยึดธาตุอาหาร (ความจุในการแลกเปลี่ยนประจุบวก, การอิ่มตัวด้วยค่าด่าง) ความจุในการอุ้มน้ำ (เนื้อดิน) สภาวะการหยั่งลึกของราก ซึ่งได้จำแนกระดับความเหมาะสมของดิน ออกเป็น 4 ชั้นความเหมาะสม ดังนี้ คือ S_1 หมายถึง ชั้นที่ดินมีความเหมาะสม (Highly Suitable) S_2 หมายถึง ชั้นที่ดินมีความเหมาะสมปานกลาง (Moderately Suitable) S_3 หมายถึง ชั้นที่ดินมีความเหมาะสมเล็กน้อย (Marginal Suitable) N หมายถึง ชั้นที่ดินไม่มีความเหมาะสม (Not Suitable)
1.4 ระยะห่างจากแหล่งน้ำสนับสนุน (Water Supply)	**(1)เส้นทางน้ำ** (Stream Network) คือเส้นลำน้ำผิวดินที่เป็นธรรมชาติประกอบด้วยแม้น้ำ ลำห้วย ที่มีน้ำไหลตลอดทั้งปี และเส้นทางลำน้ำที่เกิดจากการสร้างขึ้น เช่น คลองทดน้ำ คลองชลประทาน

ปัจจัย	คำอธิบาย
	(2) แหล่งน้ำผิวดิน (Water Body) พื้นที่ที่พัฒนาแหล่งน้ำผิวดินในลักษณะที่เป็นหนอง บึง สระและอ่างเก็บน้ำเพื่อใช้ในทางเกษตร โดยเป็นแหล่งน้ำสำรองสนับสนุนในบริเวณพื้นที่ที่
2.ปัจจัยด้านเศรษฐสังคม(Socio-economic)	**1. ระยะห่างจากถนน** (Distance from main road) เป็นการแสดงความสะดวกในการขนส่งวัตถุดิบจากพื้นที่ปลูกไปยังแหล่งรับซื้อ เช่น โรงงาน หรือลานรับซื้อวัตถุดิบทางการเกษตร และที่สำคัญมีผลต่อต้นทุนการขนส่ง นอกจากนี้ยังมีความสำคัญกับการลดการสูญเสียในด้านคุณภาพของพืช
	2. ระยะห่างจากที่ตั้งโรงงานน้ำตาล (Distance to sugar industry) คือโรงงานผลิตน้ำตาลซึ่งเมื่อแหล่งปลูกอยู่ใกล้กับโรงงานทำให้เกิดความสะดวก เพิ่มประสิทธิภาพในการผลิตโดยเฉพาะลดการสูญเสียจากการขนส่ง ง่ายต่อการบริหารจัดการกำลังการผลิต (Line of production)

ตอนที่ 1 ท่านคิดว่าปัจจัยแต่ละปัจจัยมีความสำคัญอย่างไรของปัจจัยหลัก และให้พิจารณาเปรียบเทียบระดับของความสำคัญเป็นรายคู่ของระดับปัจจัยที่อยู่ทางด้านซ้ายมือของแถวเปรียบเทียบกับระดับปัจจัยที่อยู่ทางด้านขวาของบรรทัดเดียวกันโดย ☒ บนหมายเลขค่าคะแนนตั้งแต่ระดับ 1 – 9 ที่กำหนดให้จนครบทุกคู่ของปัจจัย

ปัจจัย	การเปรียบเทียบค่าคะแนนมาตรฐานของปัจจัย																	ปัจจัย
	มีความสำคัญมากกว่า								เท่ากัน	มีความสำคัญน้อยกว่า								
ปัจจัยด้านชีวกายภาพ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**เศรษฐกิจสังคม**
ภูมิประเทศ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ภูมิอากาศ
ภูมิประเทศ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ศักยภาพของที่ดินตามฯ ระบบFAO
ภูมิประเทศ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	แหล่งน้ำสนับสนุน
ภูมิอากาศ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ศักยภาพของที่ดินตามฯ ระบบFAO
ภูมิอากาศ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	แหล่งน้ำสนับสนุน
ศักยภาพของที่ดินตามฯ ระบบFAO	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	แหล่งน้ำสนับสนุน

ตอนที่ 2 ท่านคิดว่าปัจจัยแต่ละปัจจัยมีความสำคัญอย่างไรของปัจจัยในกลุ่มหลัก และให้พิจารณาเปรียบเทียบระดับของความสำคัญเป็นรายคู่ของระดับปัจจัยที่อยู่ทางด้านซ้ายมือของแถวเปรียบเทียบกับระดับปัจจัยที่อยู่ทางด้านขวาของบรรทัดเดียวกันโดย ☒ บนหมายเลขค่าคะแนนตั้งแต่ระดับ 1 – 9 ที่กำหนดให้จนครบทุกคู่ของปัจจัย

ปัจจัย	**การเปรียบเทียบค่าคะแนนมาตรฐานปัจจัย**																	**ปัจจัย**
	มีความสำคัญมากกว่า								**เท่ากัน**	**มีความสำคัญน้อยกว่า**								
1. ภูมิประเทศ ความลาดชัน	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ความสูงของพื้นที่
2. ภูมิอากาศ ปริมาณน้ำฝน	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	อุณหภูมิ
3. ศักยภาพของที่ดินตามฯระบบFAO **S_1**: ชั้นที่ดินมีความเหมาะสม	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**S_2**:ชั้นที่ดินมีความเหมาะสมปานกลาง
S_1: ชั้นที่ดินมีความเหมาะสม	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**S_3**:ชั้นที่ดินมีความเหมาะสมเล็กน้อย
S_1: ชั้นที่ดินมีความเหมาะสม	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**N**: ชั้นที่ดินไม่มีความเหมาะสม
S_2:ชั้นที่ที่ดินมีความเหมาะสมปานกลาง	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**S_3**:ชั้นที่ดินมีความเหมาะสมเล็กน้อย
S_2:ชั้นที่ที่ดินมีความเหมาะสมปานกลาง	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**N**: ชั้นที่ดินไม่มีความเหมาะสม
S_3 :ชั้นที่มีความเหมาะสมเล็กน้อย	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**N**: ชั้นที่ไม่มีความเหมาะสม
4. แหล่งน้ำสนับสนุน - เส้นทางน้ำ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	แหล่งน้ำผิวดิน

ปัจจัย	การเปรียบเทียบค่าคะแนนมาตรฐานปัจจัย																	ปัจจัย
	มีความสำคัญมากกว่า								เท่ากัน	มีความสำคัญน้อยกว่า								
- เส้นทางน้ำ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	เขตชลประทาน
- แหล่งน้ำผิวดิน	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	เขตชลประทาน
5. ปัจจัยด้านเศรษฐสังคม - ระยะห่างจากถนน	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ระยะห่างจากที่ตั้งโรงงานน้ำตาล

....

ตอนที่ 3 ท่านคิดว่าในช่วงของปัจจัยแต่ละปัจจัยมีความสำคัญอย่างไร และให้พิจารณาเปรียบเทียบระดับช่วงความสำคัญเป็นรายคู่ของระดับปัจจัยที่อยู่ทางด้านซ้ายมือของแถวเปรียบเทียบกับระดับปัจจัยที่อยู่ทางด้านขวาของบรรทัดเดียวกันโดย ☒ บนหมายเลขค่าคะแนนตั้งแต่ระดับ 1 – 9 ที่กำหนดให้จนครบทุกคู่ของปัจจัย

1. ภูมิประเทศ

1.1 ความลาดชัน (slope): % slope

หมายเหตุ: A:0-2% = ราบเรียบจนถึงค่อนข้างราบเรียบ B:2-5% = ลูกคลื่นลอนลาดต่ำ C:> 5-12%= ลูกคลื่นลอนชันปาน

กลาง D:>12-20% = ชันสูง E:>20-35%= ชันหรือเนินเขา F:>35% =สูงชันมาก

ปัจจัย	การเปรียบเทียบค่าคะแนนมาตรฐานปัจจัย																	ปัจจัย
	มีความสำคัญมากกว่า								เท่ากัน	มีความสำคัญน้อยกว่า								
S1 (0-2,>2-5,>5-12)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	S2 (>12-20)
S1 (0-2,>2-5,>5-12)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	S3 (>20-35)
S1 (0-2,>2-5,>5-12)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	N (>35)
S2 (>12-20)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	S3 (>20-35)
S2 (>12-20)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	N(>35)
S3 (>20-35)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	N(>35)

2. ภูมิอากาศ (Climate)

2.1 อุณหภูมิ (Temperature): องศาเซลเซียส (°C)

ปัจจัย	การเปรียบเทียบค่าคะแนนมาตรฐานปัจจัย																	ปัจจัย
	มีความสำคัญมากกว่า								เท่ากัน	มีความสำคัญน้อยกว่า								
S1 (24-27)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	S2 (19-23,28-31)
S1 (24-27)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	S3 (15-18,32-35)
S1 (24-27)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	N (<15) ,(>35)
S2 (19-23,28-31)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	S3 (15-18,32-35)
S2 (19-23,28-31)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	N (<15) ,(>35)
S3 (15-18,32-35)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	N (<15) ,(>35)

2.2 ปริมาณน้ำฝนเฉลี่ยรายปี (Mean Annual Rainfall): มิลลิเมตร (mm.) ต่อปี

ปัจจัย	การเปรียบเทียบค่าคะแนนมาตรฐานปัจจัย																	ปัจจัย
	มีความสำคัญมากกว่า								เท่ากัน	มีความสำคัญน้อยกว่า								
S1 (>1600-2500)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	S2 (>1200-1600), (>2500-3000)
S1 (>1600-2500)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	S3 (900-1200), (>3000-4000)
S1 (>1600-2500)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	N(<900),(>4000)
S2 (>1200-1600), (>2500-3000)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	S3 (900-1200), (>3000-4000)
S2 (>1200-1600), (>2500-3000)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	N(<900),(>4000)
S3 (900-1200), (>3000-4000)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	N(<900),(>4000)

3. แหล่งน้ำสนับสนุน (Water Supply)

3.1 ระยะห่างจากเส้นทางน้ำ: เมตร (m.)

ปัจจัย	การเปรียบเทียบค่าคะแนนมาตรฐานปัจจัย																	ปัจจัย
	มีความสำคัญมากกว่า								เท่ากัน	มีความสำคัญน้อยกว่า								
S1 (<500)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	S2 (500-1000)
S1 (<500)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	S3 (>1000-1500)
S1 (<500)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	N (>1500)
S2 (500-1000)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	S3 (>1000-1500)
S2 (500-1000)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	N (>1500)
S3 (>1000-1500)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	N (>1500)

3.2 ระยะห่างจากแหล่งน้ำผิวดิน: เมตร (m.)

ปัจจัย	การเปรียบเทียบค่าคะแนนมาตรฐานปัจจัย																	ปัจจัย
	มีความสำคัญมากกว่า								เท่ากัน	มีความสำคัญน้อยกว่า								
S1 (<500)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	S2 (500-1000)
S1 (<500)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	S3 (>1000-1500)
S1 (<500)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	N (>1500)
S2 (500-1000)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	S3 (>1000-1500)
S2 (500-1000)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	N (>1500)
S3 (>1000-1500)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	N (>1500)

3.3 ระยะห่างจากเขตชลประทาน: กิโลเมตร (Km.)

ปัจจัย	การเปรียบเทียบค่าคะแนนมาตรฐานปัจจัย																	ปัจจัย
	มีความสำคัญมากกว่า								เท่ากัน	มีความสำคัญน้อยกว่า								
S1 ในเขตชลประทาน	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	S2 (นอกเขต0-1 km.)
S1 ในเขตชลประทาน	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	S3 (นอกเขต>1-5)
S1 ในเขตชลประทาน	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	N (นอกเขต >5)
S2 (นอกเขต0-1 km.)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	S3 (นอกเขต>1-5)
S2 (นอกเขต0-1 km.)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	N (นอกเขต >5)
S3 (นอกเขต>1-5)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	N (นอกเขต >5)

4. เศรษฐกิจสังคม

4.1 ระยะห่างจากถนน: กิโลเมตร (km.)

ปัจจัย	การเปรียบเทียบค่าคะแนนมาตรฐานปัจจัย																	ปัจจัย
	มีความสำคัญมากกว่า								เท่ากัน	มีความสำคัญน้อยกว่า								
S1 (<1 km.)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	S2 (1-5km.)
S1 (<1 km.)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	S3 (>5-10 km.)
S1 (<1 km.)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	N (> 10 km.)
S2 (1-5km.)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	S3 (>5-10 km.)
S2 (1-5km.)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	N (> 10 km.)
S3 (>5-10 km.)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	N (> 10 km.)

4.2 ระยะห่างจากโรงงานน้ำตาล: (km.)

ปัจจัย	การเปรียบเทียบค่าคะแนนมาตรฐานปัจจัย																	ปัจจัย
	มีความสำคัญมากกว่า								เท่ากัน	มีความสำคัญน้อยกว่า								
S1 (<50 km.)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	S2 (>50-75km.)
S1 (<50 km.)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	S3 (>75-100 km.)
S1 (<50 km.)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	N (> 100 km.)
S2 (>50-75km.)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	S3 (>75-100 km.)
S2 (>50-75km.)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	N (> 100 km.)
S3 (>75-100 km.)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	N (> 100 km.)

ข้อเสนอแนะ

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

ขอขอบพระคุณในความอนุเคราะห์

กัลยา เทียนวงศ์

ผู้ศึกษาวิจัย

เอกสารเพิ่มเติม

ปัจจัยที่ใช้ในการประเมินคุณภาพที่ดินสำหรับพื้นที่ที่เหมาะสมสำหรับการปลูกอ้อย

ความต้องการของพืช (Crop Requirement)			**ระดับค่าคะแนนของปัจจัย (Factor Rating)**				**ที่มา** (Reference)
คุณภาพของที่ดิน (Land Quality)	**ปัจจัยวินิจฉัย** (Diagnostic factor)	**หน่วย** (Unit)	**เหมาะสม** (S_1:1.0)	**เหมาะสมปานกลาง** (S_2:0.8)	**เหมาะสมน้อย** (S_3: 0.5)	**ไม่เหมาะสม** (N: 0.2)	
1.ปัจจัยด้านชีวกายภาพ **1.1 ภูมิประเทศ**	- ความลาดชัน (Slope)	ชั้นที่ (Class)	AB	C	D	>D	กรมพัฒนาที่ดิน,2539 (LDD,1996)
	- ความสูงของพื้นที่ (Elevation)	เมตร (m.)	0-100	>100 - 200	>200-300	> 300 ขึ้นไป	พิจารณาความสูงในพื้นที่ศึกษา
1.2 ภูมิอากาศ	-ปริมาณน้ำฝนเฉลี่ยรายปี(Mean Annual Rainfall)	มิลิเมตร (mm.)	>1600-2500	1200-1600 2500-3000	900-1200 3000-4000	< 900 > 4000	LDD, 1996
	-อุณหภูมิเฉลี่ย (Temperature)	เซลเซียส (° C)	24-27	28-31 19-23	32-35 15-18	> 35 <15	LDD, 1996
1.3 ศักยภาพของที่ดินตามความเหมาะสมระบบFAO (1) ความเป็นประโยชน์ต่อรากพืช (Oxygen Availability)	- การระบายน้ำของดิน (Soil drainage)	ชั้นที่ (Class)	5,6	3,4	2	1	LDD, 1996
(2) ความเป็นประโยชน์ของธาตุอาหาร (Nutrient Retention)	- ไนโตรเจน (N)	%N	> 0.2	0.2-0.1	<0.1		LDD, 1996
	- ฟอสฟอรัส (P)	ppm	>25	6-25	<6		LDD, 1996
	- โปรแตสเซียม (K)	ppm	>60	30-60	<30		LDD, 1996
	-ค่าปฏิกิริยาของดิน (pH)	pH	5.6-7.3	7.4-7.8 4.5-5.5	7.9-8.4 4.0-4.5	>8.4 <4	LDD, 1996
(3) ความจุในการดูดยึดธาตุอาหาร	-ความจุในการดูดยึดธาตุอาหาร (C.E.C)	meg/100gm soil	>15	5-15	<5		LDD, 1996
	- ความอิ่มตัวไปด้วยค่าด่าง (B.S.)	% BS	>75	35-75	<35		LDD, 1996
(4) ความจุในการอุ้มน้ำ (Water Retention)	- เนื้อดิน (Texture)	-	L,scl,Si, SiL,CL,Sl	LS	SiC	S, G, SC,C, AC	ธงชัย จารุพพัฒน์, 2003

ความต้องการของพืช (Crop Requirement)			ระดับค่าคะแนนของปัจจัย (Factor Rating)				ที่มา
คุณภาพของที่ดิน (Land Quality)	**ปัจจัยวินิจฉัย** (Diagnostic factor)	**หน่วย** (Unit)	**เหมาะสม** (S_1:1.0)	**เหมาะสมปานกลาง** (S_2:0.8)	**เหมาะสมน้อย** (S_3: 0.5)	**ไม่เหมาะสม** (N: 0.2)	(Reference)
1.4 แหล่งน้ำสนับสนุน (ระยะห่างจาก)	-เส้นทางน้ำที่มีน้ำไหลตลอดทั้งปี	เมตร (m.)	<500	500-1000	1000-1500	>1500	เดช วัฒนชัยยิ่งเจริญ, 2547
	- แหล่งน้ำผิวดิน	เมตร (m.)	<500	500-1000	1000-1500	>1500	เดช วัฒนชัยยิ่งเจริญ, 2547
	- เขตชลประทาน	กิโลเมตร(km.)	ในเขตชลประทาน	นอกเขต 0-1 km.	นอกเขต 1-5 km.	นอกเขต > 5 km.	**การศึกษาเพื่อกำหนดพื้นที่ที่เสี่ยงต่อภัยแล้ง ในพื้นที่ลุ่มน้ำภาคเหนือ**
2. ปัจจัยด้านเศรษฐสังคม (ระยะห่างจาก)	- ถนนสายหลัก	กิโลเมตร (km.)	< 1	1-5	5-10	> 10	เดช วัฒนชัยยิ่งเจริญ, 2547
	- โรงงานน้ำตาล	กิโลเมตร (km.)	< 50	50-75	>75-100	>100	เกณฑ์การพิจารณาค่าขนส่งอ้อยไปโรงงานน้ำตาล

☺☺☺☺☺☺☺☺☺☺☺☺☺☺☺☺☺☺☺☺

APPENDIX K

DETERMINATION OF AHP FACTOR WEIGHT AND CLASS WEIGHT

Step I: Parewise comparison of the criteria factors (1st order)

Criteria	Topography	Raw material	Proximity	Water supply	Environment
Topography	1.00	1.63	2.32	1.10	1.37
Raw material	0.86	1.00	1.54	1.17	1.28
Proximity	0.78	0.65	1.00	1.28	1.10
Water supply	0.91	0.89	0.78	1.00	1.08
Environment	0.73	0.78	0.91	0.93	1.00
SUM	4.28	4.95	6.55	5.48	5.83

Step II: Determination of the factor weights

Criteria	Topography	Raw material	Proximity	Water supply	Environment	SUM	Weight
Topography	0.23	0.33	0.35	0.20	0.23	1.35	0.27
Raw material	0.20	0.20	0.24	0.21	0.22	1.07	0.21
Proximity	0.18	0.13	0.15	0.23	0.19	0.89	0.18
Water supply	0.21	0.18	0.12	0.18	0.19	0.88	0.18
Environment	0.17	0.16	0.14	0.17	0.17	0.81	0.16
SUM	1.00	1.00	1.00	1.00	1.00	5.00	1.00

Step III: Determination of the consistency factors

Physical	Topography	Raw material	Proximity	Water supply	Environ-ment	SUM	Consistency vector
Topography	0.27	0.35	0.41	0.19	0.22	1.45	5.35
Raw material	0.23	0.21	0.27	0.21	0.21	1.13	5.29
Proximity	0.21	0.14	0.18	0.23	0.18	0.93	5.24
Water supply	0.25	0.19	0.14	0.18	0.17	0.93	5.26
Environment	0.20	0.17	0.16	0.16	0.16	0.85	5.27
						sum	26.40

Compute value for lambda (λ) = consistency vector / n = 26.40/5 = 5.28

Compute consistency index (CI) = (λ- n)/(n-1) = (5.28-5)/(5-1) = 0.07

Calculate the consistency ratio (CR) = CI/RI = 0.07/1.12 = 0.06

CR < 0.1 indicates the accepted validity of the comparison results.

APPENDIX L

SERVICES AREA ZONING OF CANDIDATE ETHANOL PLANT LOCATIONS

Service area zoning for crops cultivation in 2006 (district level)

Data of area coverage for sugarcane and cassava plantations in 2006 within each classified service zone of candidates 1 to 5 are shown in Tables L-2 to L-3. And if consider only within the first 50 km (or 0-50 km zone), it can be concluded that each candidate is suitable to serve observed sugarcane/cassava farming at different districts (Table B.1), for examples, candidate 1 is preferred by Tha Muang and Muang District the most (for sugarcane farming) and by Tha Ma Ka the most (for cassava farming) and candidate 2 is also needed by Tha Muang and Muang District the most (for the sugarcane farming) and Tha Ma Ka the most (for cassava farming). Note that, some districts located outside the service area of each candidate points are not listed in the table (mostly in mountain areas like Sang Ka Buri, Sri Sa Wat, or Thong Pha Phum).

Table L-1 District favor for the candidate locations (within 0-50 km zone)

Candidate	Most benefited districts	
	Sugarcane farming	Cassava farming
1	Tha Muang , Muang Kanchanaburi	Tha Ma Ka, Tha Muang
2	Tha Muang, Muang Kanchanaburi	Tha Ma Ka, Dan Ma Kham Tia
3	Tha Muang, Muang Kanchanaburi	Bo Ploi, Dan Ma Kham Tia
4	Bo Ploi, Muang Kanchanaburi	Bo Ploi, Lao Kwan
5	Bo Ploi, Muang Kanchanaburi	Bo Ploi, Lao Kwan
Existing	Tha Muang, Tha Ma Ka	Tha Ma Ka, Tha Muang

TableL-2 Service area zoning and sugarcane plantation in 2006 for candidate site 1

District	Crop area in each service zone (km^2)				
	0-25 km	25-50 km	50-75 km	75-100 km	> 100 km
Bo Phloi	0.16	74.44	132.33	55.39	0.32
Dan Ma Kham Tia	0.30	56.67	18.53	0.41	0
Huai Kra Chao	0	12.23	69.52	1.46	0
Lao Kwan	0	0	20.93	136.72	40.47
Muang Kanchanaburi	23.84	131.00	18.69	0.00	0
Nong Phu	0	0	0	20.52	3.48
Pha Nom Tuan	3.96	79.69	0.34	0	0
Sai Yok	0	0.66	18.91	0.27	0
Sri Sa Wat	0	0	46.33	575.23	510.11
Tha Ma Ka	15.92	32.87	0.11	0	0
Tha Muang	159.95	8.21	0	0	0
Thong Pha Phum	0	0	0	0	204.15
Total	204.13	395.79	325.70	789.99	785.53

Table L-3 Service area zoning and cassava plantation in 2006 for candidate site 1

District	Crop area in each service zone (km^2)				
	0-25 km	25-50 km	50-75 km	75-100 km	> 100 km
Bo Phloi	0.00	18.43	54.66	43.37	1.39
Dan Ma Kham Tia	0.00	27.60	11.27	0.17	0.00
Huai Kra Chao	0.00	3.92	37.72	1.14	0.00
Lao Kwan	0.00	0.00	10.35	81.12	96.46
Muang Kanchanaburi	1.41	15.53	0.86	0.00	0.00
Nong Phu	0.00	0.00	0.00	16.56	1.22
Pha Nom Tuan	0.02	15.12	0.00	0.00	0.00
Sai Yok	0.00	0.33	1.97	0.08	0.01
Sri Sa Wat	0.00	0.00	46.33	575.23	510.11
Tha Ma Ka	109.31	115.64	0.23	0.00	0.00
Tha Muang	10.46	11.84	0.00	0.00	0.00
Thong Pha Phum	0.00	0.00	0.00	0.00	0.05
Total	121.21	189.98	108.73	674.29	607.86

TableL-4 Service area zoning and sugarcane plantation in 2006 for candidate site 2

District	Crop area in each service zone (km^2)				
	0-25 km	25-50 km	50-75 km	75-100 km	> 100 km
Bo Phloi	3.04	85.13	97.33	15.93	0.28
Dan Ma Kham Tia	1.98	64.24	10.28	0.00	0.00
Huai Kra Chao	0.00	13.80	52.53	0.00	0.00
Lao Kwan	0.00	0.00	20.87	117.14	18.88
Muang	59.26	83.94	1.06	0.00	0.00
Pha Nom Tuan	4.85	76.44	0.01	0.00	0.00
Sai Yok	0.00	6.14	9.41	0.00	0.00
Sri Sa Wat	0.00	0.00	0.00	0.00	88.24
Tha Ma Ka	15.92	32.84	0.00	0.00	0.00
Tha Muang	160.65	7.55	0.00	0.00	0.00
Total	245.70	370.08	191.47	161.15	109.64

Table L-5 Service area zoning and cassava plantation in 2006 for candidate site 2

District	Crop area in each service zone (km^2)				
	0-25 km	25-50 km	50-75 km	75-100 km	> 100 km
Bo Phloi	0.21	21.52	35.46	11.17	0.90
Dan Ma Kham Tia	0.29	35.77	3.19	0.00	0.00
Huai Kra Chao	0.00	4.05	26.23	0.00	0.00
Lao Kwan	0.00	0.00	11.20	53.11	52.72
Muang	4.78	0.00	0.00	0.00	0.00
Sai Yok	0.00	0.87	1.19	0.00	0.00
Tha Ma Ka	109.37	115.76	0.00	0.00	0.00
Tha Muang	11.20	11.11	0.00	0.00	0.00
Total	125.85	215.95	77.28	75.12	54.14

Table L-6 Service area zoning and sugarcane plantation in 2006 for candidate site 3

District	Crop area in each service zone (km^2)				
	0-25 km	25-50 km	50-75 km	75-100 km	> 100 km
Bo Phloi	8.08	129.81	110.76	15.08	0.00
Dan Ma Kham Tia	6.84	65.79	0.11	0.11	0.21
Huai Kra Chao	0.00	24.45	51.57	0.12	0.00
Lao Kwan	0.00	0.00	28.08	132.11	16.66
Muang	67.61	98.64	0.86	0.01	0.01
Nong Phu	0.00	0.00	8.39	16.19	0.42
Pha Nom Tuan	10.94	70.63	0.00	0.00	0.00
Sai Yok	0.00	14.26	1.32	0.09	0.07
Tha Ma Ka	16.15	32.41	0.00	0.00	0.00
Tha Muang	103.48	5.43	0.00	0.00	0.00
Total	213.10	441.42	201.11	163.72	17.38

Table L-7 Service area zoning and cassava plantation in 2006 for candidate site 3

District	Crop area in each service zone (km^2)				
	0-25 km	25-50 km	50-75 km	75-100 km	> 100 km
Bo Phloi	2.59	35.68	65.15	21.73	0.00
Dan Ma Kham Tia	1.65	32.58	0.03	0.03	0.07
Huai Kra Chao	0.00	5.74	36.95	0.01	0.00
Lao Kwan	0.00	0.00	18.69	75.59	50.18
Muang	8.32	9.40	0.00	0.00	0.00
Nong Phu	0.00	0.00	3.45	10.54	0.23
Pha Nom Tuan	1.56	13.47	0.00	0.00	0.00
Sai Yok	0.00	1.94	0.14	0.03	0.01
Sri Sa Wat	0.00	0.00	204.28	219.26	430.48
Tha Ma Ka	0.11	0.06	0.00	0.00	0.00
Tha Muang	6.40	5.01	0.00	0.00	0.00
Thong Pha Phum	0.00	0.00	0.00	0.00	27.62
Total	20.62	103.89	328.69	327.19	508.59

Table L-8 Service area zoning and sugarcane plantation in 2006 for candidate site 4

District	Crop area in each service zone (km^2)				
	0-25 km	25-50 km	50-75 km	75-100 km	> 100 km
Bo Phloi	209.00	54.72	0.00	0.00	0.00
Dan Ma Kham Tia	0.00	0.00	65.94	26.40	0.00
Huai Kra Chao	30.92	45.37	0.00	0.00	0.00
Lao Kwan	0.00	101.08	73.44	0.01	0.00
Muang Kanchanaburi	0.00	109.39	63.95	0.28	0.02
Nong Phu	5.58	18.76	0.50	0.00	0.00
Pha Nom Tuan	4.24	73.69	3.35	0.01	0.00
Sai Yok	0.00	0.00	18.57	0.08	0.00
Tha Ma Ka	0.00	0.00	39.09	9.58	0.00
Tha Muang	0.00	19.93	113.14	35.27	0.00
Total	249.76	422.96	377.98	71.63	0.018

Table L-9 Service area zoning and cassava plantation in 2006 for candidate site 4

District	Crop area in each service zone (km^2)				
	0-25 km	25-50 km	50-75 km	75-100 km	> 100 km
Bo Phloi	89.79	35.36	0.00	0.00	0.00
Dan Ma Kham Tia	0.00	0.00	38.56	7.81	0.00
Huai Kra Chao	14.68	28.01	0.00	0.00	0.00
Lao Kwan	0.00	78.77	63.23	0.04	0.00
Muang Kanchanaburi	0.00	15.47	2.34	0.34	0.00
Nong Phu	0.99	12.94	0.25	0.00	0.00
Pha Nom Tuan	1.13	13.90	0.01	0.00	0.00
Sai Yok	0.00	0.00	2.22	0.07	0.00
Sri Sa Wat	0.00	57.08	204.68	370.94	187.09
Tha Ma Ka	0.00	0.00	0.00	0.00	0.00
Tha Muang	0.00	1.14	9.77	11.52	0.00
Total	106.58	242.65	321.05	390.71	187.09

Table L-10 Service area zoning and sugarcane plantation in 2006 for candidate site 5

District	Crop area in each service zone (km^2)				
	0-25 km	25-50 km	50-75 km	75-100 km	> 100 km
Bo Phloi	208.36	55.37	0.00	0.00	0.00
Dan Ma Kham Tia	0.00	0.00	64.73	27.69	0.00
Huai Kra Chao	31.37	44.96	0.00	0.00	0.00
Lao Kwan	0.00	102.81	71.65	0.01	0.09
Muang	0.00	107.59	65.74	0.12	0.02
Nong Phu	5.80	17.13	0.46	0.00	0.01
Pha Nom Tuan	3.78	74.09	3.42	0.00	0.00
Sai Yok	0.00	0.07	18.05	0.00	0.00
Tha Ma Ka	0.00	0.00	38.97	9.66	0.00
Tha Muang	0.00	19.29	112.99	36.03	0.00
Total	249.30	421.32	376.01	73.52	0.12

Table L-11 Service area zoning and cassava plantation in 2006 for candidate site 5

District	Crop area in each service zone (km^2)				
	0-25 km	25-50 km	50-75 km	75-100 km	> 100 km
Bo Phloi	89.77	35.38	0.00	0.00	0.00
Dan Ma Kham Tia	0.00	0.00	38.16	8.12	0.00
Huai Kra Chao	15.02	27.67	0.00	0.00	0.00
Lao Kwan	0.00	79.91	62.10	0.04	0.13
Nong Phu	1.43	12.48	0.23	0.00	0.00
Pha Nom Tuan	1.10	13.92	0.01	0.00	0.00
Sai Yok	0.00	0.00	2.07	0.00	0.00
Sri Sa Wat	0.00	57.15	204.81	371.61	186.44
Tha Ma Ka	0.00	0.00	149.71	26.76	0.00
Tha Muang	0.00	1.14	9.39	11.88	0.00
Total	107.32	227.64	466.47	418.41	186.57

Table L-12 Service area zoning and sugarcane plantation in 2006 for existing plant

District	Crop area in each service zone (km^2)				
	0-25 km	25-50 km	50-75 km	75-100 km	> 100 km
Bo Phloi	0.00	0.48	27.16	55.08	0.00
Dan Ma Kham Tia	0.00	7.09	35.95	0.07	0.00
Huai Kra Chao	0.00	0.00	30.44	12.35	0.00
Lao Kwan	0.00	0.00	3.65	76.71	107.14
Muang	0.00	4.30	12.46	0.00	0.00
Nong Phu	0.00	0.00	0.00	0.66	16.20
Pha Nom Tuan	8.72	6.32	0.00	0.00	0.00
Sai Yok	0.00	0.00	0.87	1.57	0.04
Tha Ma Ka	216.48	8.65	0.00	0.00	0.00
Tha Muang	0.87	21.14	0.00	0.00	0.00
Total	226.07	47.98	110.53	146.44	123.38

Table L-13 Service area zoning and cassava plantation in 2006 for existing plant

District	Crop area in each service zone (km^2)				
	0-25 km	25-50 km	50-75 km	75-100 km	> 100 km
Bo Phloi	0.00	3.54	103.75	109.85	0.00
Dan Ma Kham Tia	0.00	6.68	75.16	0.77	0.00
Huai Kra Chao	0.00	0.45	69.33	7.61	0.00
Lao Kwan	0.00	0.00	9.50	139.31	49.46
Muang	0.00	54.28	88.65	1.37	0.00
Nong Phu	0.00	0.00	0.00	4.16	0.00
Pha Nom Tuan	1.37	62.61	17.54	0.00	0.00
Sai Yok	0.00	0.00	6.20	11.78	0.05
Tha Ma Ka	46.95	34.35	0.00	0.00	0.00
Tha Muang	28.26	139.87	0.00	0.00	0.00
Total	76.57	301.78	370.14	274.84	49.52

APPENDIX M

SERVICES AREA ZONING FOR CLASSIFIED LAND SUITABILITY AREA (FOR EACH CROP)

Likewise, the service zoning system can be applied with the land suitability maps for sugarcane and cassava developed in Chapter 5 (Figures 5.6 and 5.7) to find the most suitable sites located within these maps and results are shown in Figures 6.6 to 6.11 and Tables B.15 to B.26. And if consider only within the first 50 km (or in the 0-50 km zone) and only highly/moderately suitable areas are considered (S1+S2 area), it can be concluded that each candidate is having different area cover for this defined class (Table B.14). In general, the higher the S1/S2 area covers, the more preferred of the candidate location the plant should be. Here, in case of sugarcane, it is candidate site 3 (1454.06 km^2) and for cassava, it is also candidate point 3 (1166.85 km^2).

Table M-1 Amount of classified S1+S2 area within 0-50km zone for each candidate

Candidate	Amount of S1+S2 area (km^2)	
	Sugarcane	Cassava
1	1279.40	350.37
2	1296.21	705.4
3	1454.06	1166.85
4	964.76	907.74
5	957.34	944.90

Table M-2 Service area zoning and sugarcane's land suitability for candidate site 1

Suitable class	Amount of area (km^2)				
	0-25 km	25-50 km	50-75 km	75-100 km	> 100 km
Highly suitable	46.06	79.56	62.79	7.16	32.23
Percent	6.56	6.03	5.32	1.56	15.77
Moderately suitable	464.97	688.81	423.30	123.03	63.71
Percent	66.21	52.21	35.84	26.72	31.18
Marginally suitable	167.75	536.62	671.42	312.66	102.86
Percent	23.89	40.68	56.85	67.92	50.34
Not suitable	16.91	14.25	23.49	17.52	5.53
Percent	2.41	1.08	1.99	3.80	2.71
Total	702.31	1,319.24	1,180.99	460.37	204.33

Table M-3 Service area zoning and cassava's land suitability for candidate site 1

Suitable class	Amount of area (km^2)				
	0-25 km	25-50 km	50-75 km	75-100 km	> 100 km
Highly suitable	46.64	49.38	23.03	36.28	76.41
Percent	7.68	10.85	20.82	51.04	42.62
Moderately suitable	175.88	78.47	40.26	13.80	58.93
Percent	28.98	17.24	36.40	19.42	32.87
Marginally suitable	367.11	317.82	45.28	19.85	38.83
Percent	60.49	69.83	40.94	27.93	21.66
Not suitable	17.22	9.47	2.04	1.15	5.13
Percent	2.84	2.08	1.84	1.62	2.86
Total	606.85	455.14	110.61	71.07	179.30

Table M-4 Service area zoning and sugarcane's land suitability for candidate site 2

Suitable class	Amount of area (km^2)				
	0-25 km	25-50 km	50-75 km	75-100 km	> 100 km
Highly suitable	63.74	66.95	26.38	0.40	0.06
Percent	7.66	5.53	3.49	0.14	0.35
Moderately suitable	533.13	632.39	220.64	29.39	1.80
Percent	64.07	52.24	29.17	10.44	10.54
Marginally suitable	209.24	491.13	493.21	242.18	14.22
Percent	25.15	40.57	65.21	86.01	83.15
Not suitable	25.99	20.05	16.16	9.62	1.02
Percent	3.12	1.66	2.14	3.42	5.96
Total	832.09	1,210.52	756.39	281.59	17.10

Table M-5 Service area zoning and cassava's land suitability for candidate site 2

Suitable class	Amount of area (km^2)				
	0-25 km	25-50 km	50-75 km	75-100 km	> 100 km
Highly suitable	96.46	189.77	150.33	39.70	2.70
Percent	11.59	15.68	19.88	13.30	14.59
Moderately suitable	293.72	407.58	66.51	8.15	0.81
Percent	35.30	33.68	8.79	2.73	4.38
Marginally suitable	412.67	603.08	469.01	201.07	13.76
Percent	49.59	49.83	62.01	67.35	74.46
Not suitable	29.23	9.81	70.53	49.61	1.22
Percent	3.51	0.81	9.33	16.62	6.58
Total	832.09	1,210.24	756.39	298.53	18.48

Table M-6 Service area zoning and sugarcane's land suitability for candidate site 3

Suitable Class	Amount of area (km^2)				
	0-25 km	25-50 km	50-75 km	75-100 km	> 100 km
Highly suitable	63.80	79.78	23.70	2.65	29.11
Percent	7.35	5.59	2.81	0.82	33.73
Moderately suitable	551.84	758.64	268.78	70.98	31.15
Percent	63.56	53.16	31.84	22.03	36.10
Marginally suitable	234.45	575.93	541.30	239.10	24.81
Percent	27.01	40.36	64.13	74.20	28.75
Not suitable	18.06	12.61	10.35	9.51	1.22
Percent	2.08	0.88	1.23	2.95	1.42
Total	868.15	1,426.97	844.14	322.23	86.30

Table M-7 Service area zoning and cassava's land suitability for candidate site 3

Suitable Class	Amount of area (km^2)				
	0-25 km	25-50 km	50-75 km	75-100 km	> 100 km
Highly suitable	105.52	269.56	183.98	63.39	77.77
Percent	12.11	18.72	22.82	19.69	72.52
Moderately suitable	309.73	482.04	35.19	11.57	19.79
Percent	35.53	33.47	4.37	3.59	18.46
Marginally suitable	433.22	669.62	495.64	201.94	8.11
Percent	49.70	46.49	61.48	62.74	7.57
Not suitable	23.17	19.12	91.31	44.99	1.56
Percent	2.66	1.33	11.33	13.98	1.45
Total	871.63	1,440.35	806.12	321.89	107.23

Table M-8 Service area zoning and sugarcane's land suitability for candidate site 4

Suitable class	Amount of area (km^2)				
	0-25 km	25-50 km	50-75 km	75-100 km	> 100 km
Highly suitable	21.19	78.32	83.09	17.90	0.82
Percent	2.88	5.50	6.54	10.02	4.77
Moderately suitable	294.54	570.71	727.17	78.92	10.54
Percent	40.02	40.09	57.24	44.17	61.52
Marginally suitable	407.59	729.20	445.40	81.23	5.74
Percent	55.38	51.22	35.06	45.46	33.53
Not suitable	12.70	45.31	14.79	0.64	0.03
Percent	1.73	3.18	1.16	0.36	1.44
Total	736.03	1,423.55	1,270.46	178.68	17.13

Table M-9 Service area zoning and cassava's land suitability for candidate site 4

Suitable class	Amount of area (km^2)				
	0-25 km	25-50 km	50-75 km	75-100 km	> 100 km
Highly suitable	143.06	282.67	193.15	35.09	10.79
Percent	21.52	42.52	29.05	5.28	1.62
Moderately suitable	150.97	331.03	379.02	44.00	2.16
Percent	16.64	36.49	41.78	4.85	0.24
Marginally suitable	526.99	588.49	650.19	97.86	3.99
Percent	28.22	31.51	34.82	5.24	0.21
Not suitable	25.70	110.67	47.95	1.60	0.04
Percent	13.82	59.51	25.78	0.86	0.02
Total	846.73	1,312.86	1,270.31	178.55	16.98

Table M-10 Service area zoning and sugarcane's land suitability for candidate site 5

Suitable Class	Amount of area (km^2)				
	0-25 km	25-50 km	50-75 km	75-100 km	> 100 km
Highly suitable	21.08	76.42	83.78	18.38	0.82
Percent	2.86	5.39	6.63	10.01	4.71
Moderately suitable	294.20	565.64	725.98	82.12	10.74
Percent	39.93	39.91	57.42	44.75	61.56
Marginally suitable	408.90	729.59	440.01	82.39	5.86
Percent	55.49	51.48	34.80	44.90	33.59
Not suitable	12.66	45.52	14.63	0.63	0.03
Percent	1.72	3.21	1.16	0.35	0.15
Total	736.85	1,417.16	1,264.40	183.52	17.44

Table M-11 Service area zoning and cassava's land suitability for candidate site 5

Suitable Class	Amount of area (km^2)				
	0-25 km	25-50 km	50-75 km	75-100 km	> 100 km
Highly suitable	144.37	311.82	220.00	35.58	11.16
Percent	19.59	22.02	17.40	19.40	63.95
Moderately suitable	149.23	339.28	385.11	45.31	2.26
Percent	20.25	23.96	30.46	24.71	12.93
Marginally suitable	417.31	698.21	644.93	100.84	4.00
Percent	56.64	49.31	51.02	54.99	22.92
Not suitable	25.93	66.64	14.12	1.66	0.04
Percent	3.52	4.71	1.12	0.90	0.21
Total	736.85	1415.95	1264.16	183.38	17.45

APPENDIX N

LIST OF CORRESPONDING EXPERTS ON ETHANOL INDUSTRY LOCATION

Table N-1 List of experts who gave opinions through distributed questionnaires

ชื่อ-สกุล	ตำแหน่ง	สถานที่ปฏิบัติงาน
1.รศ.ดร. ชาลี นาวานุเคราะห์	รองศาสตราจารย์ ระดับ9	คณะทรัพยากรธรรมชาติและสิ่งแวดล้อม ม. มหิดล
2. รศ.สุเพชร จิระขจรกุล	รองศาสตราจารย์	ภาควิชาเทคโนโลยีชนบท ม. ธรรมศาสตร์
3. รศ.ดร.วิชัย ศรีคำ	รองศาสตราจารย์ระดับ 9	ภาควิชาภูมิศาสตร์ คณะอักษรศาสตร์ ม. ศิลปากร
4. ผศ.อภิเศก ปั้นสุวรรณ	ผู้ช่วยศาสตราจารย์ระดับ 7	
5. ดร.องอาจ ผ่องลักษณ์	คณะกรรมการเอทานอล	กระทรวงการคลัง
6. นายวุฒิชาติ สิริช่วยชู	ผู้เชี่ยวชาญด้านสำรวจและจำแนกดิน (8.)	สำนักผู้เชี่ยวชาญ กรมพัฒนาที่ดิน
7. ดร.อุกฤษฏ์ อัษฎาธร	กรรมการผู้จัดการใหญ่ บริษัทน้ำตาลสระบุรี จำกัด	บริษัทไทยเพิ่มพูนอุตสาหกรรม จำกัด (กลุ่มไทยรุ่งเรือง)
8. นายศุภารมย์ มณีจุฑากร	ผู้จัดการโรงงาน	บริษัทน้ำตาลไทยเอทานอล จำกัด
9. นายสหวัฒน์ โสภา	หัวหน้าฝ่ายโรงงานอุตสาหกรรม	สำนักงานอุตสาหกรรมจังหวัดสุพรรณบุรี
10. นายมงคล พฤกษ์วัฒนา	วิศวกร 8 ว.	สำนักงานอุตสาหกรรมรายสาขา1 กรมโรงงานอุตสาหกรรม
11. นายสุทธิ ตันติพิสิฐกุล	วิศวกร 7ว.	ส่วนมลพิษทางน้ำ สำนักงานเทคโนโลยีน้ำและการจัดการมลพิษโรงงาน กรมโรงงานอุตสาหกรรม
12. นางอัญชลี ยิ่งทวีสิทธิกุล	นักวิทยาศาสตร์ 7 ว.	
13. นายมนตรี อินทนา	ผู้อำนวยการโรงงาน	โรงงานไทยอะโกรเอ็นเนอร์ยี่ จำกัด
14 นายสันทัด นาคประเสริฐ	เจ้าหน้าที่ตรวจโรงงาน	สำนักงานอุตสาหกรรมจังหวัดกาญจนบุรี
15.นายไพโรจน์ จิระศรีไพฑูรย์	หัวหน้าฝ่ายโรงงานอุตสาหกรรม	
16. นายนราธิป อันนตสุข	สมาคมกลุ่มชาวไร่อ้อย	สมาคมกลุ่มชาวไร่อ้อยเขต7 จังหวัดกาญจนบุรี
17. ดร.พิชัย คณีวีปากรณ์	ผู้อำนวยการ	บริษัท KSL จำกัด (กลุ่มน้ำตาลขอนแก่น)

APPENDIX O

DISTRIBUTED QUESTIONAIRE TO CONTRACTED EXPERTS

แบบสอบถามผู้เชี่ยวชาญเรื่อง
การวิเคราะห์ที่ตั้งที่เหมาะสมของโรงงานผลิตเอทานอล

เรียน ท่านผู้ตอบแบบสอบถาม

เนื่องจากข้าพเจ้า นางสาวกัลยา เทียนวงศ์ นักศึกษาระดับปริญญาเอก สาขาการรับรู้จากระยะไกล สำนักวิชาวิทยาศาสตร์ มหาวิทยาลัยเทคโนโลยีสุรนารี กำลังทำวิทยานิพนธ์เรื่อง การประยุกต์เทคโนโลยีภูมิสารสนเทศในการประเมินคุณภาพที่ดินสำหรับพืชเศรษฐกิจที่ให้พลังงานในภาคตะวันตก ซึ่งจากแบบสอบถามนี้เป็นหนึ่งในวัตถุประสงค์เพื่อต้องการหาพื้นที่ที่มีความเหมาะสมกับการตั้งโรงงานผลิตเอทานอล ในจังหวัดกาญจนบุรี โดยใช้เทคโนโลยีทางด้านภูมิสารสนเทศ (Geoinformatics) ในการนี้ข้าพเจ้ามีความจำเป็นที่ต้องการทราบข้อมูลใน 2 ส่วน ดังนี้คือ

1. การให้ค่าน้ำหนักหรือค่าคะแนนความสำคัญของปัจจัย (Weighting Score)
2. การให้ค่าคะแนนระดับปัจจัยหรือค่าคะแนนความเหมาะสมของช่วงปัจจัย (Rating Score) เพื่อนำมาวิเคราะห์หาระดับของพื้นที่ที่มีความเหมาะสมกับการตั้งโรงงานดังกล่าว

โดยในการค่าคะแนนความเหมาะสมของค่าน้ำหนักและคะแนนในแต่ละช่วงของปัจจัยนั้น มีความจำเป็นที่จะต้องให้ผู้เชี่ยวชาญและผู้ที่มีประสบการณ์ที่เกี่ยวข้องกับโรงงานอุตสาหกรรมได้พิจารณาในการกำหนดค่า เพราะถือว่าเป็นผู้ที่มีความรู้ ความเชี่ยวชาญ ซึ่งจะมีผลต่อผลลัพธ์ที่ถูกต้องตามหลักวิชาการ ข้าพเจ้าจึงใคร่ขอความอนุเคราะห์จากท่านผู้ตอบแบบสอบถามในการให้ค่าคะแนนต่าง ๆ ดังกล่าว อีกทั้งปัจจัยต่าง ๆ ที่นำมาพิจารณานั้นผู้วิจัยได้ศึกษาทั้งพระราชบัญญัติ ข้อกำหนดต่าง ๆ ที่เกี่ยวข้องกับการจัดตั้งโรงงาน ทฤษฎี และงานวิจัยที่เกี่ยวข้อง ดังนั้นถ้าหากท่านคิดว่ามีปัจจัยที่นอกเหนือจากนี้กรุณาให้ขอเสนอแนะกับผู้วิจัยด้วย

จึงเรียนมาเพื่อขอความอนุเคราะห์ในการตอบแบบสอบถามดังกล่าว เพื่อประโยชน์ในการศึกษาวิจัยครั้งนี้ด้วย จักเป็นพระคุณยิ่ง

ขอขอบพระคุณอย่างสูง
กัลยา เทียนวงศ์ (ผู้วิจัย)

แบบสอบถามชุดที่ 3 (การหาพื้นที่ที่เหมาะสมกับตั้งโรงงานผลิตเอทานอล)

การให้ค่าน้ำหนักสำหรับผู้เชี่ยวชาญในแต่ละสาขาที่เกี่ยวข้องเพื่อประกอบการศึกษาวิจัย
เรื่อง
การประยุกต์เทคโนโลยีภูมิสารสนเทศในการประเมินคุณภาพที่ดินสำหรับพืชเศรษฐกิจที่
ให้พลังงานในภาคตะวันตกของประเทศไทย

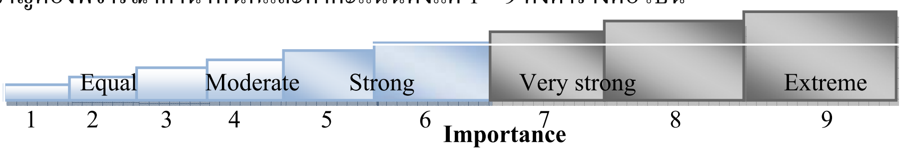
จัดทำโดย

นางสาวกัลยา เทียนวงศ์
สาขาวิชาการรับรู้จากระยะไกล
สำนักวิชาวิทยาศาสตร์ มหาวิทยาลัยเทคโนโลยีสุรนารี

ชื่อ-นามสกุล...ตำแหน่ง..................................
ระดับ .... สถานที่ปฏิบัติงาน...
ฝ่าย .... กอง...
กรม .... กระทรวง ....

คำชี้แจง การวิเคราะห์หาที่ตั้งที่เหมาะสมกับโรงงานผลิตเอธานอล ในจังหวัดกาญจนบุรี ซึ่งเป็นวัตถุประสงค์ประการหนึ่งในการทำวิทยานิพนธ์เรื่อง การประยุกต์เทคโนโลยีภูมิสารสนเทศในการประเมินหาพื้นที่เหมาะสมสำหรับปลูกพืชเศรษฐกิจที่ให้พลังงานในภาคตะวันตกของประเทศไทย

โดยแบบสอบถามชุดนี้มีความต้องการข้อมูลทั้งค่าคะแนนของค่าน้ำหนัก (Weight) ความสำคัญของปัจจัย และค่าคะแนนความเหมาะสมของช่วงปัจจัย (Rating) ซึ่งจะนำไปใช้วิเคราะห์โดยใช้เทคนิคกระบวนการแบบลำดับชั้นเชิงวิเคราะห์ หรือ Analytical Hierarchical Process (AHP) ซึ่งเป็นหนึ่งในวิธีการตัดสินใจแบบหลายเกณฑ์ (Multicriteria Decision Method) และใช้เทคนิคการเปรียบเทียบปัจจัยเป็นรายคู่ หรือ Pairwise Comparison จึงได้นำมาประยุกต์กับการหาที่ตั้งที่เหมาะสมของโรงงานผลิตเอาธานอล ในจังหวัดกาญจนบุรี และมีค่าคะแนนที่ผู้เชี่ยวชาญต้องพิจารณาค่าน้ำหนักและค่าคะแนนตั้งแต่ 1 – 9 ดังตารางต่อไปนี้



เกณฑ์มาตรฐานที่ใช้ในการเปรียบเทียบความสำคัญของค่าน้ำหนัก

ค่าความสำคัญ	ความหมาย	คำอธิบาย
1	มีความสำคัญเท่ากัน (Equal Importance)	ปัจจัยทั้งสองที่กำลังพิจารณาเปรียบเทียบมีความสำคัญเท่าเทียมกัน (Two activities contribute equally to the objective)
3	มีความสำคัญมากกว่าพอประมาณ (Moderate Importance)	ปัจจัยที่กำลังพิจารณาเปรียบเทียบ มีความสำคัญมากกว่าปัจจัยตัวหนึ่งพอประมาณ (Experience and judgements slightly favour one activity over another)
5	มีความสำคัญมากกว่าอย่างเด่นชัด (Strong Importance)	ปัจจัยที่กำลังพิจารณาเปรียบเทียบมีความสำคัญมากกว่าปัจจัยอีกตัวหนึ่งอย่างเด่นชัด (Experience and judgements strongly favour one activity over another
7	มีความสำคัญมากกว่าอย่างเด่นชัด (Very strong or demonstrated importance)	ปัจจัยที่กำลังพิจารณาเปรียบเทียบ มีความสำคัญมากกว่าปัจจัยอีกตัวหนึ่งอย่างเด่นชัดมาก (An activity is favoured very strongly over another and dominance is demonstrated in practice)
9	มีความสำคัญมากกว่าอย่างยิ่ง (Extreme Importance)	ค่าความสำคัญสูงสุดที่จะเป็นไปได้ ในการพิจารณาเปรียบเทียบปัจจัยทั้งสอง (The evidence favouring one activity over another is of the highest possible order of affirmation)
2, 4, 6, 8	เป็นค่าความสำคัญระหว่างกลางของค่าที่กล่าวไว้ข้างต้น	ค่าความสำคัญในการเปรียบเทียบปัจจัย ถูกพิจารณาว่าควรเป็นค่าระหว่างกลางของค่าที่กล่าวไว้ข้างต้น

ตัวอย่างการตอบแบบสอบถาม

จากแบบสอบถามที่แสดงไว้เป็นตัวอย่างนี้ ผู้ตอบแบบสอบถามจะต้องพิจารณาให้ค่าความสำคัญของปัจจัยเมื่อเปรียบเทียบกับปัจจัยตัวอื่นในแต่ละแถวของตาราง ตัวอย่างเช่นการพิจารณาให้ค่าความสำคัญของปัจจัยในแถวแรกของตาราง ท่านจะต้องพิจารณาดูว่าปัจจัย A1 มีความสำคัญมากกว่าปัจจัย A2 มากน้อยเพียงใด

ถ้าท่านคิดว่าปัจจัย A1 มีความสำคัญมากกว่าปัจจัย A2 อย่างเด่นชัดมาก ท่านก็ให้ค่าความสำคัญเป็น 7 ในคอลัมน์ของช่อง มากกว่า ในตารางแบบสอบถามหรือ

ถ้าท่านคิดว่าปัจจัย A1 มีความสำคัญน้อยกว่าปัจจัย A3 อย่างพอประมาณ ท่านก็ให้ค่าความสำคัญเป็น 3 ในคอลัมน์ของช่อง น้อยกว่า ในตารางแบบสอบถาม

ถ้าท่านคิดว่าปัจจัย A2 มีความสำคัญน้อยกว่าปัจจัย A3 อย่างยิ่ง ท่านก็ให้ค่าความสำคัญเป็น 9 ในคอลัมน์ของช่องน้อยกว่า ในตารางแบบสอบถาม

ปัจจัย	การเปรียบเทียบค่าคะแนนมาตรฐานปัจจัย																	ปัจจัย
	มากกว่า								เท่ากัน	น้อยกว่า								
A1	9	8	⑦	6	5	4	3	2	1	2	3	4	5	6	7	8	9	A2
A1	9	8	7	6	5	4	3	2	1	2	③	4	5	6	7	8	9	A3
A2	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	⑨	A3

....

คำอธิบายปัจจัยสำหรับพิจารณาการให้ค่าน้ำหนักความสำคัญและค่าคะแนนของช่วงปัจจัย

ปัจจัยที่ใช้ในการศึกษา	ความสำคัญของปัจจัย
1.ปัจจัยด้านภูมิประเทศ (Topography)	ลักษณะภูมิประเทศมีอิทธิพลต่อการเลือกที่ตั้งของโรงงานอุตสาหกรรม จังหวัดกาญจนบุรีมีลักษณะภูมิประเทศประกอบไปด้วย 3 ลักษณะคือเขตภูเขาและที่สูงอยู่ทางตอนเหนือและทางตะวันตก เขตที่ราบลูกฟูกเป็นที่ราบเชิงเขาสลับกับเนินเขาเตี้ย ๆ อยู่ทางตะวันออกเฉียงเหนือของจังหวัดและเขตที่รายลุ่มแม่น้ำจะอยู่ทางทิศใต้ของจังหวัด ดังนั้นปัจจัยที่เป็นตัวแทนนำมาประกอบการพิจารณาคือ **ความสูงของพื้นที่ (Elevation)**:จังหวัดกาญจนบุรีมีระดับความสูงจากระดับน้ำทะเลปานกลางตั้งแต่ 100 เมตรในทางตอนล่างของจังหวัดและมากกว่า 1,000 เมตรในพื้นที่ตอนกลางถึงตอนบนของจังหวัด และจากแนวคิดด้านผังเมืองวามสูงต่ำของพื้นที่มีผลต่อที่ตั้งของโรงงาน
2.ปัจจัยด้านที่ตั้งของแหล่งวัตถุดิบ (Raw Material Sources)	แหล่งวัตถุดิบที่นำมาใช้ในการผลิตเอธานอลนั้น เนื่องจากจังหวัดกาญจนบุรีมีศักยภาพต่อการจัดตั้งโรงงานดังกล่าวเนื่องจากมีวัตถุดิบที่สำคัญคือคือกากน้ำตาล เพราะเป็นจังหวัดที่มีโรงงานตั้งอยู่มาก ประกอบกับมีลักษณะภูมิประเทศที่เหมาะกับการปลูกอ้อยโรงงาน และมันสำปะหลัง ซึ่งเป็นแหล่งวัตถุดิบที่นำมาใช้ในการผลิตได้เป็นอย่างมาก ดังนั้นปัจจัยที่นำมาพิจารณาคือ 2.1 ระยะห่างจากโรงงานน้ำตาล 2.2 ระยะห่างจากลานรับซื้อมันสำปะหลัง 2.3 พื้นที่เหมาะสมกับการปลูกอ้อย 2.4 พื้นที่เหมาะสมกับการปลูกมันสำปะหลัง
3.ปัจจัยด้านความใกล้ (Proximity) หรือปัจจัยด้านการตลาด	ความใกล้ในการศึกษานี้จะเป็นการแทนด้านการตลาดอันเนื่องมาจากความสะดวกการขนส่ง ความใกล้กับแหล่งรับซื้อผลผลิตทำให้สามารถขนส่งสินค้าได้สะดวก รวดเร็วทำให้ต้นทุนการขนส่งต่ำดังนั้นปัจจัยที่นำมาเป็นตัวแทนคือ 3.1 ระยะห่างจากเส้นทางคมนาคม (Distance to Transport Network) ความยากง่ายในการขนส่งออกจากโรงงานผลิตเอธานอล โดยใช้เส้นทางถนนเป็นหลัก ซึ่งมีผลต่อมูลค่าราคาการขนส่งลำเลียงและที่สำคัญคือสามารถขนส่งสินค้าไปยังแหล่งโรงงานกลั่นน้ำมันหรือผลิตGasohol
4.ปัจจัยด้านแหล่งน้ำสนับสนุน (Water Supply)	น้ำเป็นปัจจัยที่มีความสำคัญกับกระบวนการผลิตชะล้างทำความสะอาดและในภาพรวมอุตสาหกรรมมีความจำเป็นต้องการใช้น้ำปริมาณมาก 4.1 ปริมาณน้ำใต้ดิน(แกลลอน/นาที) เป็นตัวแทนของแหล่งน้ำสำรองที่ใช้ในอุตสาหกรรม 4.2 แหล่งน้ำผิวดิน เช่นเดียวกับปัจจัยข้างต้นที่สามารถทำมาใช้ในการผลิต และการตั้งโรงงานที่มีผลต่อสารพิษที่จะไหลซึมไปยังแหล่งน้ำ **หมายเหตุ:** พิจารณาในแง่ของประโยชน์ต่อโรงงาน

ปัจจัยที่ใช้ในการศึกษา	ความสำคัญของปัจจัย
5.ปัจจัยด้านสิ่งแวดล้อม (Environment)	6.1 ระยะห่างจากแม่น้ำมีผลต่อคุณภาพของน้ำเพราะถ้ามีสารพิษที่สามารถซึมได้และการปล่อยน้ำเสีย 6.2 ระยะห่างจากถนน ซึ่งมีผลต่อทัศนียภาพ การมองเห็น ความสะดวกต่อการสัญจร **หมายเหตุ:** พิจารณาในแง่ผลกระทบต่อสิ่งแวดล้อม
6.ปัจจัยด้านสิ่งแวดล้อม (Environment)	6.3 แหล่งชุมชนหรือเขตที่อยู่อาศัยเป็นเขตที่อยู่อาศัยของประชาชน 6.4 ระยะห่างจากที่ตั้งสาธารณสถานสาธารณสถาน ซึ่งเป็นที่ที่ใช้ประโยชน์ร่วมกันเป็นปัจจัยในการตั้งโรงงาน ซึ่งเป็นปัจจัยที่มีความจำเป็นในการส่งเสริม-ดำรงรักษาสถานที่หรือวัตถุที่มีประโยชน์ หรือคุณค่าทางศิลปกรรม สถาปัตยกรรม ประวัติศาสตร์ หรือโบราณคดี ซึ่งเมื่อตั้งโรงงานจะต้องไม่ก่อให้เกิดความรำคาญต่อสาธารณสถาน ประกอบด้วย - โรงเรียนหรือสถาบันการศึกษาต่าง ๆ - ศาสนสถานหรือวัด --สถานที่ราชการ

....

ตอนที่ 1 ท่านคิดว่าปัจจัยแต่ละปัจจัยมีความสำคัญอย่างไรของปัจจัยหลัก และให้พิจารณาเปรียบเทียบระดับของความสำคัญเป็นรายคู่ของระดับปัจจัยที่อยู่ทางด้านซ้ายมือของแถวเปรียบเทียบกับระดับปัจจัยที่อยู่ทางด้านขวาของบรรทัดเดียวกันโดย ☒ บนหมายเลขค่าคะแนนตั้งแต่ระดับ 1 – 9 ที่กำหนดให้จนครบทุกคู่ของปัจจัย

ปัจจัย	การเปรียบเทียบค่าคะแนนมาตรฐานของปัจจัย																	ปัจจัย
	มีความสำคัญมากกว่า								เท่ากัน	มีความสำคัญน้อยกว่า								
ภูมิประเทศ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ที่ตั้งแหล่งวัตถุดิบ
ภูมิประเทศ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ความใกล้/การตลาด
ภูมิประเทศ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	แหล่งน้ำสนับสนุน
ภูมิประเทศ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	สิ่งแวดล้อม
ที่ตั้งแหล่งวัตถุดิบ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ความใกล้/การตลาด
ที่ตั้งแหล่งวัตถุดิบ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	แหล่งน้ำสนับสนุน
ที่ตั้งแหล่งวัตถุดิบ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	สิ่งแวดล้อม
ที่ตั้งแหล่งวัตถุดิบ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	สังคม
ความใกล้/การตลาด	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	แหล่งน้ำสนับสนุน
ความใกล้/การตลาด	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	สิ่งแวดล้อม
แหล่งน้ำสนับสนุน	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	สิ่งแวดล้อม

ตอนที่ 2 ท่านคิดว่าปัจจัยแต่ละปัจจัยมีความสำคัญอย่างไรของปัจจัยในกลุ่มหลัก และให้พิจารณาเปรียบเทียบระดับของความสำคัญเป็นรายคู่ของระดับปัจจัยที่อยู่ทางด้านซ้ายมือของแถวเปรียบเทียบกับระดับปัจจัยที่อยู่ทางด้านขวาของบรรทัดเดียวกันโดย ☒ บนหมายเลขค่าคะแนนตั้งแต่ระดับ 1 – 9 ที่กำหนดให้จนครบทุกคู่ของปัจจัย

1. ปัจจัยด้านลักษณะภูมิประเทศ (Topography)

ปัจจัย	การเปรียบเทียบค่าคะแนนมาตรฐานของปัจจัย																	ปัจจัย
	มีความสำคัญมากกว่า								เท่ากัน	มีความสำคัญน้อยกว่า								
- ความสูงของพื้นที่	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	-ความสูงของพื้นที่

2. ปัจจัยด้านแหล่งวัตถุดิบ (Material Sources)

ปัจจัย	การเปรียบเทียบค่าคะแนนมาตรฐานของปัจจัย																	ปัจจัย
	มีความสำคัญมากกว่า								เท่ากัน	มีความสำคัญน้อยกว่า								
- ระยะห่างจากโรงงานน้ำตาล	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	-ระยะห่างจากลานรับซื้อมันสำปะหลัง
- ระยะห่างจากโรงงานน้ำตาล	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	- พื้นที่เหมาะสมกับการปลูกอ้อย
- ระยะห่างจากโรงงานน้ำตาล	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	- พื้นที่เหมาะสมกับการปลูกมันสำปะหลัง
- ระยะห่างจากลานรับซื้อมันสำปะหลัง	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	- พื้นที่เหมาะสมกับการปลูกอ้อย
- ระยะห่างจากลานรับซื้อมันสำปะหลัง	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	- พื้นที่เหมาะสมกับการปลูกมันสำปะหลัง
- พื้นที่เหมาะสมกับการปลูกอ้อย	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	- พื้นที่เหมาะสมกับการปลูกมันสำปะหลัง

3. ปัจจัยด้านความใกล้ หรือด้านการตลาด (Proximity/Marketing)

ปัจจัย	การเปรียบเทียบค่าคะแนนมาตรฐานของปัจจัย																	ปัจจัย
	มีความสำคัญมากกว่า								เท่ากัน	มีความสำคัญน้อยกว่า								
- ระยะห่างจากเส้นทางคมนาคม	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**- ระยะห่างจากเส้นทางคมนาคม**

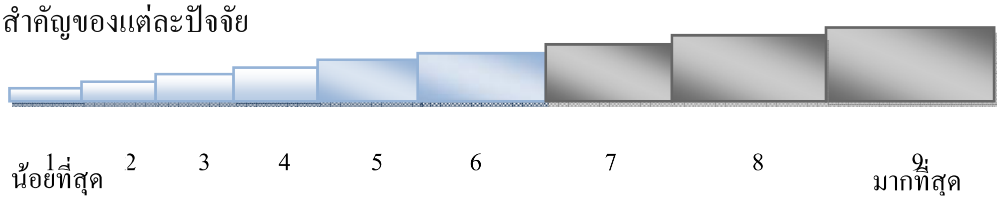
4. ปัจจัยด้านแหล่งน้ำสนับสนุน (Water Supply)

ปัจจัย	การเปรียบเทียบค่าคะแนนมาตรฐานของปัจจัย																	ปัจจัย
	มีความสำคัญมากกว่า								เท่ากัน	มีความสำคัญน้อยกว่า								
แหล่งน้ำผิวดิน	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	แหล่งน้ำผิวดิน

5. ปัจจัยด้านสิ่งแวดล้อม (Environment)

ปัจจัย	การเปรียบเทียบค่าคะแนนมาตรฐานของปัจจัย																	ปัจจัย
	มีความสำคัญ								เท่ากัน	มีความสำคัญ								
ระยะห่างจากแม่น้ำ	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ระยะห่างจากถนน
แหล่งชุมชน/ที่อยู่อาศัย	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	ระยะห่างจากสาธารณสถาน

ตอนที่ 2 การให้ค่าคะแนน (Rating Score) ความสำคัญของช่วงปัจจัยที่มีผลต่อการตั้งโรงงานผลิตเอธานอล โดยให้ท่านเติมหมายเลขตั้งแต่ 1 – 9 ลงในช่องว่างที่กำหนดให้ตามที่ท่านเห็นความสำคัญของแต่ละปัจจัย



ปัจจัยที่ใช้ในการศึกษา	ระดับของปัจจัย	ค่าคะแนน(1-9)
1.ปัจจัยด้านภูมิประเทศ (Topography)	1.1 ความสูงของพื้นที่	
	0 – 100 เมตร	....
	> 100 – 500 เมตร	....
	> 500 – 1000 เมตร	....
	>1000 – 1500 เมตร	....
	> 1500 เมตร ขึ้นไป	....
2. ปัจจัยด้านแหล่งวัตถุดิบ (Raw Material Sources)	2.1 ระยะห่างจากโรงงานน้ำตาล	
	< 50 กิโลเมตร	....
	> 50-75 กิโลเมตร	....
	> 75-100 กิโลเมตร	....
	>100 กิโลเมตร ขึ้นไป	....
	2.2 ระยะห่างจากลานรับซื้อมันสำปะหลัง	
	< 50 กิโลเมตร	....
	> 50-75 กิโลเมตร	....
	> 75-100 กิโลเมตร	....
	>100 กิโลเมตร ขึ้นไป	....

ปัจจัยที่ใช้ในการศึกษา	ระดับของปัจจัย	ค่าคะแนน(1-9)
	2.3 ระยะห่างจากพื้นที่ปลูกอ้อย < 50 กิโลเมตร > 50-75 กิโลเมตร > 75-100 กิโลเมตร >100 กิโลเมตร ขึ้นไป	 ....
2. ปัจจัยด้านแหล่งวัตถุดิบ **(Raw Material Sources)**	2.4 พื้นที่ปลูกมันสำปะหลัง < 50 กิโลเมตร > 50-75 กิโลเมตร > 75-100 กิโลเมตร >100 กิโลเมตร ขึ้นไป	 ....
3. ปัจจัยด้านความใกล้/การตลาด **(Proximity/ Marketing)**	3.1 ระยะห่างจากเส้นทางคมนาคม < 0 – 5 กิโลเมตร > 5 – 10 กิโลเมตร > 10 – 50 กิโลเมตร > 50 – 100 กิโลเมตร > 100 กิโลเมตร	 ....
4. ปัจจัยด้านแหล่งน้ำสนับสนุน	4.1 ระยะห่างจากแหล่งน้ำผิวดิน 100-200 เมตร > 200 – 300 เมตร > 300 – 500 เมตร > 500 – 1000 เมตร > 1000 ขึ้นไป	 ....
6.ปัจจัยด้านสิ่งแวดล้อม **(Environment)**	6.1 ระยะห่างจากแม่น้ำ 0-50 เมตร > 50 – 150 เมตร > 150-300 เมตร >300-500 เมตร > 500-1000 เมตร > 1000 เมตรขึ้นไป	 ....
	6.2 ระยะห่างจากเส้นทางคมนาคม 0-50 เมตร > 50 – 150 เมตร > 150-300 เมตร >300-500 เมตร > 500-1000 เมตร > 1000 เมตรขึ้นไป	 ....

ปัจจัยที่ใช้ในการศึกษา	ระดับของปัจจัย	ค่าคะแนน(1-9)
	6.3 ระยะห่างจากแหล่งชุมชน	
	0-100 เมตร	....
	>100-500 เมตร	....
	>500-1000 เมตร	....
	> 100 เมตร ขึ้นไป	....
	6.4 ระยะห่างจากสาธารณสถาน	
	0-100 เมตร	....
	>100-500 เมตร	....
	>500-1000 เมตร	....
	> 100 เมตร ขึ้นไป	....

ข้อเสนอแนะ:..
....
....
....

ขอขอบพระคุณอย่างสูง

กัลยา เทียนวงศ์

ผู้ศึกษาวิจัย

CURRICULUM VITAE

Kanlaya Tienwong was born on March 22, 1976. She obtained BA in major of social study from the Faculty of Education, Silpakorn University in 1998, and MA in Industry Geography from the Faculty of Arts, Silpakorn University in 2003. She has received a scholarship for her Ph.D. from The Royal Thai Government Scholarship (The Commission on Higher Education). Her main research interests lies in land use/land cover change and land evaluation for energy economic crops.