การสร้างแบบจำลองสารสนเทศภูมิศาสตร์แบบบูรณาการเพื่อการวางแผนการใช้ที่ดินสำหรับการเกษตร-อุตสาหกรรมอย่างยั่งยืน: กรณีศึกษาจังหวัดพระนครศรีอยุธยา

นางสาวสุรีพร จรุงธนะกิจ

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
สาขาวิชาภูมิสารสนเทศ
มหาวิทยาลัยเทคโนโลยีสุรนารี
ปีการศึกษา 2553

AN INTEGRATED GIS-BASED MODELING FOR SUSTAINABLE INDUSTRIAL-AGRICULTURAL LAND-USE PLANNING: CASE STUDY OF PHRA NAKHON SI AYUTTHAYA PROVINCE

Suriporn Charungthanakij

A Thesis Submitted in Partial Fulfillment of the Requirements for the

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AN INTEGRATED GIS-BASED MODELING FOR SUSTAINABLE INDUSTRIAL-AGRICULTURAL LAND-USE PLANNING: CASE STUDY OF PHRA NAKHON SI AYUTTHAYA PROVINCE

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

Thesis Examining Committee

Suwit Ong.

(Asst. Prof. Dr. Suwit Ongsomwang)

Chairperson

S. Sarapirome

(Asst. Prof. Dr. Sunya Sarapirome)

Member (Thesis Advisor)

Kaew Nualchawee

(Assoc. Prof. Dr. Kaew Nualchawee)

Member

Wichai Srikam

(Assoc. Prof. Dr. Wichai Srikam)

Member

(Dr. Surachai Ratanasermpong)

Member

P. Manyum

(Assoc. Prof. Dr. Prapun Manyum)

Dean of Institute of Science

(Dr. Wut Dankittikul)

Acting Vice Rector for Academic Affairs

สุรีพร จรุงธนะกิจ : การสร้างแบบจำลองสารสนเทศภูมิศาสตร์แบบบูรณาการเพื่อการวางแผนการใช้ที่ดินสำหรับการเกษตร-อุตสาหกรรมอย่างยั่งยืน: กรณีศึกษาจังหวัดพระนครศรีอยุธยา (AN INTEGRATED GIS-BASED MODELING FOR SUSTAINABLE INDUSTRIAL-AGRICULTURAL LAND-USE PLANNING: CASE STUDY OF PHRA NAKHON SI AYUTTHAYA PROVINCE) อาจารย์ที่ปรึกษา : ผู้ช่วยศาสตราจารย์ ดร.สัญญา สราภิรมย์, 234 หน้า.

การวิจัยนี้มีวัตถุประสงค์หลักเพื่อพัฒนาแบบจำลองสารสนเทศภูมิศาสตร์แบบบูรณาการเพื่อการวางแผนการใช้ที่ดินสำหรับการเกษตร-อุตสาหกรรมอย่างยั่งยืน เป็นเครื่องมือใหม่เพื่อใช้ในการประเมินและทำนายค่าดัชนีความยั่งยืนในด้านเศรษฐกิจ สังคม สิ่งแวดล้อมและดัชนีโดยรวมของการใช้ที่ดินในแผนการใช้ที่ดินจำลองรูปแบบต่างๆ (land-use scenarios) ในระดับท้องถิ่นโดยใช้จังหวัดพระนครศรีอยุธยาเป็นพื้นที่ศึกษา การศึกษานี้ ได้นำเสนอแบบจำลองการใช้ที่ดินอย่างยั่งยืนที่สร้างขึ้นโดยใช้สมการถดถอยแบบถ่วงน้ำหนักทางภูมิศาสตร์ (Geographically Weighted Regression Sustainability Model) ใน 4 ด้าน คือ ด้านเศรษฐศาสตร์ (EGWRSM) ด้านสังคม (SGWRSM) ด้านสิ่งแวดล้อม (EnGWRSM) และด้านภาพรวม (TGWRSM) การศึกษานี้ใช้กระบวนการวิเคราะห์ที่ต่อเนื่องกันเป็นลูกโซ่เพื่อให้บรรลุเป้าหมายหลักของการศึกษา กระบวนการเหล่านี้ประกอบด้วย (1) การประเมินความเหมาะสมของการใช้ที่ดิน (2) การจัดสรรการใช้ที่ดิน (3) การประเมินดัชนีความยั่งยืนของที่ดิน (4) การสร้างแบบจำลองและการทำนายค่าดัชนีความยั่งยืนของที่ดิน

ผลของการประเมินความเหมาะสมของการใช้ที่ดิน แสดงให้เห็นว่าเกือบร้อยละ 80 ของพื้นที่ศึกษาเหมาะสมสำหรับการเกษตร และประมาณร้อยละ 70 ของพื้นที่เหมาะสมสำหรับอุตสาหกรรม พื้นที่เหมาะสมนี้ได้นำไปใช้ในการจัดสรรตามนโยบายจำลองการใช้ที่ดิน 4 รูปแบบซึ่งมีความแตกต่างที่มุ่งส่งเสริมเกษตรกรรม (แบบที่ 1) หรืออุตสาหกรรม (แบบที่ 2) หรือแบบประสมประสานที่เน้นเกษตรกรรม (แบบที่ 3) หรือเน้นอุตสาหกรรม (แบบที่ 4)

ดัชนีความยั่งยืนพัฒนาขึ้นโดยใช้เทคนิคการวิเคราะห์องค์ประกอบ (factor analysis) โดยใช้ข้อมูลกชช 2ค และจปฐ ของปี พ.ศ. 2550 ซึ่งประกอบด้วย ดัชนีความยั่งยืนทางเศรษฐกิจ (CESI) ทางสังคม (CSSI) ทางสิ่งแวดล้อม (CEnSI) และดัชนีความยั่งยืนโดยรวม (CTSI) จากนั้นทำการสร้างความสัมพันธ์ของดัชนีความยั่งยืนต่างๆ ที่ได้รับกับสัดส่วนการใช้ที่ดินด้วยการวิเคราะห์ถดถอยแบบถ่วงน้ำหนักทางภูมิศาสตร์ (GWR) โดยให้ชื่อว่า แบบจำลองความยั่งยืนแบบถ่วงน้ำหนักทางภูมิศาสตร์(GWRSM) และเปรียบเทียบกับแบบจำลองความยั่งยืนแบบกำลังสอง

น้อยที่สุดปกติ (OLSSM) ผลการศึกษาพบว่า การใช้แบบจำลองความยั่งยืนแบบถ่วงน้ำหนักทางภูมิศาสตร์(GWRSM) มีสมรรถนะที่สูงกว่า แบบจำลองความยั่งยืนแบบกำลังสองน้อยที่สุดปกติ (OLSSM)

ในส่วนสุดท้าย ได้ทำการเปรียบเทียบผลการทำนายดัชนีความยั่งยืนของพื้นที่ตามนโยบายจำลองการใช้ที่ดินทั้ง 4 รูปแบบ และพบว่าการใช้ที่ดินรูปแบบที่1 ให้ค่าดัชนีความยั่งยืนดีที่สุดในด้านสิ่งแวดล้อม ในขณะที่รูปแบบที่ 2 ให้ค่าดัชนีความยั่งยืนดีที่สุดในด้านเศรษฐกิจ สังคมและภาพรวม ผลการศึกษาเสนอแนะได้ว่านักวางแผนการใช้ที่ดินควรเลือกการใช้ที่ดินรูปแบบที่ 2 หากต้องการกระตุ้นการพัฒนาด้านเศรษฐกิจ สังคมและการพัฒนาโดยรวม อย่างไรก็ตามการใช้ที่ดินรูปแบบที่ 1 ควรจะนำมาใช้ หากพิจารณาในด้านสิ่งแวดล้อมเป็นสำคัญ

สาขาวิชาการรับรู้จากระยะไกล ลายมือชื่อนักศึกษา________________

ปีการศึกษา 2553 ลายมือชื่ออาจารย์ที่ปรึกษา________________

SURIPORN CHARUNGTHANAKIJ : AN INTEGRATED GIS-BASED MODELING FOR SUSTAINABLE INDUSTRIAL-AGRICULTURAL LAND-USE PLANNING: CASE STUDY OF PHRA NAKHON SI AYUTTHAYA PROVINCE. THESIS ADVISOR : ASST. PROF. SUNYA SARAPIROME, Ph.D. 234 PP.

LAND SUITABILITY/ LAND-USE PLANNING/ SUSTAINABILITY ASSESSMENT/ SUSTAINABILITY INDEX/ SUSTAINABILITY MODELING

The main objectives of this research were to develop the integrated GIS-based models for sustainability industrial-agricultural land-use planning as the new tools for assessing and predicting the sustainability indexes in economic, social, environment, and total sustainability aspects of the different land-use scenarios at local level. Phra Nakhon Si Ayutthaya province was selected to be the study area. This study introduced the Geographically Weighted Regression Sustainability Models (GWRSM) in four aspects which were economics (EGWRSM), social (SGWRSM), environment (EnGWRSM), and total sustainability (TGWRSM). To achieve the ultimate goal of the study, four main processes were integrated as a chain. They were (1) land suitability assessments (2) land allocations (3) sustainability index assessments (4) sustainability index modeling and predictions.

The results of land suitability assessment showed that almost 80% of the study area was suitable for agriculture. About 70% of the area was suitable for industries. The results were compromised to allocate areas for four different land-use scenarios of different policies, which were promotions of agriculture, industries, and their combinations with orientation of either one.

The sustainability indexes (SIs) were developed using factor analysis based on the NRD and BMN data of the year 2007 which were the current sustainability indexes of economics (CESI), social (CSSI), environment (CEnSI), and total sustainability (CTSI). Then, the relationships between the proportions of land-use types and CSIs of aspects were established through Geographically Weighted Regression Sustainability Models (GWRSM) and global Ordinary Least Square Sustainability Models (OLSSM). The result revealed that the GWRSMs showed better performance than the OLSSM.

Finally, the predicted sustainability indexes (PSIs) of four land-use scenarios were calculated and compared. As a result, the scenario I was the best for social aspect while the scenario II exhibited the best performance for economic, social, and total aspects. Thus, land-use planners are recommended to apply the scenario II as a guideline if they want to stimulate economic, social and overall sustainability. However, the scenario I should be applied if the environment sustainability is of serious concerned.

School of Remote Sensing Student's Signature S. Chanongthanakij

Academic Year 2010 Advisor's Signature S. Sarapirome

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Suriporn Charungthanakij

CONTENTS

Page

CHAPTER

CONTENTS (Continued)

Page

CONTENTS (Continued)

Page

CONTENTS (Continued)

Page

CONTENTS (Continued)

Page

CONTENTS (Continued)

Page

LIST OF TABLES

Table **Page**

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

Table **Page**

LIST OF TABLES (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF FIGURES (Continued)

LIST OF ABBREVIATIONS

ACEnSI = Accumulated Current Environment Sustainability Index

ACESI = Accumulated Current Economic Sustainability Index

ACSI = Accumulated Current Sustainability Index

ACSSI = Accumulated Current Social Sustainability Index

ACTSI = Accumulated Current Total Sustainability Index

AEnSI = Accumulated Environment Sustainability Index

AESI = Accumulated Economic Sustainability Index

AHP = Analytical Hierarchy Process

AIC/AICc = Akaike Information Criteria

APESI = Accumulated Predicted Economic Sustainability Index

APEnSI = Accumulated Predicted Environment Sustainability Index

APSI = Accumulated Predicted Sustainability Index

APSSI = Accumulated Predicted Social Sustainability Index

APTSI = Accumulated Predicted Total Sustainability Index

ASI = Accumulated Sustainability Index

ASSI = Accumulated Social Sustainability Index

ATSI = Accumulated Total Sustainability Index

BMN = Basic Minimum Need

BOI = Board of Investment of Thailand

LIST OF ABBREVIATIONS (Continued)

CDD = Community Development Department

CEnSI = Current Environment Sustainability Index

CERES = Coalition for Environmentally Responsible Economics

CESI = Current Economic Sustainability Index

CSD = Commission on Sustainable Development

CSI = Current Sustainability Index

CSSI = Current Social Sustainability Index

CTSI = Current Total Sustainability Index

CV = Cross-validation

DIW = Department of Industrial Works

DPT = Department of Public Works and Town& Country planning

EGWRSM = Economic Geographically Weighted Regression Sustainability Model

EnGWRSM = Environment Geographically Weighted Regression Sustainability Model

EnOLSSM = Environment Ordinary Least Square Sustainability Model

EnSM = Environment Sustainability Model

EOLSSM = Economic Ordinary Least Square Sustainability Model

ESDA = Exploratory Spatial Data Analysis

ESM = Economic Sustainability model

EU = European Union

FA = Factor Analysis

LIST OF ABBREVIATIONS (Continued)

FAO = Food and Agricultural Organization of the United Nations

GDP = Gross Domestic Product

GIS = Geographic Information System

GISTDA = Geo-Informatics and Space Technology Development Agency

GNP = Gross National Product

GPP = Gross Provincial Product

GWR = Geographically Weighted Regression

GWRSM = Geographically Weighted Regression Sustainability Model

HDI = Human Development Index

IEAT = Industrial Estates Authority of Thailand

ISEW = Index of Sustainable Economic Welfare

IUCN = The International Union for Conservation of Nature

KMO = Kaiser-Meyer-Olkin value

LDD = Land Development Department

LSCM = Land Suitability Combination Matrix

LULC = Land Use and Land cover

MCDA = Multi-Criteria Decision Analysis

Moran’s I = Moran’s Autocorrelation coefficient

NCSU = North Carolina State University

NESDB = National Economic and Social Development Board

NRD = National Rural Development

LIST OF ABBREVIATIONS (Continued)

NSO = National Statistical Office

OLS = Ordinary Least Square

PCA = Principal Components Analysis

PCD = Pollution Control Department

PEA = Provincial Electricity Authority

PEnSI = Predicted Environment Sustainability Index

PESI = Predicted Economic Sustainability Index

PSI = Predicted Sustainability Index

PSSI = Predicted Social Sustainability Index

PTSI = Predicted Total Sustainability Index

QOL = Quality of Life

RID = Royal Irrigation Department

SAW = Simple Additive Weighted

SD = Sustainability Development

SDI = Sustainability Development Indicators

SGWRSM= Social Geographically Weighted Regression Sustainability Model

SI = Sustainability Index

SMCDA = Spatial Multi-Criteria Decision Analysis

SOLSSM = Social Ordinary Least Square Sustainability Model

SPSS = Statistical Package for the Social Sciences

SSM = Social Sustainability Model

LIST OF ABBREVIATIONS (Continued)

SU = Silpakorn University

SUT = Suranaree University of Technology

TGWRSM= Total Geographically Weighted Regression Sustainability Model

TOLSSM= Total Ordinary Least Square Sustainability Model

TSI = Total Sustainability Index

TSM = Total Sustainability Model

UCLA = University of California, Los Angeles

UN = United Nations

UNCED = United Nations Conference on Environment and development

UNCSD = United Nations Commission for Sustainable Development

UNDP = United Nations Development Programme

UNEP = United Nations Environment Programme

WBCSD = World Business Council on Sustainable Development

WCED = World Commission on Environment and Development

WWF = World Wildlife Fund

CHAPTER I

INTRODUCTION

1.1 Introduction

Land is the non-renewable natural and fundamental resources on which almost all human activities take place. Human activities or interest often conflict one another in making use of the finite quantity of land. Land-use planning is therefore important and necessary to optimize the future sustainability of land. This study will propose an integrated GIS-based modeling for sustainable industrial-agricultural land-use planning of Phra Nakhon Si Ayuthaya Province as a case study.

1.2 Background problem

In developing countries, the land demand is increasing and the conflicts in land use frequently occur and become the major problems. According to the population, economics, and industrial growths, the agricultural land is constantly being converted into urban built-up and industrial areas without caring of land suitability and its sustainability. The growth of industrial sector is definitely one of the key factors indicating progress in economics and the standard of living whereas the growth in agricultural sector indicates the adequacy of food to maintain the basic quality of living. However, as a consequence the growth of industrial sector will cause more pollution to the environment than agricultural sector. Thus, the industrial promotion should be planned carefully while the agriculture should not be neglected.

Recently, with the growing concern of sustainability concept, it is important to advise the ways to manage land resources in manners covering economical, social, and environmental sustainability. Since the standard of living and quality of life are influenced by the activities of the land-use manner, therefore land management and land-use planning should be considered seriously to optimize, both conceptually and spatially, the agriculture and industrial areas and maximize the sustainability index.

The land suitability that indicates the potential of the area is the essential information in land-use allocation and land-use planning. The land suitability of agriculture will indicate how well of the land for the agriculture, while the land suitability of industry specifies the area where should be employed for industries. However, the previous works in land-use planning focus mainly on land suitability of specific land uses such as agriculture, forestry, grazing land, and even more specific on several alternative crops. Almost all of studies were interested in only either the land potential for industrial or the land suitability for agriculture. The integrated land-use planning cases are few. The results of these studies may not be the overall answer of land allocation and not be adequate to ensure the whole sustainable development. In practical, land-use planning needed to consider land suitability for agriculture and industry simultaneously.

To optimize, compromise conflicts, and maximize the benefit of land use, this study therefore aims at developing integrated GIS-based model to evaluate and allocate the lands for industry and agriculture relying on land suitability and development policies over the area with reference to sustainability approach. The study area selected should fall into the problematic criterion of the presence of conflict between agricultural and industrial development. To develop the spatial models, techniques in geographic information system (GIS), spatial multi-criteria decision analysis (SMCDA), and GIS-mathematical and statistical modeling were employed to this study.

1.3 Research objectives

The ultimate goal of the study is to develop the integrated GIS-based model for industrial-agricultural sustainable land-use planning.

The specific objectives are:

1. To assess the land suitability for agriculture and industry;
2. To establish the land allocation for alternative scenarios according to different policies;
3. To assess current sustainability index based on existing land use;
4. To develop sustainability model for industrial-agricultural land-use planning;
5. To predict and compare sustainability indexes of land uses based on the different alternative scenarios;
6. To recommend land-use planning according to sustainability indexes in aspects of economic, social, and environmental indicators.

1.4 Conceptual framework and scope of the study

This research attempts to present the new approach for land-use planning emphasizing on “integrated”. The meaning of “integrated” herein could be interpreted in many meanings. First, it means the integrated data and analyses. In this case the researcher attempted to integrate the suitability of major land uses within the study area. Industrial suitability and agricultural suitability are considered together in allocating the area for the best suitable activities. Also, the researcher tried to integrate all related factors altogether to develop the sustainability indices. The physical, economic, social and environment factors affecting sustainability of land usage were taken into account to indicate how sustainable the area is. Second, “integrated” means the integrated techniques. GIS, SMCDA, and the mathematical and statistical models such as SAW, AHP, and geographical weighted regression (GWR) were used altogether. Third, the study integrated many fields of knowledge such as the industrial location theory, agricultural land suitability, and the concept of sustainability in social sciences.

The research conceptual framework can be divided into six parts, namely land potential/suitability evaluation, land allocation process, current sustainability index assessment, sustainability modeling and prediction, comparison and recommendation for land-use planning result . Their flow relationship can be displayed as diagram in Figure 1.1. All parts and their relationships were explained in the structure of the dissertation at the end of this Chapter and the details of any parts were described in other Chapters.

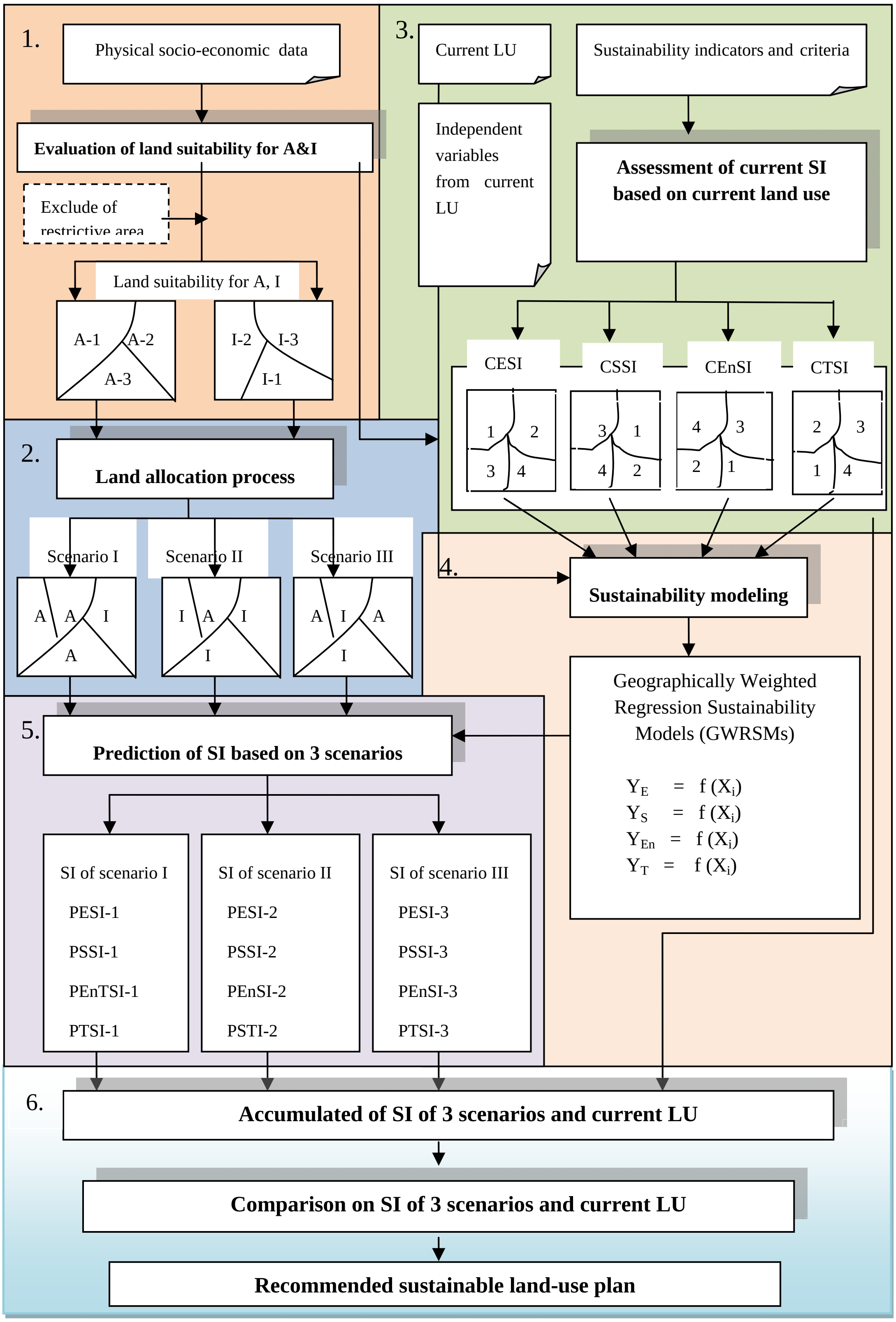


Figure 1.1 Conceptual framework of the study.

The results of the study included:

1. Land suitability for agriculture and industry;
2. The probable alternative 3 scenarios of land use;
3. Current sustainability index of existing land use;
4. The integrated GIS-based regression model for industrial-agricultural sustainable land-use planning;
5. Predicted sustainability indexes of land use in 3 scenarios;
6. Comparison of the alternative land-use scenarios using the cumulative sustainability index and recommendation on specific land-use plans of Phranakhon Si Ayutthaya based on predicted sustainability indexes of different policies.

The scope of the study was focused on the area of Phra Nakhon Si Ayutthaya Province. Land-use data and other data used in this research such as Basic Minimum Need (BMN) and National Rural Development (NRD) were the data in the year 2007. The term ‘C*urrent’* used in this study is based on the year 2007.

1.5 The study area

Phra Nakhon Si Ayutthaya province (Figure 1.2) is located in the central region of Thailand with 75 km. from Bangkok. It is composed of 16 districts covering the total area of 2.556.60 km^2 or 1,597,900 rai. (1 rai equal to 1,600 m^2). The population was 751,636 in January 2007. The Gross Provincial Product (GPP) was 345,549 million Baht in 2007 which increased from 53,973.169 million Baht in 1994. GPP per capita was 454,026 Baht/ person. (Phra Nakhon Si Ayutthaya Provincial Office, 2007).

The important economic sectors of the area are agriculture and industries. In 2007, about 287,244 million baht of GPP came from industrial sector and 7,011 million baht of GPP came from agricultural sector. From the total area of 1,597,900 rai, the agricultural area is 1,126,459 rai in 2006. Rice is the major crops, covering the area of 1,074,861 rai. Ladbualuang, Wangnoi, Bangsai, Ayutthaya, Sena, Bang pa-in, Bangban and Uthai districts have been declared to be the agricultural land reform since 2001. According to the industrial promotion policy, Phra Nakhon Si Ayutthaya Province is in the second zone of industrial promotion zone set up by the Broad of Investment (BOI). In 2006, there are three industrial estates in the province consisting of total 1,581 factories with the investment values of 263,407.32 million Baht and 211,455 labors. Both skilled and unskilled labors are required. Unskilled labors were flown from the outside into the industrial zone of the province. This causes the economical, social and environmental impact. While economic blooms, many social problems such as the criminal rate, drug, additive are increasing. The air and water were increasingly polluted as a consequence.

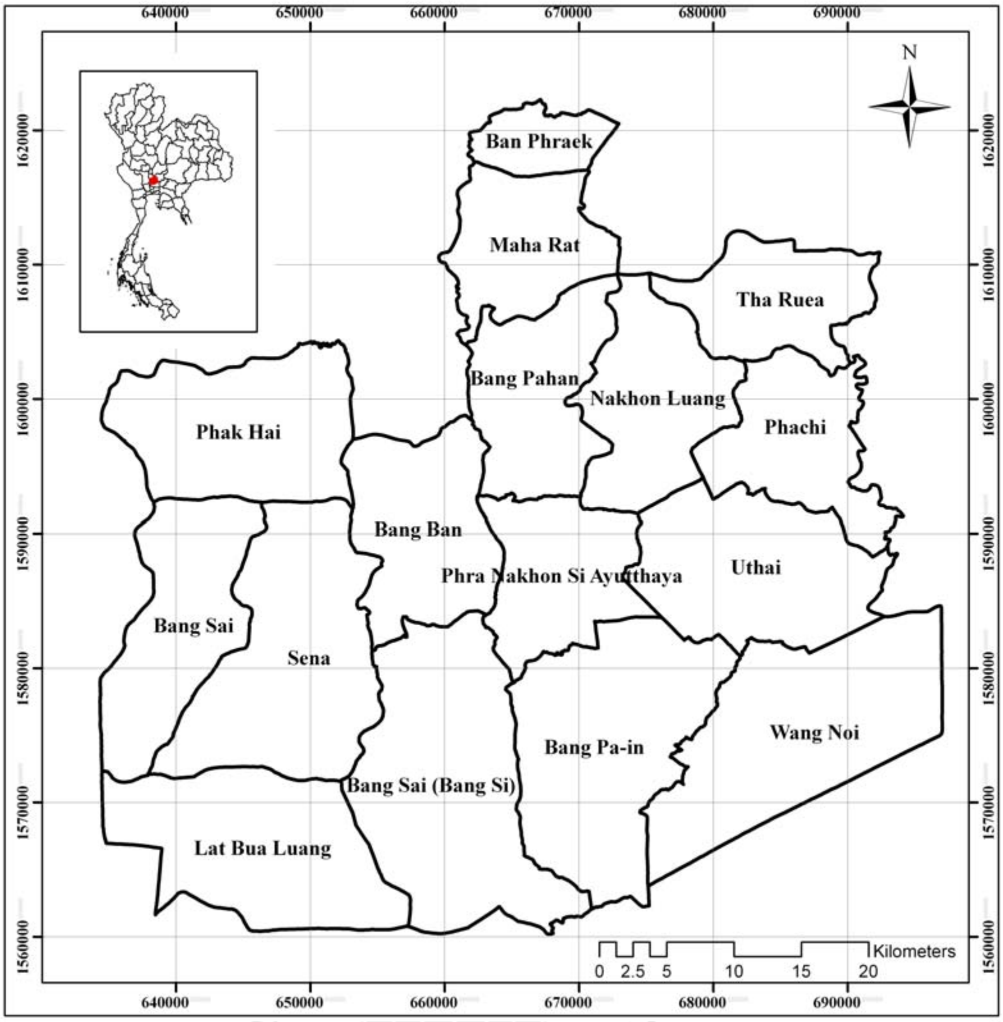


Figure 1.2 Map of the study area**,** Phra Nakhon Si Ayutthaya Province (Adopted from LDD).

Phra Nakhon Si Ayutthaya Province was selected to be the study area because of the presence of conflicts among various high potential themes of development within it. Apart from being historical and archeological world heritage, it was also the well-known area of being the centers of rice cultivation and industrial expansion overflow from Bangkok. According to the 9th (2002-2006) and 10th (2007-2011) national economic and social development plan, the goals of national development have concentrated more to sustainability concern together with the strategic planning

(National Economic and Social Development Board, 2007) of the province which aims at promoting the area to be centers of commerce, investment, and tourism as well as rice production (Phra Nakhon Si Ayutthaya Provincial Office, 2010). The required balance of land development should be carried out by allocating potential areas for all promising developments mentioned simultaneously.

1.6 Structure of the dissertation

According to the objectives of research and the conceptual framework, this dissertation can be divided into seven Chapters as follows:

In the first Chapter, the overview of the study including the background problem, research objectives, conceptual framework and the important characteristic of the study area are explained. This Chapter shows the relationship of all parts of the study and it can be the guideline to follow and understand all the next Chapters.

The second Chapter is about the review of concepts and previous studies that related to land suitability assessment, industrial location, quality of life, sustainability and land-use planning. It also mentions about the research orientation which attempted to integrate various fields of studies to create the new methodology and results by using the spatial techniques such as GIS, spatial multi-criteria decision analysis and geo-mathematical and statistical techniques altogether.

In the third Chapter, the land suitability assessment was accomplished to find the degree of land potential for agriculture and the industry. This Chapter describes the whole processes starting from the input GIS data layers used, methodology, and the results as maps. This Chapter provides the output that meets the first objective of the study. These results were used as the inputs of the land allocation process in the next Chapter.

The fourth Chapter attempted to allocate the land into two major sectors of land use, the land for agriculture and the land for the industry. As mentioned earlier the essential inputs are the land suitability maps from Chapter III. The land-use options are demonstrated in 3 scenarios namely, maximizing the agricultural area, maximizing the industrial area and optimizing the agricultural-industrial area. The rules for allocation were set up in form of the combination matrix between the land suitability of agriculture and the land suitability for industry .The results were used for sustainability prediction in the sixth Chapter.

The fifth Chapter presents the sustainability assessment process. The researcher attempted to develop the sustainability indices to specify how sustainable the area is. The indicators were categorized into the economic, social and environmental sustainability using the factor analysis technique. The result of this process was employed the sustainability modeling of the next Chapter.

In the sixth Chapter, the sustainability modeling was developed and used to predict the sustainability for each land-use scenario. The sustainability modeling was processed through the spatial statistical modeling and geographical weighted regression (GWR). Also, the predicted sustainability indices of different scenarios were calculated by GWR modeling.

The final Chapter is the conclusion and recommendation. The sustainability index of each scenario was compared and applied to recommendation in land-use planning. Recommendation for further research was suggested as well.

CHAPTER II

LITERATURE REVIEW

This part aims to review the previous studies of sustainability land-use planning. There are many concepts related in this study. Concepts, methodologies and techniques used in the previous studies were reviewed including (1) land-use planning, (2) land suitability and land evaluation, (3) Land allocation, (4) industrial location, (5) sustainability development, (6) previous studies of land-use planning, and (7) synthesis for the research approach

2.1 Land-use planning

Land use is a set of biological and technical human activities, engaged in economic and social purposes. These activities are directed towards the management and improvement of land resources (Vink, 1978). There are many different kinds of land use such as agricultural, industrial area, commercial area, residential area, forestry, and recreation area. Land-use types are classified by different criteria depend on the purposes of the study.

According to the limitation of land and the increasing in human activities due to the population growth, the conflicts of land use occurred. To reduce the conflicts and to use the land in sustainable way, land-use planning is needed.

Land-use planning is the systematic assessment of land and water potential, alternatives for land use, economic and social conditions in order to select and adopt the best land-use options (FAO, 1993). Land-use planning means the planning for the optimum use of the land considering the physiography, demand and other planning factors (FAO, 1993). Land-use planning aims to allocate land to different kinds of land uses by assessing present and future needs and systematically evaluating the land ability to supply them. It is needed to identifying and resolving conflicts between competing uses and serves the needs of present and future generation. Land-use planning should propose the sustainable options that best meet specific needs.

2.2 Land suitability and land evaluation

FAO (1976) defined land suitability as the fitness of a given type of land for a specified kind of land use. Vise versa, limitation is a land quality or its expression as a diagnostic criterion, which adversely affects the potential of land for a specified kind of use. Differences in the degree of suitability are determined by the relationship, actual or anticipated, between benefits and required inputs associated with the use on the trace in question (Brinkman, 1973).

Soil is one important parameter determining land suitability. Soil suitability is defined as physical suitability of soil for production of specific crops or group or sequence of crops, or for other defined uses or benefits, within a specified socio-economic context but not considering economic factors specific to areas of land. Investigations of the soil suitability are found useful for many purposes of land suitability predictions (Vink and Zuilen, 1974).

According to FAO (1993) land can be order into suitable and not suitable for the use under consideration. Suitable land can be classified into highly suitable (S1), moderately suitable (S2) and marginally suitable (S3).

Land evaluation is defined in different point of view such as FAO (1976) defined land evaluation is the process of assessment of land performance when used for specified purpose. Ceballos and Lopez (2003) stated that land evaluation is the systematic assessment of land potential to find out the most suitable area for cultivating some specific crops. Theoretically, the potential of land for agricultural use is usually determined by an evaluation process of climate, soil quality, water resources, topographical and environmental factors under criteria given and the local biophysical restraints.

There are many studies applied the FAO framework as a guideline in land suitability and land evaluation process. Geographic Information Systems (GIS) and many techniques were used in the land suitability assessment such as Pairwise comparison method and Analytical Hierarchical Process (AHP), one of the widely used techniques of Multi-Criteria Decision Analysis (MCDA). For examples, Lui, Lv, Qin, Guo, Yu, Wang, and Mao (2007) had assessed the land suitability in the Hanyang lake using AHP method to calculate the weights of criteria, including pairwise comparisons and weighting matrix establishment. Ceballos and Lopez (2003) had studied land suitability for maize and potato in Toluca, Central Mexico using Multi-criteria approach. Thapa and Murayama (2007) had evaluated land suitability for peri-urban agriculture in Hanoi city using AHP technique. Prakash (2003) had studied land suitability for rice in Dehradum district, India using AHP technique integrated with fuzzy logic. Also and Rivai (1997) had studied land suitability for residential areas in north Bandang, west Java using pairwise comparison method.

According to FAO (1993) framework, land can be evaluated in physical or economic term. Ideally, both a physical and economic land evaluation are undertaken.

A physical land evaluation is based only on physical factors that determine whether a Land Utilization Types (LUT) can be implemented on a land area, and the nature and severity of physical limitations or hazards. An economic land evaluation is based on some economic measure of net benefits, should a given LUT can be implemented on a given land area. The physical evaluation reveals the nature of limitations and hazards, which is useful information to the land manager; however, the economic evaluation reveals the expected economic benefits, which in general drive the decision making process (Rossiter, 1994).

Many studies had used both physical and economic factors but some studies used only the physical factors. However, the factors selected in the study should be considered due to the purposes of the studies. Reshmidevi, Eldho, and Jana (2009) used both physical and economic factors for land suitability evaluation in agricultural watersheds including soil texture, terrain slope, soil depth, drainage density, pH, CEC, OC, rainfall, temperature, elevation, proximity of surface water body, proximity of road, and land use. Prakash (2003) had studied land suitability for rice in Dehradum district, India using soil quality, climate, irrigation area, and some socio-economic factors such as market and infrastructure as parameters in land evaluation. Messing, Fagerstrom, Chen, and Fu (2003) had studied criteria for land suitability evaluation in a small catchment on the Loess Plateau in China. Soil properties and other information were considered to be relevant for his study including soil water content, soil nutrients, soil water storage capacity, rooting condition, tillage constraints, slope, aspect, infiltration capacity, slope gradient, and flooding hazard. Mahaxay (1996) had studied land suitability for rice and other crops for forest land-use planning. The parameters used for land suitability for paddy rice were both physical and economic factors including soil depth, soil texture, soil pH, soil nutrient, soil drainage, distance from village, and distance from rivers.

In Thailand, Karnchanasutham (1999) had evaluated land suitability for field crops, rice, rubber and fruit tree or other perennials for agricultural land-use zoning in Chantaburi province. In this study, soil quality, slope, water shortage risk and flood hazard were selected as parameters. Akter (2003) had studied land suitability for agriculture and industry for urban land planning in Khon Kaen province. The parameters used in agricultural land suitability were slope, aspect, elevation, soil quality, and distance from water body. In his study, suitable lands for industry were categorized into 4 classes and the area of class 1 or high suitable area is 8.21%, the moderately suitable area covers 34.23%. The study found that the high suitable area was along the road within acceptable distance of 300 meters and located in the north and west side of the province. According to the land-use planning guidelines, land suitability fro industry were permitted to allocate beside the road.

2.3 Land allocation

The term *land allocation* may be seen in two dimensions. Land allocation may be defined as the legal right on the area or parcel of particular land use provided by the government or land-use planner. In the other sense, which most used in the computer science, land allocation or land-use allocation were defined as the area assigned for the particular land-use such as residential area, farms, commercial by using various techniques of operation researches. According to the objective of this study, which emphasis at determining the agriculture area and industrial area by comparing its suitability, the latter were used. However, after the land allocation in the latter sense was applied, the result of land allocation in the first sense was then applied for land-use planning in practical.

As stated by Eldrandaly (2010), land-use planning is a special allocation problem, where the planner, by manipulating the proportions and locations of land uses, seeks to satisfy one or more goals. Land-use planning is a potentially challenging search and optimization task, as the planner must frequently take into account complex non-linear interactions between parcels of land allocated to particular land uses. In these circumstances, land-use allocation must try to reconcile multiple conflicting interests as rationally and transparently as possible, which, among other things, involves evaluating land units not only with regard to their suitability for competing uses but also with regard to such factors as contiguity among units assigned to the same use, and the compactness of the single-use land masses so created.

There are many studies tried to allocate land into appropriate uses in order to increase the overall land efficiency. Multi-Objective Decision Analysis (MODA) was a widely technique used in land allocation process. Multi-objective decision problems refer to the problems that have a very large number of feasible alternatives, where the objectives and constraints are functionally related to the decision variables. Therefore, this category of multi-criteria approaches involves designing the alternatives and searching for the best decision among an infinite or very large set of feasible alternatives. Each alternative is defined implicitly in terms of the decision variables and evaluated by means of objective functions (Malczewski, 1999). Multi-site Land-use Allocation Problems (MLUAs) which refer to the problem of allocating more than one land-use type in an area is an example of a generic class of multi-objective decision problems (Eldrandaly, 2010).

Also, spatial decision making problems such as land-use planning are multi-facetted challenges. Not only have they often involved numerous technical requirements, but may also contain economical, social, environmental and political dimensions that may have conflicting values. Solutions for these problems involve highly complex spatial data analysis processes. Geographic Information Systems (GIS) have increasingly been used for solving spatial decision problems such as land-use planning. However, GIS cannot adequately support decision making. One response to these shortcomings is the development of Spatial Decision Support Systems (SDSS) which are explicitly designed to support decision process for complex spatial problems. Eldrandaly (2010) presented Gene Expression Programming (GEP) for solving MLUA problems which integrating Artificial Intelligence (AI) techniques with Geographic Information Systems (GIS). The results indicated that the proposed approach gives good and satisfactory results.

Lui et al. (2007) had presented an integrated GIS-based analysis system (IGAS) for supporting land-use management of lake areas in urban fringes in China. The IGAS consists of modules of land-use suitability assessment and change/demand analysis, and land evaluation and allocation. Multi-criteria analysis and system dynamics techniques are used to assess land-use suitability and forecast potential land-use variation, respectively. A case study implementing the system was performed on the Hanyang Lake area in the urban fringe of Wuhan City, central China, which is under significant urbanization pressure. Five categories of suitability were investigated by analyzing 11 criteria and related GIS data. Two scenarios for potential land-use changes from 2006 to 2020 were predicted, based on a systematic analysis and system dynamics modeling, and a hierarchical land-use structure was designed for the conservation of aquatic ecosystems. The IGAS may help local authorities better understand and address the complex land-use system, and develop improved land-use management strategies that better balance urban expansion and ecological conservation.

Verburg, Veldkamp, and Fresco (1999) presented a model for simulating country-wide changes in the land-use pattern of China. It is based upon an empirical analysis of the spatial distribution of land-use types in China which takes into account socioeconomic as well as geophysical variables. The empirical analysis indicates that a reasonably complete description of the land-use distribution can be made by including demographic, soil-related, geomorphological, and climatic variables. A multi-scale approach is followed to capture top-down as well as bottom-up factors affecting land-use allocation. Competition between different land-use types determines which changes will actually take place. The most important land-use conversions in China, caused by urbanization, desertification and afforestation, are simulated for a scenario based upon a trend analysis of present land-use dynamics. The spatially explicit results allow an analysis of the consequences of a decrease in cultivated area and related production capacity. A preliminary analysis shows that the average production capacity of the lost arable lands is somewhat less than the average production capacity of all agricultural lands together. In this study, the land-use allocation process was developed using grid based allocation in the allocation module based on the demand and population module.

Hengzhou, Futian, and Zhongxing (2007) had presented the optimal allocation of arable land conversion in transition of Jiangsu province in China. This article tries to analyze the change of arable land in Jiangsu, and then uses the model of arable land conversion (MAC) to get the optimal amount of arable land that can be changed, and can make a deadline for protecting the arable land and come up with a method for optimal allocation. It is indicated that with the rapid development of industrialization and urbanization in Jiangsu province, the land comparative benefit drives the arable land to the sector that has higher benefits. The arable land is scarce in Jiangsu. The dynamic equilibrium of the total arable land directly affects sustainable development of industries and urban areas. Hence, from the integrated purpose of economic development, food security and ecological safety scientifically confirm that the amount of arable land conversion has an important value and significance. Using the model of arable land conversion, the study determine the maximum amount of arable land conversion in the process of urbanization (3,412,805 ha). Then the result provides a scientific basis for the socio-economic development and sustainable development of land use.

2.4 Industrial location

The earliest explanation on the existence of cities and industry is provided by Lösch's central place theory which assumed that firms locate in such a way as to maximize profits (Parr, 2002).There are many factors that the entrepreneur considered to locate the manufactures such as road network or transportation, electricity , labor, facilities, land price, the agglomeration of manufacture (Miller, 1977; Bradford and Kent, 1977; Lloy and Dicken, 1977; Smith, 1971; Weber, 1965; Hoover, 1948).

Martin and Rogers (1995) had examined the impact of public infrastructure on industrial location and found that regional policies which finance domestic infrastructure in a poor country lead the firms to relocated in that country.

Leitham, McQuaid, and Nelson (2000) introduced and applied to an investigation of the influence of road transport and other factors on industrial location. The study found that good public transport provision emerged as a statistically significant factor in certain scenarios of location.

Cohen, Morrison, and Pual (2005) stated that thick market or agglomeration effects were associated with own-industry, supply side, and demand side spillovers. This study estimated cost-effects in order to evaluate its contribution to location decisions. It is indicated that indicated that locating a firm in close proximity to similar types of firms or suppliers may have economic motivations in terms of enhanced productivity or reduce costs. The implied agglomeration economies across firms may be due to various factors, including a conglomeration of specialized inputs, and information or knowledge spillovers.

Sridhar and Wan (2010) studied firm location choice in cities in China, India and Brazil .It is indicate that proximity to inputs has a positive impact on firm location in China. While availability of inputs has a positive impact on firm location in India. Firms established in post-reform period in India tend to locate in large cities; in China, these firms avoid medium and large cities.

2.5 Sustainability development

Sustainability development was defined in 1987 by the World Commission on Environment and Development (WCED) or Brundland Commission. Since sustainability was embedded into global agenda, Agenda 21, at the Rio Summit in 1992, sustainability development has been defined in many ways. The most frequency quoted definition is from *Our Common Future*, as "*Sustainability development is* *development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (Brundtland, 1987).

According to Kates, Clark, Corell, Hall, Jaeger et al. (2001), the purpose of sustainability assessment is to provide decision-makers with an evaluation of global to local integrated nature-society systems in short- and long-term perspectives in order to assist them to determine which actions should or should not be taken in an attempt to make society sustainable. The need for an integral systematic approach to indicators definition and measurement is recognised (Bossel, 1999) in order to give well-structured methodologies, easy to reproduce and to assure that all important aspects are included in the measurement. However, before developing the methodology and the indicators what is needed is the clear definition of the policy goals towards sustainability. This appears to be even more difficult since in most cases the development of indicators has started while there are still arguments over what constitutes sustainable development (Singh, Murty, and Dikshit, 2009).

Starting from the call for sustainable development indicators in Agenda 21, the UN Commission on Sustainable Development (CSD) published a list of about 140 indicators, which cover social, economic, environmental and institutional aspects of sustainable development (CSD, 2001). In order to simultaneously evaluate both the environmental and social components of sustainable development, the barometer of sustainability has been developed (Prescott, 1995). It consists of two components, namely ecosystem well-being and human well-being that both have to be improved for achieving sustainable development. The ecological footprint (Wackernagel and Rees, 1996) measures the total land area that is required to maintain the food, water, energy and waste-disposal demands per person, per product or per city. The eco-efficiency framework of the WBCSD attempts to measure progress towards economic and environmentally sustainability using indicators that are relevant and meaningful for business (WBCSD, 1999).

In 1997, the United Nations Environment Programme (UNEP) together with the United States nongovernmental organisation, Coalition for Environmentally Responsible Economics (CERES) launched the GRI with the goal of “enhancing the quality, rigour and utility of sustainability reporting”. Reporting is therefore the strong focal point of the guidelines. The GRI uses a hierarchical framework in three focus areas, namely social, economic, and environmental. The United Nations Commission on Sustainable Development (CSD) constructed a sustainability indicator framework for the evaluation of governmental progress towards sustainable development goals. A hierarchical framework groups indicators into 38 sub-themes and 15 main themes, which are divided between the four aspects of sustainable development. The Wuppertal Institute proposed indicators for the four dimensions of sustainable development, as defined by the United Nations CSD, together with interlinkage indicators between these dimensions. For the past two decades, there have been many local, regional, state/provincial, national and international efforts to find useful sustainability indicators. The UN Commission on Sustainable Development (UNCSD) from its working list of 134 indicators derived a core set of 58 indicators for all countries to use (Singh et al., 2009).

There are number of initiatives working on indicators and frameworks for sustainable development (SD) (Graymore, Wall, and Richards, 2009; Marcotullio, 2001; Bosshard, 2000; Shen, Ochoa, Shah, and Zhang, 2010; Singh et al., 2009; Vallance, Perkins, Dixon, and Dixon, 2011; Baumgärtner and Quaas, 2009; Houghton, 2004; Li and Weng, 2006). Here are some studies of sustainable development. There are some studies were reviewed in the sixth Chapter.

Marcotullio (2001) had studied on Asian urban sustainability in the era of globalization. The study address the economic, environmental and social health of the city and this task were accomplished by approaching each of these issues at different scales using the Asia-Pacific region as a case study, a framework relates regional transnational flows to the state of the urban environment and the social conditions of linked rapidly developing cities.

Bosshard (2000) had presented a methodology and terminology of sustainability assessment and its perspectives for rural planning. This study intended to clarify the logic and terminology of the assessment process in general, to provide an effective assessment concept for sustainability in the field of agricultural land-use, and to demonstrate possible perspectives for rural planning practices.

Shen et al. (2010) had presented the application of urban sustainability indicators. This paper examines 9 different practices and proposes a comparative basis, namely, International Urban Sustainability Indicators List (IUSIL), for allowing the better understanding of drivers and goals of each practice and identifying under what circumstances various practices selected their indicators. Discussions made on the comparative analysis are categorized in four different dimensions: environmental, economic, social and governance. Research results show how comparative basis can lead to knowledge sharing between different practices, which can be used to guide the selection of indicators of sustainable urbanization plans and improve the effective communication of the status of practices. The study not only reveals how different indicators are selected but also suggests the need for consistent processes of choosing indicators based on the benchmarks obtained from best practices.

Li and Weng (2006) had studied on measuring the quality of life in city of Indianapolis by integration of remote sensing and census data. This paper develops a methodology for integration of remote sensing and census data within a GIS framework to assess the quality of life in Indianapolis, Indiana, United States. Environmental variables, i.e. greenness, impervious surface and temperature, were derived from a Landsat ETM+ image. Socio-economic variables, including population density, income, poverty, employment rate, education level and house characteristics from US census 2000, were integrated with the environmental variables at the block group level to derive indicators of quality of life. Pearson’s correlation was computed to analyze the relationships among the variables. Further, factor analysis was conducted to extract unique information from the combined dataset. Three factors were identified and interpreted as material welfare, environmental conditions and crowdedness respectively. Each factor was viewed as a unique aspect of the quality of life. A synthetic index of the urban quality of life was created and mapped based on weighted factor scores of the three factors. Finally, regression models were built to estimate the quality of life in the city of Indianapolis based on selected environmental and socioeconomic variables.

Graymore et al. (2009) had studied Regional sustainability. This paper evaluates the effectiveness of current sustainability assessment methods-ecological footprint, wellbeing assessment, ecosystem health assessment, quality of life and natural resource availability at the regional scale. Each of these assessment methods are tested using South East Queensland (SEQ) as a case study. The applicability of each of these methods to regional assessment was examined using an evaluation criteria matrix, which describes the attributes of an effective method and the characteristics that make these methods useful for regional management and building community capacity to progress sustainability. This study found that the methods tested failed to effectively measure progress toward sustainability at the regional scale, demonstrating the need for a new method for assessing regional sustainability.

2.6 Previous studies of land-use planning

Land-use planning involves several tasks and need to integrate various fields of studies. The related studies such as land potential evaluation for industrial and agricultural, industrial land-use planning, land allocation and sustainable studies will be reviewed as follow.

Naiyutti (1997) studied the land-use plan for industrial development in Phra Nakhon Si Ayutthaya Province. The study proposed the guideline for land-use planning. The industrial location should be the areas that are not suitable for agriculture, accessible to the public infrastructure, without flood problem, and restriction for industrial development. This study recommended that new industries should be located in industrial estates, new industrial areas should be closed to the existing industrial zones, and industrial outside the industrial estates should be controlled in order to prevent the spill over effects into agriculture areas as well as historical sites and areas that are environmental sensitive.

Sroisayumphu (2000) studied the potential for industrial development of Om Noi District municipality, Samut Sakhon Province and Om Yai District Municipality, Nakhon Pathom Province. Factors that had influenced on industrial development were selected in the analysis, which were road accessibility, natural water resources, land price, water supply network, sanitation service, available empty space, and the distance from the CBD. Sieve Analysis technique was used in the study. The highest industrial potential areas were identified as the results. The study also proposed the guidelines to reduce the environmental impacts from industrial development.

Chongdi (2000) also used Sieve Analysis technique to study land-use planning for industrial development in suburban Nakhon Ratchasima. Factors affecting decision making on selection of location consist of transportation, infrastructure and public facilities. These factors were accessibility, land price, distance from existing manufacturing, distance from urban center, investment density, and flood condition.

Apawootichai (2001) developed the inclusion of environmental criteria for light industrial estate site selection in Supanburi Province. The main objective is to identify and quantify environmental criteria used for light industrial estate site selection and to find preliminary suitable land for establishing an industrial estate. These criterions were reserved forest, watershed classes, elevation, slope, distance to water bodies, soil, and distance to communities.

Nguyen (1996) developed the methodology to determine the potential locations for industrial park development using remote sensing and GIS technique, a case study of Ho Chi Minh City. The factors such as population density, transportation, soil, water supply, electricity and land use were ranged and scored to generate the value and weight. The study suggested three alternative potential locations for industrial estate development according to the objectives and policies.

Akter (2003) established a GIS-based multi-criteria spatial decision support system for urban land-use planning in Khon Kaen province, Thailand. The important land-use types in the study were industry and agriculture. In this case, the physical factors were used for agriculture suitability such as soil texture, soil depth, soil temperature, pH in upper and lower, For industry, the socio-economic factors were used such as accessibility to road, accessibility to canal, flood condition, land use and village buffer.

Xu (1996) developed the GIS aided rural land-use planning in China. The study pointed out that land evaluation, land demand and land-use analysis was the key bases on land-use planning. The study included land suitability assessment of agriculture and industry, and land allocation process. The study recommended social, economic and environmental considerations should be incorporated in land-use planning.

Drukpa (1996) studied on “Land resources analysis using GIS for sustain agricultural land use: a case study in Tredtsho and Baap Blocck, Bhutan”. The objectives are to evaluate land suitability for paddy and suggest the options for sustaining agriculture land use.

Shrestha (1999) studied on “Developing sustainable land-use systems through soil and water conservation in the Sakae Krang watershed, Central Thailand”. The study focused on developing a methodology for sustainability evaluation and development of land-use options for major agricultural crops.

Praneetvatakul, Janearnkij, Potchanasin, and Pryoonwong (2001) assessed the sustainability of agriculture in Mae Cham catchment, northern Thailand. The study focused on determining the critical indicators of agricultural sustainability by applied the sustainability indicator developed by FAO.

Wang, Yu, and Huang (2004) developed the land allocation based on integrated GIS-optimization model at a watershed level. The study proposed the process of land allocation by using the optimization model.

Hung (1998) analyzed the development impacts of urbanization and industrialization in Chiang Mai-Lamphun area ,Thailand using advanced spatial data analysis techniques The exploratory spatial data analysis (ESDA) techniques and spatial modeling within GIS were used in analysis. The study found that the limit of significant spreading impacts of urbanization and industrialization on rural peripheries was found around 25-30 km. With significant concentration of development around Chiang Mai City and Lamphun municipality, this could be interpreted as the people closed to these major growth pole get much benefit from rapid economic growth in term of employment, household income and income distribution.

Sumonmaethi (1995) studied the socio-economic changes in land utilization around industrial estate case study of Lumphun province. The study used the distance from the industrial estate as a proxy of its influence on the rural communities. Path analysis technique was applied in the analysis. The study showed that the industrial estate had a direct effect on income and had a negative indirect effect on the amount of land used for agriculture through the way it brought about increased in telephone lines, land prices and the development of the other types of land uses.

From the related studies above, some studies interested in agricultural land use which focused on the land suitability for agriculture and selection of land for several crops, some focused on land potential for industrial and some interested on the land allocation process and several studies focused on the agricultural sustainable land use, there are very few studies focusing on the industrial sustainable land use or integrated the various field altogether and it had been stated that specific land-use planning is not adequate to ensure a sustainable development, the integrated studies should be made to meet the overall objectives of sustainable land use.

2.7 Synthesis for the research approach

It can be concluded from the literature reviews that most studies were mainly focused on the specific topics. It has been hardly seen that they have been integrated. Therefore, their studies results can be adequately applied to specified problems. However, the information obtained from the various studies may lack of interrelation. Although the decision makers attempt to tie all information together, the results may be distorted due to the different in scale, time, methodology, and even points of view of information. This is the main problem that planners or executives always encounter in decision making. For example, the land suitability assessment for agriculture provide only the information where the highly, moderately, marginally suitable land are for agriculture. For the industrial assessment the results shows only the industrial suitability classes. In this case, if land-use planners want to determine whether agricultural area or industrial area should be suitable in the same area, the separate information cannot provide the answer. Their conflict of interest might be then active. The proper consideration to combine or trade off these two suitability classes is useful for solving this problem. As a result, the land allocation techniques should be developed. If the impacts of land-use plans on quality of life or sustainability development are anticipated and compared before launching the plans, it will be beneficial for the land-use planners to select the land-use options which meet the different development policies. Therefore, the sustainability of existing land use should be assessed and the relationship between proportion of land-use types and sustainability indexes should be investigated and developed to be spatial statistical models. These models can be used in spatial sustainability prediction of each scenario of land use.

From those reasons, objectives of the study aim at developing the integrated GIS-based models for industrial-agricultural sustainable land-use planning and prediction in different land-use scenarios. There were many processes involved for this. The integrated models combine many techniques and a series of processes. The outputs from the first process were further used as inputs of the following processes or models. There were mainly five processes in this study including land suitability assessment, land allocation, sustainability assessment, sustainability modeling, and sustainability prediction. The output of the land suitability assessment, which aims to classify land suitability for agriculture and industrial, were the input for land allocation process. The outputs of sustainability assessment and land-use proportion were the inputs of sustainability modeling. Then the outputs of the land allocation process, which aim to allocate the types of land into different land-use scenarios, together with the output from the sustainability assessment were the inputs of sustainability prediction. The term ‘integrated’ also means that the integration of techniques used in each process. For example, the factor analysis was integrated with the GWR technique to develop the sustainability model.

From the literature reviews, most of the physical and economic factors were used for the land suitability process. Effectively, the factors for the study should be selected based on the study purposes. In this study, only the physical factors were used in agricultural land suitability assessment. The economic factors were omitted because the study aims to evaluate the physical land suitability which is the initial suitability without the interferences of human managements. The other reason is the study aims to properly allocate the suitability of land for either agriculture or industry. The interference of economic factor may make the purpose deviated.

According to the literature reviews, it is demonstrating the need for a new method for assessing regional sustainability. GWR is the recent technique which is mostly applied in the social science. However, it never been used in the sustainability modeling. In this study, GWR technique was applied as a new technique for developing the spatial sustainability models instead of applying global regression or ordinary least squares (OLS), due to spatial non-stationarity of the relationships between land-use types and sustainability indexes in the study area. The OLS and GWR models were compared to discuss the better performance between GWR and OLS models. Therefore, the GWRSMs of aspects were presented in this study as the new sustainability models which can be applied in the sustainability assessment in the local scale.

CHAPTER III

LAND SUITABILITY ASSESSMENT

3.1 Introduction

The important economic sectors in Phra Nakhon Si Ayutthaya are agriculture and industry. In the agriculture sector, rice is the major crops that covering almost 70 percent of the total area. Phra Nakhon Si Ayutthaya is the one of the rice production sources in Thailand due to the high potential of soil properties, topography and the water availability. On the other hand, because of being nearby Bangkok, industrial promotion policies and other facilities availability, Phra Nakhon Si Ayutthaya becomes one of the most attractive industrial locations to the entrepreneur. In order to point out how appropriate is the area for rice cultivation and/or for manufacturing, the land suitability assessment using the GIS techniques is applied.

3.2 Methodology

Land suitability is the fitness of a given type of land for a defined use. Land suitability or land potential evaluation is a method to classify the land into different suitability classes for specific use (FAO, 1976). This research aims to evaluate land suitability for two major land-use types, agriculture and industry. Therefore, this chapter can be divided into agricultural land suitability assessment and (2) agricultural land suitability assessment. The steps of the assessment processes of both were parallel as displayed in Figure 3.1. They include factor selection, criterion map creation, weighting and scoring and then incorporation for land potential maps.

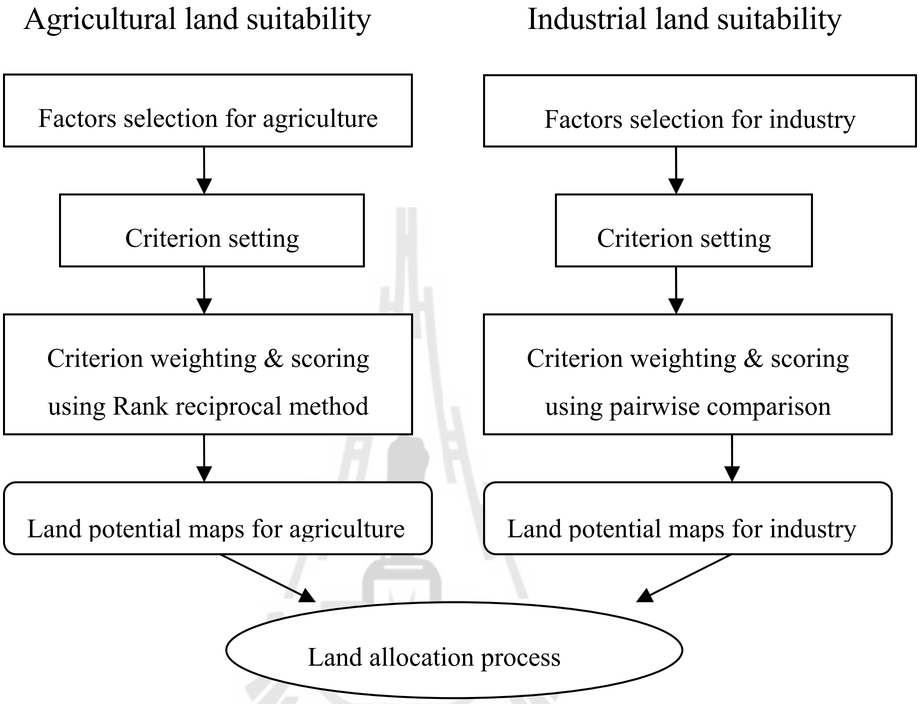


Figure 3.1 Steps of land suitability assessment for agriculture and industry.

3.3 Agricultural land suitability assessment

3.3.1 Factors and input GIS data layers

Land suitability for agriculture can be defined as the fitness of a given unit for it optimum cultivation. The consideration of fitness of a given land unit is relative and is categorized on the basis of its capability to support the growth of the selected crop. The main purpose of conducting this particular analysis was to classify the study area into various suitability classes for rice with the ultimate goal of ensuring the sustainability of agricultural land use (Drukpa, 1996). This study aims to evaluate land suitability for rice cultivating based on SMCDA technique and GIS based processing.

The process of agricultural land suitability assessment started from examining of factors required for rice cultivation which are the input of the processes. Basically, physical factors such as soil quality are powerful directly to all cultivation. Soil nutrient is the basic factors to be considered as well as temperature rainfall and topography such as slope, aspect, elevation. Irrigation, water body and flooding condition are the accompanying factors required. (FAO, 1976; Shrestha, 1999) Factors used in land suitability for agricultural were adapted from previous studies of FAO. Since the main crop in Phra Nakhon Si Ayutthaya is rice, factors and criteria of paddy field suitability were referred for assessment. These factors are soil properties, rainfall temperature, and topography such as slope, aspect and elevation, distance from water body, irrigation and flood hazard.

Due to the characteristics and scale of the study area, variation in temperature, rainfall and topography is so small that these factors used only as a guide rather than as a specific parameter for the analysis. Therefore, the main influencing factors in this study are soil properties, distance from water body, irrigation and flood hazard. Types and sources of data gathering in this work are exhibited in Table 3.1.

Table 3.1 Types and sources of data used in the agricultural land suitability process.

No.	Data layers	Data contents	Year	Scale	Source
1	Soil series map	Soil properties	2007	1: 100,000	Land Development Department (LDD).
2	Land-use map	River and water body	2007	1: 4,000	Land Development Department (LDD).
3	Irrigation map	Irrigation zone	2007	1: 250,000	Royal Irrigation Department (IRD).
4	Flooding maps	Flooding area	2004-2007	1: 250,000	Geo-informatics and Space Technology Development Agency (GISTDA).

(1) Soil series map

Soil series consist of pedons that are grouped together because of their similar pedogenesis, soil chemistry, and physical properties. More specifically, each series consists of pedons having soil horizons that are similar in soil color, soil texture, soil structure, soil pH, consistence, mineral and chemical composition, and arrangement in the soil profile. These result in soils which perform similarly for land-use purposes.

In soil series map, the physical and chemical characteristics of soil which is the important factors for cultivation can be explored. The database of soil series map of Phra Nakhon Si Ayutthaya province obtained from the land Development Department of which comprised of polygon of soil series with attribute information including types, its characteristics and area covered. This map was the data input layer for the soli properties in the process of land suitability assessment for agriculture.

(2) Land-use map

Land-use map in year 2007 of Phra Nakhon Si Ayutthaya province was prepared by the LDD. Land-use map provides the types of land-use and its areal cover and other basic geographical information such as administration boundary, road, rivers and water bodies. From the land-use map the distance from rivers and water bodies can be estimated.

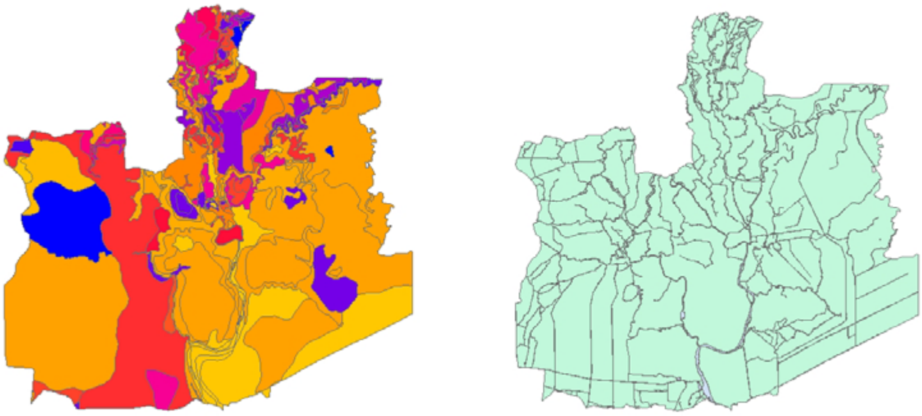
(3) Irrigation map

Irrigation map obtained from the Royal Irrigation Department (RID) comprises both irrigation and non-irrigation zones.

(4) Flooding maps

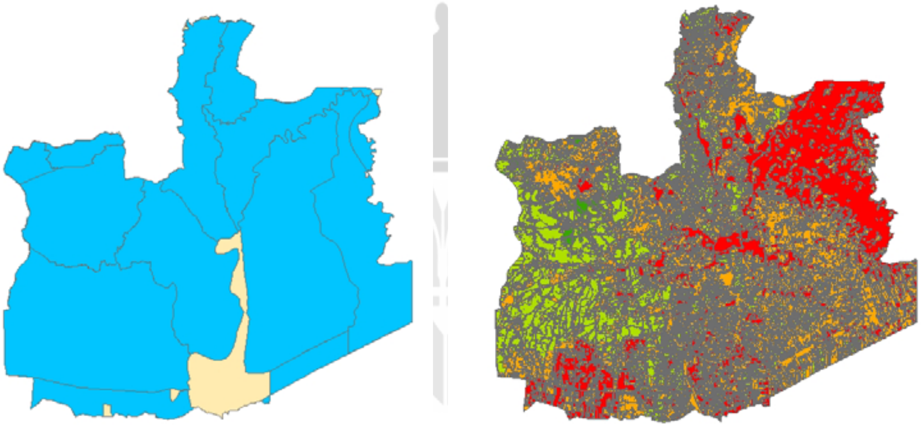
Flooding maps were obtained from Geo-Informatics and Space Technology Development Agency (GISTDA) during 2004-2007. Since each flooding maps can showed the flood in a specific date only, the frequency of flood in the area was then attained from the overlay analysis and flood hazard map can be generated.

Input data layers for agriculture land suitability analysis were illustrated in Figure 3.2.



(a) Soil Series

(b) River



(c) Irrigation

(d) Flood frequency

Figure 3.2 Input data layers for agricultural land suitability analysis.

3.3.2 Scoring and weighting

As mention before factors and criteria were followed from the FAO guidelines (FAO, 1976) and the experts from the LDD as the following,

(1) Soil qualities

The soil qualities obtained from soil series were comprises of 12 characteristics considered as the input in the soil qualities evaluation process.

Soil Drainage

Soil drainage represents the condition in which water is passed by from the soil. The drainage was classified according to the rate of water loss from the soil as very poor drained, poorly drained, moderately drained, well drained, well drained and excessively drained. Soil drainage for paddy rice should be poorly drained.

Soil texture

Soil texture refers to the fineness or coarseness of the soil as determined by the proportion of sand, silt and clay which has a direct influence on the permeability and available water content of the soil, and is considered as a good indicator of the water holding capacity of the profile (Drukpa, 1996). Clay to loam texture is more suitable for paddy rather than sandy loam to clay texture (Mahaxay, 1996).

Soil depth

Soil depth refers to the rooting zone where limiting depth is a lithic contact, parathic contact, petroferric layer to hard pan, throught which it is very difficult or impossible for roots to penetrate. It is a crop requirement, determine by the natural rooting habit of the crops. (Drukpa, 1996) In this case, deep soil was suitable for paddy.

Soil salinity

Salt is a natural element of soils and water. Salt affected soils are caused by excess accumulation of salts, typically most pronounced at the soil surface.Soil Salinity is an important land degradation problem. Salt is harmful for plant growth and yield. According to FAO, soil salinity should be over 8mmho/cm for rice cultivation (Drukpa, 1996).

Soil pH

Soil pH is a measure of the soil acidity or soil alkalinity. Soil pH is the important considerations for farmer since pH can affect the availability of nutrients in the soil. Diseases affecting plants also tend to thrive in soil with a particular pH range. The majority of food crops prefer a neutral (pH 7) or slightly acidic soil (between 3.0 and 5.0). Soil pH between 5.0-7.5 should be most for paddy (Mahaxay, 1996).

Nitrogen (N)

Nitrogen is apart of chlorophyll, the green pigment of the plant that is responsible for photosynthesis. Nitrogen is the key element to increase yield of rice. The paddy plant depends mainly for its nitrogen upon the decomposition of organic matter under anaerobic condition, and in the early stages of growth takes up nitrogen in the form of ammonia (Grist, 1986).

Phosphorus (P)

Like nitrogen, phosphorus (P) is an essential part of the process of photosynthesis. Plants need phosphorous for rapid growth, strong root growth; fruit, stem and seed development; disease resistance; and general plant vigor. Deficiency symptoms include stunted plants with dark green foliage, reddish-purple stems or leaves, and fruits that drop early (NCAGR, 2010).

Potassium (K)

Potassium is supplied to plants by soil minerals, organic materials, and fertilizer. Potassium (K) This nutrient, sometimes called potash, is essential for vigorous growth, disease resistance, fruit and vegetable flavor and development, and general plant function. Deficiency symptoms include yellow areas along the leaf veins and leaf edges, crinkled and rolled-up leaves, and dead twigs (NCAGR, 2010).

Organic matter (OM)

Organic matter is widely used as a vital component of a healthy soil. It is an important part of soil physical, chemical and biological fertility. OM influences the physical properties of the soil and increases the supply and availability of nutrients. High nutrient in soil should be suitable for rice (NCAGR, 2010).

Jarosite

The soil property that represents soil toxicities is the depth of jarosite. Jarosite is a basic hydrous sulfate of potassium and iron. Depth of jarosite should deep over 100 cm.

Cation exchange capacity (CEC)

The Cation exchange capacity (CEC) is a value indicating its capacity to hold cation nutrients. It represents the nutrient retention capacity of soil. The CEC of the soil is determined by the amount of clay or humus that is present. This property was effects the growth of plant.

Base Saturation (BS)

Base saturation refers to the proportion of the cation exchange sites in the soil that are occupied by the various cations (hydrogen, calcium, magnesium, potassium).Base saturation is the amount of positively charged ions, excluding hydrogen and aluminum ions, that are absorbed on the surface of soil particles and is measured and reported as a percentage. Base saturation is positively related to soil pH because a high base saturation value would indicate that the exchange sites on a soil particle are dominated by non-acidic ions (Ehow, On-line, 2010)

Criteria and score used in the analysis were also adopted from FAO guidelines and the experts of Land Development Department as shown in Table 3.2. On the soil quality evaluation process, criteria incorporation was performed through Simple Additive Weighting (SAW) decision rules of the Spatial Multi-Criteria Decision

Analysis (SMCDA). Then, the map of soil quality was generated (Figure 3.3) and changed into the criterion map to use as one of input data layers in the agricultural land suitability assessment (Figure 3.4).

Table 3.2 Criteria used of soil quality evaluation.

Soil quality	**unit**	**Classes S1 (Score=1.0)**	**Classes S2 (Score=0.8)**	**Classes S3 (Score=0.5)**	**Classes N (Score=0.2)**
Soil Drainage	class	1,2,3	4	5	6
Soil Texture	texture	L, Cl,, C, SICL, SCL	SI,SIL,SIC,SC	LS	S, V.Gr
Soil Depth	cm	>50	25-50	15-25	<15
Soil Salinity	mmho/cm	<2	2-5	5-8	>8
Soil pH	pH	5.6-7.3	7.4-7.8, 5.1-5.5	7.8-8.4, 4.0-5.0	>8.4 <4.0
Nitrogen (N)	%	>0.2	0.1-0.2	<0.1	
Phosphorus (P)	ppm	>25	10-25	<10	
Potassium (K)	ppm	>60	30-60	<30	
Organic Matter (OM)	%	>3	1-3	<1	
Depth of Jarosite	cm	>150	100-150	50-100	<50
CEC	meq/100g	>15	5-15	<5	
Base Saturation (BS)	%	>50	35-50	<35	

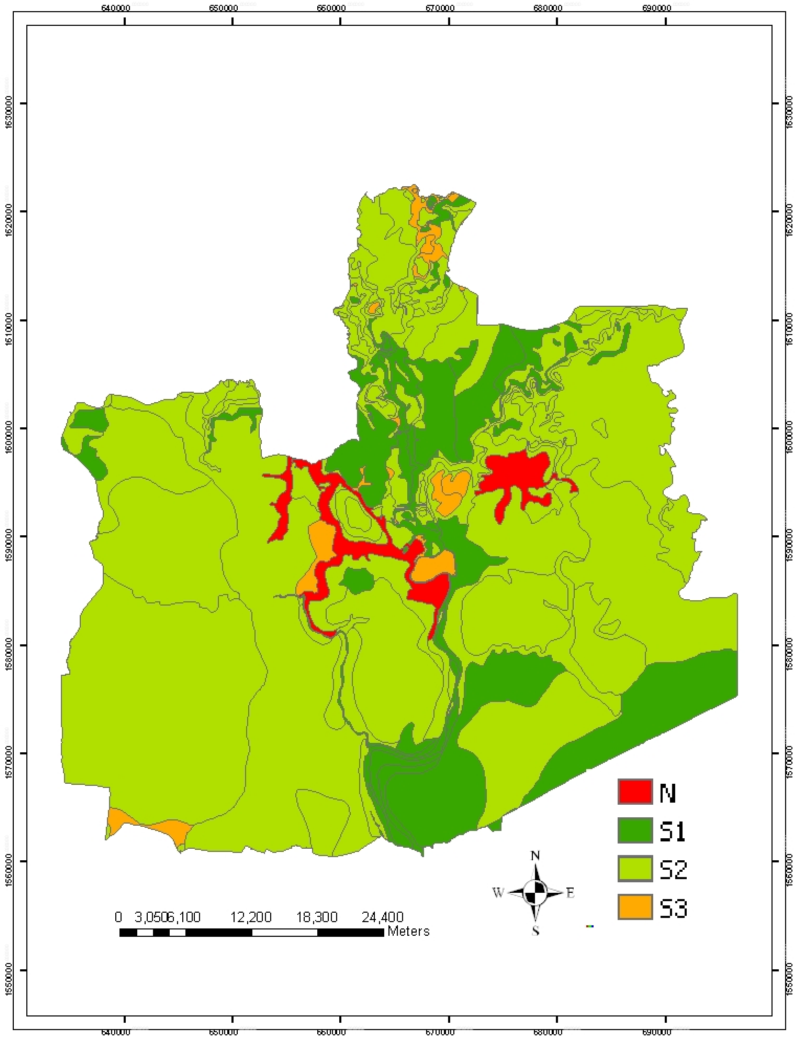


Figure 3.3 Soil quality map, the output of the soil quality evaluation process.

(2) Distance from water body

Water is important for agriculture. The rivers and water bodies were sources of water supplies for cultivation. The area near water body which can get water easily is more suitable than the others. In this study, multiple buffer rings were used to classify area to be zones of neighborhood from water body based on distance apart. The buffering zones from water body of the study area were displayed in Figure 3.4.

(3) Irrigation

Irrigation zone was provided by the Royal Irrigation Department (RID). In the zones, irrigation canals were constructed to distribute water for agriculture in dry season. Irrigation helps the farmer to be able to cultivate many times in a year. Thus, the area in the irrigation zone is more suitable than the others. The irrigation zones of the study area are shown in Figure 3.4.

(4) Flood hazard

Pragmatically, paddy field in the area is usually flooded before the rice seedling until the grain is mature. Flood hazard which much influences to the rice cultivation in the area can be determined through the frequency of flooding during the specific time. The more frequencies of flooding, the more damage the area is. The overlay of flood map in many date were needed to calculate the frequency of flood in the area. Therefore flood hazard map can be generated as shown in Figure 3.4.

The criteria scored were obtained from FAO guidelines and the opinion of the LDD experts as shown in Table 3.3. The rank reciprocal method was used to determine the weight of each factor as shown in Table 3.4.

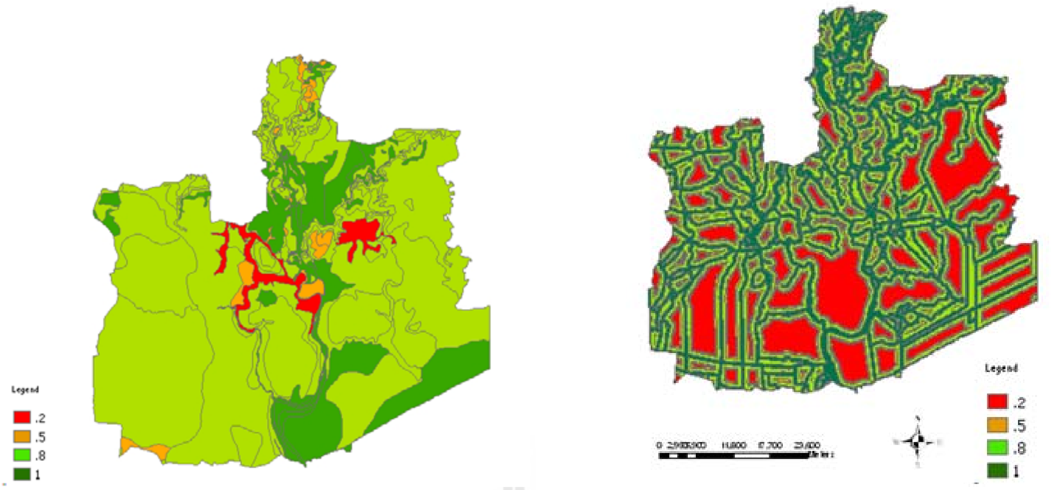
Table 3.3 Scores of criteria in the agricultural land suitability assessment.

Factors	**Criteria**	**Range of measurement**	**Score**	**Weight***
Soil quality	Class	S1	4	0.480
		S2	3	
		S3	2	
		N	1	
Distance from water body	Distance from water body (m)	<=250	4	0.120
		251-750	3	
		751-1,000	2	
		>=1001	1	
Irrigation	Irrigation zone	Irrigation	1	0.160
		Non-irrigation	0	
Flood hazard	Frequency of flooding	Never	4	0.240
		Seldom	3	
		Often	2	
		Very often	1	

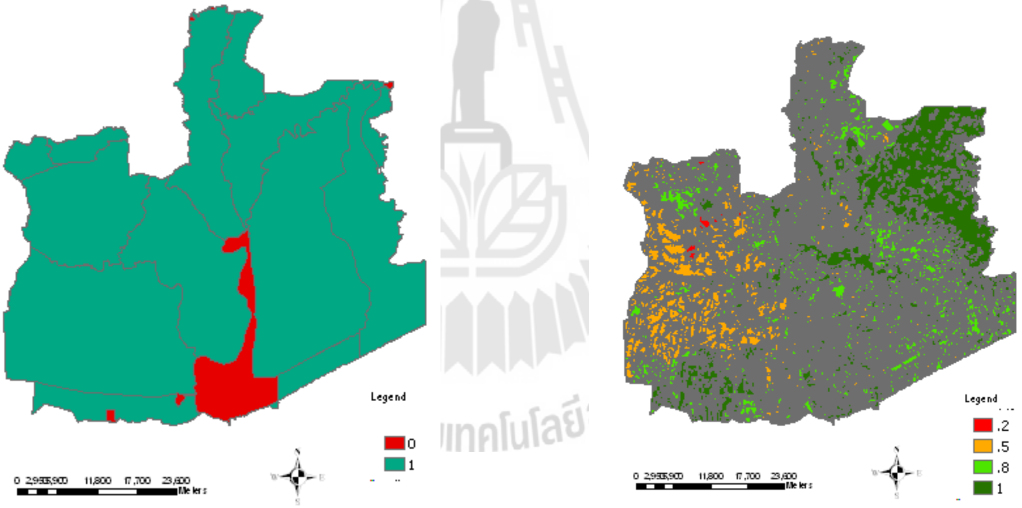
*From The rank reciprocal weighted method

Table 3.4 The rank reciprocal weighted method.

Factor	**Straight Rank (r)**	**Recipocal Weight (1/r)**	**Normalized weight (1/r) / ∑(1/r)**
Soil Quality	1	1.000	0.480
Distance from water body	4	0.250	0.120
Irrigation	3	0.333	0.160
Flood	2	0.500	0.240
		∑(1/r) = 2.083	1.000



(a) Soil quality (b) Distance from water body



(c) Irrigation zone (d) Flood hazard

Figure 3.4 Criterion maps for agricultural land suitability assessment.

The total indexes were calculated using SAW method. Then, the total suitability indexes ranging 0 to 1 were classified into 4 classes according to FAO guideline as seen in Table 3.5. The SMCDA process of agricultural land suitability was shown in Figure 3.5.

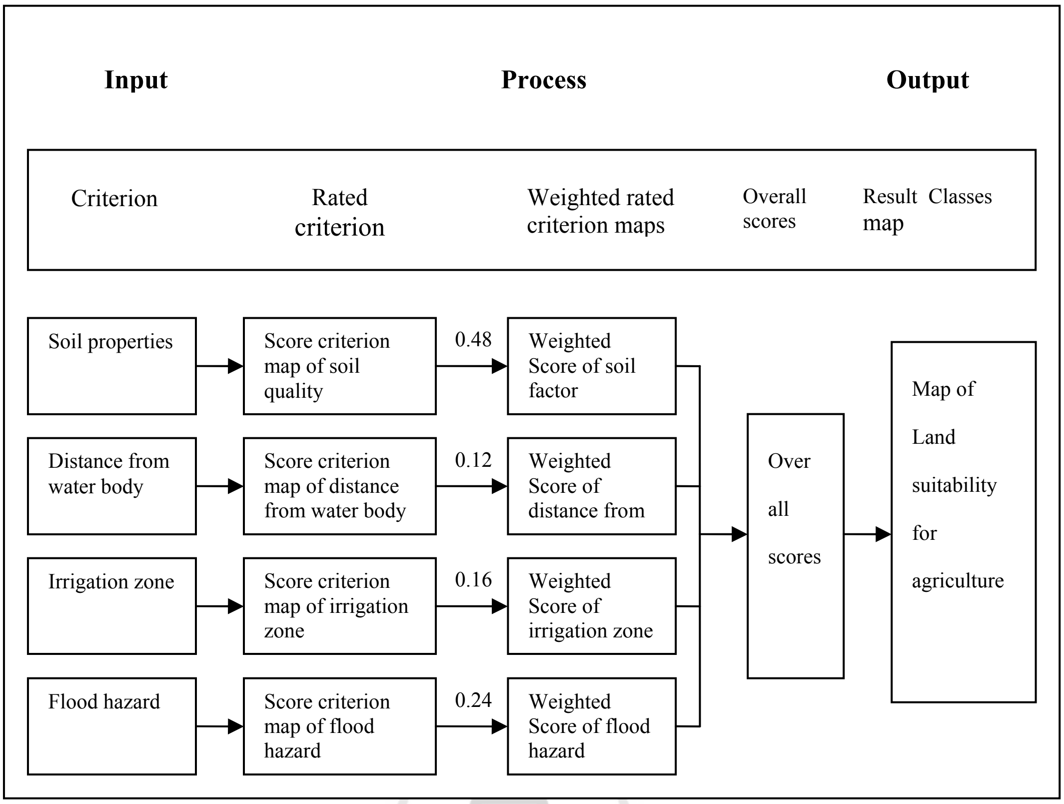


Figure 3.5 The Spatial Multi-criteria Decision Analysis (SMCDA) process of agricultural land suitability.

Table 3.5 Classification of land suitability indexes.

Suitability indexes range	**Suitability classes**
0.8-1.0	Highly suitability (S1)
0.4-0.8	Moderately suitability (S2)
0.2-0.4	Marginally suitability (S3)
0.0-0.2	Not Suitable (N)

3.3.3 Result and discussion

The land suitability map for agriculture was generated as shown in Figure 3.6. The area cover of each suitability class is tabulated in Table 3.6. The urban areas, roads, and river were excluded from suitability map. Most suitable areas (S1) for crops were located in the upper central and the northeast of the province due to the presence of high quality soil and marginal flood hazard. Only small areas in the northwest were classified as not suitable (N). The marginally suitable areas (S3) were located in the western of province due to the presence of flood hazard and long distance from water body. However, rice cultivation of the area can be conducted by water supply from irrigation canal in dry season.

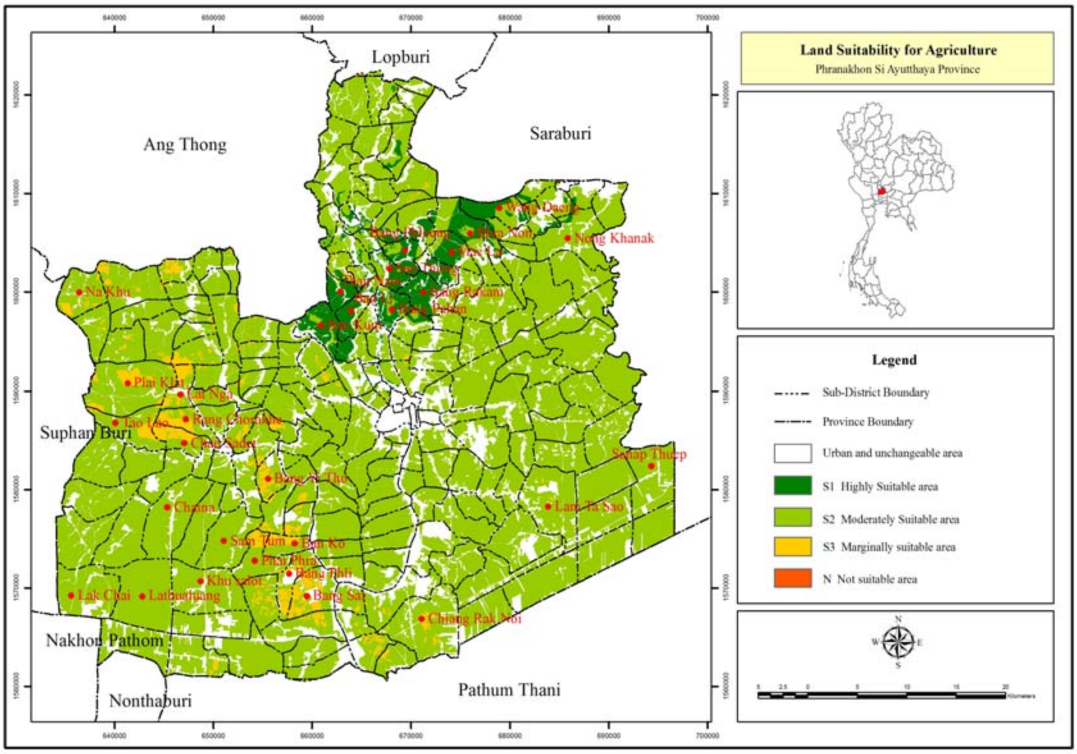


Figure 3.6 Land suitability map for agriculture.

Table 3.6 Area coverage on classified land suitability for agriculture.

Land Suitability classification	Area (Sq. km.)	Area (Rai)	Area (%)
Highly Suitability (S1)	105.84	66,151	4.21
Moderately Suitability (S2)	1,891.12	1,181,948	75.28
Marginally Suitability (S3)	75.71	47,318	3.01
Not Suitable (N)	0.02	10	0.01
Other area	439.43	274,640	17.49
Total	2,512.12	1,570,067	100.00

4.21 and 75.28 percent of the total area were respectively classified as highly and moderately suitable for agriculture. Only few percent of total area was classified as marginally and not suitable for rice cultivation. Sub-districts with large area coverage of different suitability classes included S1, S2, and S3 were listed in Tables 3.7-3.9, respectively.

Table 3.7 Sub-districts with large area coverage of S1 for agriculture.

Sub-district ID	Sub-district Name	District Name	Area (Sq. km.)	Area (Rai)	Area (%)
140516	Ban Kum	Bang Ban	10.54	6,585	70.63
140306	Bang Rakam	Nakhon Luang	9.40	5,877	75.32
140312	Phra Non	Nakhon Luang	8.24	5,150	35.40
140206	Wang Daeng	Tha Ruea	7.70	4,813	54.19
140701	Bang Pahan	Bang Pahan	7.30	4,563	64.45
140308	Mae La	Nakhon Luang	7.03	4,396	53.52
140710	Thap Nam	Bang Pahan	6.45	4,031	82.75
140706	Bang Phloeng	Bang Pahan	6.44	4,029	61.55
140713	Ban Li	Bang Pahan	6.21	3,878	69.54

Table 3.8 Sub-districts with large area coverage of S2 for agriculture.

Sub-district ID	Sub-district Name	District Name	Area (Sq. km.)	Area (Rai)	Area (%)
141001	Lat Bua Luang	Lat Bua Luang	37.86	23,660	97.18
141304	Plai Klat	Bang Sai	31.88	19,925	78.71
141212	Chai Na	Sena	30.73	19,203	92.22
140602	Chiang RakNoi	Bang Pa-in	30.02	18,763	73.71
141101	Lam Ta Sao	Wang Noi	28.32	17,699	79.46
141006	Khu Salot	Lat Bua Luang	28.12	17,574.	86.51
141002	Lak Chai	Lat Bua Luang	24.82	15,513	67.54
141105	Sanup Thuep	Wang Noi	24.56	15,352	84.85
140209	Nong Khanak	Tha Ruea	23.34	14,590	86.65
141213	Sam Tum	Sena	23.02	14,386	91.91

Table 3.9 Sub-districts with large area coverage of S3 for agriculture.

Sub-district ID	Sub-district Name	District Name	Area (Sq. km.)	Area (Rai)	Area (%)
140401	Bang Si	Bang Si	6.50	4,062	33.48
141304	Plai Klat	Bang Sai	6.02	3,764	14.87
141217	Chao Sadet	Sena	4.86	3,039	44.82
141209	Rang Chorakhe	Sena	4.56	2,845	39.94
140402	Bang Phli	Bang Si	3.67	2,294	28.44
141214	Lat Nga	Sena	3.62	2,261	37.34
140406	Bang Yi Tho	Bang Si	3.38	2,112	32.37
141303	Tao Lao	Bang Sai	3.28	2,047	17.33
140414	Phai Phra	Bang Si	2.68	1,675	16.96
140418	Ban Ko	Bang Si	2.48	1,547	27.99

3.4 Industrial land suitability assessment

There are four steps of the process to evaluate industrial land suitability. First, the factors affecting the industrial location were selected based on theories and previous researches and criteria were setup. Second, all classes of factors were scored in the suitability range. Third, the weights of all factors were determined using the pairwise comparison method through entrepreneur opinion. Finally, GIS operation of Simples Additive Weighted (SAW) decision rule was performed to generate the final industrial suitability map. The overall framework is illustrated in the Figure 3.7 and the details of all steps were described below.

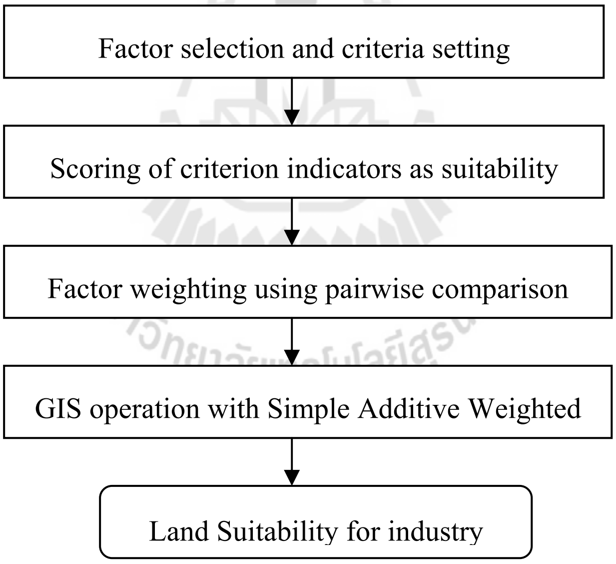


Figure 3.7 Steps in the industrial land suitability assessment process.

3.4.1 Factors and input GIS data layers

There are many factors affecting the industrial location. Theories and concepts about industrial location had been developed since 1875 when J. H. Von Thunen attempted to incorporate a location into the general framework of economics.

The book about industrial location theory was published by Alfred Weber in 1909. According to Weber, there are three factors concerning of industrial location i.e. the cost of transportation, cost of labor, and advantage of agglomeration. Many factors were considered for site selection in the past. Recently, many studies suggested that the significant factors were both physical and socioeconomic such as accessibility, infrastructure and facilities, labor availability, land price, topography and flooding, etc. (Chobpattana, 1989; Panjarongkha, 2003; Piracha, 2001; Tianpajeegoon, 2001; Weerakoon, 1996; Xu, 1996)

In this study the factors used were recommended by 10 experts from Industrial Estate Authority of Thailand and synthesized as criteria indicators. Their weights were obtained from 30 entrepreneurs by questionnaire and interview (See questionnaire in Appendix A). The factors included 1) accessibility, 2) electricity, 3) labor, 4) facilities, 5) agglomeration, 6) land price, and 7) flood hazard. Types and sources of data gathered are exhibited in Table 3.10.

Table 3.10 Types and sources of data in the industrial land suitability assessment.

No.	Data layers	Data contents	Year	Scale	Source
1	Road map	Road Accessibility	2007	1:4,000	Department of Highways (DOH)
2	Electric line map	Electricity	2007	1:4,000	Provincial Electricity Authority (PEA)
3	Land-use map	Village, urban area, municipal area (Labor and facility)	2007	1: 4,000	Land Development Department (LDD)
4	Industrial map	Industrial location (Agglomeration)	2007	1: 4,000	Department of Industrial Works (DIW)
5	Land price	Land price	2007		The Treasury Department (TD)
6	Flood maps	Flooding area	2004-2007	1: 250,000	Geo-informatics and Space Technology Development Agency (GISTDA)

(1) Road map

Road map obtained from Department of Highways provides distance from road or the accessibility of the industrial location. Multiple buffer rings were used to classify the accessibility according to the criteria set up.

(2) Electricity map

Electricity map obtained from Provincial Electricity Authority (PEA) in year 2007 provides the electricity line of high and medium voltages. The electricity accessibility was classified by multiples buffer rings.

(3) Land-use map

Land-use map in 2007 from the Land Development Department presents the villages in which the labor are available. Further more the land-use map can show the urban and buildup areas in where facilities are available.

(4) Industrial map

Industrial map in 2007 from the Department of Industrial Works (DIW) gives the information of industrial location. Agglomeration presents the concentration of economic activities in selected region such as industry or manufactures.

(5) Land price

The land price in block appraised by The Treasury Department in year 2007 was used to generate land price zone in the study area.

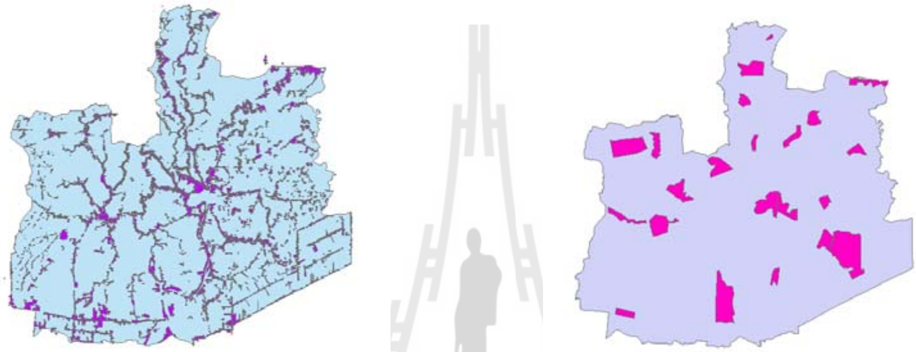
(6) Flood maps

As mentioned before, flood hazard map was generated from overlaying the flooding maps of many dates during 2004-2007 obtained from the GISTDA. The frequency of floods was classified to indicate the intensity of flood hazard.

Input data layers for industrial land suitability assessment were illustrated in Figure 3.8.

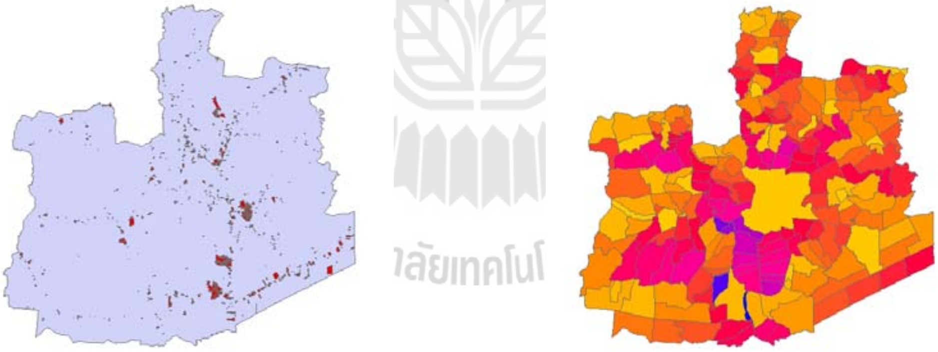
(a) Road

(b) Electricity



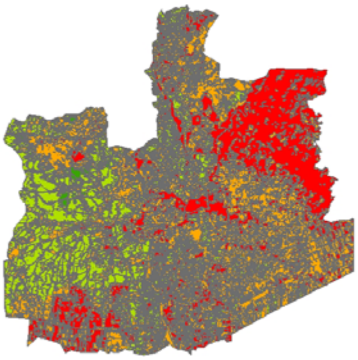
(c) Village

(d) Municipal and



(e) Industrial Area

(f) Price Zone



(g) Flood Area

Figure 3.8 Input data layers for Industrial land suitability assessment.

3.4.2 Scoring and weighting

Criteria used for evaluating the land suitability of industrial location were obtained from previous researches and approved by the experts from Industrial Estate Authority of Thailand and the entrepreneurs. All criteria indicators were scored (4 to 1) based on their four grades of suitability: very good, good, fair, and poor or not suitable. The factors and their criteria range of measurement, and scores were shown in Table 3.11.

(1) Accessibility

The accessibility was determined by the distance from road. Easy access to the road network is essential for transportation of raw materials, goods distribution, and flow of labor force.

(2) Electricity

Electricity is necessary for the production process. The manufacturing should be located close to high or medium voltage line. The more distance apart, the more capital to be invested.

(3) Labor

Availability of labor or man power is vital for industries. The plant location study must assure that the types and number of employees will be available. Labor can come from the residential areas or villages nearby. The industries located near the labor sources or communities will be advantaged.

(4) Facility

Successful operation of the plant will require essential services. Facilities such as water supply pipeline, police station, fire protection station, government office, academic, institutes, bank, shops or markets and other facilities will give benefits to industries and motivated the workers. Most of these facilities are available in town or urban area.

(5) Agglomeration

Since the products of one manufacture may be the raw material of the others, it will be useful if the manufactures locate nearby to each other. They can deal easily and the transaction between industries will be enhanced and transport cost will be reduced.

(6) Land price

Land price is the initial fixed cost that the entrepreneur concerned in deciding where to be located because it influences the profit of the manufactures. The higher fixed costs, the higher break even point they have to do and the payback period will be longer. Land price is very high if it is close to main road or town.

(7) Flood hazard

Flood is harmful for all businesses and industries. The plants may be damaged and the processes may be interrupted and these will affect the total costs, revenues and profits of the manufactures. The manufactures avoided locating in the possible flooded risk area. The frequency of floods in the past could be indicator for classification of flooded risk area.

The criteria score was obtained from previous studies and the expert of The Industrial Estates Authority of Thailand as shown in Table 3.11. Pairwise comparison method was used in weighting of criterion maps for industrial land potential evaluation (Table 3.12). Factors related to industrial land suitability were prepared as criterion maps in form of raster layers. Grid cells in different range of measurements contain different score. Then, the GIS local operation which is the summation of the weight-score products of all data layers were performed to serve the Simple Additive Weighted (SAW) decision rule. The land suitability ranking of the area was achieved as a map. The industrial suitability map was classified into 4 classes; highly suitable, moderately suitable, marginally suitable and not suitable

Table 3.11 Scores of criteria in the industrial land suitability assessment.

Factors	**Criteria**	**Range of measurement**	**Score**	**Weight***
Accessibility	Distance from road (m)	<=500	4	0.299
		501-1,000	3	
		1,001-1,500	2	
		>=1,501	1	
Electricity	Distance from electricity line (m)	<=500	4	0.222
		501-1,000	3	
		1,001-1,500	2	
		>=1,501	1	
Labor	Distance from village (m)	<=1,000	4	0.091
		1,001-2,000	3	
		2,001-3,000	2	
		>=3,001	1	
Facility	Distance from urban area or municipals	<=1,000	4	0.116
		1,001-2,000	3	
		2,001-3,000	2	
		>=3,001	1	
Agglomeration	Distance from existing industrial area (m)	<=1,000	4	0.095
		1,001-2,000	3	
		2,001-3,000	2	
		>=3,001	1	
Land price	Land price zone (bath/rai)	<=400,000	4	0.070
		400,001-2,000,000	3	
		2,000,001-4,000,000	2	
		>4,000,000	1	
Flood hazard	Frequency of flooding	Never	4	0.107
		Seldom	3	
		Often	2	
		Very often	1	

*From Pairwise Comparison Method

Table 3.12 Weights determination using Pairwise comparison method.

Step I Development of pairwise comparison matrix.

Factor	**Accessibility**	**Electricity**	**LP**	**Labor**	**Facility**	**Agglomer**	**Flood**
Accessibility	1.00	2.00	3.00	3.00	3.00	4.00	3.00
Electricity	0.50	1.00	3.00	3.00	2.00	3.00	3.00
Land price	0.33	0.33	1.00	1.00	0.33	1.00	0.50
Labor	0.33	0.33	1.00	1.00	2.00	1.00	0.50
Facility	0.33	0.50	3.00	2.00	1.00	0.50	1.00
Agglomeration	0.25	0.33	1.00	1.00	2.00	1.00	1.00
Flood	0.33	0.33	2.00	2.00	1.00	1.00	1.00
Total	3.07	4.82	14.00	13.00	11.33	11.50	10.00

Step II Computation of the factor weights.

Factor	**Access**	**Electric**	**L P**	**Labor**	**Facility**	**Agglomer**	**Flood**	**Sum**	**Weight**
Access	0.324	0.414	0.214	0.231	0.264	0.348	0.300	2.095	0.299
Electric	0.162	0.207	0.214	0.231	0.177	0.261	0.300	1.551	0.222
Land price	0.108	0.069	0.071	0.077	0.029	0.087	0.050	0.491	0.070
Labor	0.108	0.069	0.0071	0.077	0.177	0.087	0.050	0.639	0.091
Facility	0.108	0.103	0.216	0.154	0.088	0.043	0.100	0.813	0.116
Agglomeration	0.082	0.069	0.071	0.076	0.177	0.087	0.100	0.662	0.095
Flood	0.108	0.069	0.143	0.154	0.088	0.087	0.100	0.749	0.107
Total	1.000	1.000	1.000	1.000	1.000	1.000	1.000	7.000	1.000

Step III Determine the consistency ratio.

Factor	**Access**	**Electric**	**L P**	**Labor**	**Facility**	**Agglo**	**Flood**	**Sum**	**Consistency Vector**
Access	0.299	0.444	0.210	0.273	0.348	0.380	0.321	2.275	7.61
Electric	0.150	0.222	0.210	0.273	0.232	0.285	0.321	1.693	7.62
Land price	0.100	0.074	0.070	0.091	0.038	0.095	0.054	0.521	7.45
Labor	0.100	0.074	0.070	0.091	0.232	0.095	0.054	0.715	7.86
Facility	0.100	0.111	0.212	0.182	0.116	0.048	0.107	0.875	7.55
Agglomeration	0.075	0.074	0.070	0.091	0.232	0.095	0.107	0.744	7.83
Flood	0.100	0.074	0.140	0.182	0.116	0.095	0.107	0.814	7.60
Total									53.52

λ = consistency vector/ n = 53.52/ 7 = 7.6457

CI= (λ –n)/ n-1 = 7.64/6 = 0.1067

CR=CI/RI = 0.1067/1.32 = 0.0800 (CR< 0.10, Consistency, Weights is acceptable)

The criterion maps of all factors were displayed in Figure 3.9. Each criterion map shows the area in four suitability classes which are 4 for highly suitable, 3 moderately suitable, 2 marginally suitable and 1 for not suitable.

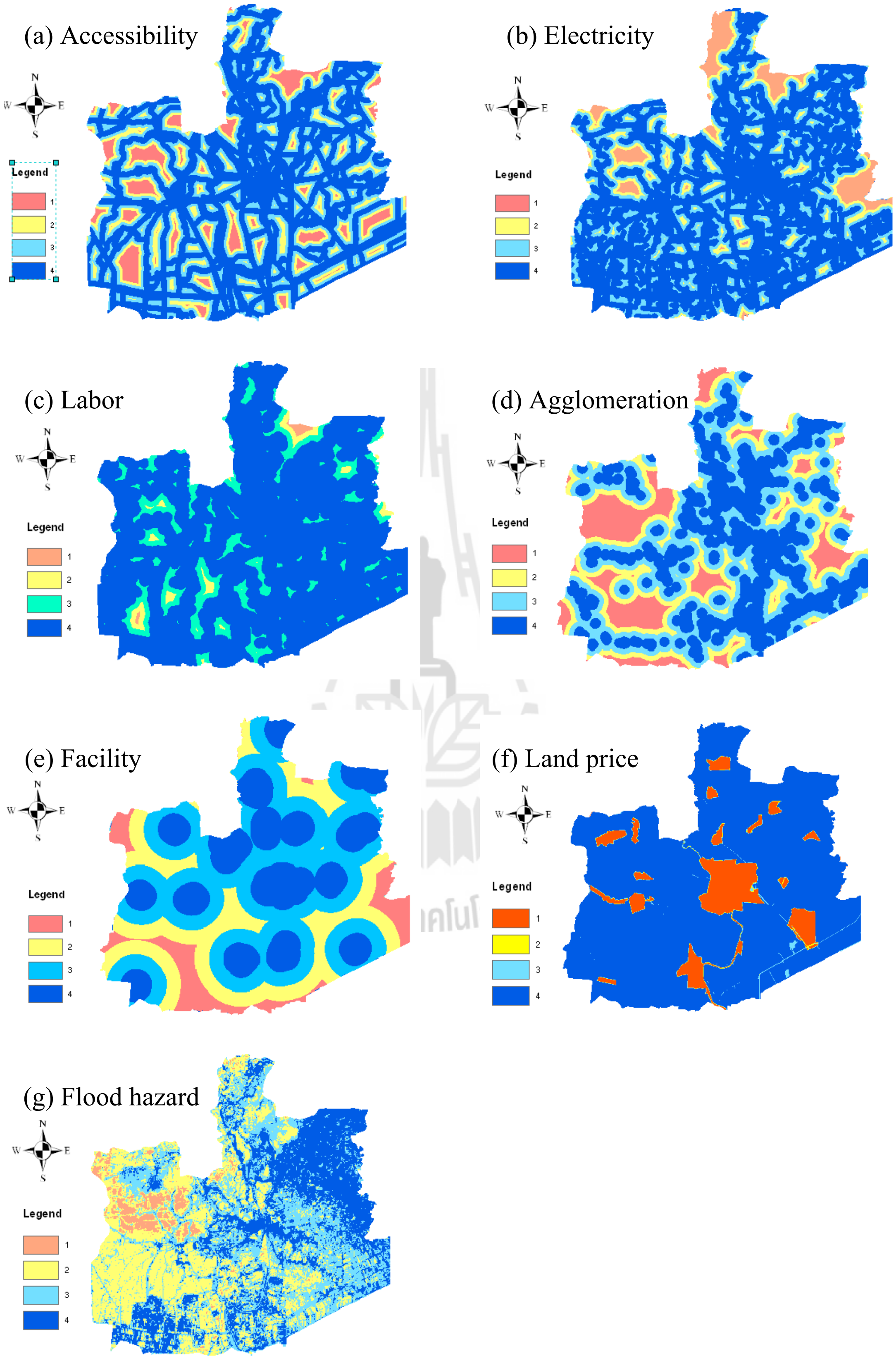


Figure 3.9 Criterion maps for industrial land suitability assessment.

3.4.3 Results and discussion

As a result of GIS operation, the final industrial suitability map was generated as shown in Figure 3.10. Since the urban areas were seldom changed, they were excluded from the map.

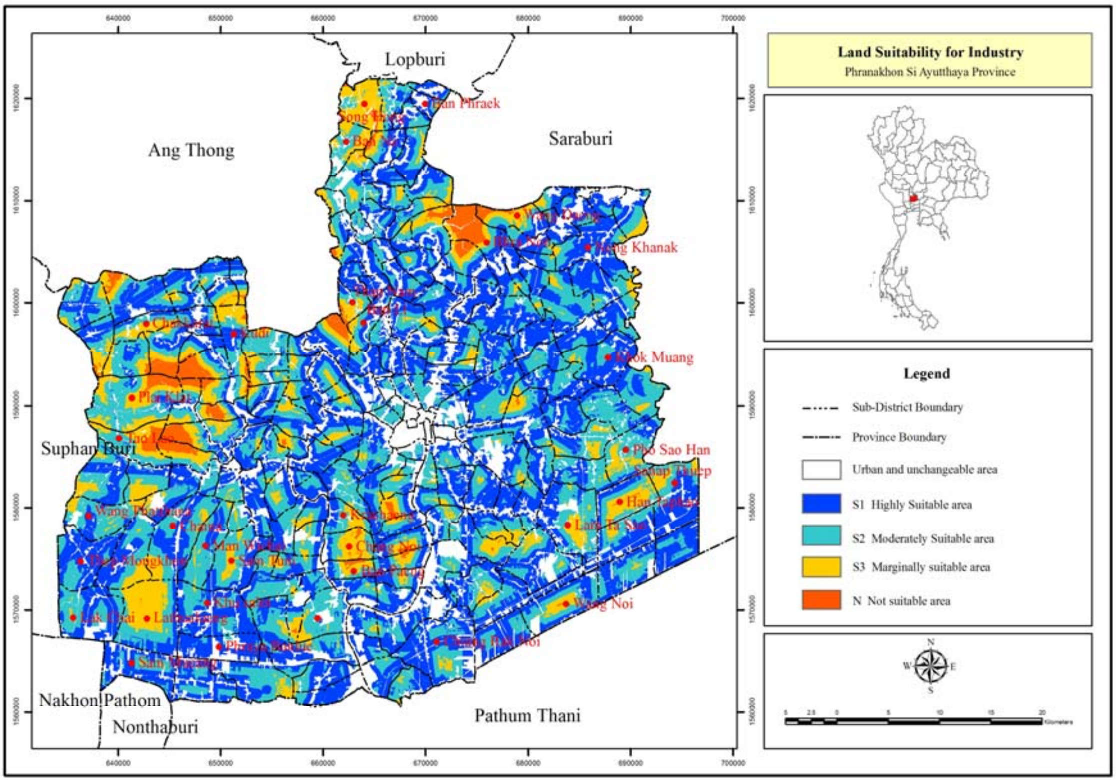


Figure 3.10 Classified land suitability for industry.

The map shows the areas with different suitability which is highly suitable, moderately suitable, marginally suitable and not suitable. The results revealed that the most suitable area is more likely to be located nearby the main road and electricity line. The most suitable area appeared in the east due to the good of accessibility, electricity, labor, facility, and agglomeration such as Nakhon Luang, Bang Pahan, Uthai, and Wang Noi Districts. Obviously, not suitable area and marginally suitable area were located in the west of the study area such as Phak Hai, Bang Sai, and Se Na Districts due to the impact of flood hazard, accessibility, and agglomeration factors. Other marginally suitable appears in the southeast of the area such as Lat bua Luang District due to flood hazard and the poor accessibility, facility and agglomeration factors.

35.59 and 33.14 percent of the total area were classified as highly and moderately suitable for industry. Only few percent of total area was classified as marginally and not suitable for industry (Table3.13). Sub-districts with large area coverage of different suitability classes included S1, S2, S3, and N were listed in Tables 3.14-3.17, respectively.

Table 3.13 Area coverage on classified land suitability for industry.

Land Suitability classification	**Area (Sq. km.)**	**Area (Rai)**	**Area (%)**
Highly Suitability (S1)	893.40	558,372	35.59
Moderately Suitability (S2)	831.66	519,787	33.14
Marginally Suitability (S3)	283.87	177,420	11.31
Not Suitable (N)	61.54	38,462	2.45
Other area	439.55	274,717	17.51
Total	2,510.02	1,568,758	100.00

Table 3.14 Sub-districts with large area coverage of S1 for industry.

Sub-district ID	Sub-district Name	District Name	Area (Sq. km.)	Area (Rai)	Area (%)
140602	Chiang Rak Noi	Bang Pa-in	20.53	12,828	50.40
141006	Khu Salot	Lat Bua Luang	17.86	11,159	54.93
141305	Thep Mongkhon	Bang Sai	16.48	10,300	55.86
140209	Nong Khanak	Tha Ruea	16.08	10,048	59.67
140902	Khok Muang	Pha Chi	14.33	8,954	61.45
141105	Sanap Thuep	Wang Noi	14.26	8,909	49.24
141003	Sam Mueang	Lat Bua Luang	13.30	8,312	51.43
141002	Lak Chai	Lat Bua Luang	12.44	7,774	33.85
141212	Chai Na	Sena	12.24	7,647	36.73
141004	Phraya Ban Lue	Lat Bua Luang	12.17	7,606	61.42

Table 3.15 Sub-districts with large area coverage of S2 for industry.

Sub-district ID	Sub-district Name	District Name	Area (Sq. km.)	Area (Rai)	Area (%)
141304	Plai Klat	Bang Sai	19.12	11,948	47.20
141101	Lam Ta Sao	Wang Noi	14.55	9,090	40.81
141212	Chai Na	Sena	14.38	8,986	43.16
141001	Lat Bua Luang	Lat Bua Luang	13.13	8,209	33.72
141207	Man Wichai	Sena	12.86	8,035	65.97
141306	Wang Phatthana	Bang Sai	12.38	7,740	57.68
141002	Lak Chai	Lat Bua Luang	11.97	7,480	32.57
141409	Pho Sao Han	Uthai	11.63	7,270	53.56
140401	Bang Si	Bang Si	11.39	7,118	58.67
141213	Sam Tum	Sena	11.39	7,117	45.47

Table 3.16 Sub-districts with large area coverage of S3 for industry.

Sub-district ID	Sub-district Name	District Name	Area (Sq. km.)	Area (Rai)	Area (%)
141001	Lat Bua Luang	Lat Bua Luang	17.65	12,603	45.30
141605	Song Hong	Ban Phraek	12.72	9,086	69.98
141304	Plai Klat	Bang Sai	12.67	9,049	31.28
141107	Han Taphao	Wang Noi	7.77	5,552	38.73
140412	Chang Noi	Bang Si	6.95	4,965	49.43
141303	Tao Lao	Bang Sai	6.72	4,800	35.54
140809	Kudi	Phak Hai	5.12	3,660	31.93
141101	Lam Ta Sao	Wang Noi	4.71	3,362	13.21
141509	Ban Na	Maharat	4.61	3,296	38.53
140206	Wang Daeng	Tha Ruea	4.32	3,089	30.43

Table 3.17 Sub-districts with large area coverage of N for industry.

Sub-district ID	Sub-district Name	District Name	Area (Sq.km.)	Area (Rai)	Area (%)
140312	Phra Non	Nakhon Luang	9.35	5,844	40.17
140806	Tha Din Daeng	Phak Hai	5.03	3,142	39.81
141209	Rang Chorakhe	Sena	4.22	2,636	36.99
140814	Lat Chit	Phak Hai	4.04	2,525	25.52
141304	Plai Klat	Bang Sai	3.78	2,360	9.32
141217	Chao Sedet	Sena	3.69	2,307	34.04
141303	Tao Lao	Bang Sai	3.26	2,035	17.23
140516	Ban Kum	Bang Ban	3.19	1,995	21.40
140206	Wang Daeng	Tha Ruea	2.36	1,476	16.62
140308	Mae La	Nakhon Luang	2.13	1,330	16.19

3.5 Conclusion

The main objective in this chapter, which is corresponding to research objective 1, is to assess the land suitability for agriculture and industry. The factors and criteria and their scores used for agricultural land suitability assessment were adopted from FAO guideline and the LDD expert opinions. The factors used for industrial land suitability assessment were obtained from previous studies, the entrepreneurs and the expert opinions. The rank reciprocal method was applied to weighting criteria in agricultural land suitability assessment while the pairwise comparison was applied to the industrial land suitability assessment. The SAW was used to generate the land suitability maps which were classified into highly suitable, moderately suitable, marginally suitable, and not suitable. These maps were further used for the land allocation process in the fourth chapter.

CHAPTER IV

LAND ALLOCATION FOR THE DIFFERENT SCENARIOS

4.1 Introduction

One of the most essential issue land-use planners are always facing is the land allocation problems, particularly at any area which has potential or policy for a variety of uses. However, deciding how resources should be allocated among competing uses is a classic economics problem. To ensure that the area is allocated for the best is probably to encourage sustainability of the land. The information about land suitability of particular area is necessary in consideration. Thus, the land suitability maps of the major land use of the study area were took into account. This chapter aims at choosing areas for proper use of agriculture and/or industries. The agricultural and industrial land suitability maps from the previous chapter were compared.

All possible alternatives of agricultural and industrial land use or scenarios, principles or rules for land allocation, and steps in allocating processes were described. Finally, different potential uses of land were allocated according to scenarios.

4.2 Scenarios of land use

According to economic structure of Thailand, the main source of income in a town or city came from three major economic activities: agriculture, industrial and services. The economic structure used to determine the growth rate of cities economy is a function of the sum of all the different economic activities in the geo-political boundaries of the area.

In the past, economic structure of Thailand was mainly characterized by the agricultural sector. Since the late 1980s the economic structure of Thailand has changed dramatically with a rapid industrialization. Share of agricultural sector in GDP has fallen from 23.2% in 1980 to less than 10% in 2000. On the contrary, ratio of GDP increased in manufacturing, commercial, and service sector. It should be noted that agriculture sector employs a great number of people in 2000, or 48.4% of total population. In 2007 Thailand economic structure came from agriculture 12.3%, industry 44%, and services 43.7%. Although almost 42.4% of the employment is generated through agriculture, the agricultural sector contributes only 12.3% of the total GDP (EconomyWatch, 2010).

Alongside rapid economic growth, urbanization, and industrialization, Thailand is facing various social and environmental challenges such as experiencing industrial pollution, unsanitary urban environment, and destruction of natural environment. Major air pollutants in Thailand are particulate matters. One of the emission sources of those pollutants is from factories. Central region of Thailand accounts for 60-70 % of all industrial emissions. As well as air pollution, water quality and waste disposal come from industries (Pollution Control Department, 2010).

As mention above, the economic structure directly affects the economic growth, the standard of living or quality of life of the people and causes the pollution in the area. The industrial sector leads more in the economic growth than the agricultural sector but it also causes more unwanted impacts. Thus, the optimum proportion of agricultural and industrial sectors should be determined to develop sustainability of land use.

Based on the economic structure, land use in Phra Nakhon Si Ayutthaya province can be classified into the 3 major types which are agricultural land, industrial land, and other land. Agricultural land comprised of rice paddy, field crops, perennial, orchard, farming, and other agricultural land. Industrial land comprises of industrial estate, manufacturing or factory, and commercial and services land. Other land can be the urban and built up or residential area, infrastructure and transportation, temple and historical land, forest and parks, water body, and miscellaneous land (Figure 4.1). In general, the proportion of any type of land use is determined by the growth of particular economic activities. However, land can be allocated in the better way according to the national economic plan of the country and the local policies in the area.

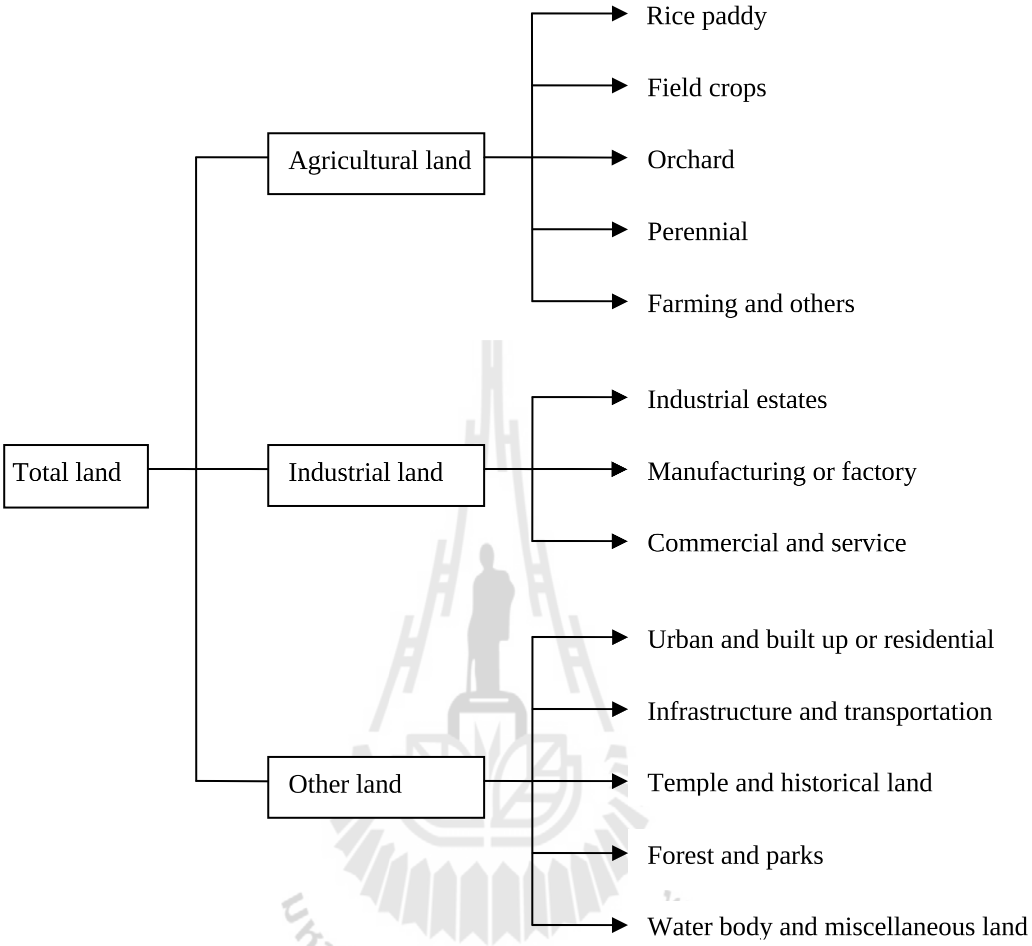


Figure 4.1 Land-use classification based on economic activities.

With the interest in the impact of agricultural sector and industrial sectors, the land use could be set up into three possible scenarios namely Scenario I: maximizing agricultural area, scenario II: maximizing industrial area, and scenario III: optimizing agricultural-industrial area.

In scenario I which aims at maximization of agricultural area, the land was allocated for agriculture as much as possible to its suitability.

On the contrary, scenario II aims at maximization of industrial area so the land was allocated for industry as feasible as its suitability.

With compromising, scenario III seeks for the optimized land allocation for agricultural and industrial sectors by comparing their suitability on land. This process determines which land should be allocated for the agriculture or industry.

4.3 Methodology

As mentioned before, land should be used in the proper manner to pursue the sustainable land use. Land can be allocated in different ways therefore the rule for allocating should be set up first. The advantages comparison is an attractive principle to approach the land allocation process. In this study, land suitability of agriculture and industry was compared and was generated in the matrix form called the Land Suitability Combination Matrix (LSCM). This process was done in the raster format. The suitability maps of both sectors from the chapter three were used. Each raster cell of these maps contains the quantified potential relative to particular Land-uses. For example, considering a particular raster cell within the study area where agricultural land suitability is most suitable (S1) but industrial suitability is moderate (S2), this cell has a relatively low potential for industry, and hence will be assigned to agricultural land. This whole process is illustrated in Figure 4.2 and can be split into six steps as follows:

1. Set up prioritization rules.
2. Develop land suitability combination matrix (LSCM).
3. Reclassify the new value of suitability in the raster grid cell.
4. Use raster calculator in ArcGIS to combine the suitability value.

5. Determine the land use for each grid cells.
6. Generate the land allocation map for each scenario.

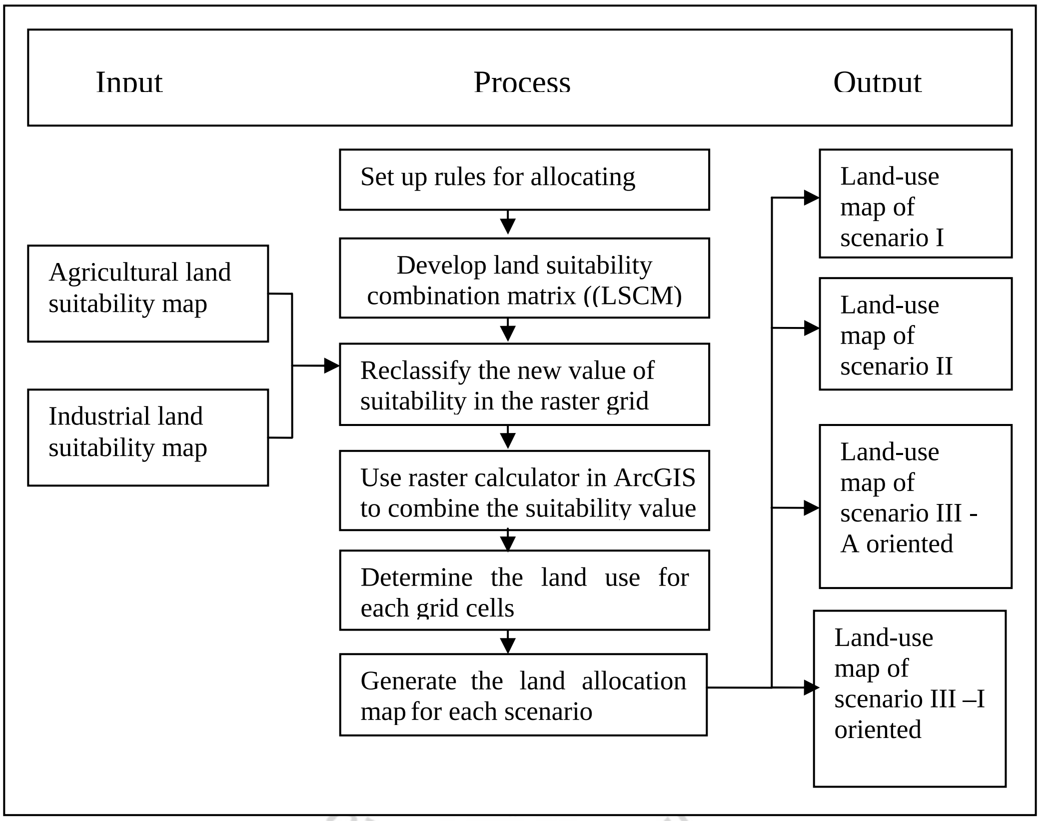
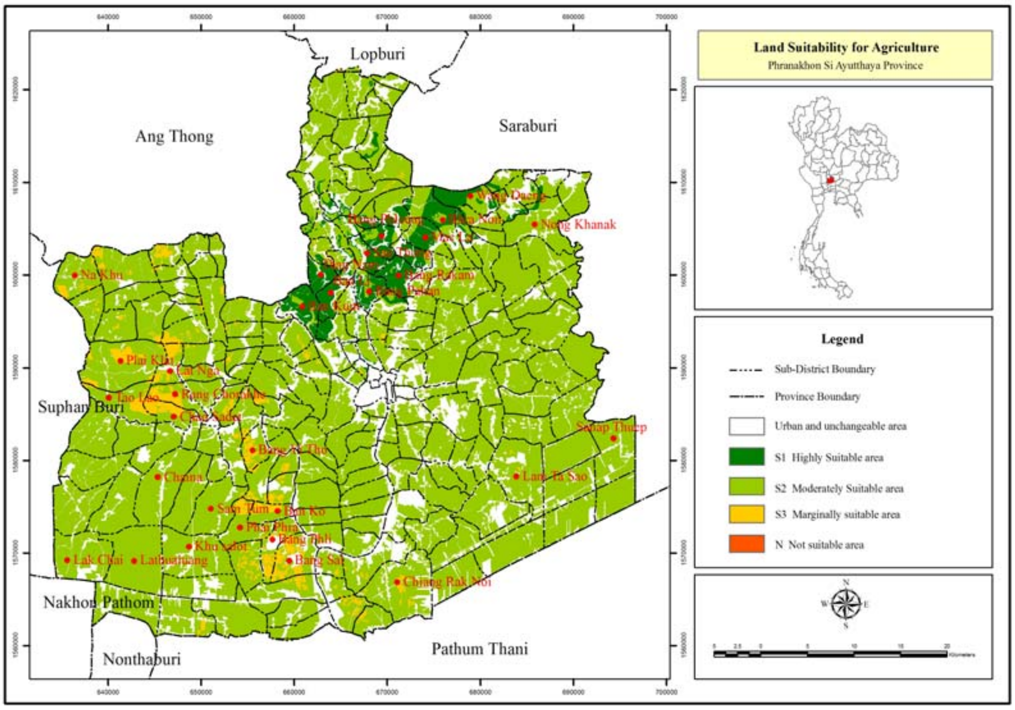


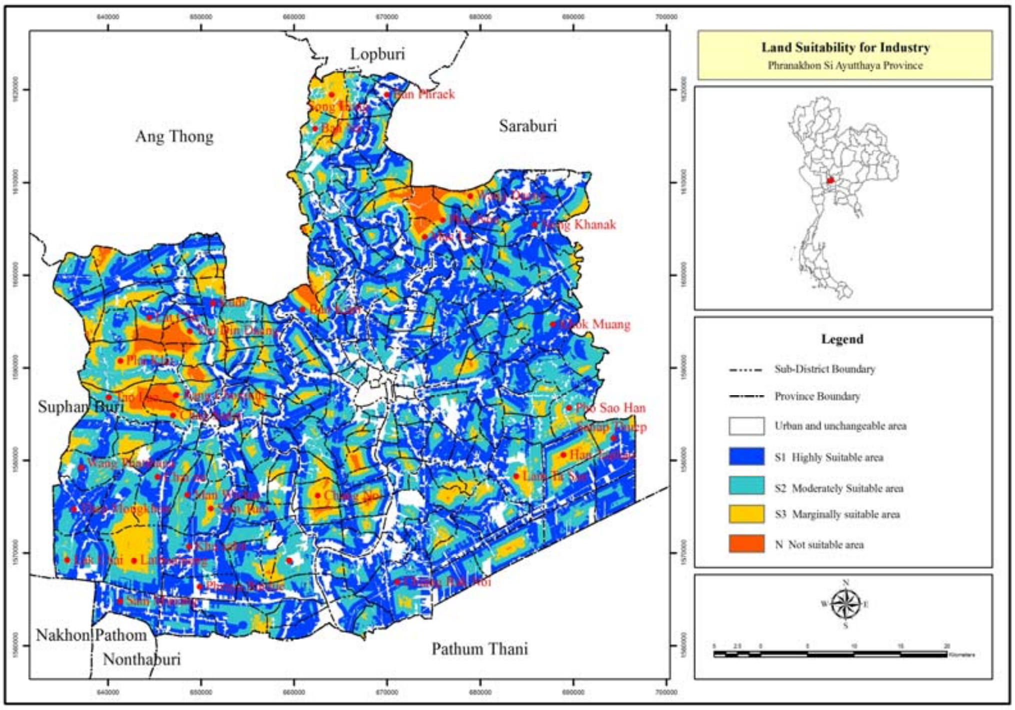
Figure 4.2 Land allocation process.

4.3.1 Input GIS data layers

The inputs for land allocation process were obtained from the third chapter. They are the results of the land suitability assessment process. The agricultural land suitability map and the industrial land suitability map in raster format with grid size 20×20 m. (Figure 4.3) were reclassified, calculated, and reassigned the land use for each cell.



(a) Agricultural land suitability.



(b) Industrial land suitability.

Figure 4.3 Input GIS data layers for land allocation process.

4.3.2 Land suitability combination matrix (LSCM)

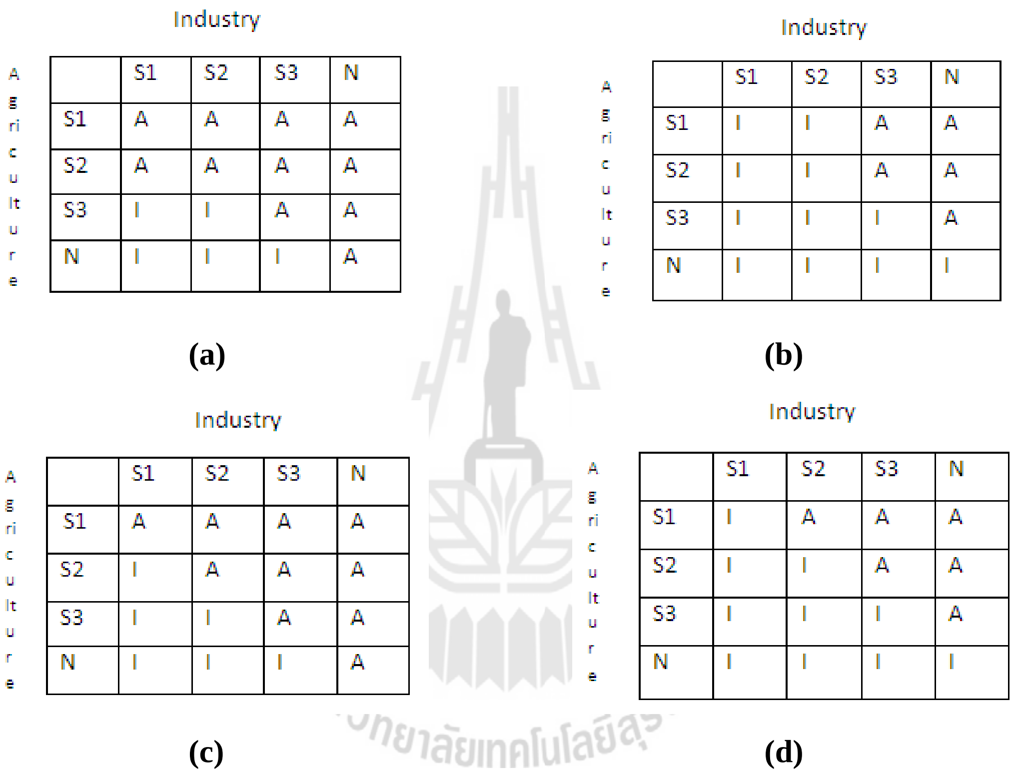
LSCM was generated under the rules of advantage comparison which attempted to pick up specific land-use types, either agriculture or industrial, for each cell. Then, four LSCMs were developed according to three main scenarios (Figure 4.4).

The scenario I which aims at maximizing the agricultural area, the land was allocated to the agricultural land as possible as its suitability. Cells with S1 and S2 of agricultural suitability were reassigned to be suitable for agricultural land. Cells with S3 were compared to the industrial suitability. If their agricultural suitability values of the same cells are less than their industrial suitability values, they were reassigned to be industrial land. Otherwise they were reassigned to be agricultural land.

In the contrary, the scenario II aims at maximizing the industrial land, so the land was allocated to industrial land as feasible as its suitability. With the advantage comparative rules, the LSCM developed is the reverse of scenario I. Cells with the S1 and S2 of industrial suitability were reassigned to be industrial land. Cell with S3 were compared to the agricultural suitability. If their industrial suitability values are less than their agricultural suitability values, they were reassigned to be agricultural land. Otherwise they were reassigned to be industrial land.

The scenario III seeks for allocation optimization between agricultural and industrial sectors. This scenario could be divided into two sub-scenarios according to different policies: scenario IIIa-agricultural orientation and scenario IIIb-industrial orientation. Therefore, cells were reassigned to be suitable for agricultural or industrial land according to their dominant suitability. Cells with equivalent suitability were reassigned to be the agricultural land or industrial land depending on the orientation of the policy.

Table 4.1 Land Suitability Combination Matrix (LSCM) for (a) scenario I (b) scenario II and (c) scenario IIIa (d) scenario IIIb.



Industry

Agriculture

	S1	S2	S3	N
S1	A	A	A	A
S2	A	A	A	A
S3	I	I	A	A
N	I	I	I	A

(a)

Industry

Agriculture

	S1	S2	S3	N
S1	I	I	A	A
S2	I	I	A	A
S3	I	I	I	A
N	I	I	I	I

(b)

Industry

Agriculture

	S1	S2	S3	N
S1	A	A	A	A
S2	I	A	A	A
S3	I	I	A	A
N	I	I	I	A

(c)

Industry

Agriculture

	S1	S2	S3	N
S1	I	A	A	A
S2	I	I	A	A
S3	I	I	I	A
N	I	I	I	I

(d)

4.4 Results and discussion

The result maps of land allocation process in particular scenarios included scenario I, II, IIIa, and IIIb were generated in raster form as shown in Figures 4.4-4.7, respectively. Agricultural and industrial areas of current and allocated land use in the scenarioes I, II, IIIa, and IIIb were compared in Table 4.2.

In the scenario I, almost all of the study area (80.88%) was suitable for agricultural land. Only 1.56% should be allocated to be the industrial land (Figure 4.4).

In the scenario II, 69.53% of the area was allocated to be industrial land and only 12.90 % should be agricultural land (Figure 4.5). In the scenario IIIa, almost half of the land (47.61%) was allocated to be agricultural land and 34.81% should be industrial land (Figure 4.6). In the scenario IIIb, the land was allocated to be suitable for industrial more than agricultural. 68.31% of the study area was allocated to be industrial land and only 14.12% to be the agricultural land (Figure 4.7). In fact, current land use in 2007 was mostly similar to the scenario I than the others. Hence, it can be concluded that the current land use in 2007 is more likely to be in traditional maximizing agricultural area.

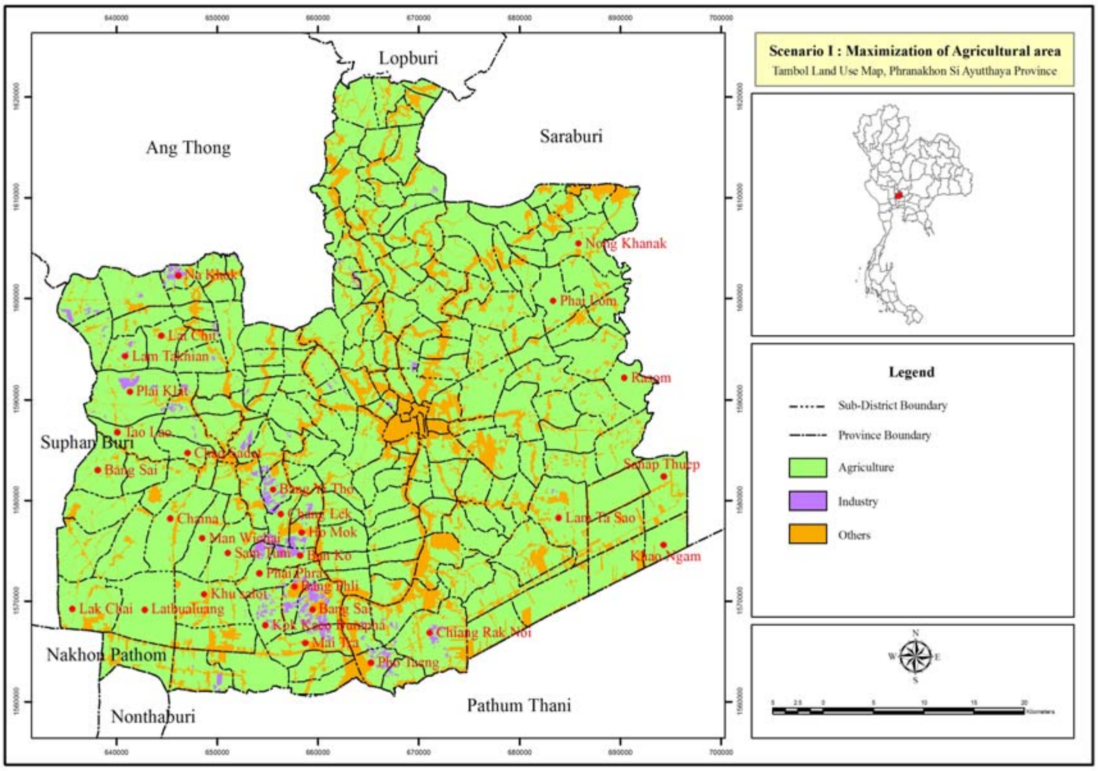


Figure 4.4 Land allocation of the scenario I: Maximizing agricultural area.

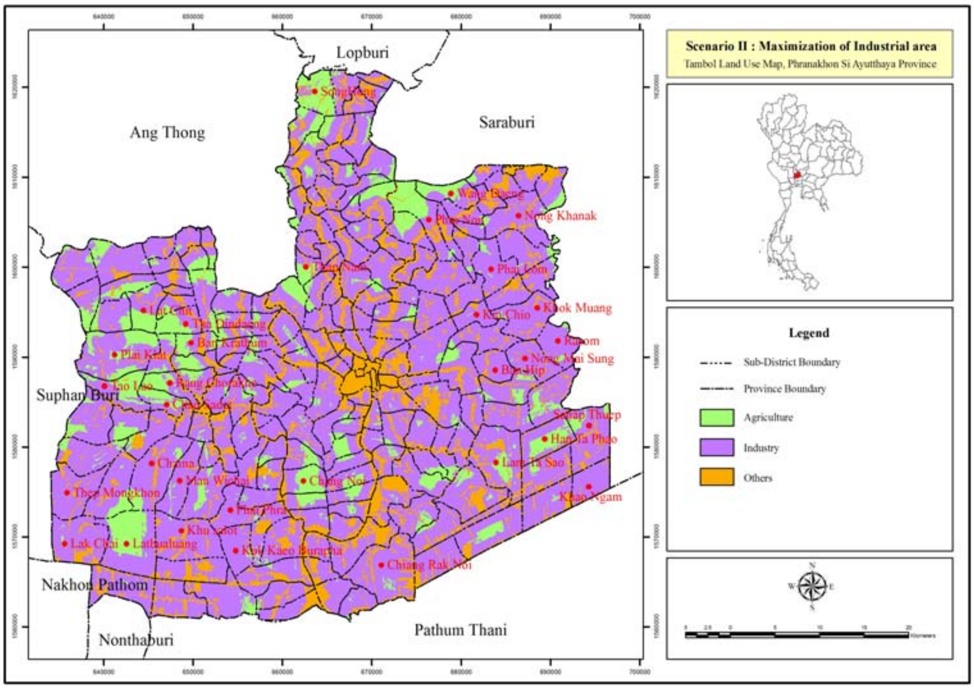


Figure 4.5 Land allocation of the scenario II: Maximizing Industrial area.

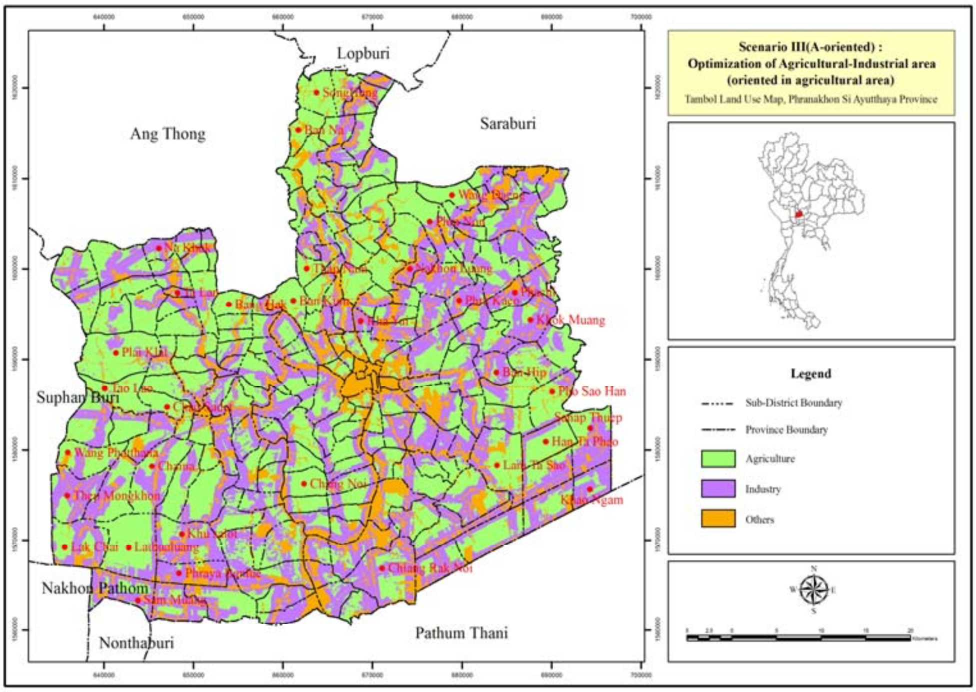


Figure 4.6 Land allocation of the scenario IIIa: Optimizing A-I area with agricultural orientation.

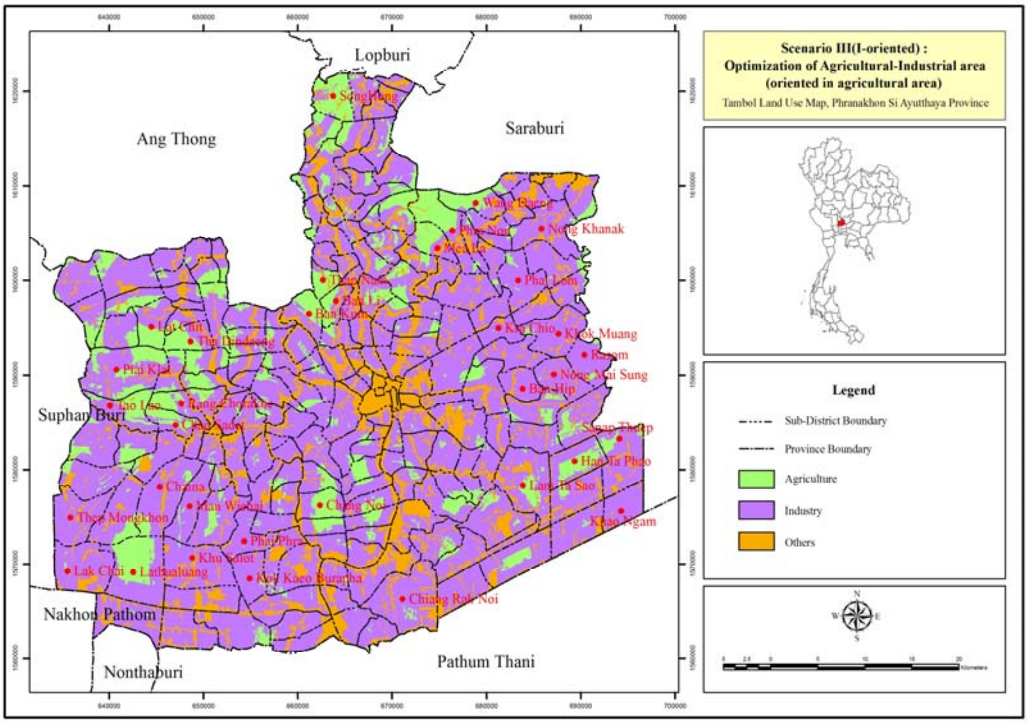


Figure 4.7 Land allocation of the scenario IIIb: Optimizing A-I area with industrial orientation.

Table 4.2 Comparison of agricultural and industrial areas between current land use in 2007 and land-use scenario I, II, IIIa, and IIIb.

	Agricultural area		Industrial area		Other area		Total	
	Rai	**Percent**	**Rai**	**Percent**	**Rai**	**Percent**	**Rai**	**percent**
Current	1,163,249	74.09	29,153	1.86	377,677	24.05	1,570,079	100
Scenario I	1,269,845	80.88	24,448	1.56	275,786	17.56	1,570,079	100
Scenario II	202,626	12.90	1,091,637	69.53	275,816	17.57	1,570,079	100
Scenario IIIa	747,562	47.61	546,516	34.81	276,001	17.58	1,570,079	100
Scenario IIIb	221,711	14.12	1,072,540	68.31	275,828	17.57	1,570,079	100

Tables 4.3-4.6 show descriptive statistics of land use of sub-districts in scenario I, II, IIIa, and IIIb, respectively. They include minimum, maximum, mean, sum, and standard deviation of agricultural, industrial, and other areas. It is interesting to note that the area allocated for agricultural of a sub-district can be predicted to cover an area up to 98.97% as found in Rasom (Table 4.7) and the area allocated for industrial of a sub-district can be up to 93.50% as found in Kok Kaeo Burapha (Table 4.8).

Basically, Land-use scenarios set up were simulated to seek for optimum agricultural and industrial alternatives based on the suitability of land. In fact, the set up variety of scenarios is more likely being extreme in order that obvious sustainability index of the area can be investigated and predicted. Therefore, four scenarios were generated to provide the options in land-use planning to the decision makers. The impacts of land-use planning for each scenario to the quality of life (QOL) or sustainability development (SD) should be able to anticipate so that the decision makers can use them as a guide to fit their policies.

Table 4.3 Descriptive statistics of land-use area in the scenario I.

Land use		**Minimum**	**Maximum**	**Mean**	**Sum**	**Standard deviation**
Agriculture	Area (Rai)	0.00	23,645.00	6,075.00	1,269,845	4,271.00
	Percent	0.00	98.97	75.76	15,833	19.33
Industry	Area (Rai)	0.00	3,092.00	116.95	24,448	350.03
	Percent	0.00	28.56	1.57	328	4.33
Other	Area (Rai)	104.00	6,474.00	1,313.00	275,786	955.72
	Percent	1.02	100.00	22.67	4737	19.23

Table 4.4 Descriptive statistics of Land-use area in the scenario II.

Land use		**Minimum**	**Maximum**	**Mean**	**Sum**	**Standard deviation**
Agriculture	Area (Rai)	0.00	11,052.00	969.00	202,626	1,563.24
	Percent	0.00	79.06	11.41	2,385	14.53
Industry	Area (Rai)	0.00	19,489.00	5222.00	1,091,637	3728.11
	Percent	0.00	93.50	65.91	13,775	19.13
Other	Area (Rai)	104.00	6,474.00	1,313.00	275,816	955.69
	Percent	1.02	100.00	22.67	4,738	19.23

Table 4.5 Descriptive statistics of land-use area in the scenario IIIa.

Land use		**Minimum**	**Maximum**	**Mean**	**Sum**	**Standard deviation**
Agriculture	Area (Rai)	0.00	21,025.00	3,576.00	747,562	3,035.44
	Percent	0.00	90.45	44.78	9,358	21.70
Industry	Area (Rai)	0.00	13,311.00	2,614.00	546,516	2,324.83
	Percent	0.00	72.76	32.54	6,799.95	18.05
Other	Area (Rai)	105.00	6,479.00	1,314.00	276,001	956.31
	Percent	1.04	100.00	22.68	4,741	19.24

Table 4.6 Descriptive statistics of land-use area in the scenario IIIb.

Land use		**Minimum**	**Maximum**	**Mean**	**Sum**	**Standard deviation**
Agriculture	Area (Rai)	0.00	11,052	1,060.00	221,711.00	1,625.85
	Percent	0.00	79.06	12.92	2,699.00	15.74
Industry	Area (Rai)	0.00	19,489.00	5,131.00	1,072,540.00	3,764.31
	Percent	0.00	93.50	64.40	13,460.00	19.88
Other	Area (Rai)	104.00	6,474.00	1,313.00	275,828.00	955.68
	Percent	1.02	100.00	22.67	4,738.00	19.23

Table 4.7 Sub-districts with highest proportion of agricultural area allocated in the land-use scenario I.

No.	Sub-district ID	Sub-district Name	District Name	Agricultural area		
				km^2	Rai	Percent
1	140903	Rasom	Pha Chi	16.04	10,027	98.97
2	141001	Lat Bua Luang	Lat Bua Luang	37.83	23,645	97.12
3	141207	Man Wichai	Sena	18.82	11,764	96.58
4	140906	Phai Lom	Pha Chi	19.25	12,028	96.38
5	141217	Chao Sadet	Sena	10.21	6,378	94.07
6	141303	Tao Lao	Bang Sai	17.63	11,019	93.38
7	141301	Bang Sai	Bang Sai	21.65	13,532	92.98
8	140810	Lam Takhian	Phak Hai	13.47	8,421	92.87
9	141109	Khao Ngam	Wang Noi	14.04	8,773	92.54
10	140814	Lat Chit	Phak Hai	14.66	9,159	92.53

Table 4.8 Sub-districts with highest proportion of industrial area allocated in the land-use scenario II.

No.	Sub-district ID	Sub-district Name	District Name	Industrial area		
				km^2	Rai	Percent
1	140415	Kok Kaeo Burapha	Bang Si	14.40	9,002	93.50
2	141109	Khao Ngam	Wang Noi	14.04	8,773	92.54
3	141207	Man Wichai	Sena	17.81	11,128	91.37
4	140906	Phai Lom	Pha Chi	18.22	11,386	91.23
5	140414	Phai Phra	Bang Si	14.41	9,006	91.17
6	140907	Kra Chio	Pha Chi	8.65	5,409	90.94
7	141405	Nong Mai Sung	Uthai	15.24	9,526	90.73
8	140903	Rasom	Pha Chi	14.62	9,135	90.17
9	141404	Ban Hip	Uthai	11.17	6,979	90.06
10	140902	Khok Muang	Pha Chi	20.83	13,016	89.63

4.5 Conclusion

In this chapter, alternative land-use scenarios were established based on land suitability for agriculture and industry and different policies as declared in the research objective 2. Land suitability maps of both agriculture and industry were combined to be 4 scenarios using Land Suitability Combination Matrix (LSCM). These scenarios include scenario I: maximizing agricultural area, scenario II: maximizing industrial area, scenario IIIa: optimizing A-I area with agricultural orientation, and scenario IIIb: optimizing A-I area with industrial orientation. This resulted in 4 maps of scenarios. Finally, descriptive statistics of Land-use areas of each scenario were able to enumerate.

CHAPTER V

SUSTAINABILITY ASSESSMENT

This chapter intends to present the overall system assessment of the economic, social and environmental sustainability. It comprises of overview of sustainability, sustainability indicators, data and methodology, and all kinds of sustainability assessments including their result discussion and conclusion.

5.1 Introduction and overview of sustainability

The idea of Sustainable Development grew from numerous environmental movements in earlier decades and was defined in 1987 by the *World Commission on Environment and development (WCED)* or *Brundland Commission*. Agenda 21, the Rio Declaration on Environment and Development, and the Statement of principles for the Sustainable Management of Forests were adopted by more than 178 Governments including Thailand at the United Nations Conference on Environment and Development (UNCED) held in Rio de Janerio, Brazil, 3 to 14 June 1992 (UN, 2010).

Since sustainability was embedded into global agenda at the Rio Summit in 1992 sustainable development has been defined in many ways. The most frequently quoted definition is from *Our Common Future*, also known as the Brundtland Report as "*Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (Brundtland, 1987).

Pearce, Makandia, and Barbier (1989) stated that "*sustainable development involves devising a social and economic system, which ensure that these goals are sustained, i.e. that real incomes rise, that educational standards increase, that are the health of the nation improves, that the general quality of life is advanced*" (Referred in University of Reading, 2000).

The International Union for Conservation of Nature (IUCN, 2000), United Nations Environment Programme (UNEP, 2000), and World Wildlife Fund (WWF, 2000) stated that "*Sustainable development, sustainable growth, and sustainable use have been used interchangeably, as if their meanings were the same. They are not. Sustainable growth is a contradiction in terms: nothing physical can grow indefinitely. Sustainable use, is only applicable to renewable resources. Sustainable development is used in this strategy to mean: improving the quality of human life whilst living within the carrying capacity of the ecosystems*" (Referred in University of reading, 2000).

Sustainable Seattle organization defined sustainability as "*long-term, cultural, economic and environmental health and vitality*" *with emphasis on long-term,* "*together with the importance of linking our social, financial, and environmental well-being*" (Sustainableseattle, 1999).

World Business Council on Sustainable Development describes the concept of the sustainability as "*Sustainable development involves the simultaneous pursuit of economic prosperity, environmental quality and social equity*" (WBCSD, 2000).

According to the various definitions of sustainability, we can conclude that sustainability development mean the development that can increase the quality of life and provide the well being of economic, social, environment and cultural to the people in the area for long term. In order to assess these elements, quantitative sustainability measurement is needed. Therefore, sustainability assessment is a way to quantify the level of sustainability development in the area which is valuable information beneficial for decision making to the planner.

5.2 Sustainability indicators

There are a wide range of approaches taken to sustainability assessment including indicators, product-related assessment and integrated assessment tools (Ness, Urbel-Piirsalu, Anderbergd, and Olsson, 2007). The assessment which indicators are used as a framework for measuring progress towards sustainability can be found at the global, national, regional and the local scale. Yet to date no generic frameworks for assessing sustainability using indicators have emerged at any these scale (Graymore et al., 2009).This is because of the complexity of interrelated ecological and human systems. Sustainability of a system is characterized by the co-evolution of social, economic and environmental systems and the organization of these systems called the institutional or political system (O’Connor, 2006). Thus, the sustainability assessment of a system cannot be understood by examining only one component, either social or nature (Gunderson and Holling, 2002; Wu and Hobbs, 2002; Zurlini, Ritters, Zaccarelli, Petrosillo, Jones, and Rossi, 2006; Graymore et al., 2009). Further more, it needs to take a systems approach to provide essential information about all important aspects of system viability, performance and sustainability (Bossel, 2001).

The sustainability can be measured in many ways according to the concept of sustainability development (SD) which is an important objective of policy makers. Sustainability indicators are recognized as a useful tool for policy making on countries performance in fields such as environment, economy, society, or technological improvement. Kates et al. (2001) mentioned that the purpose of sustainability assessment is to provide decision-makers with an evaluation of global to local integrated nature–society systems in short and long-term perspectives in order to assist them to determine which actions should or should not be taken in an attempt to make society sustainable. In order to give well structure methodologies and to assure that all important aspects are all included in the measurement, the integral systematic approach to indicators is needed (Bossel, 1999). However, before developing the methodology and the indicators what is needed is the clear definition of the policy goals towards sustainability.

Distaso (2007) presented the quality of life through a multidimensional index of sustainability of EU countries. The aim of his paper is to demonstrate that Sen's theory of well-being can be applied to make the concept of sustainable human development operational through the building of a multidimensional index of sustainability which takes into account, at the same time, economic, social and environmental variables. This index may be considered an alternative to the current measures of welfare/sustainability since not only conventional measures such as GDP, but also multi-attribute indices, such as Human Development Index (HDI), Genuine Savings, Index of Sustainable Economic Welfare (ISEW) etc., are found to be inadequate to make the concept of sustainable development operational. Therefore, the limitations of these measures of welfare/sustainability justify the search for a new index of sustainability. This index will show, at the operational level, how Sen’s theory of well-being can be useful to sustainable development. It was applied to EU countries using the standardized deviation methodology being the closest and most suitable methodology to be adopted for building multidimensional indices. Lastly, the comparison between Sen's trend of sustainability and GDP trend index number which are both of them applied to Italy will show how much the criticism and the limitations directed towards the indicator of GDP are founded.

From previous studies, we can conclude that the sustainability can be measured by the different indicators and criteria according to the area scale and what aspects the study emphasizes on. However, in general, almost all of the indicators used in these studies also look at the economic, social and environmental aspects. The sustainability theme indicators framework adapted from The United Nations Commission for Sustainable Development (UNCSD) used in any aspect can illustrated in Figure 5.1. However these indicators were adjusted due to the scale of the study area. For example, in the economic sustainability which aim to promote a healthy economy and generate the resource to meet people’s need and increase the standard of living, the indicators can be Gross National Product (GNP) or Gross Domestic Product (GDP), in national sustainability scale but in the local scale, the indicators represent economic welfare may be the average income of the people in the village instead of GNP or GDP. Hence, the sustainability indicators used in this study were selected according to data available at the local scale of the study area.

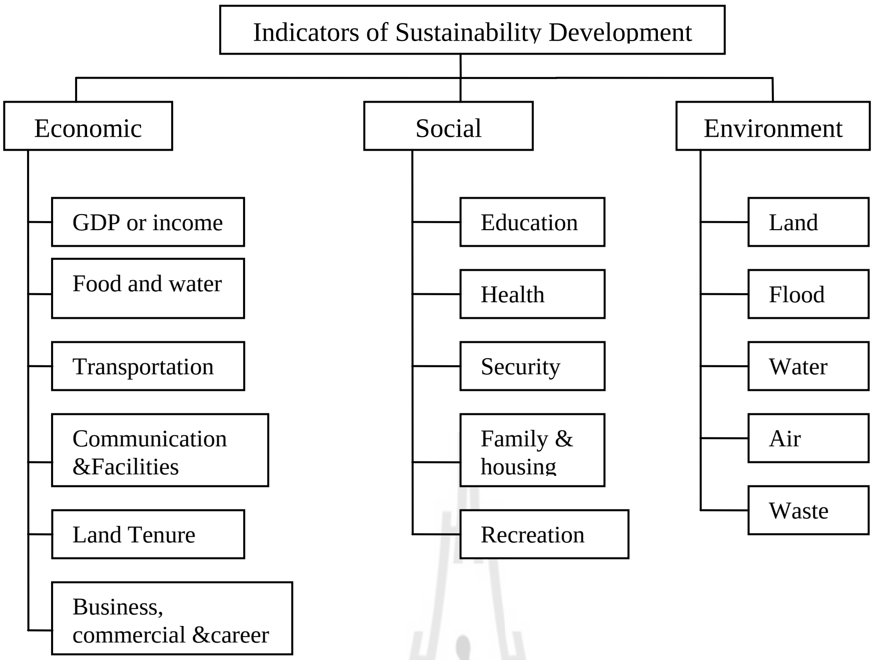


Figure 5.1 Sustainability theme Indicator frameworks adapted from UNCSD.

5.3 Data and methodology

5.3.1 Framework and Input data

The objective of this part is to evaluate the sustainability of Phra Nakhon Si Ayutthaya based on the existing land use which derived from its economic structures and economic activities in the area. The overall system of sustainability land-use planning and study framework can be illustrated by flow diagram as illustrates in Figure 5.2. The system starts from the human economic activities in forms of land use which reflects the quality of life in three dimension as economic, social and environment. In order to evaluate how the sustainability related to human economic activities which definitely influence to types of land use, the sustainability assessment was carried out. The results will be useful for further sustainable land-use planning.

The sustainability of current land use was assessed and classified in this process. According to the NESDB (2007), the sustainable indicators were categorized into three groups which are economic indicators such as, gross output per area, per capita income, land owner, infrastructure and facility etc.; social indicators such as population, educational, health, family and housing, etc., and environmental indicators: such as, soil quality, waste disposal, and water quality and flood hazard problem, etc.

According to the objectives of the study which aim at assessing the sustainability at sub-district level, NRD and BMN data at village level were employed and categorized into sub-district level to determine the sustainability of economic, social and environmental aspects.

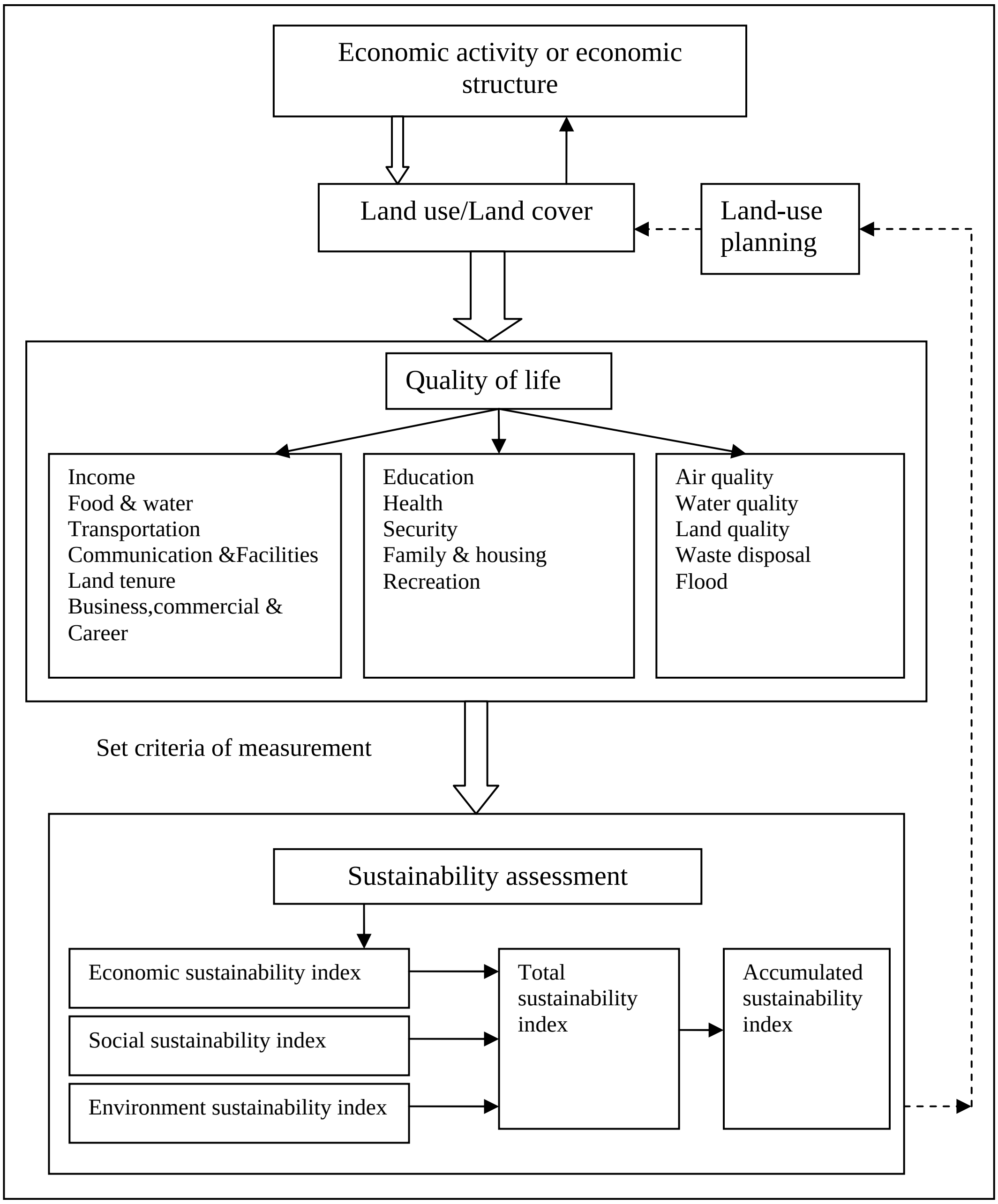


Figure 5.2 Study framework and relation of economic activities, quality of life, sustainability and land-use planning.

5.3.2 Methodology

The steps of sustainability assessment process in this study consist of data extraction of variables, factor analysis of variables, development of sustainability index and its accumulation as illustrated in Figure 5.3.

Basically, many studies of complex geographic phenomena begin with a set of data and notion of hypotheses and theories that are vague at best. Factor analysis is used as a data reduction method to reduce a data set containing a large number of variables down to one of more manageable size. When many of the original variables are highly correlated, it is possible to reduce the original data from a large number of original variables to a small number of underlying factors (Rogerson, 2001).

Principle components and factor analysis are also often used for data reduction. Benefits of this approach include uncovering latent variables for easy interpretation and removing multicollinearity for subsequent regression analysis. In many socio-economic applications, variables extracted from census data are often correlated with each other, and thus contain duplicated information to some extent. Principal Components Analysis (PCA) and factor analysis (FA) use fewer factors to represent the original variables, and thus simply the structure for analysis. Resulting component or factor scores are uncorrelated to each other (Wang, 2006).

Due to the various data in NRD and BMN, the data should be extracted in order to pick up the data that represent criterion in any of aspect. These data sets of variables were reduced into fewer factors by factor analysis (FA). Then, the sustainability index such as Current Economic Sustainability Index (CESI), Current Social Sustainability Index (CSSI) and Current Environment Sustainability Index (CEnSI) were developed through the factor scores calculation. Furthermore, the

Current Total Sustainability Index (CTSI) based on current or existing land use was integrated. In order to compare which scenario of land use can provides the highest sustainability index for the whole area of study, The accumulated of CESI,CSSI, CEnSI, and CTSI of individual spatial units (sub-district level) were generated. This process of sustainability assessment was illustrated in Figure 5.3.

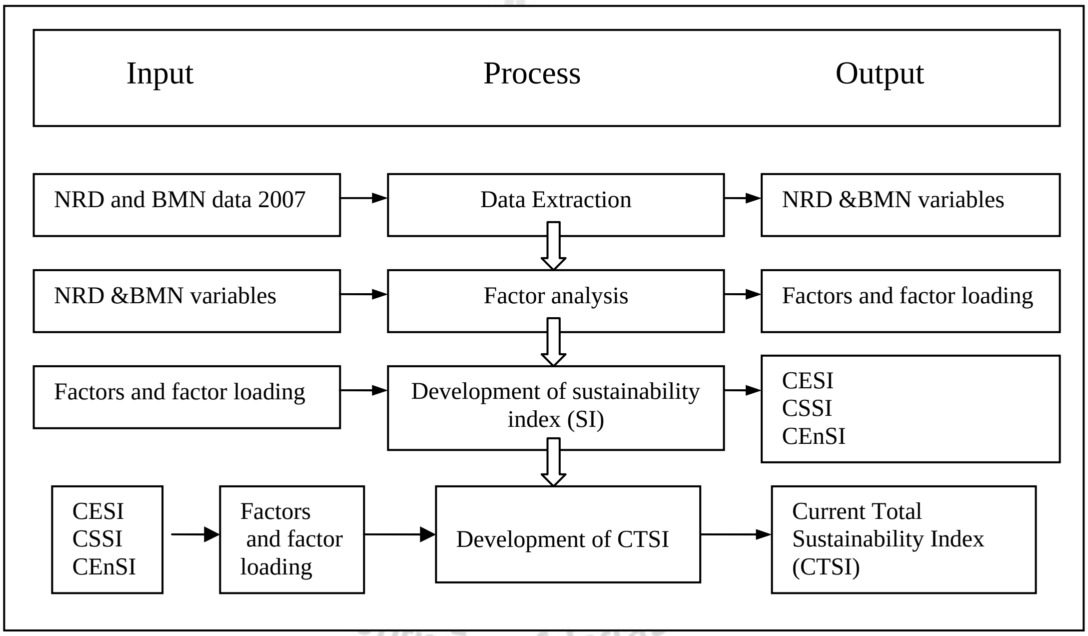


Figure 5.3 Process of sustainability assessment.

5.4 Economic sustainability assessment

Economic indicators at household level were extracted from NRD and BMN data in 2007. All indicators were summed and averaged at sub-district level.

5.4.1 Extraction of economic variables

Economy of the area can be indicated by average income, food and water consumption, transportation, facility or infrastructure, and employment. In this study, 14 economic indicators within 6 groups of economic indicators were selected from NRD and BMN data. The coding and description of these variables are as follow:

Food and water

E1	Number of households that have pipe water

Transportation

E2	Number of households that have cars
E3	Number of cars per household
E4	Number of households that have motorcycles
E5	Number of motorcycles per household

Communication and facilities

E6	Number of households that have telephone
E7	Number of households that have basic telephone
E8	Number of households that have mobile telephone
E9	Number of households that have home Internet

Business, commercial and career

E10	Number of grocery store
E11	Number of car accessory or car care center
E12	Number of petrol or gasoline station

Land Tenure

E13	Number of households that were land tenure

Average income

E14	Average income per household

The descriptive statistical data of these variables were summarized and shown in Table 5.1.

5.4.2 Factor analysis of economic variables

Factor analysis attempts to identify underlying variables, or factors, that explain the pattern of correlations within a set of observed variables. Factor analysis is often used in data reduction to identify a small number of factors that explain most of the variance observed in a much larger number of manifest variables.

The major steps in factor analysis consist of (1) variable standardization, (2) variable selection, (3) factor extraction, and (4) factor interpretation.

(1) Variable standardization

In this study, 14 extracted variables were analyzed by factor analysis through SPSS version 16.0. The descriptive statistics as shown in Table 5.1 was standardized in order to diminish the different in ranges and units between variables as shown in Table 5.2. These standardized data of variables represented by the Z score value were used for the variable selection.

Table 5.1 Descriptive statistics of economic variables before standardization.

Variables	Minimum	Maximum	Mean	Std. Deviation	Unit
E1	43.00	100.00	94.46	11.095	Percent
E2	16.00	81.00	36.42	13.967	Percent
E3	0.00	1.00	0.41	0.157	Car/household
E4	41.00	95.00	70.81	10.578	Percent
E5	0.00	3.00	0.86	0.369	Motorcycle/household
E6	61.00	100.00	82.71	9.069	Percent
E7	24.00	84.00	47.73	15.144	Percent
E8	50.00	100.00	78.09	10.434	Percent
E9	1.00	15.00	4.37	3.038	Percent
E10	2.00	15.00	5.39	2.793	shop/village
E11	1.00	10.00	2.51	1.764	shop/village
E12	1.00	10.00	2.02	1.520	Station/village
E13	2.00	79.00	16.82	16.852	Percent
E14	117,924.00	388,976.00	1.79E5	38,942.129	Baht/person/year

Table 5.2 Descriptive statistics of economic variables after standardization.

Variables	Minimum	Maximum	Mean	Std. Deviation
Zscore(E1)	-4.63806	0.49959	0.0000000	1.00000000
Zscore(E2)	-1.44246	3.15934	-7.5982582E-16	1.00000000
Zscore(E3)	-1.37691	3.18314	-1.4555711E-16	1.00000000
Zscore(E4)	-2.78322	2.24046	0.0000000	1.00000000
Zscore(E5)	-1.19286	5.32157	-5.3692550E-16	1.00000000
Zscore(E6)	-2.39797	1.90615	-3.0347505E-15	1.00000000
Zscore(E7)	-1.58779	2.42178	-1.9960755E-16	1.00000000
Zscore(E8)	-2.66106	2.09988	0.0000000	1.00000000
Zscore(E9)	-1.11060	3.57013	0.0000000	1.00000000
Zscore(E10)	-1.21300	3.44116	0.0000000	1.00000000
Zscore(E11)	-0.85770	4.24376	0.0000000	1.00000000
Zscore(E12)	-0.67081	5.24964	-4.0703321E-17	1.00000000
Zscore(E13)	-0.89201	3.66695	-7.1748519E-16	1.00000000
Zscore(E14)	-1.56161	5.39876	0.0000000	1.00000000

(2) Variable selection

To select variables for sustainability assessment using factor analysis, correlation matrix of variables was examined and their communalities were considered. The correlation matrix based on Kaiser-Meyer-Olkin (KMO) value and Barlett's test of sphericity was examined. The variables with low correlation coefficient to the others should be dropped out. In fact, KMO varies between 0 and 1 and values closer to 1 are better. KMO should not be less than 0.5 and 0.771 is considered as moderate suitable for factor analysis (Field, 2005) If the KMO value of 0.90-1.00, the degree of common variance is marvelous (Friel, 2010). Barlett's test of sphericity is the test of the null hypothesis that the correlation matrix is identity matrix. Li and Weng (2006) suggested that the significant level of Barlett's test of sphericity should be less than 0.1. Owing to these rules, in this study, KMO is 0.911, while significant of Barlett's test of sphericity is 0.000 (Table 5.3). Thus, all of these variables are appropriate to use for further SI assessment.

Communality is the proportion of each variable's variance that can be explained by the factors and may be interpreted as the reliability of the indicator (NCSU, 2010). It is also note as h^2 (or R^2) and can be defined as the sum of square factor loadings for the variables (UCLA, 2010). In fact, communality varies between 0 and 1 and appropriate variables should have communality value more than 0.5 (Field, 2005). According to this rule, the communality of E4 in the first iteration (Table 5.4) was 0.442 and dropped out.

Table 5.3 KMO and Barlett's Test of 14 economic variables in the first iteration.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.911
Bartlett's Test of Sphericity	Approx. Chi-Square	2.504E3
	df	91
	Sig.	0.000

Table 5.4 Communalities value of 14 economic variables in the first iteration.

Variables	Initial	Communalities
Zscore (E1)	1.000	0.725
Zscore (E2)	1.000	0.870
Zscore (E3)	1.000	0.839
Zscore (E4)	1.000	0.442
Zscore (E5)	1.000	0.835
Zscore (E6)	1.000	0.734
Zscore (E7)	1.000	0.684
Zscore (E8)	1.000	0.673
Zscore (E9)	1.000	0.780
Zscore (E10)	1.000	0.783
Zscore (E11)	1.000	0.743
Zscore (E12)	1.000	0.751
Zscore (E13)	1.000	0.802
Zscore (E14)	1.000	0.779

In second iteration, after E4 was dropped, KMO was 0.908 and Barlett's test of sphericity was 0.000. Thus all variables are appropriate. But by considering the communalities, communality of E1 was 0.073 and should be dropped.

In the third iteration, after E1 was dropped, the KMO was 0.907 and Barlett's test of sphericity was 0.000 (Table 5.5). All of communalities values are more than 0.5. As the result, the remained 12 variables were appropriate to use for factor analysis as shown in Table 5.6

Table 5.5 KMO and Barlett's Test of 12 economic variables in the third iteration.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.907
Bartlett's Test of Sphericity	Approx. Chi-Square	2.396E3
	df	66
	Sig.	0.000

Table 5.6 Communalities value of 12 economic variables in the third iteration.

Variable	**Initial**	**Communalities**
Zscore (E2)	1.000	0.867
Zscore (E3)	1.000	0.839
Zscore (E5)	1.000	0.820
Zscore (E6)	1.000	0.653
Zscore (E7)	1.000	0.672
Zscore (E8)	1.000	0.586
Zscore (E9)	1.000	0.791
Zscore (E10)	1.000	0.738
Zscore (E11)	1.000	0.748
Zscore (E12)	1.000	0.744
Zscore (E13)	1.000	0.802
Zscore (E14)	1.000	0.722

(3) Factor extraction

Herein, the large numbers of factor were extracted into fewer factors. The factors whose eigenvalues greater than 1 were extracted. Eigenvalues are the variances of sum of square loading of the factors in relation to total variance. A factor's eigenvalue may be computed as the sum of its squared factor loadings for all variables (NCSU, 2010). The rotation of initial factors in this study, only one factor was extracted and account for sum of square loading 74.847% of the total variance of all components (Table 5.7). In the case which two or more factors were extracted, the rotation of initial factors was needed using Varimax rotation to clarify the factor pattern in order to better interpret the nature of the factors. Varimax rotation tried to maximize the variance of each of the factors, so the amount of variance account for is redistributed (UCLA, 2010).

Table 5.7 Sum of squared loading of economic factors.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**
1	8.982	74.847	74.847	8.982	74.847	74.847
2	0.818	6.814	81.662			
3	0.571	4.759	86.421			
4	0.416	3.470	89.891			
5	0.323	2.692	92.582			
6	0.232	1.934	94.517			
7	0.192	1.601	96.117			
8	0.157	1.307	97.425			
9	0.148	1.232	98.657			
10	0.079	0.660	99.316			
11	0.047	0.390	99.706			
12	0.035	0.294	100.000			

Extraction Method: Principal Component Analysis.

(4) Factor interpretation

To interpret the significant of variables, a range of factor loading values were considered in order to determine how relationship of variables to the factor. Factor loading value shows the influence of the variables to the factor. In fact, the more value of factor loading, the more power the variables have on that factor.

Table 5.8 illustrates the factor loading of 12 variables in order for economic sustainability index assessment: first, the transportation comprising number of households that have cars (E2), number of cars per household (E3), and number of motorcycles per household (E5) have the most influence to economic sustainability index. Second, the land tenure shown in number of households that were land tenure (E13), third, number of households that have home Internet (E9), forth, the commercial group which represent by number of car care shops (E11), number of oil station (E12), number of shops (E10), fifth, average income per household (E14), and finally, the communication both basis telephone and mobile telephone.

Table 5.8 Factor loading and factor score coefficient of economic variable.

Variables	**Factor loading**	**Factor score coefficient**
Zscore (E2)	0.931	0.104
Zscore (E3)	0.916	0.102
Zscore (E5)	0.905	0.101
Zscore (E13)	0.896	0.100
Zscore (E9)	0.889	0.099
Zscore (E11)	0.865	0.096
Zscore (E12)	0.863	0.096
Zscore (E10)	0.859	0.096
Zscore (E14)	0.850	0.095
Zscore (E7)	0.820	0.091
Zscore (E6)	0.808	0.090
Zscore (E8)	0.765	0.085

5.4.3 Development of Current Economic Sustainability Index (CESI)

According to the objectives, the current sustainability index was developed to measure the quality of life of the area. Based on the powerful economic variables from factor analysis, the weighted sum of factor score calculated from these variables can be used as economic sustainability index of particular area.

Factor scores are the score of each sub-district on each factor. The factor score calculated by multiplying the standardized score on each variable with its corresponding factor loading, and sums of these products. Computing factor scores allows one to look for factor outliers. Also, factor scores may be used as variables in subsequent modeling (NCSU, 2010).

Based on factor score and the percentage of variance, Current Economic Sustainability Index (CESI) was developed by the following equation.

$$\mathrm{CESI} = F_1W_1 + F_2W_2 + \ldots\ldots\ldots + F_nW_n \tag{5.1}$$

Where n is the number of economic factor extracted, F_i is economic factor i score, W_i is the variance percentage of economic factor i.

Owing to this procedure, factor scores were computed through SPSS. The value of factor score of economic in 149 sub-district of Phra Nakhon Si Ayutthaya varies between -1.34452 and 4.14962. The distribution of economic factor score was illustrated in Figure5.4. Due to the result of factor analysis, 12 variables were grouped into only one factor and used to determine the economic sustainability. Therefore, current sustainability index (CESI) was calculated by Equation 5.2. CESI varied between -1.00633 and 3.10586 and classified in 3 classes as poor, fair, and good (Table 5.9). The geographic pattern of CESI was shown in Figure 5.5.

$$\text{CESI} = (74.847 \times \text{F1}) / 100 \tag{5.2}$$

Where F1 is economic factor score values. In this study there is only one economic factor and 74.847 represented W1 in the equation 5.1, the variance percentage of economic factor.

Table 5.9 CESI value, normalized CESI, and CESI classification.

CESI value	**Normalized CESI**	**CESI classes**	**Number of sub-district**
-1.00633 – - 0.61106	0.00000 - 0.09612	Poor	27
- 0.611105 – 0.21986	0.09613 – 0.29818	Fair	85
0.21987 – 3.10586	0.29819 – 1.00000	Good	37

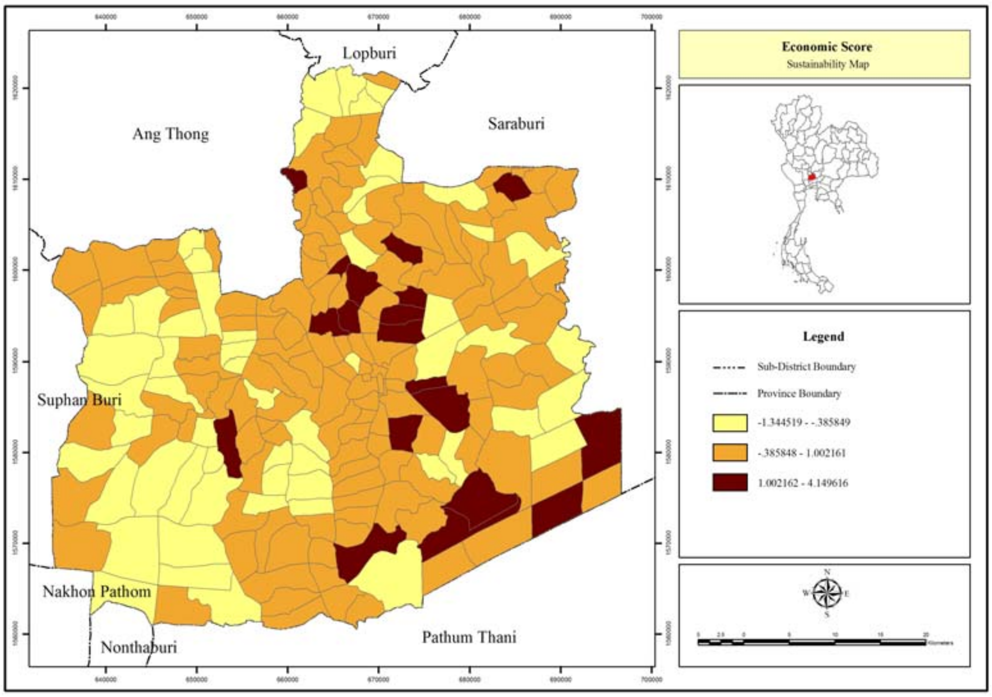


Figure 5.4 Distribution of economic factor scores as the only one economic factor.

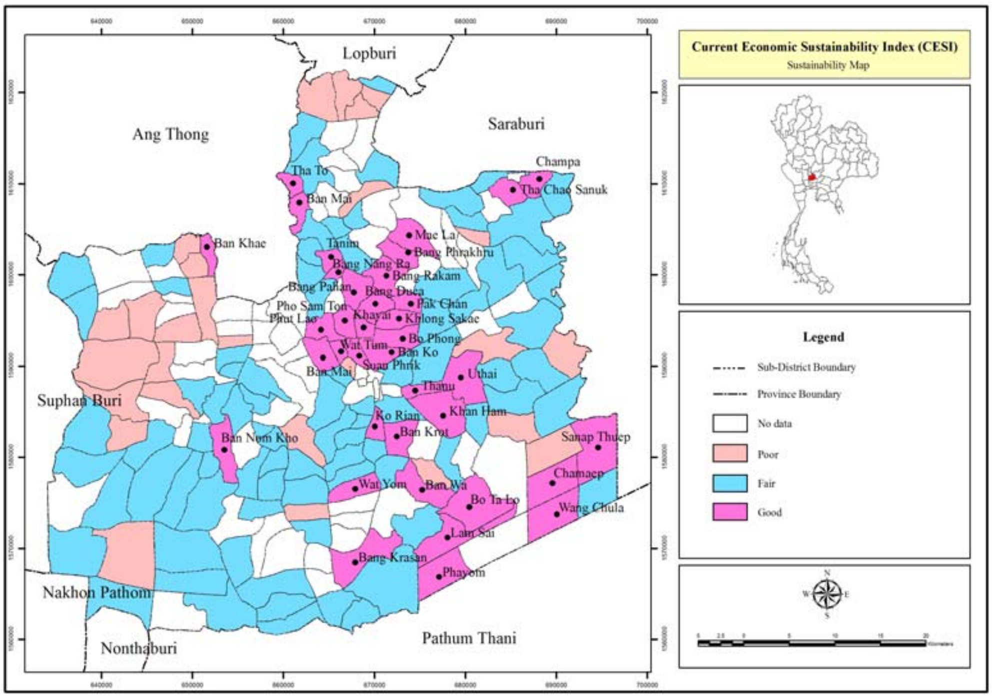


Figure 5.5 The Current Economic Sustainability Index (CESI) at sub-district level of Phra Nakhon Si Ayutthaya Province.

Figure 5.5 illustrates CESIs distribution of sub-districts in Phra Nakhon Si Ayutthaya which were influenced by 12 economic factors using factor analysis. The factors included the transportation (E2, E3, E5), land tenure (E13), communication (E9), commercial (E11, E12, E10), and average income (E14) and other communication and facility (E7, E6, E8). It is noticeable that most areas with good CESIs appeared in 37 sub-districts which were concentrated in the central part and scattered to the southeast of the province. They included Khan Ham, Bamg Phrakhru, Bang Krasan, Khlong Sakae, Lam Sai, Bo Phong, Bang Nom Kho, Pak Chan, Thanu, wang Chula, etc. The fair ones appeared in 85 sub-districts which were dispersed in all parts of the study area. The poor ones covering 27 sub-districts concentrated in the northwest were rice paddy or agricultural areas and always flooded during the rainy season. Table 5.10 shows CESIs and their classifications of sub-districts.

Table 5.10 CESIs and their classifications of sub-districts.

Sub-district ID	Sub-district Name	District Name	CESI	CESI Class
141401	Khan Ham	Uthai	3.1058	Good
140307	Bang Phrakhru	Nakhon Luang	2.6969	Good
140605	Bang Krasan	Bang Pa-in	2.5834	Good
140310	Khlong Sakae	Nakhon Luang	2.2295	Good
141104	Lam Sai	Wang Noi	1.9834	Good
140303	Bo Phong	Nakhon Luang	1.8437	Good
141205	Bang Nom Kho	Sena	1.7973	Good
140305	Pak Chan	Nakhon Luang	1.5498	Good
141410	Thanu	Uthai	1.4460	Good
141108	Wang Chula	Wang Noi	1.2381	Good
140603	Ban Pho	Bang pa-in	-0.0140	Fair
140207	Pho En	Tha Ruea	-0.0331	Fair
141510	Ban Khwang	Maharat	-0.0498	Fair
140815	Na Khok	Phak Hai	-0.0577	Fair
140618	Khanon Luang	Bang Pa-in	-0.0582	Fair
140711	Ban Ma	Bang Pahan	-0.0692	Fair
140203	Tha Luang	Tha Ruea	-0.0801	Fair
140421	Pho Taeng	Bang Si	-0.0980	Fair
140409	Chang Lek	Band Si	-0.0981	Fair
140906	Phai Lom	Pha Chi	-0.0992	Fair
140806	Tha Din Daeng	Phak Hai	-0.7425	Poor
141107	Han Ta Phao	Wang Noi	-0.7493	Poor
141603	Sam Phaniang	Ban Phraek	-0.7693	Poor
140809	Ku Di	Phak Hai	-0.7895	Poor
141605	Song Hong	Ban Phraek	-0.8143	Poor
141604	Khlong Noi	Ban Phraek	-0.8177	Poor
141502	Kathum	Maharat	-0.8203	Poor
140814	Lat Chit	Phak Hai	-0.8314	Poor
140615	Taling Chan	Bang Pa-in	-0.9316	Poor
141407	Sena	Uthai	-1.0000	Poor

5.5 Social sustainability assessment

To assess the Current Social Sustainability Index (CSSI) of the study area, social indicators at household level were also extracted from NRD and BMN data in 2007 and were summed and averaged at sub-district level.

5.5.1 Extraction of social variables

As mention before, social can be indicated by education, health, security housing or family, and recreation. In this study, 11 social variables which represent 5 groups of social indicators were selected from NRD and BMN data. The coding and description of these variables are as follow:

Education

S1	Number of people accessible to learning center
S2	Number of people finished diploma
S3	Number of people finished Bachelor Degree or higher
S8	Number of secondary school
S11	Number of internet knowledge center

Family and housing

S4	Number of household divorced
S6	Number of unemployment

Security

S5	Number of criminal case
S7	Number of drug addicted

Recreation

S9	Number of park or garden

Health

S10 Number of health care center or hospital

The descriptive statistic data of these variables was summarized shown in Table 5.11

Table 5.11 Descriptive statistics of social variables before standardization.

Variables	Minimum	Maximum	Mean	Std. Deviation	Unit
S1	0.00	20.00	4.19	3.914	Percent
S2	1.00	24.00	6.03	4.392	Percent
S3	1.00	20.00	4.97	3.865	Percent
S4	1.00	12.00	3.96	2.580	Percent
S5	2.00	14.00	5.95	1.969	Case/village
S6	1.00	4.00	2.09	0.586	Percent
S7	1.00	10.00	3.35	1.867	Person/village
S8	0.00	1.00	0.49	0.502	School/village
S9	1.00	5.00	1.45	0.812	Park/village
S10	0.00	1.00	0.24	0.431	Center/village
S11	0.00	1.00	0.78	0.414	Center/village

5.5.2 Factor analysis of social variables

By following the major steps of factor analysis, all of social factors were standardized, selected, and extracted with the same process mentioned in economic variable analysis. Finally, the result obtained from factor analysis was interpreted.

(1) Variable Standardization

Basically, 11 extracted variables were analyzed by factor analysis through SPSS 16.0. The descriptive statistics as shown in Table 5.11 was standardized in order to dispose of the different in ranges and units between variables as shown in Table 5.12. These standardized variables represented by the Z score value were used in the step of variable selection.

Table 5.12 Descriptive statistics of social variables after standardization.

Variables	Minimum	Maximum	Mean	Std. Deviation
Zscore (S1)	-1.06964	4.07866	0.0000000	1.00000000
Zscore (S2)	-1.06706	4.09280	0.0000000	1.00000000
Zscore (S3)	-1.01855	4.01572	0.0000000	1.00000000
Zscore (S4)	-1.14913	3.17407	-3.0157083E-16	1.00000000
Zscore (S5)	-2.00449	4.08916	-1.0898629E-15	1.00000000
Zscore (S6)	-2.36983	3.99873	0.0000000	1.00000000
Zscore (S7)	-1.25778	3.56196	-1.1732169E-16	1.00000000
Zscore (S8)	-0.98368	1.00991	0.0000000	1.00000000
Zscore (S9)	-0.55090	4.37477	-6.6946731E-17	1.00000000
Zscore (S10)	-0.56535	1.75717	-9.7629653E-17	1.00000000
Zscore (S11)	-1.89271	0.52487	0.0000000	1.00000000

(2) Variable selection

In the first iteration of correlation matrix calculation, KMO is 0.754 and Barlett’s test of sphericity is 0.000 (Table 5.13). However, the communality shows the low relationship among S8 and other variables and should be dropped (Table 5.14). When continuing to the second iteration, S9 and S10 were dropped. After S8, S9, and S10 were dropped, the third iteration, KMO is 0.722 and Barlett’s test of sphericity is 0.000 (Table 5.13). These values decrease from the first iteration but owing to the rules, the value with higher than 0.7 is quite good (Field, 2005) Thus, all of these variables are appropriate to use for factor analysis. When examined sum of square loading of the third iteration compared to the first iteration, it increased from 77.215 to 85.033 (Table 5.15). Thus, the remaining 8 variables are appropriated and able to explain the social sustainability index more than 85% of all data.

Table 5.13 KMO and Barlett's Test of 11 social variables in the first iteration.

		Iteration1	Iteration2	Iteration3
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.754	0.748	0.722
Bartlett's Test of Sphericity	Approx. Chi-Square	1.022E3	983.539	905.604
	df	55	45	28
	Sig.	0.000	0.000	0.000

(3) Factor extraction

In the first extraction from initial 11 factors, 4 factors with eigenvalues higher than 1 were extracted with the sum of square loading 77.215. After S8, S9, and S10 were dropped, 3 factors were extracted with sum of square loading 85.033% of total variance (Table 5.15).

Table 5.14 Communalities value of 11 social variables in iteration 1, 2, and 3.

Variables	**Initial communalities**	**Iteration 1 Communalities of 11 variables**	**Iteration 2 Communalities of 10 variables**	**Iteration 3 Communalities of 8 variables**
Zscore (S1)	1.000	0.792	0.812	0.856
Zscore (S2)	1.000	0.862	0.868	0.889
Zscore (S3)	1.000	0.881	0.879	0.898
Zscore (S4)	1.000	0.679	0.663	0.672
Zscore (S5)	1.000	0.927	0.923	0.929
Zscore (S6)	1.000	0.855	0.850	0.852
Zscore (S7)	1.000	0.771	0.759	0.773
Zscore (S8)	1.000	0.486		0.773
Zscore (S9)	1.000	0.829	0.097	
Zscore (S10)	1.000	0.522	0.489	
Zscore (S11)	1.000	0.889	0.926	0.933

Table 5.15 Sum of squared loading of social factors.

Component	**Initial Eigen values**	**Iteration1 Rotation Sums of Squared Loadings**			**Iteration2 Rotation Sums of Squared Loadings**			**Iteration3 Rotation Sums of Squared Loadings**		
	Total	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4..306	3.271	29.736	29.736	3.252	32.522	32.522	2.834	35.425	35.425
2	2.030	2.585	23.499	53.235	2.639	26.392	58.915	2.570	32.123	67.548
3	1.153	1.504	13.672	66.906	1.375	13.748	72.663	1.399	17.485	85.033
4	1.004	1.134	10.309	77.215						
5	0.821									
6	0.562									
7	0.432									
8	0.321									
9	0.195									
10	0.103									
11	0.072									

(4) Factor interpretation

According to the factors extraction, social variables were extracted into 3 factors. The first factor which was the most powerful included a number of people finished diploma (S2), number of people finished Bachelor Degree or higher (S3), and a number of households divorced (S4). The second factor consisted of a number of criminal cases (S5), a number of unemployment (S6), and a number of drug addicted (S7). The third factor comprised a number of people accessible to learning center (S1) and a number of internet knowledge centers (S11). Due to the context of the factor, factor 1 could indicate *education and social status*. Factor 2, the negative factors, indicated *insecurity status*. Factor 3 indicated *knowledge accessibility*. Table 5.16 illustrates the factor loading of social variables.

Table 5.16 Factor loading of social variable.

Variables	**Factor**		
	1	**2**	**3**
Zscore (S3)	0.930	0.128	0.131
Zscore (S2)	0.918	0.163	0.140
Zscore (S4)	0.816	0.073	-0.044
Zscore (S5)	0.111	0.952	0.099
Zscore (S6)	0.066	0.920	0.020
Zscore (S7)	0.198	0.856	0.027
Zscore (S11)	0.023	0.020	0.966
Zscore (S1)	0.636	0.185	0.646

5.5.3 Development of Current Social Sustainability Index (CSSI)

Basically, the factor scores were generated after factor extraction. Scores of factor 1 ranged between -1.24483 and 3.69187. Factor 2 scores were between -2.04238 and 4.24635, and factor 3 score were between -2.52602 and 1.93198. All social factor scores in 149 sub-districts of Phra Nakhon Si Ayutthaya were illustrated as geographic pattern in Figures 5.6-5.8, respectively.

As same as the CESI assessment, the Current Social Sustainability Index (CSSI) was developed by the following equation.

$$\text{CSSI} = \text{F1W1} + \text{F2W2} + \ldots\ldots\ldots + \text{FnWn} \qquad (5.3)$$

Where n is the number of social factor extracted, F_i is social factor i score, W_i *is* the variance percentage of social factor i.

According to the meaning of the factor, factor 2 was unwanted due to its high value which represented the poor status. Thus, factor 2 should be minus in CSSI calculation. The CSSI was calculated by summation of multiplication between factor score and weight as follows:

$$\text{CSSI} = (35.425\times\text{Factor1} - 32.123\times\text{Factor2} + 17.485\times\text{Factor3})/100 \qquad (5.4)$$

Where Factor 1, Factor 2, and Factor 3 are social factor score values. Factor 1 is scores of education and social status, factor 2 is scores of insecurity status and factor 3 is scores of knowledge accessibility.

35.425, -32.123 and 17.485 represented the variance percentage of social factors: W1, W2 and W3 in the equation 5.3, respectively.

As the result, CSSI varied from -1.2854 to 1.6061. The normalized CSSI were calculated and classified into 3 categories; poor fair and good (Table 5.17). The distribution of CSSI the study area is shown in Figure 5.9.

Table 5.17 CSSI value, normalized CSSI, and CSSI classification.

CSSI value	Normalized CSSI	CSSI classes	Number of sub-districts
-1.28542 – -0.56413	0.00000 – 0.24945	Poor	18
-0.56412 – 0.29302	0.24946 – 0.54589	Fair	95
0.29303 – 1.60607	0.54590 – 1.00000	Good	36
			149

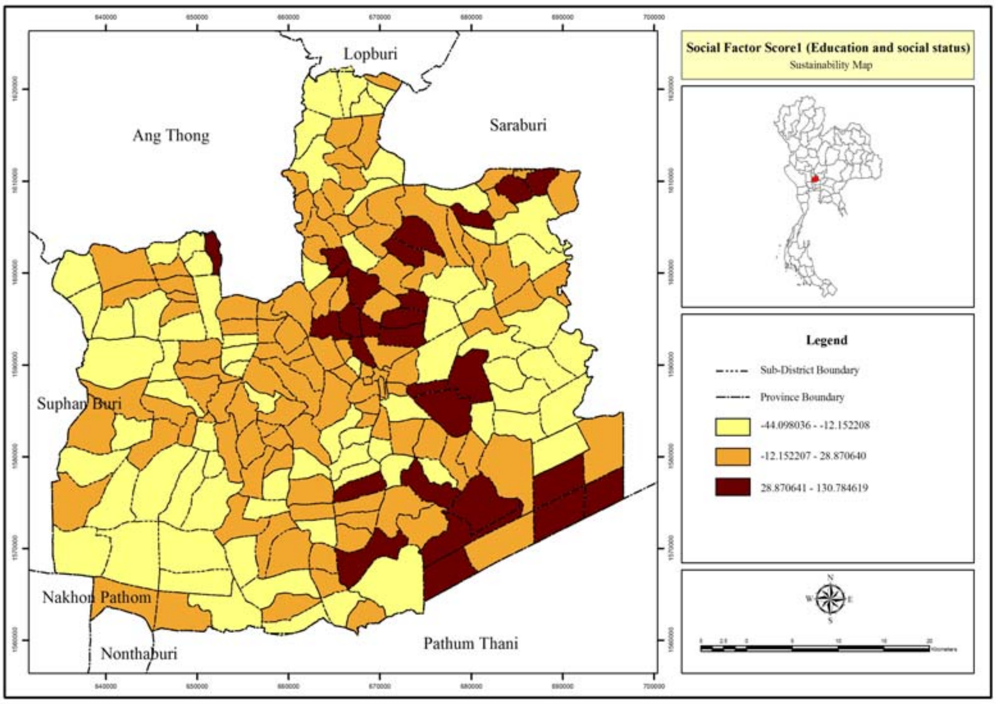


Figure 5.6 Scores of education and social status at sub-district level of Phra Nakhon Si Ayutthaya Province.

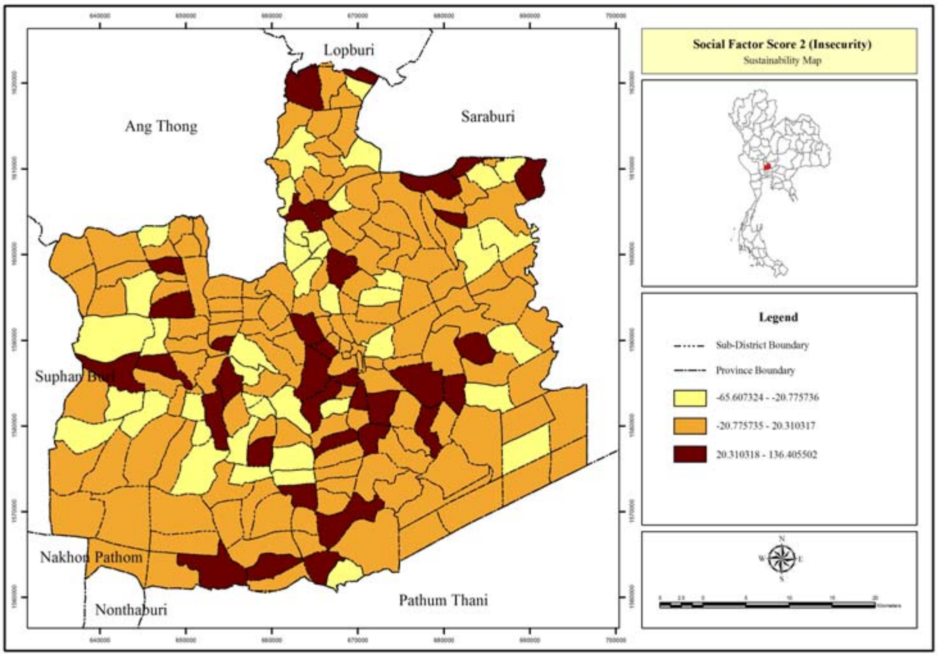


Figure 5.7 Scores of insecurity status at sub-district level of Phra Nakhon Si Ayutthaya Province.

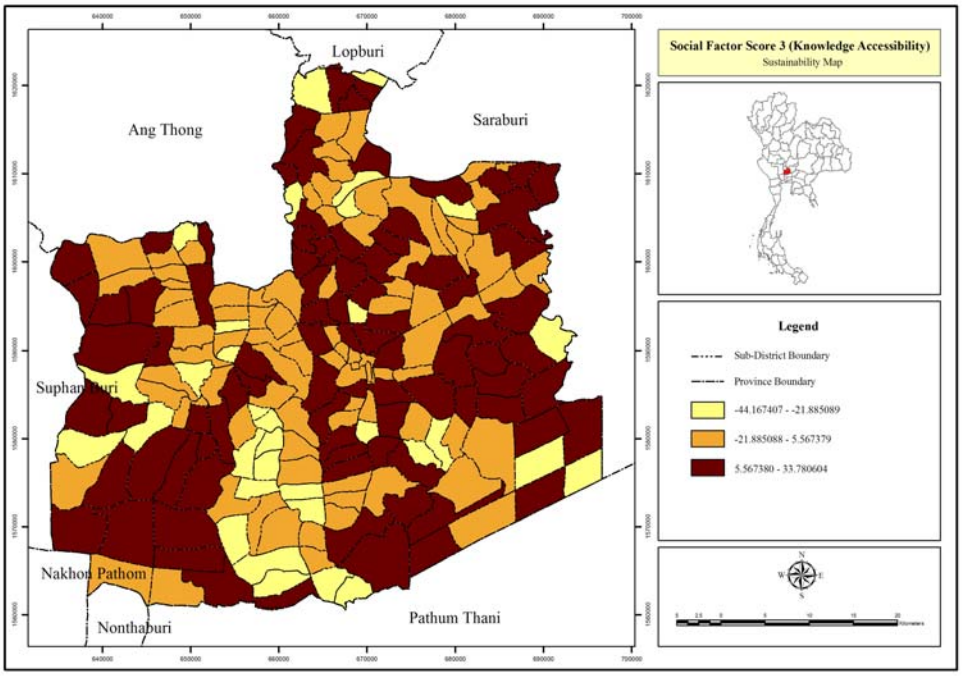


Figure 5.8 Scores of knowledge accessibility at sub-district level of Phra Nakhon Si Ayutthaya Province.

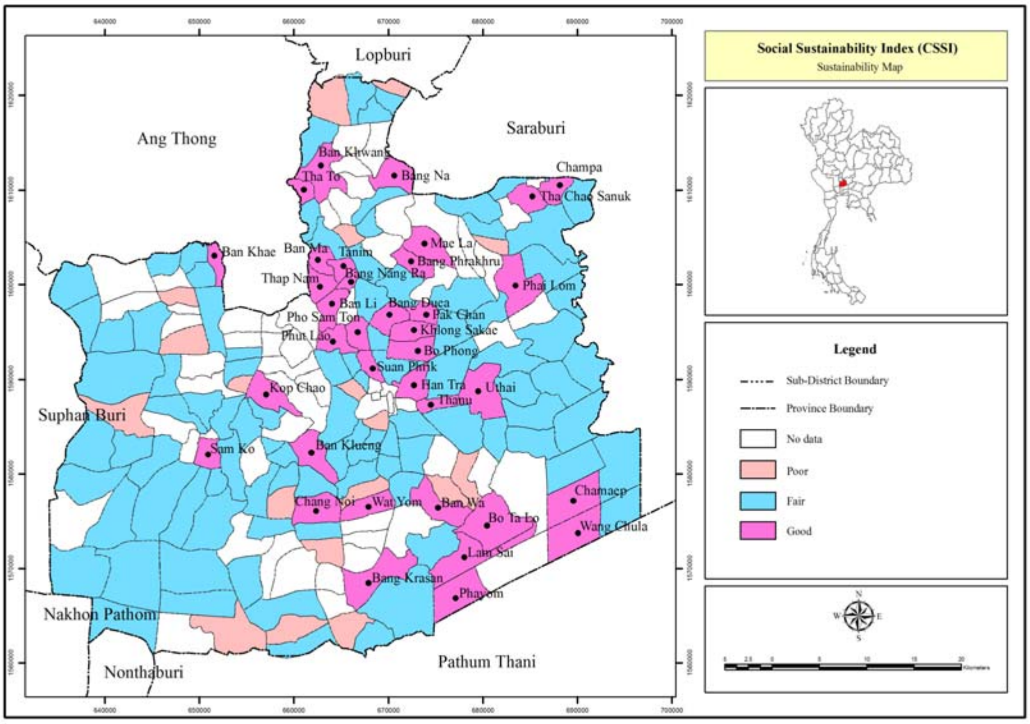


Figure 5.9 The CSSI at sub-district level of Phra Nakhon Si Ayutthaya Province.

Figure 5.9 illustrates CSSIs of sub-districts in the study area which were influenced by 8 social factors using factor analysis. The factors included education and social status (S3, S2, S4), security status (S5, S6, S7), knowledge accessibility (S11, S1). It is noticeable that most of the good CSSIs covering 36 sub-districts which were concentrated in the central part and scattered in the southeast and the northeast of the province. They included Khlong Sakae, Pak Chan, Bang Nang Ra, Tanim, Bo Phong, Tha Chao Sanuk, Bang Phrakhru, Pho Sam Ton, Champa, Bang Krasan, etc. The fair ones appeared in 95 sub-districts which were found in all parts of the study area. The poor ones covering 18 sub-districts are most scattered in the periphery of the province due to the influences of insecurity factors which are the negative effects of the urban and industrial expansion. Table 5.18 shows CSSIs and their classifications of sub-districts.

Table 5.18 CSSIs and their classifications of sub-districts.

Sub-district ID	Sub-district Name	District Name	CSSI	CSSI Class
140310	Khlong Sakae	Nakhon Luang	1.6061	Good
140305	Pak Chan	Nakhon Luang	1.3796	Good
140708	Bang Nang Ra	Bang Pahan	1.2590	Good
140709	Tanim	Bang Pahan	1.1125	Good
140303	Bo Phong	Nakhon Luang	1.0261	Good
140210	Tha Chao Sanuk	Tha Ruea	1.0046	Good
140307	Bang Phrakhru	Nakhon Luang	0.9699	Good
140714	Pho Sam Ton	Bang Pahan	0.9608	Good
140202	Champa	Tha Ruea	0.9039	Good
140605	Bang Krasan	Bang Pa-in	0.8452	Good
140207	Pho En	Tha Ruea	0.2930	Fair
141304	Plai Klat	Bang Sai	0.2786	Fair
140409	Chang Lek	Bang Si	0.2721	Fair
140507	Ban Khlang	Bang Ban	0.2691	Fair
141302	Kaeo Fa	Bang Sai	0.2659	Fair
140905	Don Ya Nang	Pha Chi	0.2605	Fair
140701	Bang Pahan	Bang Pahan	0.2599	Fair
141214	Lat Nga	Sena	0.2356	Fair
140815	Na Khok	Phak Hai	0.2051	Fair
141105	Sanap Thuep	Wang Noi	0.1932	Fair
140705	Thang Klang	Bang Pahan	-0.7099	Poor
140806	Tha Din Daeng	Phak Hai	-0.7289	Poor
140801	Phak Hai	Phak Hai	-0.7327	Poor
140510	Thang Chang	Bang Ban	-0.7591	Poor
140417	Ban Ma	Bang Si	-0.7619	Poor
140421	Pho Taeng	Bang Si	-0.8302	Poor
140403	Sanam Chai	Bang Si	-0.9405	Poor
140108	Phu Khao Thong	Phranakhon Si Ayutthaya	-1.0217	Poor
141605	Song Hong	Ban Phraek	-1.1785	Poor
140109	Sam Phao Lom	Phranakhon Si Ayutthaya	-1.2854	Poor

5.6 Environment sustainability assessment

Like economic and social sustainability assessments, to determine the Current Environment Sustainability Index (CEnSI), environment indicators at household level were also extracted from NRD and BMN data in 2007and were summed and averaged at sub-district level.

5.6.1 Extraction of environment variables

In this study, environment sustainability index were derived from the quality of soil, the water sufficiency, the susceptibility of being flood prone area, the wasted disposal problem the water pollution. Thus, 5 environments variables which represent 5 groups of environment indicators were selected from NRD and BMN data. The coding and description of these variables are as follow:

EN1	Percent area that have soil quality problem
EN2	Percent area that have insufficient water problem
EN3	Percent area that confront flood problem
EN4	Percent area that have waste disposal problem
EN5	Percent area that have water pollution problem

The descriptive statistic data of these variables were summarized shown in Table 5.19

Table 5.19 Descriptive statistics of environment variables before standardization.

Variables	Minimum	Maximum	Mean	Std. Deviation	Unit
EN1	0	100	10.19	17.938	Percent
EN2	0	100	8.90	16.558	Percent
EN3	0	100	10.02	17.888	Percent
EN4	0	100	17.54	24.830	Percent
EN5	0	100	15.26	23.445	Percent

5.6.2 Factor analysis of environment variables

All of environment factors were standardized, selected, and extracted. Finally the result obtained from factor analysis was interpreted.

Basically, five extracted variables were standardized by factor analysis through SPSS version 16. These standardized variables displayed in Table 5.20

Table 5.20 Descriptive statistics of environment variables after standardization.

Variables	Minimum	Maximum	Mean	Std. Deviation
Zscore (EN1)	-0.56788	5.00695	0.0000000	1.00000000
Zscore (EN2)	-0.53742	5.50213	-4.2154056E-16	1.00000000
Zscore (EN3)	-0.56022	5.03018	0.0000000	1.00000000
Zscore (EN4)	-0.70626	3.32107	-1.7235977E-16	1.00000000
Zscore (EN5)	-0.65082	3.61446	-1.6180870E-16	1.00000000

KMO of the environment variables is 0.840 and Barlett’s test of sphericity is 0.000 (Table 5.21). The communality values showed that all variables are appropriated for factor analysis (Table 5.22).

Herein, only one factor was extracted with its Eigenvalues 3.904 and the sum of square loading is 78.084 percent of total variance (Table 5.23).

Table 5.21 KMO and Barlett’s Test of 5 environment variables in the first iteration.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.840
Bartlett's Test of Sphericity	Approx. Chi-Square	644.876
	df	10
	Sig.	0.000

Table 5.22 Communalities value of 5 environment variables.

Variables	Initial	Communalities
Zscore (EN1)	1.000	0.765
Zscore (EN2)	1.000	0.828
Zscore (EN3)	1.000	0.735
Zscore (EN4)	1.000	0.758
Zscore (EN5)	1.000	0.818

Table 5.23 Sum of squared loading of environment factor.

Componen	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.904	78.084	78.084	3.904	78.084	78.084
2	0.510	10.194	88.278			
3	0.252	5.049	93.328			
4	0.211	4.218	97.546			
5	0.123	2.454	100.00			

Extraction Method: Principal Component Analysis.

After examining the factor loading of environment variables, it can be conclude that all of the environment variables were slightly different in values. The most powerful problem affected environment sustainability index is the water insufficiency (EN2) of which factor loading is 0.910.and the flood problem (EN3) is the least affecting variable to the environment sustainability index (Table 5.24).

Table 5.24 Factor loading and factor score coefficient of environment variable.

Variables	**Factor loading**	**Factor score coefficient**
Zscore (EN2)	0.910	0.233
Zscore (EN5)	0.904	0.232
Zscore (EN1)	0.875	0.224
Zscore (EN4)	0.870	0.223
Zscore (EN3)	0.858	0.220

5.6.3 Development of Current Environment Sustainability Index (CEnSI)

CEnSI was also developed based on the factor scores and factor loading as following equation:

$$\text{CEnSI} = F1W1 + F2W2 + \ldots\ldots\ldots + FnWn \tag{5.5}$$

Where n is the number of environment factors extracted, F_i is environment factor *i* score, W_i is the variance percentage of environment factor *i*.

The factor score of environment variables in 149 Tambols of Phranakhon Si Ayutthaya vary between -0.53391 and 3.97192 and were shown in Figure 5.10. According to the result of factor analysis, there is only one factor can be used to measure the environment sustainability. Therefore, the CEnSI was calculated by equation 5.6 and classified in 3 classes as poor, fair, and good (Table 5.25). The geographic pattern of CEnSI was shown in Figure 5.11.

$$\text{CEnSI} = (78.084 \times F1)/100 \tag{5.6}$$

Where F1 is environment factor score values. In this study there is only one environment factor and 78.084 represented W1 in the equation 5.5, the variance percentage of environment factor.

Table 5.25 CEnSI value, normalized CEnSI, and CEnSI classification.

CEnSI value	Normalized CEnSI	CEnSI classes	Number of Tambols
-0.53391 - -0.45676	0.00000 - 0.05100	Good	32
-0.45675 - 0.80330	0.05101 - 0.29999	Fair	103
0.80331 - 3.97193	0.30000 - 1.00000	Poor	14
			149

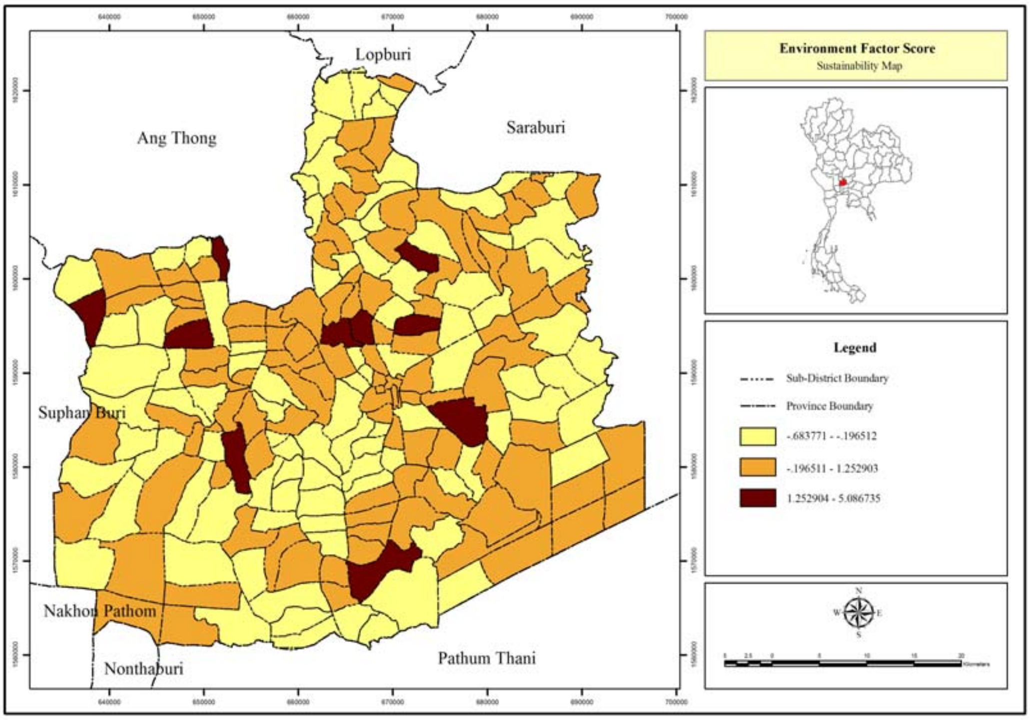


Figure 5.10 Distribution of environmental factor scores as the only one environmental factor.

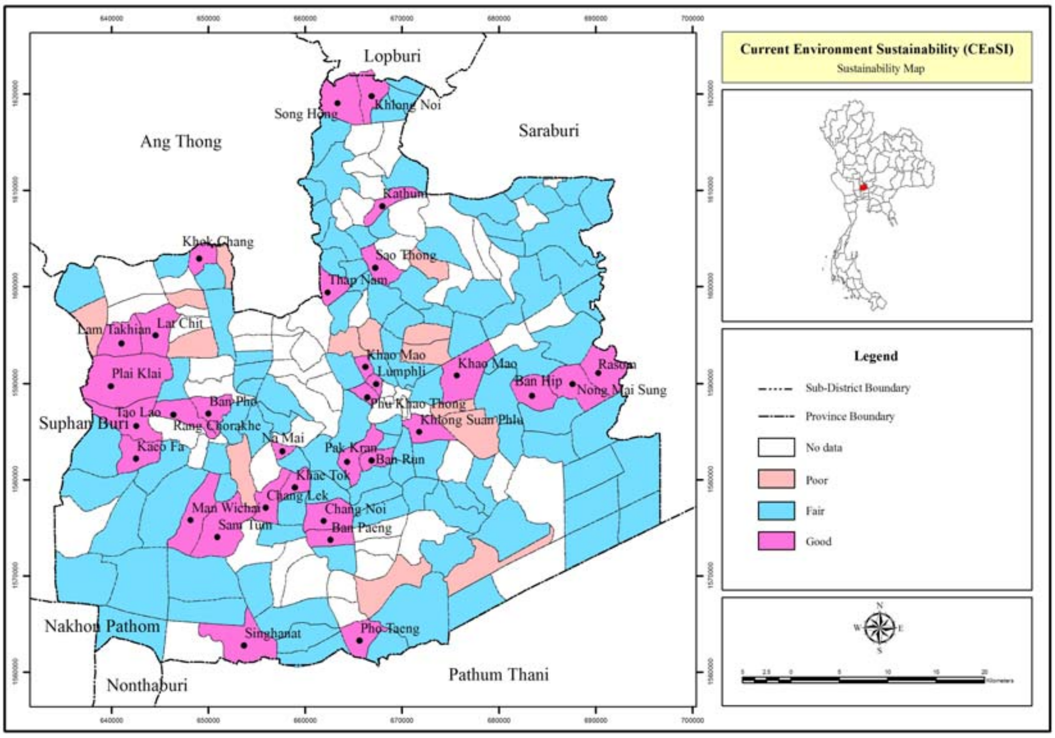


Figure 5.11 The CEnSI at sub-district level of Phra Nakhon Si Ayutthaya Province.

Figure 5.11 illustrates CEnSIs of sub-districts in the study area which were influenced by 5 environment factors using factor analysis. The factors included water sufficiency (EN2), water pollution (EN5), soil quality (EN1), waste disposal (EN4), and flood hazard (EN3). It is noticeable that most areas with good CEnSIs appeared in 32 sub-districts which were concentrated in the northwest and scattered to southwest and the central of province. They included Pak Kran, Phu Khao Thong, Khae Tok, Lam Ta Khien, Lat Chit, Sing Hanat, Sam Tum, Kaeo Fa, Plai Klat, Mai Sung, etc. The fair ones appeared in 103 sub-districts which were found in all parts of the study The poor ones covering 14 sub-districts were scattered in the central and the south of the province. Table 5.26 shows CEnSIs and their classification of sub-districts.

Table 5.26 CEnSIs and their classifications of sub-districts.

Sub-district ID	Sub-district Name	District Name	CEnSI	CEnSI Class
140107	Pak Kran	Phranakhon Si Ayutthaya	-0.5339	Good
140108	Phu Khao Thong	Phranakhon Si Ayutthaya	-0.5339	Good
140408	Khae Tok	Bang Si	-0.5339	Good
140810	Lam Ta Khien	Phak Hai	-0.5339	Good
140814	Lat Chit	Phak Hai	-0.5339	Good
141005	Sing Hanat	Lat Bua Luang	-0.5339	Good
141213	Sam Tum	Sena	-0.5339	Good
141302	Kaeo Fa	Bang Sai	-0.5339	Good
141304	Plai Klat	Bang Sai	-0.5339	Good
141405	Mai Sung	Uthai	-0.5339	Good
140417	Ban Ma	Bang Si	-0.4463	Fair
140511	Wat Taku	Bang Ban	-0.4463	Fair
140416	Mai Tra	Bang Si	-0.4380	Fair
140506	Kop Chao	Bang Ban	-0.4380	Fair
140618	Khanon Luang	Bang Pa-in	-0.4380	Fair
141403	Sam Bandit	Uthai	-0.4380	Fair
140409	Pho Sao Han	Uthai	-0.4380	Fair
140403	Sanam Chai	Bang Si	-0.4375	Fair
140606	Khlong Chik	Bang Pa-in	-0.4375	Fair
140610	Sam Ruean	Bang Pa-in	-0.4364	Fair
141205	Bang Nom Kho	Sena	1.424	Poor
140714	Pho Sam Ton	Bang Pahan	1.719	Poor
140715	Phut Lao	Bang Pahan	1.8024	Poor
140605	Bang Krasan	Bang Pa-in	1.8935	Poor
140310	Khlong Sakae	Nakhon Luang	2.0644	Poor
140803	Ban Khae	Phak Hai	2.1122	Poor
140307	Bang Phrakhru	Nakhon Luang	2.2591	Poor
141401	Khan Ham	Uthai	2.5050	Poor
140806	Tha Din Daeng	Phak Hai	3.9719	Poor
140807	Don Lan	Phak Hai	3.9719	Poor

5.7 Total sustainability assessment

5.7.1 Extraction of total sustainability variables

In order to determine the overall sustainability index, Current Total Sustainability Index (CTSI) was developed. Overall measurement of CTSI regarding economic, social, and environment aspects were therefore the integration of CESI, CSSI, and CEnSI.

5.7.2 Factor analysis of total sustainability variables

Once more, the factor analysis was used to extract the factors for TSI using all CESI, CSSI, and CEnSI variables. Due to the difference in value and direction of variables, normalized CESI, CSSI and inversion of normalized CEnSI were used. Table 5.27 shows the relationship among these variables. The normalized value of CESI, CSSI and inversed normalized value of CEnSI were standardized (Table 5.28).

KMO value of the total sustainability variables is 0.624 and Barlett's test of sphericity is 0.000 (Table 5.29). The communality values in Table 5.30 showed that all variables are appropriated for factor analysis.

Herein, only one factor with Eigenvalues of 1.990 and the sum of square loading 66.344 percent of total variance was extracted (Table 5.31).

Table 5.27 Correlation matrix of total sustainability variables.

Variables		**Normalized CESI**	**Normalized_ CSSI**	**Inv_Normalized _CEnSI**
Normalized_CESI	Pearson Correlation	1	0.563^{**}	-0.567^{**}
	Sig. (2-tailed)		0.000	0.000
Normalized_CSSI	Pearson Correlation	0.563^{**}	1	-0.346^{**}
	Sig. (2-tailed)	0.000		0.000
Inv_Normalized_CEnSI	Pearson Correlation	-0.567^{**}	-0.346^{**}	1
	Sig. (2-tailed)	0.000	0.000	

Table 5.28 Descriptive statistics data of total sustainability variables after standardization.

Variables	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
Zcore (Normalized_CESI)	-1.34452	4.14962	…..	1.00000000
Zscore (Normalized_CSSI)	-2.52455	3.15429	…..	1.00000000
Zscore(Inv_Normalized_CEnSI)	-5.08674	0.68377	-7.53E-16	1.00000000

Table 5.29 KMO and Barlett’s Test of 3 total sustainability variables.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.624
Bartlett's Test of Sphericity	Approx. Chi-Square	114.854
	df	3
	Sig.	0.000

Tables 5.30 Communalities value of 3 variables of Total Sustainability.

Variables	**Initial communalities**	**Extracted communalities**
Zcore (Normalized_CESI)	1.000	0.784
Zscore (Normalized_CSSI)	1.000	0.601
Zscore (Inv_Normalized_CEnSI)	1.000	0.605

Table 5.31 Sum of squared loading of total sustainability factors.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	1.990	66.344	66.344	1.990	66.344	66.344
2	0.654	21.796	88.141			
3	0.356	11.859	100.00			

Extraction Method: Principal Component Analysis.

After examining the factor loading of total sustainability variables, it can be concluded that all of total sustainability variables have slightly different values. The most powerful aspect affecting the CTSI was the CESI with factor loading of 0.886. The CEnSI affected CTSI in negative way with factor loading of 0.778. The CSSI affected CTSI with factor loading of 0.775 (Table 5.32).

Table 5.32 Factor loading and factor score coefficient of Total Sustainability variables.

Variables	Factor loading	Factor score coefficient
Zscore (CESI)	0.886	0.445
Zscore (CEnSI)	0.778	0.391
Zscore (CSSI)	0.775	0.390

5.7.3 Development of the Current Total Sustainability Index (CTSI)

The CTSI was also developed through the factor score and percentage of variance or factor loading as following equation:

$$\text{CTSI} = F1W1 + F2W2 + \ldots\ldots\ldots + FnWn \tag{5.7}$$

Where n is the number of total factor extracted, F_i is total factor i score, W_i is the variance percentage of total factor i.

The value of factor scores of total sustainability variables in 149 sub-districts vary between -1.09659 and 2.37992 and is shown in Figure 5.12.

According to factor score and the percentage of variance, CTSI was calculated by equation 5.7 and classified in 3 classes as poor, fair, and good (Table 5.33). The geographic pattern of CTSI was shown in Figure 5.13.

$$\text{CTSI} = (66.344 \times F1) / 100 \tag{5.8}$$

Where F1 is total factor score values. In this study there is only one total factor and 66.344 represented W1 in the equation 5.7, the variance percentage of total factor.

Table 5.33 CTSI value, normalized CTSI, and CTSI classification.

CTSI value	**Normalized CTSI**	**CTSI classes**	**Number of sub-districts**
-1.09659 - -0.51385	0.00000 - 0.16762	Poor	27
-0.51384 - 0.47857	0.16763 - 0.45308	Fair	95
0.47856 - 2.37992	0.45309 - 1.00000	Good	27
			149

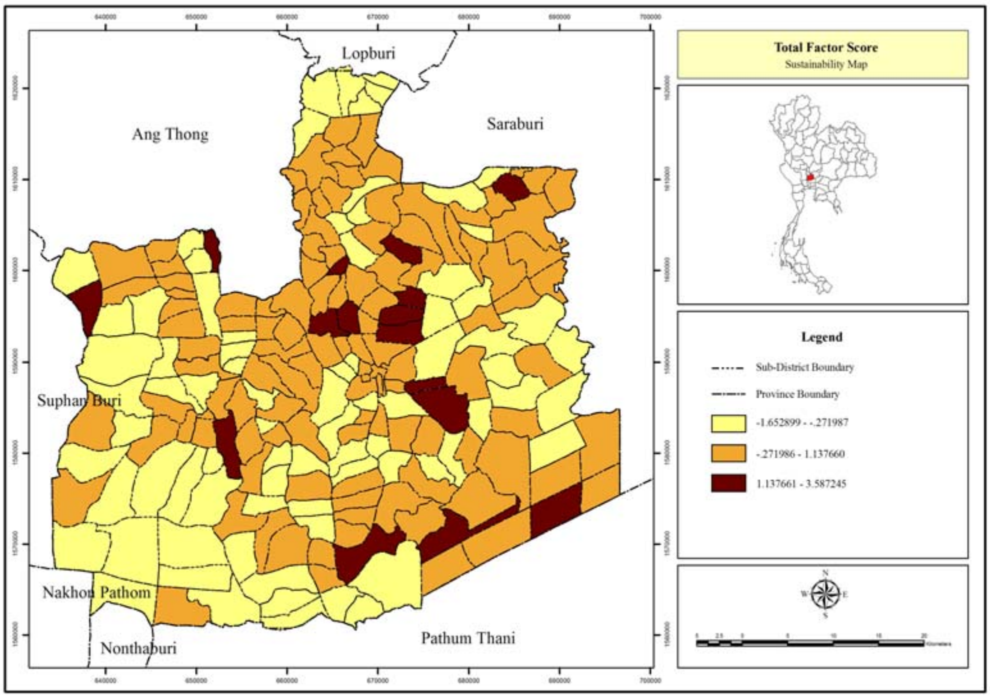


Figure 5.12 Distribution of total sustainability factor scores in the area as the only one total sustainability factor.

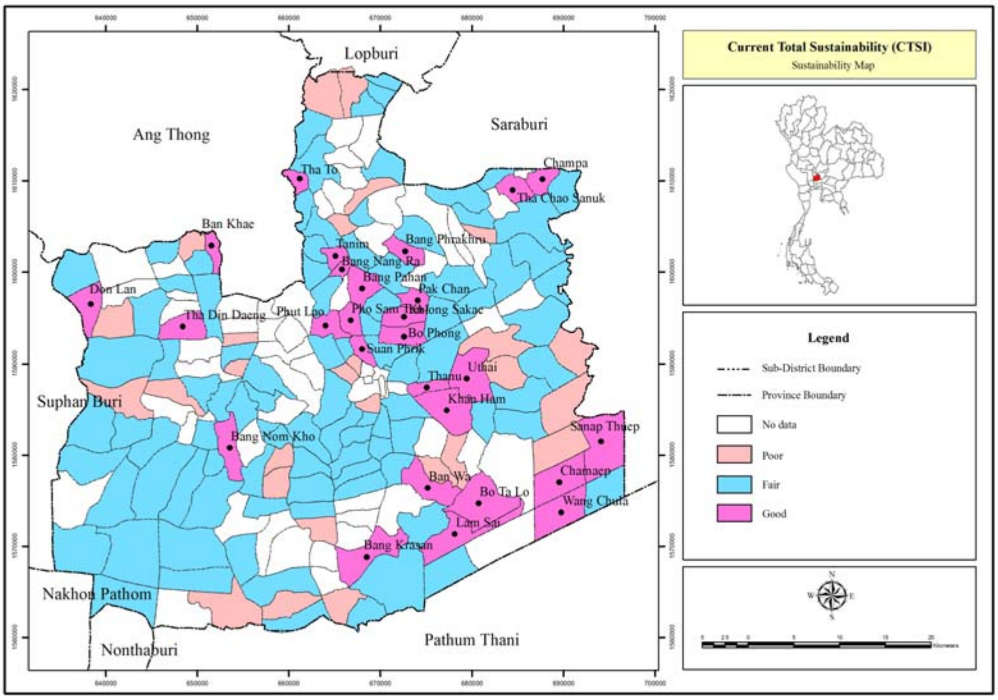


Figure 5.13 The CTSI at sub-district level of Phra Nakhon Si Ayutthaya Province.

Figure 5.13 illustrates CTSIs of sub-districts in Phranakhon Si Ayutthaya which assembled CESI, CSSI, CEnSI. From factor analysis, CESI mainly influenced CTSI while CSSI played the least influence. It is noticeable that most areas with good CTSIs appeared in 27 sub-districts which were concentrated in the north central and the southeast of province. They included Klong Sakae, Bang Phrakhru, Khan Ham, Bang Krasan, Pak Chan, Bo Phong, Pho Sam Ton, Phut Lao, Lam Sai, Don Lan, etc. The fair CTSIs covering 95 sub-districts were dispersed in all parts of the province. The poor CTSIs covering 27 sub-districts scattered in the periphery of the province were probably influenced by the poor CESIs, CSSIs and CEnSIs. Table 5.34 shows CTSIs and their classifications of sub-districts.

Table 5.34 CTSIs and their classifications of sub-districts.

Sub-district ID	Sub-district Name	District Name	CTSI	CTSI Class
140310	Klong Sakae	Nakhon Luang	2.3799	Good
140307	Bang Phrakhru	Nakhon Luang	2.3060	Good
141401	Khan Ham	Uthai	2.1425	Good
140605	Bang Krasan	Bang Pa-in	2.0766	Good
140305	Pak Chan	Nakhon Luang	1.6220	Good
140303	Bo Phong	Nakhon Luang	1.5922	Good
140714	Pho Sam Ton	Bang Pahan	1.5233	Good
140715	Phut Lao	Bang Pahan	1.3827	Good
141104	Lam Sai	Wang Noi	1.3338	Good
140807	Don Lan	Phak Hai	1.2539	Good
141106	Phayom	Wang Noi	0.4786	Fair
140608	Wat Yom	Bang Pa-in	0.4394	Fair
140113	Han Tra	Phranakhon Si Ayutthaya	0.4140	Fair
140308	Mae La	Nakhon Luang	0.4001	Fair
140711	Ban Ma	Bang Pahan	0.3969	Fair
140115	Ban Mai	Phranakhon Si Ayutthaya	0.3539	Fair
140713	Ban Li	Bang Pahan	0.3381	Fair
140604	Ban Krot	Bang Pa-in	0.3233	Fair
141109	Khao Ngam	Wang Noi	0.2999	Fair
140703	Bang Duea	Bang Pahan	0.2487	Fair
140108	Phu Khao Thong	Phranakhon Si Ayutthaya	-0.6792	Poor
140903	Rasom	Pha Chi	-0.6954	Poor
141209	Rang Chorakhe	Sena	-0.7056	Poor
140109	Samphao Lom	Phranakhon Si Ayutthaya	-0.7238	Poor
141604	Khlong Noi	Ban Phraek	-0.7250	Poor
140403	Sanam Chai	Bang Si	-0.7254	Poor
140615	Taling Chan	Bang Pa-in	-0.7303	Poor
141502	Kathum	Maharat	-0.7436	Poor
141303	Tao Lao	Bang Sai	-0.7887	Poor
141605	Song Hong	Ban Phraek	-1.0966	Poor

It is worth mentioning that CTSI is the overall sustainability index. CTSI comprises economic, social, and environment aspects. When examining the factor loading of CTSI, it can be seen that CESI is the most influencing factor to CTSI and CSSI is the least influencing. Therefore, the areas having good CESIs usually have good CEnSIs as well. However, the areas having good CESIs probably have poor CEnSIs. Hence, when calculating CTSI, the areas with good CTSIs may not always be common to areas with good CESIs. For the case like this, CTSIs may be affected and induced by CSSIs. CTSIs should be used to measure the overall sustainability index but not to notify the sustainability in detail.

Totally, we can summarize the spatial distribution of SIs of all aspects resulted from the sustainability assessment in Table 5.35. It is concluded that number of sub-districts with good CESI, CSSI, CEnSI, and CTSI are 37, 36, 32, and 27, respectively. There are 85, 95, 103, and 95 sub-districts are fair in CESI, CSSI, CEnSI, and CTSI, respectively. There are 27, 18, 14 and 27 sub-districts with poor CESI, CSSI, CEnSI, and CTSI, respectively. Most of sub-districts were fair in economic, social, environment, and total sustainability aspect.

Table 5.35 Classified CESI, CSSI, CENSI and CTSI at sub-district level.

	Good	**Fair**	**Poor**	**Total**
CESI	37	85	27	149
CSSI	36	95	18	149
CEnSI	32	103	14	149
CTSI	27	95	27	149

5.8 Conclusion

This chapter attempts to assess the SI of existing or current land use in 2007 in terms of three aspects: economic, social, and environmental aspect, including their integration. The CESI, CSSI and CEnSI were established to measure these dimensions. Then, the CTSI was developed to measure the total sustainability of each sub-district in Phra Nakhon Si Ayutthaya. Factor analysis through SPSS version 16.0 was used to identify underlying variables or factors that can effectively explain the pattern of correlations within a set of observed variables. Factor analysis was used to reduce a large number of variables into factors which share the same coefficients. The factors affecting the sustainability were extracted for SI calculation. Finally, the spatial distributions of CESIs, CSSIs, CEnSIs, and CTSIs were generated through ArcGIS version 9.3 to illustrate the geographic pattern of SIs in each sub-district of the study area. The results of this chapter were further used in the sustainability modeling in the sixth chapter.

CHAPTER VI

SUSTAINABILITY MODELING AND PREDICTION

6.1 Introduction

This chapter attempts to develop the sustainability model applying an exploratory spatial data analysis (ESDA) technique and Geographically Weighted Regression (GWR) to analyze the spatial varying relationships between land use and sustainability index with different levels of industrialization and agricultural concentration in Phra Nakhon Si Ayutthaya province. The concept and model designed were demonstrated to scope the variables specified in the model. The Geographically Weighted Regression Sustainability Models (GWRSMs) were established. Then, GWRSMs were used to predict the sustainability index of a particular land-use scenario from the forth chapter. Finally, the predicted sustainability index (PSIs) were compared to point out which scenario should be used in accordance with the development policies.

6.2 Land use and its impact on sustainability development

Land use is the results of human activities. Land use can be planned according to the subjective interest. In this study, the impacts of industrial and agricultural activities on land to the quality of life implied in terms of sustainability index were concentrated. Then, the preference on land-use types according to different policies were categorized to be industry and agriculture using the index.

Many studies indicated that industrial development can increased the economic growth and standard of living of the people in developing countries (Ernste and Meier, 1992; Suwan, 1992; Bunchorntavakul, 1976, Tu and Xia, 2008, Indhapanya, 1996). However, the growth of industrial sector may cause the pollution to the environment at the same time, while agricultural sector is the basic sector providing the food and affecting the quality of life in different way. United Nation Development Programme-Thailand states that Thailand has enjoyed remarkable growth over the past quarter-century, making the country an economic leader and prominent development partner in the region. This growth has not come without a cost. Rapid development, urbanization, and the spread of industrial activity have had a serious impact on the country's people and ecosystems. Much of the country's forest cover has been lost, while roughly half of Thailand's rivers and lakes are classified as having poor water quality. There is an overuse of land and water with a lack of proper planning in certain sectors (UNDP, 2010).

Studies on the impacts of urbanization and industrialization on the economic and social aspects have been carried out in different ways such as income, employment, education, variation in consumption, etc (Ernste et al., 1992; Suwan, 1992; Bunchorntavakul, 1976). Asian-Pacific Center (1996) indicated that Thai society has been changed with the effect of industrialization and the growth of industrial investment. Indhapanya (1996) had applied spatial analysis of social indicators to evaluate social impacts of the Eastern Seaboard Development Program in Thailand. Hung (1998) presented the impact of urbanization and industrialization to the economic and social structure such as employment, income and population growth of Chiang Mai-Lam Phun province in Thailand. Tu and Xia (2008) examined spatial varying relationships between land use and water quality. Numerous studies have been conducted worldwide to analyze the relationships between land use and environment (Tong and Chen, 2002; Little, Saffran, and Fent, 2003; Woli, Nagumo, Kuramochi, and Hatano, 2004; Williams, Hopkinson, Rastetter, Vallino, and Claessens, 2005; Rodrigruez, August, Wang, Pual, Goal, and Rubinstien, 2007).

We can conclude that land use affects on quality of life or standard of living in various aspects, namely economic, social structure, and environment, measured by sustainability index. The impacts of land use on sustainability index of a certain spatial unit are in different ways and different levels. In this study, we attempts to find the relationships of the land use and sustainability index at Tambol or sub-district level. The sustainability indexes in 2007, developed in the fifth chapter, were used in sustainability modeling to demonstrate the impacts of the existing land use in 2007.

6.3 Data and methodology

Sustainability modeling and prediction of sustainability index are the part 4 and 5 of the overall study framework as highlighted in Figure 6.1. The LDD land-use map of 2007 and the sustainability indexes from part 3 in the fifth chapter were employed to develop the sustainability models (in part 4). Then, the predicted sustainability indexes of particular scenarios established in part 2 (from the fourth chapter) were determined (in part 5) using these sustainability models from part 4. Finally, the predicted sustainability indexes (PSIs) of each scenario were accumulated and compared in order to determine which scenario should be selected for each sustainability policy (in part 6).

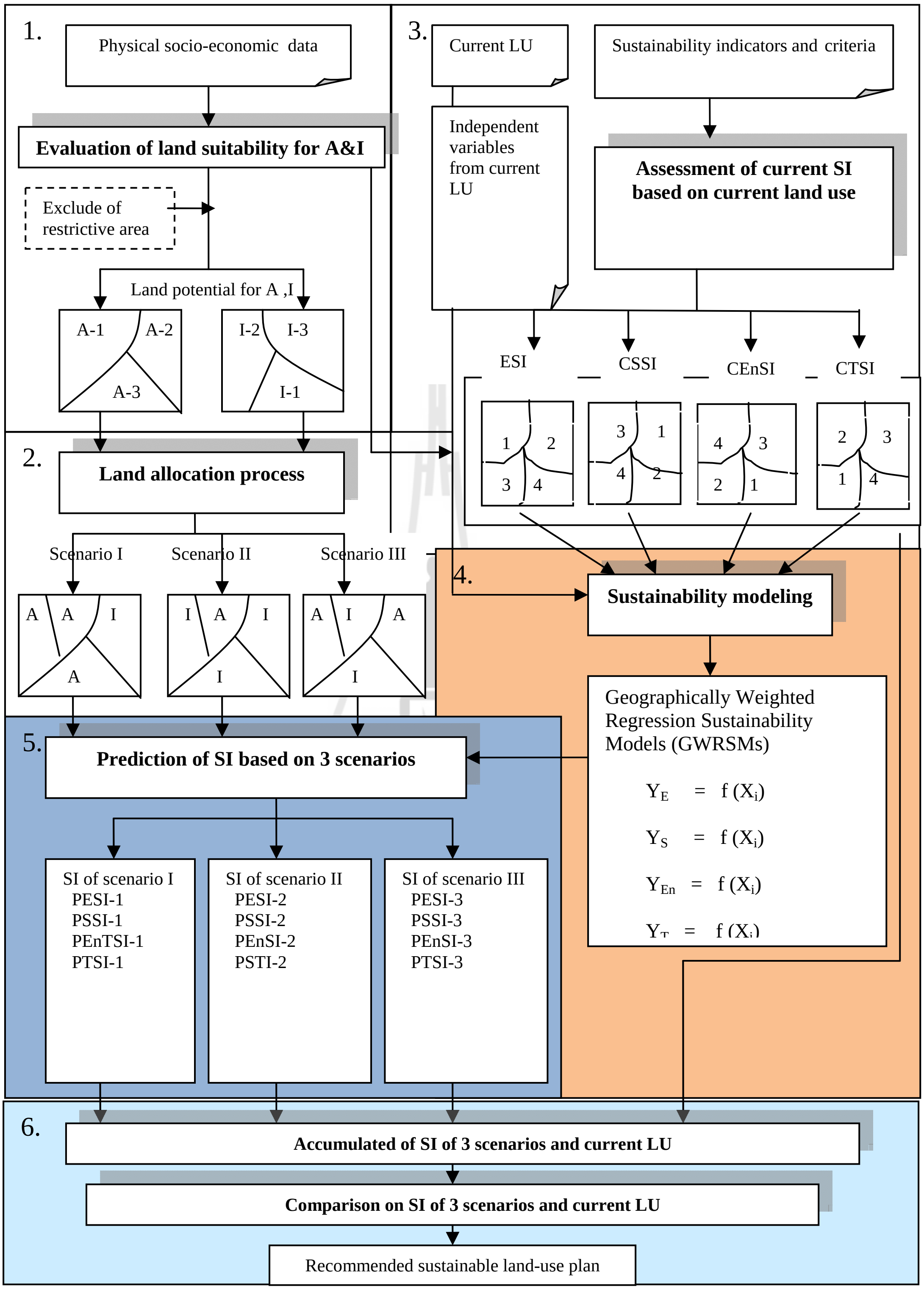


Figure 6.1 Sustainability modeling and prediction as parts of the overall conceptual framework of the study.

In the process of sustainability modeling (part 4), the researcher attempted to develop the sustainability models to be the new tools for assessing and predicting the local sustainability at sub-district level. Geographically Weighted Regression (GWR) was applied to formulate the sustainability models and were named as *Geographically Weighted Regression Sustainability Model (GWRSM*) include ones of economic (EGWRSM), social (SGWRSM), environment (EnGWRSM) and the total (TGWRSM). All of the methodologies were explained in detail in the followings.

6.4 Sustainability Modeling

6.4.1 Sustainability Model designed

The purpose of this part is to test and explore spatial variation in the relationships between sustainability indexes and land use. The relationships are commonly examined by conventional statistical methods, such as ordinary least squares regression (OLS) and Spearman’s rank correlation analysis, which assume the relationships are constant across space. However, the relationships might often vary over the space because the characteristics of dependent variables and explanatory variables are not the same in different places (Tu, 2011). Traditional regression techniques, OLS, may hide important local variations in the model parameters, and are not deal with spatial autocorrelation existing in the variables (Tu and Xia, 2008). A recently developed technique, Geographically Weighted Regression (GWR), was used to examine the relationships between current land use and current sustainability indexes of the study area. GWR models can reveal the spatial autocorrelation of the variables and the local variations in the model parameters. GWR models make great improvement of model performance over OLS model, which is proved by R square and corrected Akaike Information Criterion (AIC). GWR models also improve the reliabilities of the relationships by reducing spatial autocorrelations (Tu and Xia, 2008).

Figure 6.2 demonstrated the Geographically Weighted Regression Sustainability Model (GWRSM) of aspects. Percentage of agricultural and industrial areas of current land uses were used as the independent or explanatory variables and the CESI, CSSI, CEnSI, and CTSI, were used as the dependent variables in GWR modeling. The results of the model building are the regression equations for all sub-districts. The Geographically Weighted Regression Sustainability Models (GWRSM) include ones of economic (EGWRSM), social (SGWRSM), environment (EnGWRSM), and the total (TGWRSM).

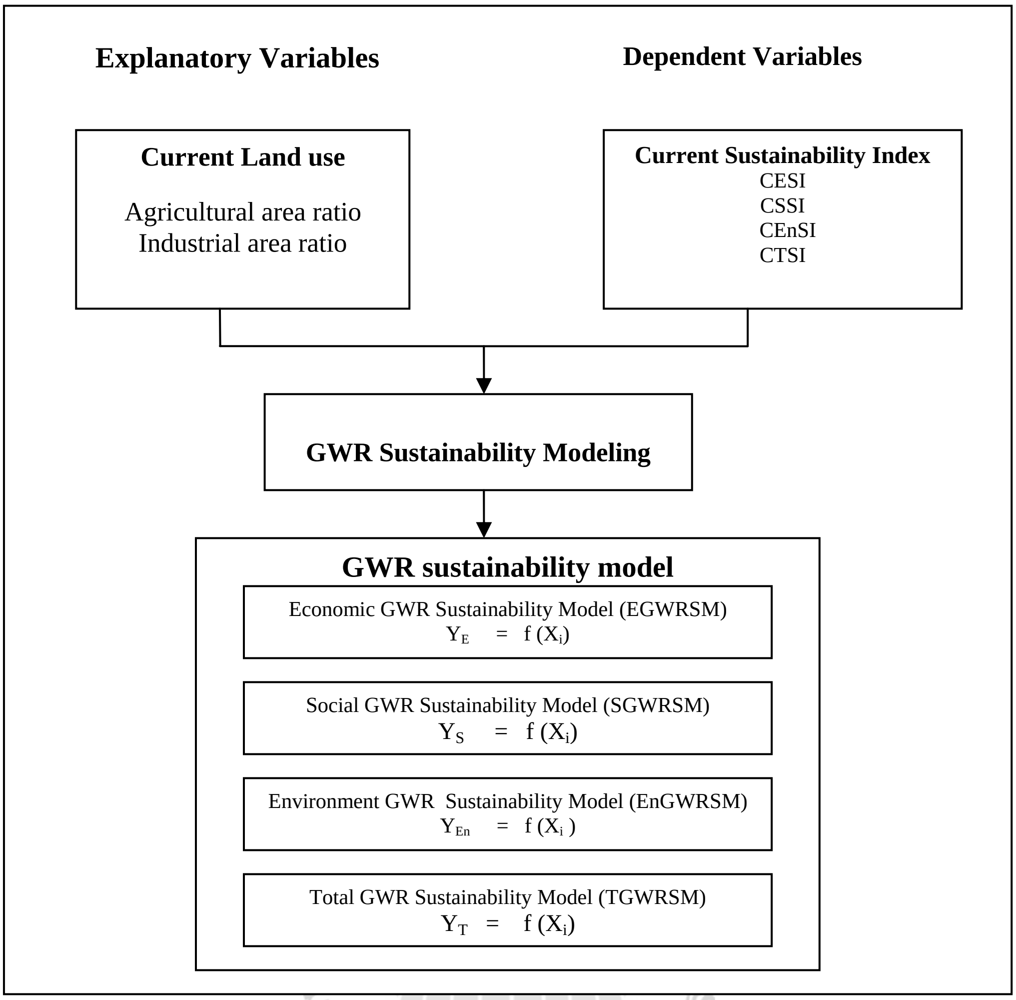


Figure 6.2 Geographically Weighted Regression Sustainability Models (GWRSM) of aspects.

6.4.2 Land use in Phra Nakhon Si Ayutthaya province

According to the purpose of the studies which emphasized on impacts of agricultural and industrial sectors to the quality of life and societies, their proportion of land use were assessed.

Based on the land-use map in 2007 from the LDD, agricultural land use was represented by rice paddy area. The industrial land use from the LDD was updated and modified by the map of manufacturing from the Department of Industrial Works

(DIW) in the year 2007. The simplified land use of Phra Nakhon Si Ayutthaya Province in 2007 was illustrated in Figure 6.3.

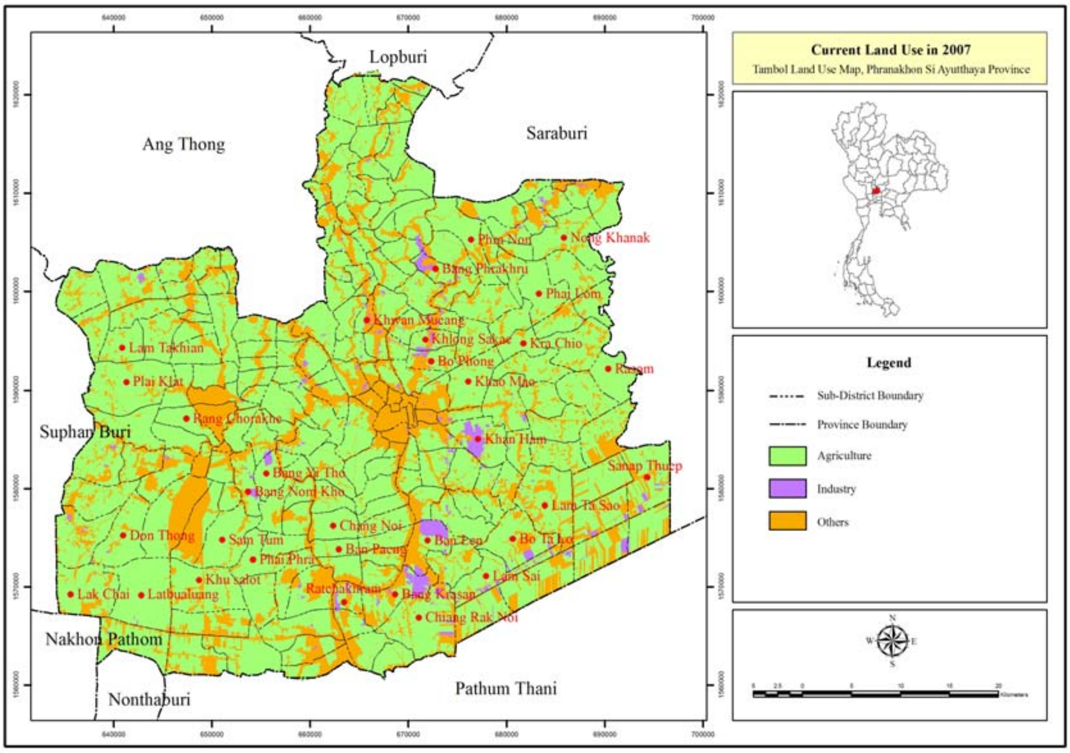


Figure 6.3 Simplified land use of Phra Nakhon Si Ayutthaya Province in 2007.

Phra Nakhon Si Ayutthaya Province is the main rice cultivation area in Thailand. Almost 80 percent of it is rice paddy (Phra Nakhon Si Ayutthaya Provincial Office, 2007). Sub-districts with the highest agricultural area is Lat Bua Luang of which 96.46% of the area is rice paddy. Table 6.1 shows ten sub-districts of Phra Nakhon Si Ayutthaya Province with the highest proportion agricultural areas.

Table 6.1 The first ten sub-districts of Phra Nakhon Si Ayutthaya with highest agricultural area.

No	Sub-district ID	Sub-district Name	District Name	Agricultural area		
				Square km.	Rai	Percent
1	141001	Lat Bua Luang	Lat Bua Luang	37.58	23,485	96.46
2	141304	Plai Klat	Bang Sai	35.94	22,460	88.73
3	140422	Chiang Rak Noi	Bang Si	29.95	18,716	73.53
4	141006	Khu Salot	Lat Bua Luang	27.73	17,333	85.32
5	141101	Lam Lam Ta Sao	Wang Noi	24.63	15,392	69.10
6	141002	Lak Chai	Lat Bua Luang	23.77	14,857	64.68
7	140209	Nong Khanak	Tha Ruea	23.72	14,825	88.04
8	141213	Sam Tum	Se Na	22.56	14,101	90.09
9	141215	Don Thong	Se Na	22.37	13,983	89.36
10	140312	Phra Non	Nakhon Luang	20.14	12,586	86.51

On the other hand, Phra Nakhon Si Ayutthaya is one of the promoted industrial zones, as the investment promotion zones 2 announced by the Board of Investment of Thailand (BOI, 2007). There are three major industrial estates and two industrial parks containing 536 factories with 174 billion baht investment. There are 1,297 factories with 121 billion baht outside industrial estates. Table 6.2 shows the first ten sub-districts of the study area with highest proportion of industrial areas (Phra Nakhon Si Ayutthaya Provincial Office, 2007). Table 6.3 shows the descriptive statistics of current land use in 2007.

Table 6.2 The first ten sub-districts of Phra Nakhon Si Ayutthaya with highest industrial area.

No	Sub-district ID	Sub-district Name	District Name	Industrial area		
				Square km.	Rai	Percent
1	140601	Ban Len	Bang Pa-in	5.45	3,407	29.95
2	141401	Khan Ham	Uthai	5.43	3,396	25.97
3	140605	Bang Krasan	Bang Pa-in	4.44	2,773	20.22
4	140307	Bang Phrakhru	Nakhon Luang	2.08	1,300	25.02
5	140422	Chiang Rak Noi	Bang Si	1.78	1,113	4.37
6	141104	Lam Sai	Wang Noi	1.55	968	7.32
7	141102	Bo Ta Lo	Wang Noi	1.34	836	5.04
8	141105	Sanap Thuep	Wang Noi	1.12	700	3.87
9	141205	Bang Nom Kho	Se Na	1.07	670	7.96
10	140310	Khlong Sakae	Nakhon Luang	1.07	666	12.21

Table 6.3 The descriptive statistics of current land use of the study area in 2007.

Current Land use		Minimum	Maximum	Mean	Sum	Standard deviation
Agriculture	Area (Rai)	0.00	23,485.00	5,565.00	1,163,249.00	4,014.26
	Percent	0.00	96.46	68.23	14,261.00	22.51
Industry	Area (Rai)	0.00	3,407.00	139.48	29,153.00	415.45
	Percent	0.00	29.94	1.74	364.15	3.93
Other	Area (Rai)	163.49	9,948.54	1,807.06	377,677.06	1,401.05
	Percent	1.57	100.00	29.08	6079.33	21.91

Table 6.4 illustrates the interesting proportion of agricultural and industrial land use in some sub-districts of Phra Nakhon Si Ayutthaya Province in 2007. It is interesting to note that the higher proportion of industrial area may lead into the less proportion of agricultural area. This implies that agricultural area may be replaced by the industrial area. These proportions of current land use in 2007 were used to be the explanatory variables in GWRSM.

Table 6.4 The interesting proportion of agricultural and industrial land use in some sub-districts of Phra Nakhon Si Ayutthaya Province in 2007.

Sub-districts ID	**Sub-districts Name**	**Agriculture area (%)**	**Industrial area (%)**	**Other Area (%)**
140601	Ban Len	33.31	29.95	36.74
141401	Khan Ham	62.94	25.97	11.09
140307	Bang Phrakhru	45.89	25.02	29.09
140605	Bang Krasan	41.22	20.22	38.56
140310	Khlong Sakae	68.88	12.21	18.91
140419	Ratchakhram	53.92	11.90	34.18
140712	Khwan Mueang	40.80	9.01	50.19
140406	Bang Yi Tho	85.89	7.96	6.15
141205	Bang Nom Kho	63.93	7.96	28.11
140303	Bo Phong	63.96	7.41	28.63

6.4.3 Current Sustainability indexes of Phra Nakhon Si Ayutthaya Province

CESI, CSSI, CEnSI and CTSI of Phranakhon Si Ayutthaya for the year 2007 were assessed in the fifth chapter. All of these CSIs were input into GWRSM as dependent variables.

6.4.4 Geographically Weighted Regression Sustainability Models (GWRSM)

In this study, GWRSMs of aspects were developed by applying the GWR techniques in ArcGIS version 9.3. They comprised EGWRSM, SGWRSM, EnGWRSM, and TGWRSM. Each of them was developed as follows:

6.4.4.1 Economic Geographically Weighted Regression Sustainability Model (EGWRSM)

A recently statistical technique, Geographically Weighted Regression (GWR), developed by Fotheringham, Brunderson and Charlton in 1996 is an extension of the traditional standard regression framework. GWR is a local spatial statistical technique used to analyze spatial non-stationarity, defined as when the measurement of relationships among variables differs from location to location (Fotheringham, Brunderson, and Charlton, 2002). GWR is promoted as a means of removing spatial non-stationarity through local analysis. In standard applications of regression known as Ordinary Least Square (OLS), a dependent variable is linked to a set of independent variables with one of the main outputs of regression being the estimation of parameter that links each independent variable to the dependent variable. A major problem with this technique when applied to spatial data is that the processes being examined are assumed to be constant over space that is one model fit all or a global regression model (Charlton, Fotheringham, and Brunderson, 2006) (see the detail in Appendix C).

As the tradition global regression model, OLS may hide important local variations in the model parameters and is not able to deal with spatial autocorrelation existing in the variables, GWR model was used to resolve these problems and improve the model (Fotheringham, 2009) Thus, the Economic Ordinary Least Square Sustainability Model (EOLSSM) was developed to investigate overall relationships between CESI and land use and then a number of EGWRSMs was developed in different bandwidths to find the best fit model for every sub-district.

Herein, comparison of the EOLSSM and three EGWRSMs with bandwidth 35, 30, and 25 were carried out to justify the best appropriate model. The statistical parameters of these models analyzed using ArcGIS version 9.3 and SPSS version 16.0 were shown in Table 6.5. EGWRSM with bandwidth 30 shows more improvement in the model performance over the EOLSSM, EGWRSM with bandwidth 35 and EGWRSM with bandwidth 25. Figure 6.4 illustrates the standardized residual of the four ESMs. The more positive and the less negative standardized residuals indicate higher error of local models. The less Moran's I index of the residual indicates the lower spatial autocorrelation or higher dispersion of the residuals. This means that more accuracy can be achieved while using the GWR model. As Mitchell (2005) stated that over and under predictions for a well specified regression model should be randomly distributed. Statistically significant clustering of high and/or low residuals indicates the GWR model is misspecified. The results show that EGWRSM with bandwidth 30 provides less spatial units (sub-districts) which have the under and over predicted values than of another models. Moran's I index of residual is -0.05, indicating randomly distributed.

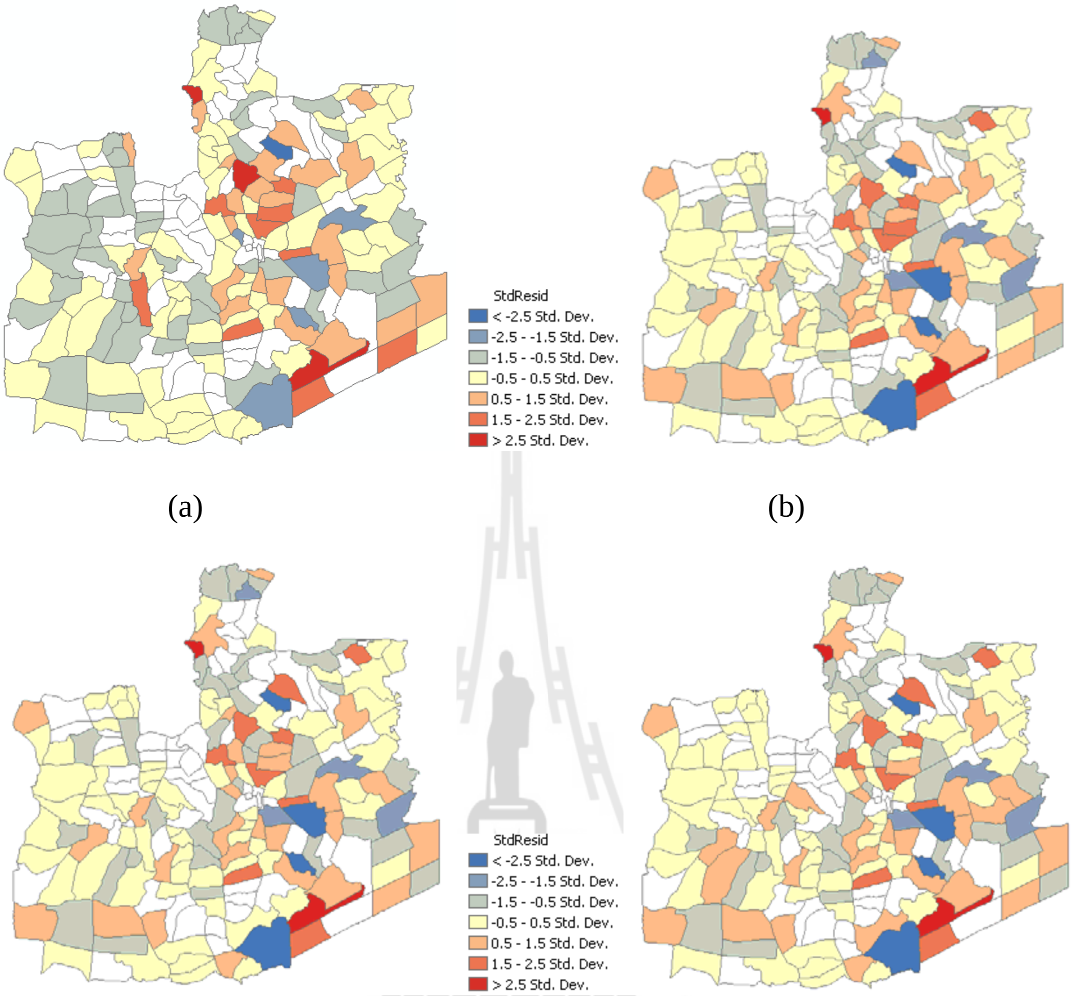
When the condition number was examined, there are non unreliable results in the EGWRSM with bandwidth 30 while some appear in the EGWRSM with bandwidth 25. The condition number used to evaluate local collinearity. In the presence of strong local collinearity, results become unstable. Results associated with condition numbers larger than 30, may be unreliable (Mitchell, 2005).

Table 6.5 Comparison of statistic parameters of the different ESM performances.

Method	**AICc**	**Residual Squares**	**R^2**	**R^2 adjusted**	**No.Unit with Cond. No > 30**	**Moran's I of residual**
EOLSSM	166.0309	25.5363	.6960	.6918	-	0.17 (clustered)
EGWRSM 35	144.6716	14.6911	.8251	.7756	0 (23.01)	0.02 (randomly)
EGWRSM 30	146.1848	13.74776	.8363	.7810	0 (26.92)	-0.05 (randomly)
EGWRSM 25	150.6976	12.3791	.8524	.7881	2 (34.23)	-0.08 (somewhat dispersed)

When the R^2 and R^2 adjusted were investigated, the EGWRSM with bandwidth 25 have the highest values. However, R^2 and R^2 adjusted of the EGWRSM with bandwidth 25 are very little higher than that of the EGWRSM with bandwidth 30, but when trade off with other statistical parameters and condition number, the EGWRSM with bandwidth 30 is considered better.

Comparing the EGWRSM with bandwidth 30 to the one with bandwidth 35, the first one is better in having lower residual squares and higher R^2 and R^2 adjusted. Therefore, the EGWRSM with bandwidth 30 was selected to be the most appropriate ESM.



(a) (b)

(c) (d)

Figure 6.4 Spatial variation of standardized residual CESI (a) EOLSSM (b) EGWRSM with bandwidth 35 (c) EGWRSM with bandwidth 30 (d) EGWRSM with bandwidth 25.

Table 6.6 illustrates the output of sub-districts using the most appropriate EGWRSM (with bandwidth 30), including fields of observed or the real CESI, estimated CESI values, condition number, local R^2, intercept or constant value, explanatory variable coefficients, residuals, standard residual and standard errors.

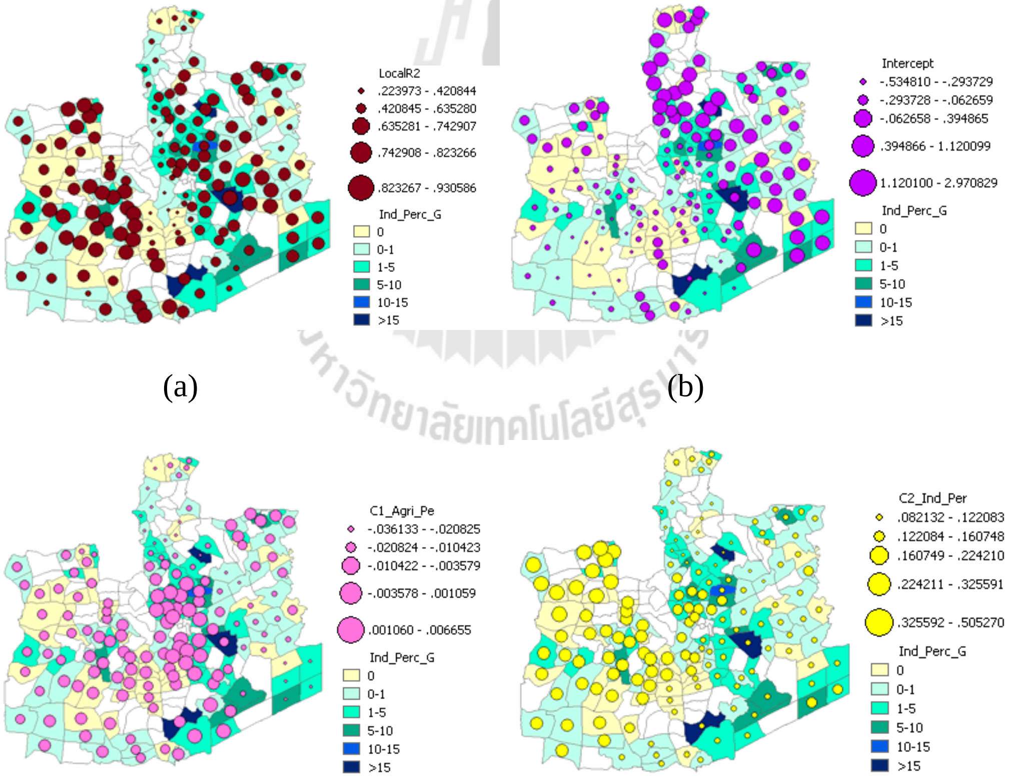
Figure 6.5 shows the spatial distribution of local R^2, intercept and coefficient of agricultural area, and coefficient of industrial area from the EGWRSM (bandwidth 30)

In this case, from the most appropriate EGWRSM (bandwidth 30) local R^2 values is 0.8363 (Table 6.5) vary from 0.2240 to 0.9306 (Table 6.6 and Figure 6.5(a)) which is better than the value 0.6960 of the global EOLSSM (Table 6.5). Figure 6.5(a) showed that high local R^2 varies between 0.742908-0.823266 and 0.823267-0.930586 were covered most of sub-districts. It indicates that this model is best fit for Economic Sustainability Index (ESI) prediction.

The spatial variation of intercepts and coefficients of explanatory variables of EGWRSM with bandwidth 30 were also presented in Table 6.6 and Figure 6.5. Spatial variation of intercepts varies between -0.5348 to 2.9708. In Figure 6.5 (b), the high intercept values were found in the east of the province which were associated with high proportion of industrial area such as Nakhon Luang, Bang Pahan, Uthai, Bang Pa-In, and Wang Noi Districts. The spatial variation of agriculture area coefficients ranges from -0.0361 to 0.0067 (Table 6.6). The high coefficients were founded in the central and the west of the province such as Bang Pahan, Phra Nakhon Si Ayutthaya, Bang Pa-In, Bang Si, Sena, Lat Bua Luang, Bang Sai, and Phak Hai Districts. (Figure 6.5(c)). The spatial variation of industrial area coefficients ranges from 0.0821 to 0.5053 (Table 6.6). The high coefficients were founded in the west of the province (Figure 6.5(d)) such as Bang Si, Sena, Lat Bua Luang, Bang Sai, and Phak Hai Districts.

Table 6.6 Output SI, model coefficients, condition number, and residuals of sub-districts analyzed using the most appropriate EGWRSM (bandwidth 30).

	Observe SI	**Condition No.**	**Local R^2**	**Predict SI**	**intercept**	**C1_Agr**	**C2_Ind**	**Residual**	**Std Error**	**Std. Residual**
Minimum	-1.0063	3.8551	0.2240	-0.6757	-0.5348	-0.0361	0.0821	-0.9481	0.0629	-4.3767
Maximum	3.1058	26.9250	0.9306	3.3281	2.9708	0.0067	0.5053	0.9033	0.3335	3.1925
Mean	0.0048	12.1150	0.7284	0.0063	0.2607	-0.0065	0.2015	-0.0014	0.2998	-0.0460
Standard deviation	0.7508	5.1636	0.1261	0.6469	0.6777	0.0087	0.0992	0.3038	0.0485	1.0827

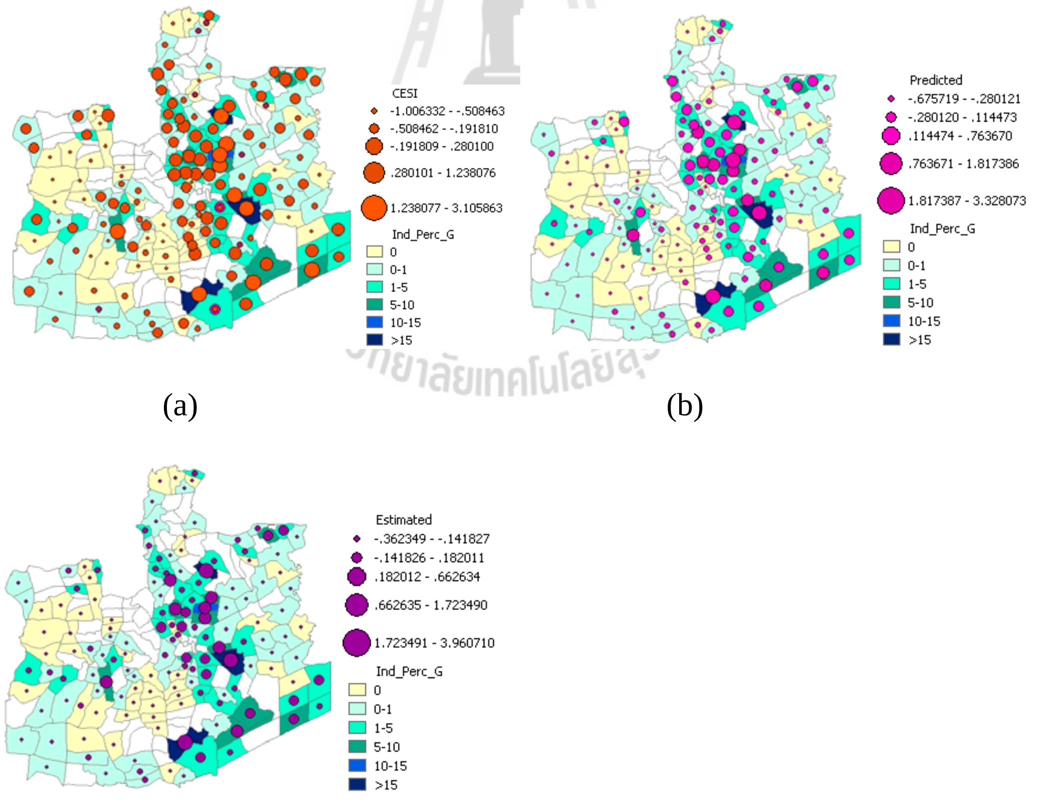


(a) (b)

(c) (d)

Figure 6.5 Spatial distribution of parameters from the best EGWRSM (bandwidth 30) (a) local R^2 (b) intercept (c) coefficient of agricultural land use (d) coefficient of industrial land use.

Finally, the spatial distribution of CESIs from observed, estimated CESI from EGWRSM with bandwidth 30 and EOLSSM were compared in Figure 6.6 to clarify the performance estimation of EGWRSM. The result obviously indicates that the estimated CESI from EGWRSM with bandwidth 30 (Figure 6.6(b)) is closer in term of spatial association to the observed (Figure 6.6(a)) than that of the EOLSSM (Figure 6.6(c)). Most of high observed CESI sub-districts (Figure 6.6(a)) were found in the east of the province and associated with the high predicted CESI from EGWRSM with bandwidth 30 Figure 6.6(b).



(a) (b)

(c)

Figure 6.6 Comparison of spatial distribution of CESI from (a) observed, (b) predicted (using EGWRSM with bandwidth 30), and (c) EOLSSM.

6.4.4.2 Social Geographically Weighted Regression Sustainability Model (SGWRSM)

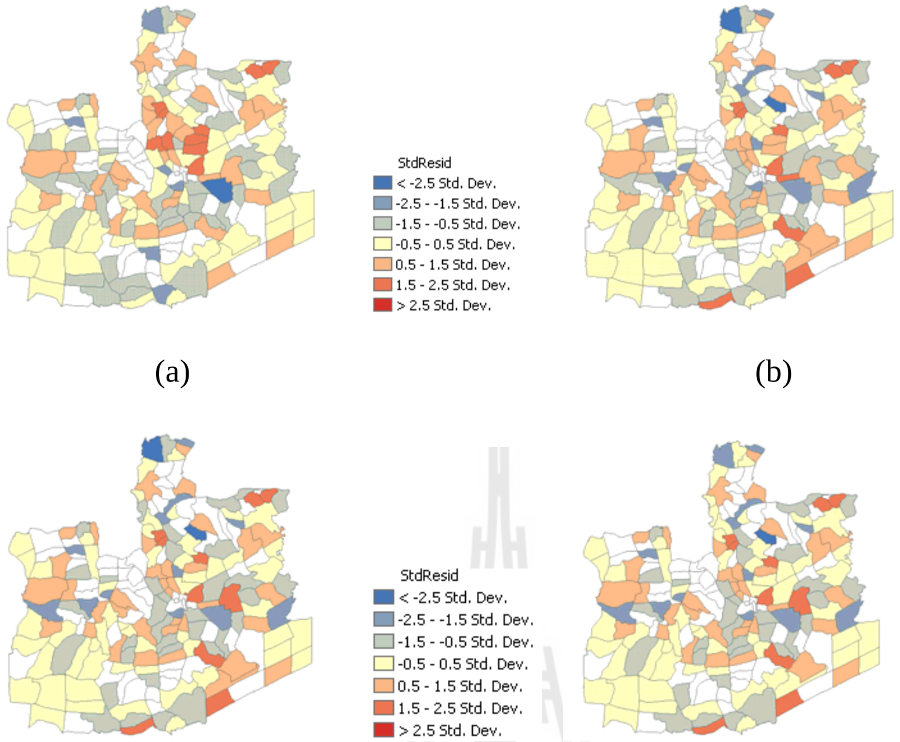
The purpose of the SGWRSM building is to explore the relationships between CSSI as the dependent variable and two types of land use as explanatory variables. The Social Ordinary Least Square Sustainability Model (SOLSSM) and the different SGWRSMs were developed and compared to find the best Social Sustainability Model (SSM). Table 6.7 shows the statistical parameters of the four models analyzed using ArcMap version 9.3 and SPSS version 16.0. These statistical parameters were investigated. R^2 and R^2 adjusted, residual squares, AICc and a number of unstable or unreliable cases in the model were examined carefully. Increasing in R^2 leads to increasing in AICc and a number of unstable cases in the model. Thus, the appropriate model should be the model tradeoff between the variance of the fitted values and the bias in the coefficient estimates.

Table 6.7 indicates that the SGWRSM with bandwidth 30 has higher performance than SOLSSM. Its R^2 value is 0.5117 and higher than of SOLSSM (0.1907), and it has smaller AICc value and square of residual. Furthermore, the Moran's I value of its residual is -0.11 which indicates that the residual is dispersed Then, the SGWRSM with bandwidth 30 is the most appropriate model.

Table 6.7 Comparison of statistical parameters of the different SSM performances.

Method	**AICc**	**Residual Squares**	**R^2**	**R^2 adjusted**	**Cond No. > 30**	**Moran's I of residual**
SOLSSM	194.6453	30.9430	0.1907	0.1796	-	0.20 (clustered)
SGWRSM 35	189.0371	19.7864	0.4825	0.3360	0 (23.02)	-0.09 (dispersed)
SGWRSM 30	191.7900	18.6706	0.5117	0.3467	0 (26.92)	-0.11 (dispersed)
SGWRSM 25	195.2485	16.7614	0.5601	0.3683	2 (34.23)	-0.12 (dispersed)

When comparing the SGWRSM with bandwidth 35 to the SGWRSM with bandwidth 30, the later has larger AICc, but higher R^2 and R^2 adjusted and lower residual squares than those of the first. Therefore, the SGWRSM with bandwidth 30 was considered more appropriate. Comparing to the SGWRSM with bandwidth 25, though the SGWRSM with bandwidth 30 has smaller R^2, R^2 adjusted and higher residual squares, but has a significantly lower AICc. It has no condition number while SGWRSM with bandwidth 25 has 2. Therefore, when tradeoff among all statistical performances was considered, the SGWRSM with bandwidth 30 was selected to be the most appropriate SSM. Figure 6.7 illustrated the spatial variation of standardized residual CSSI of four SSMs.



(a) (b)

(c) (d)

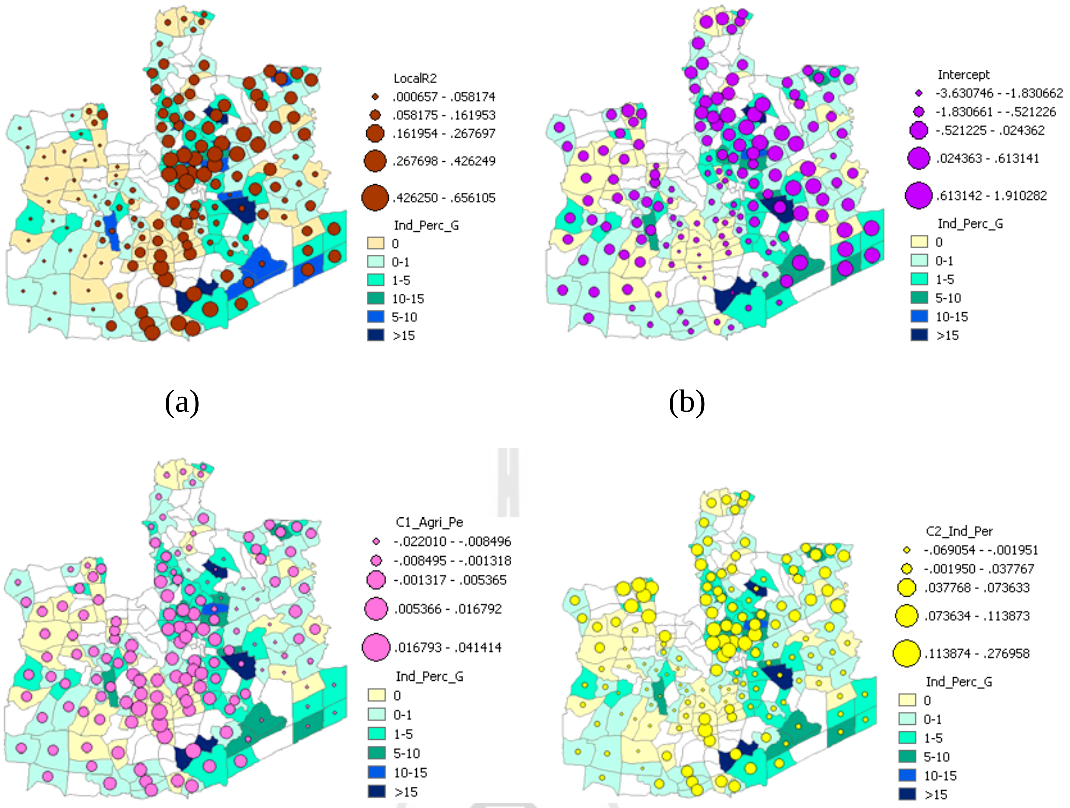
Figure 6.7 Spatial variation of standardized residual of CSSIs (a) SOLSSM (b) SGWRSM with bandwidth 35 (c) SGWRSM with bandwidth 30 (d) SGWRSM with bandwidth 25.

Table 6.8 illustrates the output of sub-districts using the most appropriate SGWRSM (with bandwidth 30) through ArcGIS software, including fields of observed or the real CSSI, condition number, local R^2 values, predicted or estimated CSSI, intercept or constant value, explanatory variable coefficients, residuals, standard residual and standard errors. The value of R^2 is 0.5117 (Table 6.7) varies between 0.007 up to 0.6561 (Table 6.8) while R^2 values of the global model is only 0.1907 (Table 6.7). The spatial distribution of the local R^2 value was shown in Figure 6.8. Most of high local R^2 sub-districts were found in the central and the east of the province such as Bang Pahan, Phra Nakhon Si Ayutthaya, Nakhon Luang, Uthai, Wang Noi, Bang Si, and Bang Pa-In Districts.

The intercepts varies from -3.6307 to 1.9103 (Table 6.8). Most of the high intercept sub-districts were distributed in the east of the province (Figure 6.8(b)).such as Bang Pahan, Nakhon Luang, Uthai and Wang Noi Districts. The coefficient of agricultural area varies from -0.0220 to 0.0414 (Table 6.8). Figure 6.8(c) shows that most of the high coefficient of agricultural area were distributed from the central to the west of the province such as Bang Pahan, Phra Nakhon Si Ayutthaya, Bang Ban, Bang Pa-In, Bang Si, Sena, Lat Bua Luang, Bang Sai and Phak Hai Districts. The coefficient of industrial area in Figure 6.8(d) varies from 0.00691 to 0.2770 (Table 6.8). The high coefficient of industrial area were found in the Bang Pahan, Nakhon Luang, Tha Rua, Pha Chi, Bang Si, Bang Pa-In and Phak Hai Districts.

Table 6.8 Output SI, model coefficients, condition number, and residuals of sub-districts analyzed using the most appropriate SGWRSM (bandwidth 30).

	Observe SI	**Condition No.**	**Local R^2**	**Predict SI**	**intercept**	**C1_Agr**	**C2_Ind**	**Residual**	**Std Error**	**Std. Residual**
Minimum	-1.2854	3.8551	0.0007	-0.6947	-3.6307	-0.0220	-0.0691	-0.9332	0.0733	-3.8738
Maximum	1.6061	26.9250	0.6561	1.3545	1.9103	0.0414	0.2770	0.8225	0.3886	2.2971
Mean	0.0017	12.1150	0.2229	0.0019	-0.2294	-0.0022	0.0488	-0.0037	0.3494	-0.0505
Standard deviation	0.5066	5.1636	0.1679	0.3048	0.7556	0.0088	0.0521	0.3540	0.0565	1.0656

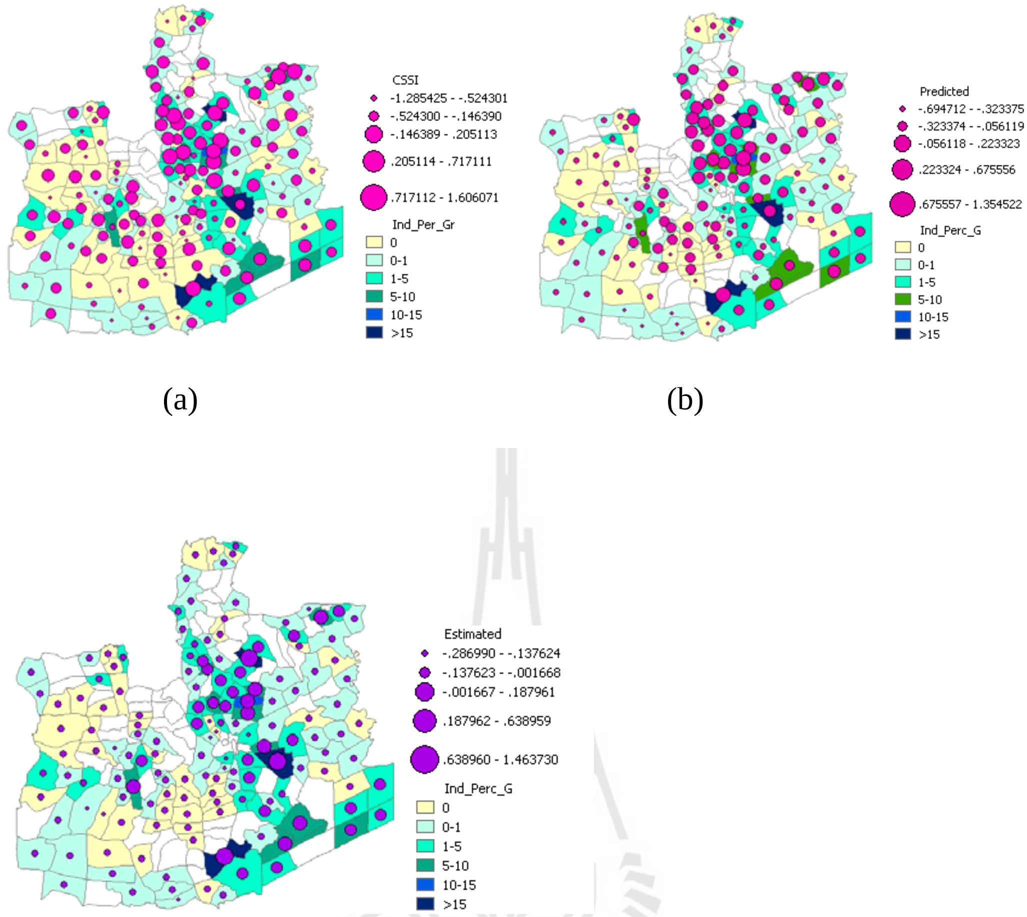


(a) (b)

(c) (d)

Figure 6.8 Spatial distribution of parameters from the best SGWRSM (bandwidth 30) (a) local R^2 (b) intercept (c) coefficient of agricultural land use (d) coefficient of industrial land use.

Finally, the spatial distribution of CSSIs from observed, estimated CSSI using SGWRSM with bandwidth 30, and estimated CSSI from SOLSSM were compared in Figure 6.9 to clarify the performance estimation of SGWRSM. The result indicates that the estimated CSSI from SGWRSM with bandwidth 30 (Figure 6.9(b)) is closer to the observed CSSI (Figure 6.9(a)) than that of the SOLSSM (Figure 6.9(c)). Most of high observed CSSI sub-districts (Figure 6.9(a)) were found in the east of the province and associated with the high predicted CSSI from SGWRSM with bandwidth 30 Figure 6.9(b).



(a) (b)

(c)

Figure 6.9 Comparison of spatial distribution of CSSI from (a) observed (b) predicted (using SGWRSM with bandwidth 30), and (c) SOLSSM.

6.4.4.3 Environment Geographically Weighted Regression Sustainability Model (EnGWRSM)

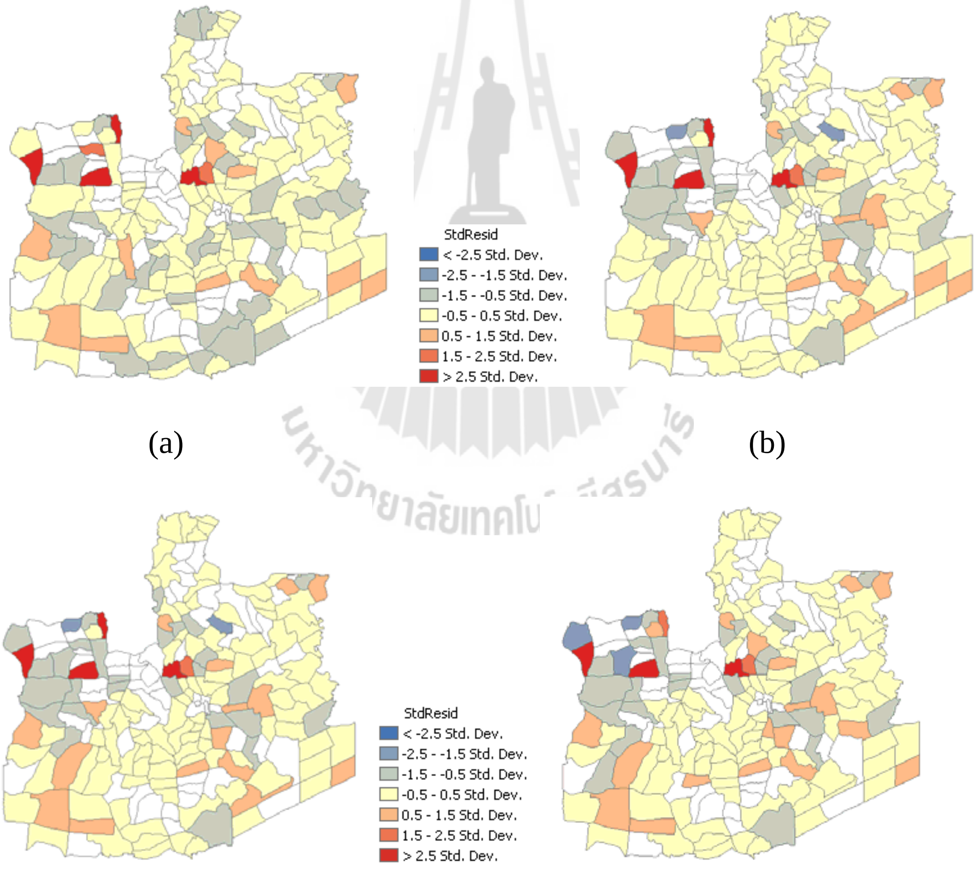
The purpose of the EnGWRSM building is to explore the relationships between CEnSI as the dependent variable and two types of land use as explanatory variables. The Environment Ordinary Least Square Sustainability Model (EnOLSSM) and the different EnGWRSMs were developed and compared to find the best Environment Sustainability Model (EnSM). Table 6.9 shows the statistical parameters of the four models analyzed using ArcMap version 9.3 and SPSS version 16.0. These statistical parameters were investigated. R^2 and R^2 adjusted, residual squares, AICc and a number of unstable or unreliable cases in the model were examined carefully. Increasing in R^2 leads to increasing in AICc and a number of unstable cases in the model. Thus, the appropriate model should be the model tradeoff between the variance of the fitted values and the bias in the coefficient estimates.

Table 6.9 indicates that the EnGWRSM with bandwidth 30 has higher performance than EnOLSSM. Its R^2 value is 0.5355 and higher than of EnOLSSM (0.3571), and it has smaller square of residual. Furthermore, the Moran's I value of its residual is -0.10 which indicates that the residual is dispersed (Table 6.9). Then, the EnGWRSM with bandwidth 30 is the most appropriate model.

Table 6.9 Comparison of statistical parameters of the different EnSM performances.

Method	**AICc**	**Residual Squares**	**R^2**	**R^2 adjusted**	**Cond. No. > 30**	**Moran's I of residual**
EnOLSSM	282.0506	55.6320	.3571	.3483	-	0.03 (randomly)
EnGWRSM 35	304.6554	42.9895	.5032	.3626	0	-0.09 (dispersed)
EnGWRSM 30	306.0177	40.1883	.5355	.3786	0	-0.10 (dispersed)
EnGWRSM 25	311.4209	36.9427	.5724	.3859	2	-0.11 (dispersed)

When comparing the EnGWRSM with bandwidth 35 to the EnGWRSM with bandwidth 30, the later has larger AICc, but higher R^2 and R^2 adjusted and lower residual squares than those of the first. Therefore, the EnGWRSM with bandwidth 30 was considered more appropriate. Comparing to the EnGWRSM with bandwidth 25, though the EnGWRSM with bandwidth 30 has smaller R^2, R^2 adjusted and higher residual squares, but has lower AICc. It has no condition number while EnGWRSM with bandwidth 25 has 2. Therefore, when tradeoff among all statistical performances was considered, the EnGWRSM with bandwidth 30 was selected to be the most appropriate EnSM. Figure 6.10 illustrates the spatial variation of standardized residual CEnSI of four EnSMs.



(a) (b)

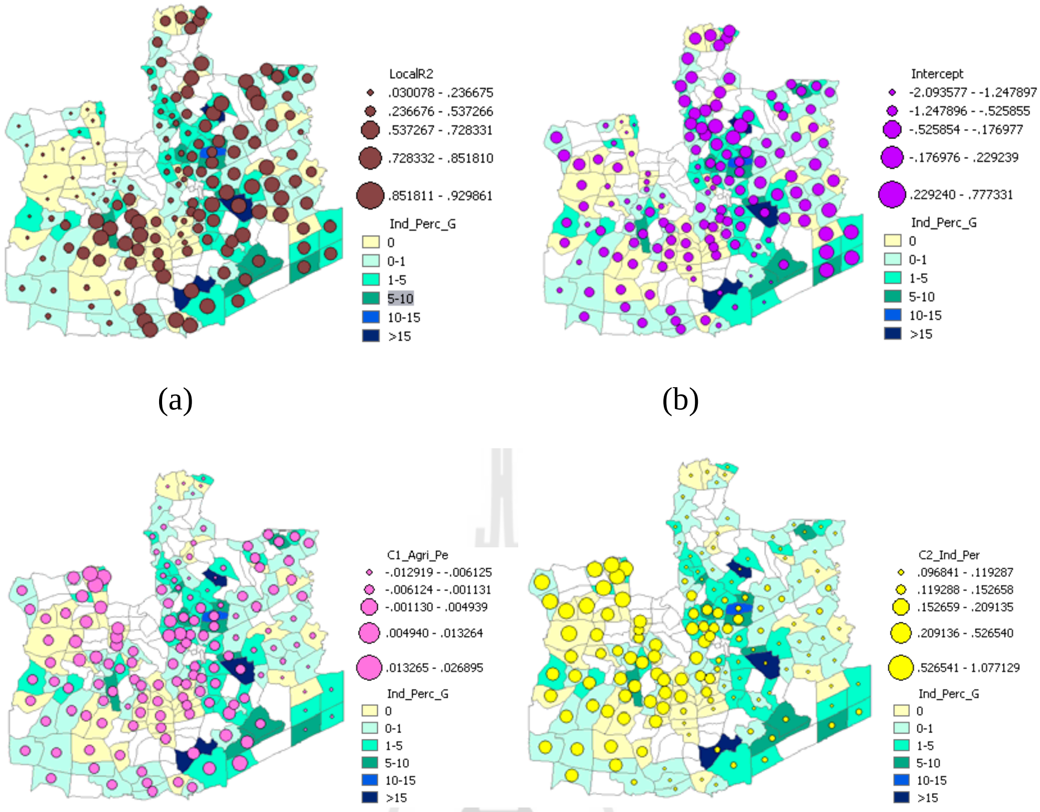
(c) (d)

Figure 6.10 Spatial variation of standardized residual CEnSI (a) EnOLSSM (b) EnGWRSM with bandwidth 35 (c) EnGWRSM with bandwidth 30 (d) EnGWRSM with bandwidth 25.

Table 6.10 illustrates the output of sub-districts using the most appropriate EnGWRSM (with bandwidth 30) through ArcGIS software, including fields of observed or the real CEnSI, estimated CEnSI values, condition number, local R^2, intercept or constant value, explanatory variable coefficients, residuals, standard residual and standard errors. The local R^2 value is 0.5355 (Table 6.9) and varies between 0.0301 up to 0.9299 (Table 6.10) while R^2 values of the global model is only 0.3571 (Table 6.9). The spatial distribution of the local R^2 value was shown in Figure 6.11(a). Most of high local R^2 sub-districts were found in central to the east of the province. The distribution of intercepts varies from -2.0936 to 0.7773 (Figure 6.11(b). Most of the high intercepts sub-districts were found in east of the province such as Bang Pahan, Phranakhon Si Ayutthaya, Nakhon Luang Uthai, and Wang Noi Districts. The coefficient of agricultural area in Figure 6.11(c) varies from -0.0129 to 0.0269 and most of the high coefficient sub-districts were found in the west of the province. The coefficient of industrial area presented in Figure 6.11(d) varies from 0.0968 to 1.0771 and most of the high coefficients sub-districts were found in the west of the province such as Bang Ban, Bang Si, Sena, Lat Bua Luang, Bang Sai, and Phak Hai Districts.

Table 6.10 Output SI, model coefficients, condition number, and residuals of sub-districts analyzed using the most appropriate EnGWRSM (bandwidth 30).

	Observe SI	**Condition No.**	**Local R2**	**Predict SI**	**Intercept**	**C1_Ag**	**C2_Ind**	**Residual**	**Std Error**	**Std. Residual**
Minimum	-0.5339	3.8551	0.0301	-0.6573	-2.0936	-0.0129	0.0968	-0.9299	0.1075	-1.7477
Maximum	3.9719	26.9250	0.9299	2.611	0.7773	0.0269	1.0771	3.7887	0.5701	6.8224
Mean	-0.0128	12.1150	0.6195	-0.0286	-0.3326	0.0010	0.2125	0.0159	0.5127	0.0234
Standard deviation	0.7621	5.1636	0.2694	0.5030	0.4239	0.0060	0.2145	0.5191	0.0829	0.9891

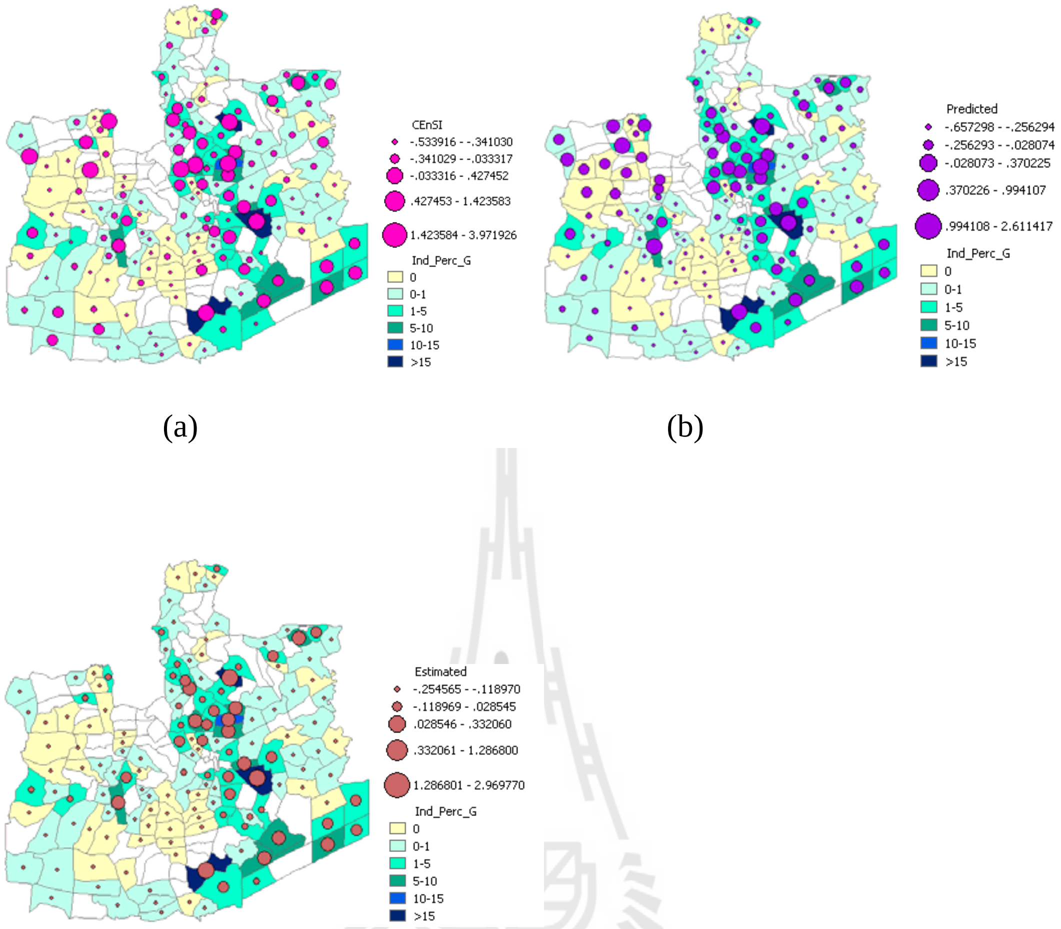


(a) (b)

(c) (d)

Figure 6.11 Spatial distribution of parameter from the best EnGWRSM with bandwidth 30 (a) local R^2 (b) intercept (c) coefficient of agricultural land use (d) coefficient of industrial land use.

Finally, the spatial distribution of CEnSIs from observed, estimated CEnSI using EnGWRSM with bandwidth 30, and estimated CEnSI from EnOLSSM were compared in Figure 6.12. The result indicates that the estimated CEnSI from EnGWRSM with bandwidth 30 (Figure 6.12(b)) is closer to the observed or existing CEnSI (Figure 6.12(a)) than that of the EnOLSSM (Figure 6.12(c)). Most of high observed CEnSI sub-districts were found in the east of the province (Figure 6.12(a)) and associated with the high predicted CEnSI from EnGWRSM with bandwidth 30 Figure 6.12(b).



(a) (b)

(c)

Figure 6.12 Comparison of CEnSI and parameters estimated (a) observed CEnSI (b) Predicted CEnSI of EnGWRSM with bandwidth 30 (c) estimated CEnSI of EnOLSSM.

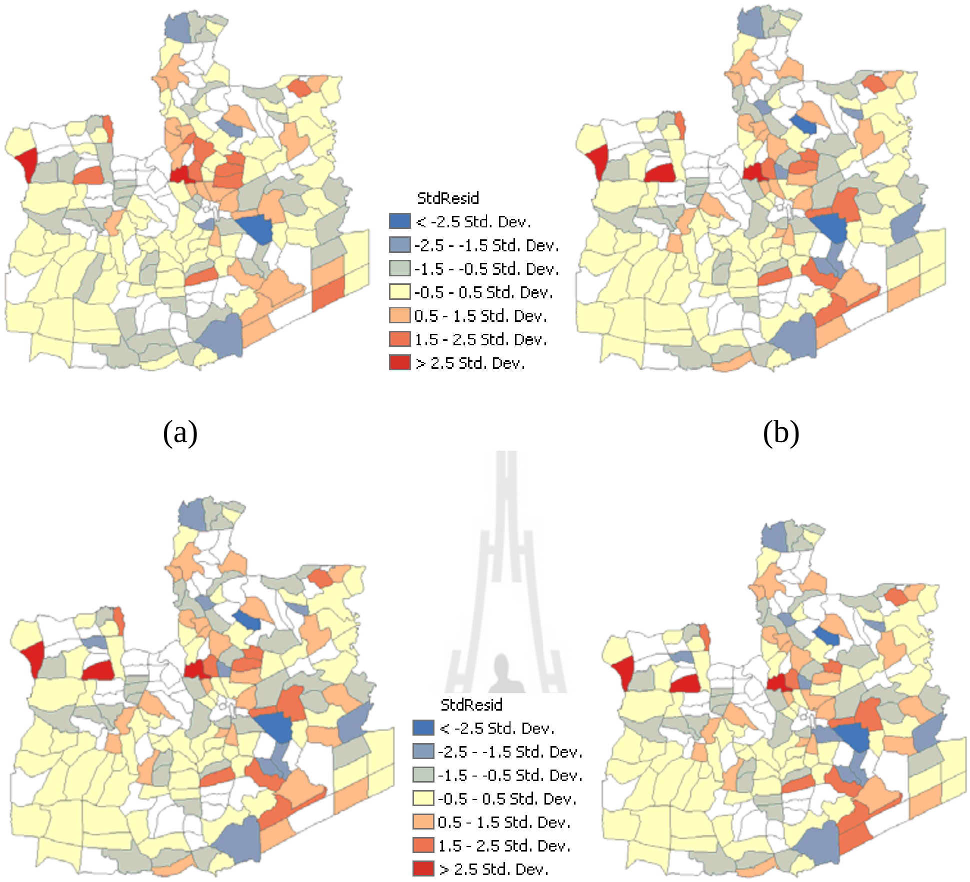
6.4.4.4 Total Geographically Weighted Regression Sustainability Model (TGWRSM)

The TGWRSM is developed to expose the relationships of the land use and overall aspects of the sustainability index mixed altogether in the total sustainability index (TSI) The Total Ordinary Least Square Sustainability Model (TOLSSM) and the a number of TGWRSMs were developed and compared to get the best model of Total Sustainability Model (TSM).

Table 6.11 indicates that the TGWRSM with bandwidth 30 has higher performance than TOLSSM. Its R^2 value is 0.7655 and higher than of TOLSSM (0.5905), and it has smaller square of residual. Furthermore, the Moran’s I value of its residual is -0.07 which indicates that the residual is somewhat dispersed. Then, the TGWRSM with bandwidth 30 is the most appropriate model. Figure 6.13 displays the spatial variation of standardized residual CTSI of four TSMs.

Table 6.11 Comparison of statistical parameter of the different TSM performances.

Method	**AICc**	**Residual Squares**	**R^2**	**R^2 adjusted**	**Cond. No. > 30**	**Moran’s I of residual**
TOLSSM	171.2880	26.4530	0.5905	0.5849	-	0.20 (clustered)
TGWRSM 35	161.1330	16.4072	0.7460	0.6741	0	-0.05 (randomly)
TGWRSM 30	160.6077	15.1450	0.7655	0.6863	0	-0.07 (somewhat dispersed)
TGWRSM 25	162.9679	13.4568	0.7914	0.7005	2 (34.2381)	-0.09 (dispersed)



(a) (b)

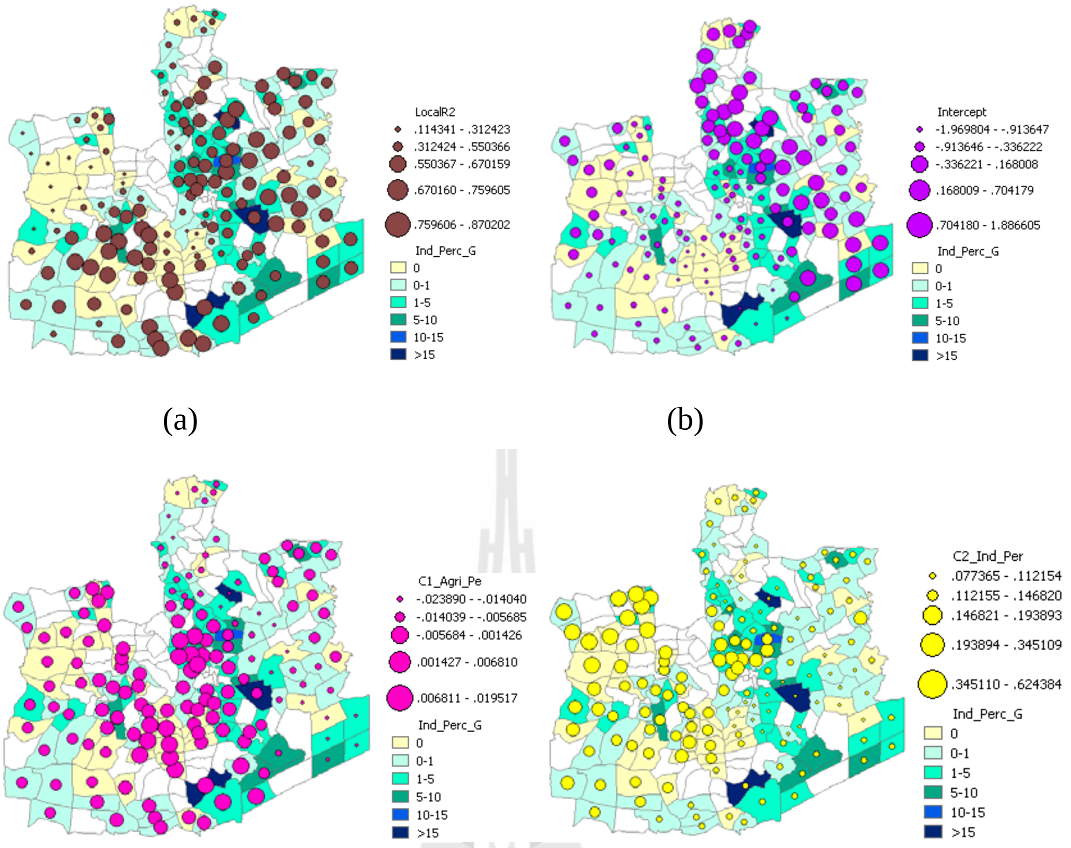
(c) (d)

Figure 6.13 Spatial variation of standardized residual CTSI (a) TOLSSM (b) TGWRSM with bandwidth 35 (c) TGWRSM with bandwidth 30 (d) TGWRSM with bandwidth 25.

Table 6.12 illustrates the output of sub-districts using the most appropriate TGWRSM (with bandwidth 30) through ArcGIS software, including fields of observed or the real CTSI, estimated CTSI values, condition number, local R^2, intercept or constant value, explanatory variable coefficients, residuals, standard residual and standard errors. The spatial distribution of the local R^2 value was shown in Figure 6.14. The local R^2 value is 0.7655 and varies between 0.1143 up to 0.8702 while R^2 values of the global model is only 0.5905 and most of the high local R^2 value were found in the east and the southwest of the province. The distribution of intercepts in Figure 6.14(b) varies from -1.9699 to 1.8866 and most of the high intercept were found in the east of the province such as Bang Pahan, Nakhon Luang, Ban Phreak, Maharat, Uthai, Wang Noi and Bang Pa-In Districts. The coefficient of agricultural area in Figure 6.14(c) varies from -0.0239 to 0.0195 and most of the high coefficient sub-districts were found in the central and the west of the province. The coefficient of industrial area presented in Figure 6.14(d) varies from 0.0774 to 0.6244 and most of the high coefficient sub-districts were found in the central and the west of the province such as Phak Hai, Bang Sai, Sena, Lat Bua Luang, Bang Ban, Bang Si, and Bang Pahan Districts.

Table 6.12 Output SI, model coefficients, condition number, and residuals of sub-districts analyzed using the most appropriate TGWRSM (bandwidth 30).

	Observed SI	**Con No**	**Local R2**	**Predict**	**intercept**	**C1_Ag**	**C2_Ind**	**Residual**	**Std Error**	**Std. Resid**
Minimum	-1.0966	3.8550	0.1143	-0.5956	-1.9699	-0.0239	0.0774	-0.7030	0.0660	-4.699
Maximum	2.3799	26.9250	0.8702	2.7262	1.8866	0.0195	0.6244	1.1821	0.3500	3.5775
Mean	-0.0032	12.1150	0.6156	-0.0061	-0.1240	-0.0011	0.1748	0.0028	0.3147	-0.0331
Standard deviation	0.6584	5.1636	0.1708	0.5286	0.6859	0.0083	0.1157	0.3188	0.0509	1.0902

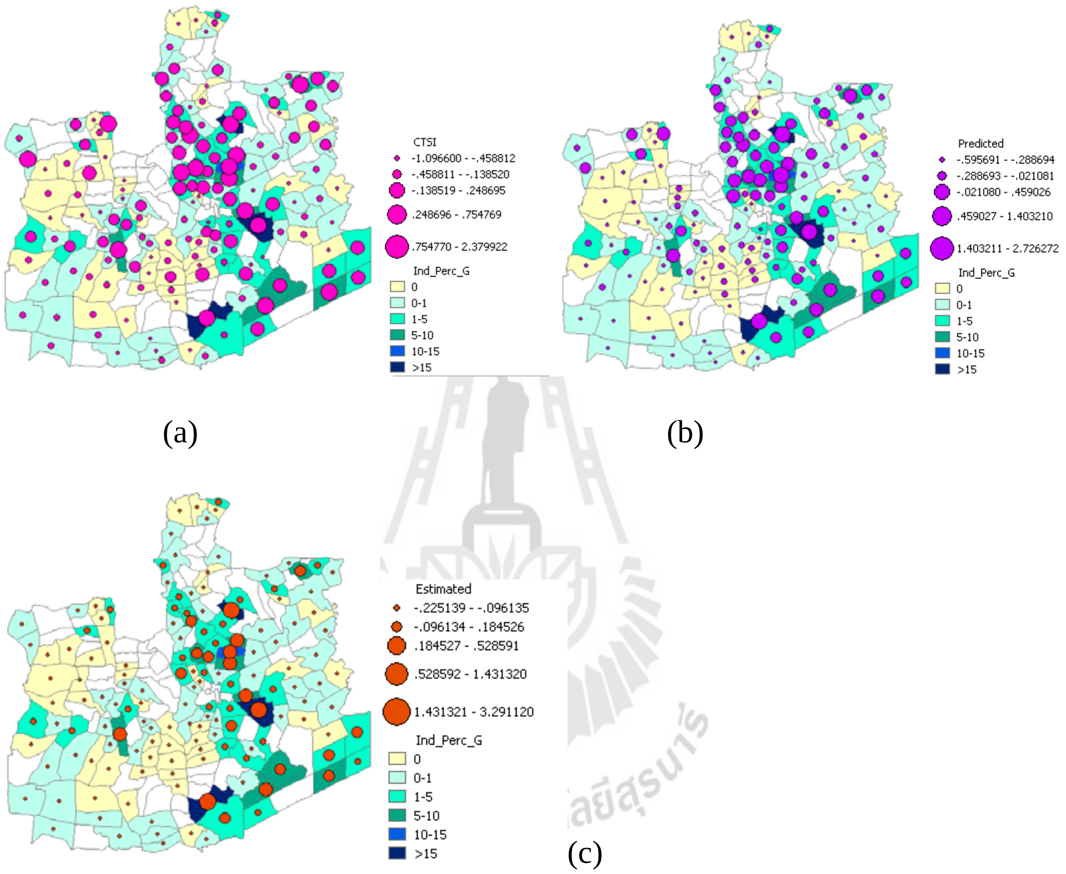


(a) (b)

(c) (d)

Figure 6.14 Spatial distribution of parameter from the best TGWRSM with bandwidth 30 (a) local R^2 (b) intercept (c) coefficient of agricultural land use (d) coefficient of industrial land use.

Finally, the spatial distribution of CTSIs from observed, estimated CTSI using TGWRSM with bandwidth 30, and estimated CTSI from TOLSSM were compared in Figure 6.15. The result indicates that the estimated CTSI from TGWRSM with bandwidth 30 is closer to the observed or existing CTSI than that of the TOLSSM. Most of high observed CTSI sub-districts were found in the east of the province (Figure 6.15(a)) and associated with the high predicted CTSI from TGWRSM with bandwidth 30 Figure 6.15(b).



(a) (b)

(c)

Figure 6.15 Comparison of CTSI and parameters estimated (a) observed CTSI (b) estimated CTSI of TGWRSM with bandwidth 30 (c) estimated CTSI of TOLSSM.

It is interesting to note that the high predicted CESI, CSSI, CEnSI, and CTSI were found in the sub-districts with high proportion of industrial area. This indicates that the proportion of industrial area affects SI of all aspects.

6.5 Sustainability Prediction

6.5.1 Sustainability prediction process

The objective of this part is to predict the sustainability indexes (SI) of different land use scenarios established by the allocation process in the fourth chapter. The process framework of SI prediction is illustrated in Figure 6.16. GWR analysis of ArcGIS version 9.3 was used as a tool. The input feature classes or prediction locations, where estimated values were computed, were sub-districts of scenario I, II, III (a), and III (b). The predicted SIs in all aspects of each sub-district corresponding to different scenarios were calculated using coefficients of EGWRSM, SGWRSM, EnGWRSM, and TGWRSM created in the modeling process.

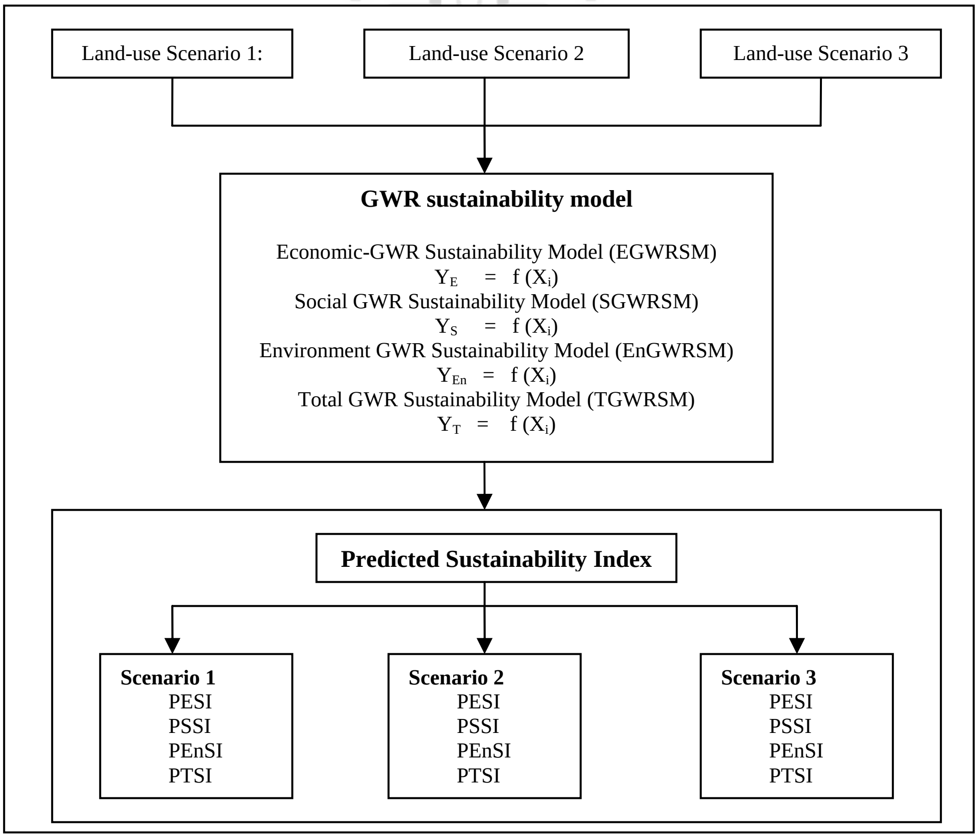


Figure 6.16 Framework of SI prediction process.

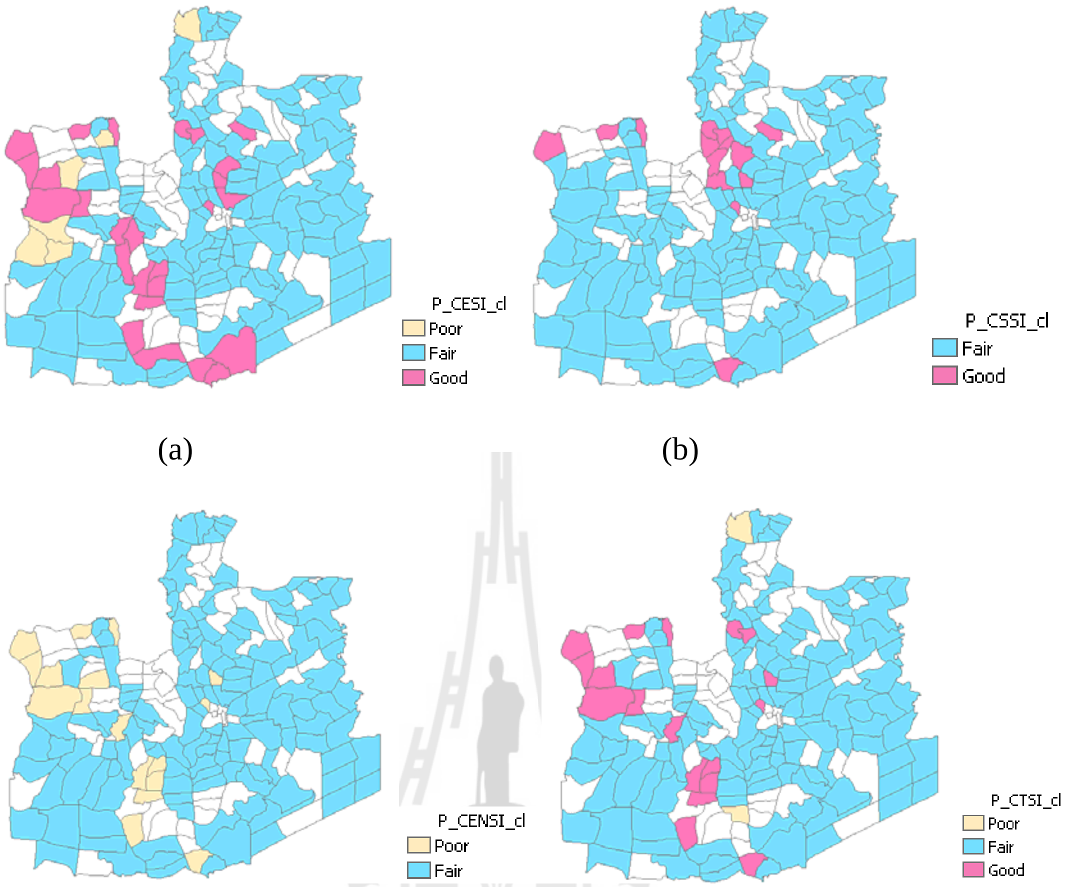
6.5.2 Predicted Sustainability Index of the scenario I

The SIs of each sub-district to be predicted include Predicted Economic Sustainability Index (PESI), Predicted Social Sustainability Index (PSSI), Predicted Environment Sustainability Index (PEnSI), and Predicted Total Sustainability Index (PTSI). In the scenario I, the assumption is maximizing agricultural area. Those 4 predicted SIs of any given sub-district were generated using input as percentage of industrial and agricultural areas in the sub-district and coefficients of EGWRSM, SGWRSM, EnGWRSM, and TGWRSM created in the GWR modeling process.

The statistics values of PESI, PSSI, PEnSI, and PTSI of scenario I were shown in Table 6.13. Figure 6.17 illustrates their spatial distributions. In order to compare with CSI, all PSIs were classified into 3 categories as poor, fair and good based on the classification ranges of CSI.

Table 6.13 Statistical values of PESI, PSSI, PEnSI, and PTSI of scenario I.

	PESI	**PSSI**	**PEnSI**	**PTSI**
Minimum	-0.7617	-0.5458	-0.4480	-0.5999
Maximum	13.9984	3.4740	30.4576	17.3967
Mean	0.1351	0.0074	0.3102	0.1600
Standard deviation	1.4280	0.3654	2.6903	1.5756



(a) (b)

(c) (d)

Figure 6.17 Spatial distributions of the classified PSIs of scenario I (a) PESI (b) PSSI (c) PEnSI (d) PTSI.

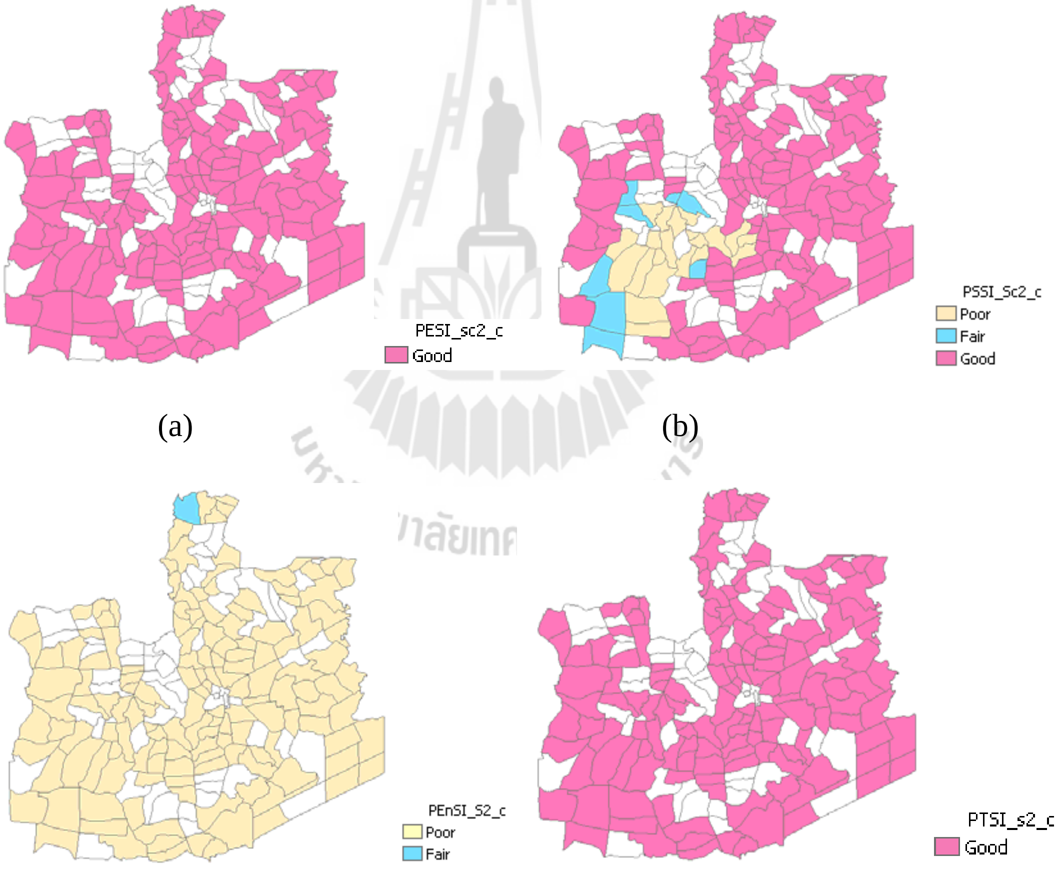
6.5.3 Predicted Sustainability Index of the scenario II

In the scenario II, the assumption is maximizing industrial area. The process to estimate all PSIs is the same as discussed in the scenario I.

The statistical values of PESI, PSSI, PEnSI, and PTSI of scenario II were shown in Table 6.14. Figure 6.18 illustrates their spatial distributions. In order to compare with CSI, all PSIs were classified into 3 categories as poor, fair and good based on the classification ranges of CSI.

Table 6.14 Statistical values of PESI, PSSI, PEnSI, and PTSI of the scenario II.

	PESI	PSSI	PEnSI	PTSI
Minimum	0.9912	-5.6508	0.7847	0.8654
Maximum	43.4582	17.4699	91.2745	54.5673
Mean	14.0381	3.0317	14.2343	11.9030
Standard deviation	7.1304	3.5231	15.1790	8.4950



(a) (b)

(c) (d)

Figure 6.18 Spatial distributions of the classified PSIs of scenario II (a) PESI (b) PSSI (c) PEnSI (d) PTSI.

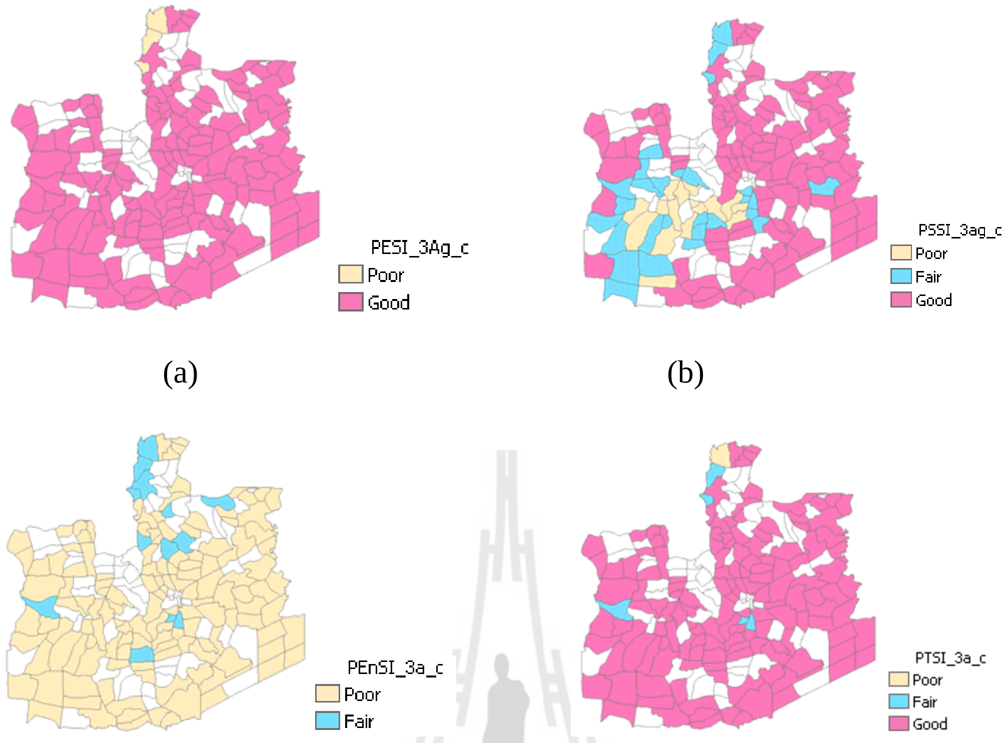
6.5.4 Predicted Sustainability Index of the scenario III

The scenario III was divided into two sub-scenarios according to land allocation in chapter four: IIIa - optimization of agricultural-industrial area oriented in agriculture and IIIb - optimization of agricultural-industrial area oriented in industry.

The statistical values of PESI, PSSI, PEnSI, and PTSI of the scenario IIIa were shown in Table 6.15 and their spatial distributions were illustrated in Figure 6.19.

Table 6.15 Statistical values of PESI, PSSI, PEnSI, and PTSI of the scenario IIIa.

	PESI	PSSI	PEnSI	PTSI
Minimum	-0.7617	-2.8059	-0.4480	-0.5998
Maximum	32.1444	10.9964	67.9186	39.3073
Mean	6.6919	1.5103	6.8032	5.6648
Standard deviation	4.6949	2.1127	8.5998	5.0454



(a) (b)

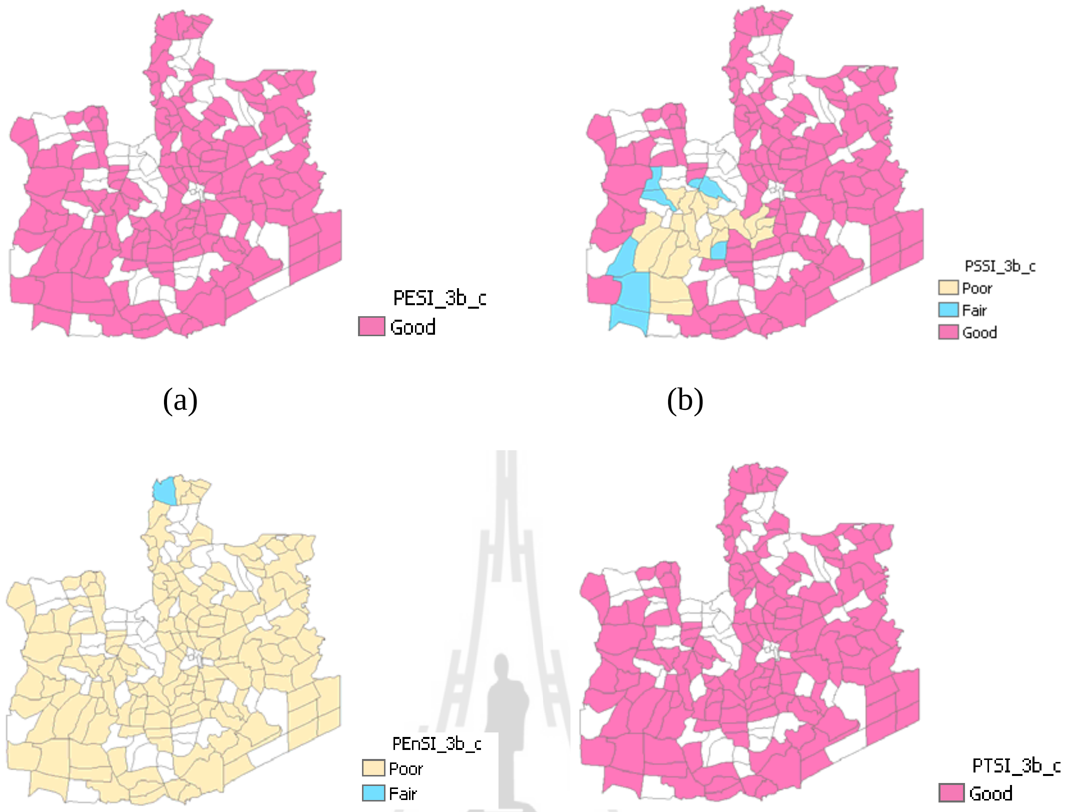
(c) (d)

Figure 6.19 Spatial distributions of the classified PSI of the scenario IIIa: (a) PESI (b) PSSI (c) PEnSI (d) PTSI.

The statistical values of PESI, PSSI, PEnSI, and PTSI of the scenario IIIb were shown in Table 6.16 and their spatial distributions were illustrated in Figure 6.20.

Table 6.16 Statistical values of PESI, PSSI, PEnSI, and PTSI of the scenario IIIb.

	PESI	**PSSI**	**PEnSI**	**PTSI**
Minimum	0.9912	-5.6508	0.7848	0.8994
Maximum	43.4582	17.4699	91.2745	52.9682
Mean	13.8130	2.9189	14.0236	11.5856
Standard deviation	7.3201	3.4770	15.2728	8.2454



(a) (b)

(c) (d)

Figure 6.20 Spatial distributions of the classified PSIs of the scenario IIIb: (a) PESI (b) PSSI (c) PEnSI (d) PTSI.

6.6 Comparisons of SIs

The purpose of PSIs comparison is to determine which scenario should be appropriate to the different development policies. Therefore, each PSI was compared separately, for example, the PESIs of all scenarios were compared in order to make the decision which scenario is the best for the economic policy. The comparison of PSSIs will provide the information that the social development can be best achieved from which scenario. The comparison of PEnSIs will notify which scenario can meet the objective of the environment policy. Finally, the comparison PTSIs will tell which scenario is suitable to improve the overall sustainability on the whole. The result of comparisons will help the decision makers in land-use planning in term of selection the suitable scenario that fits their policy.

Although the CSI and PSI can illustrate the SI of each sub-district individually, it cannot clarify the SI of province as a whole. Therefore, the sum of SI of every sub-district or the Accumulated Sustainability Index (ASI) is used to measure SI of the province as the whole. ASI includes Accumulated Economic Sustainability Indexes (AESI), Accumulated Social Sustainability Indexes (ASSI), Accumulated Environment Sustainability Indexes (AEnSI), and Accumulated Total Sustainability Indexes (ATSI) (Figure 6.21).

AESI represents the economic sustainability status of Phra Nakhon Si Ayutthaya in a given scenario of land use while ASSI, AEnSI and ATSI can tell the social, environment and total sustainability situation of the province, respectively. In order to investigate the sustainability improvement when each scenario of land use is applied, ASI of each scenario was compared to the one of current land use.

The AESI, ASSI, AEnSI and ATSI of current land use and different land-use scenarios were calculated and compared in Table 6.17.

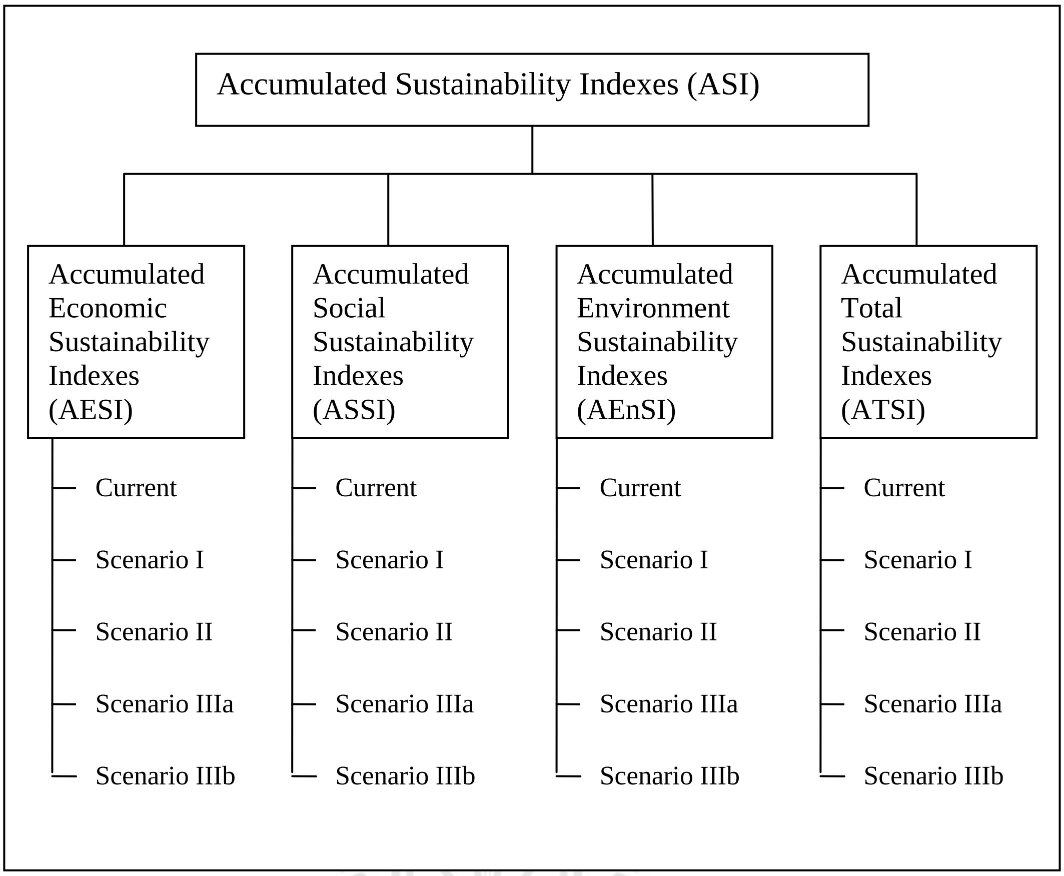


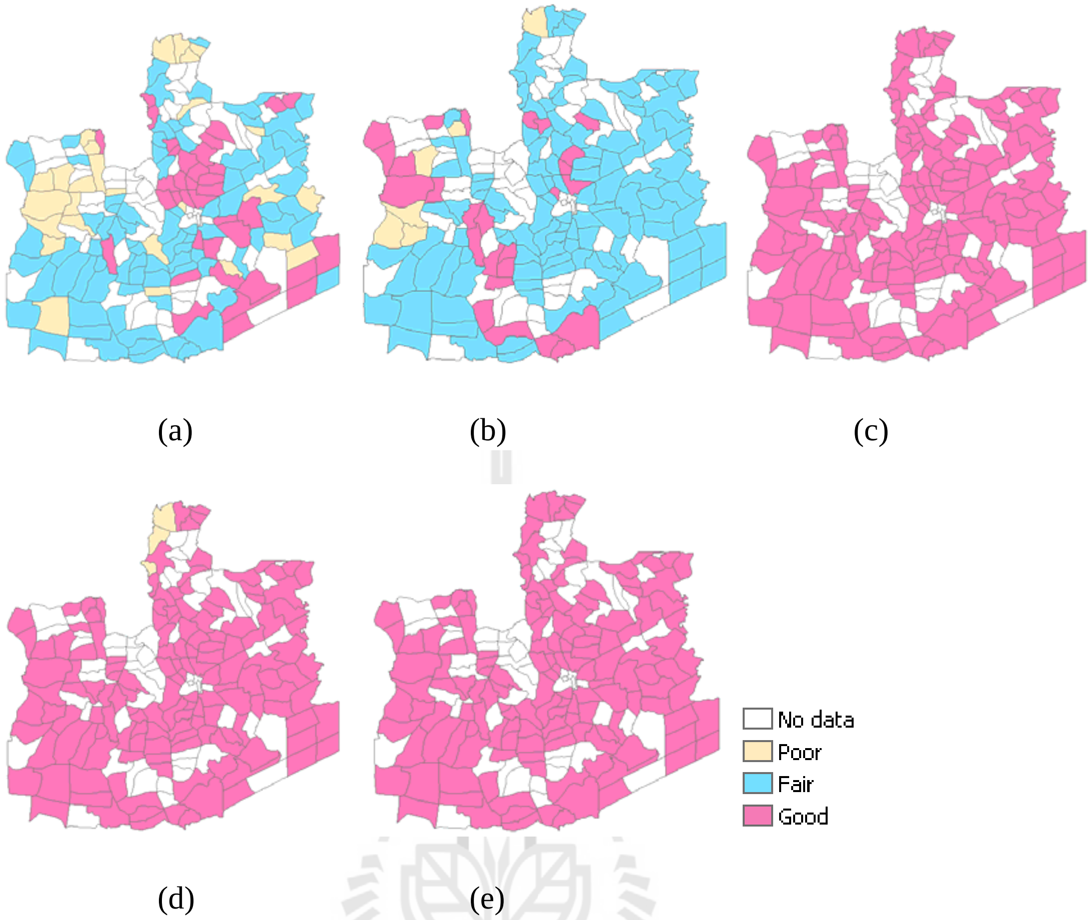
Figure 6.21 Accumulated Sustainability Indexes of different land-use scenarios.

Table 6.17 Comparison of AESI, ASSI, AEnSI and ATSI in different land-use scenarios.

	AESI	ASSI	AEnSI	ATSI
Current	0.7185	-0.2564	-1.9024	-0.4783
Scenario I	20.1338	1.10288	46.2236	23..8476
Scenario II	2091.6752	451.7296	2120.9163	1773.5457
Scenario III (a)	997.0987	225.0306	1013.6792	844.0480
Scenario III (b)	2058.1315	434.9126	2089.5132	1726.2613

6.6.1 Comparison of AESI

According to the results of sustainability assessment and prediction, the spatial distribution of CESI and PESI were compared in Figure 6.22. The Accumulated Current Economic Sustainability Indexes of current land use (ACESI) and Accumulated Predicted Economic Sustainability Indexes (APESI) of 4 scenarios were calculated and compared (Table 6.17). The comparison indicates that the scenario II has the highest AESI and the scenario I has the lowest. It also indicates that all scenarios have the great improvement of AESI compared to the current land use. Therefore, the scenario II is the highest performance scenario for economic development.



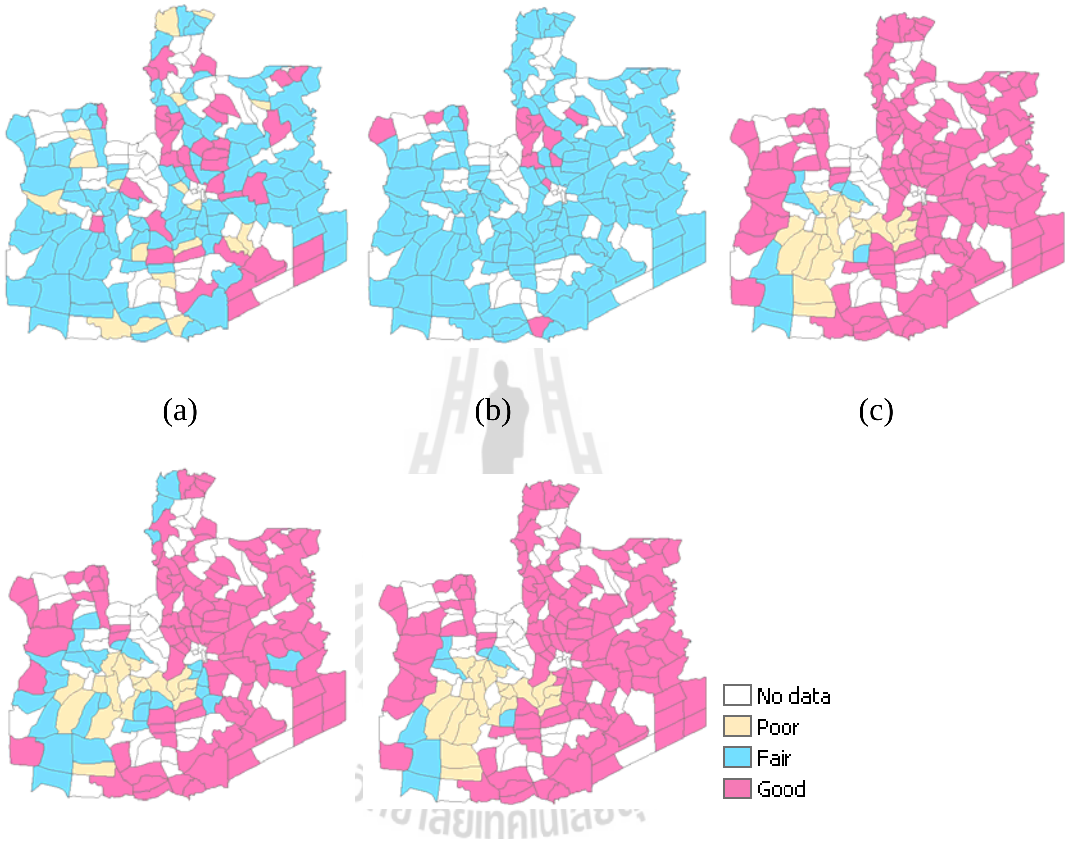
(a) (b) (c)

(d) (e)

Figure 6.22 Comparison of ESIs (a) current (b) scenario I (c) scenario II (d) scenario IIIa (e) scenario IIIb.

6.6.2 Comparison of ASSI

According to the results of sustainability assessment and prediction, the spatial distribution of CSSI and PSSI were compared in Figure 6.23. The Accumulated Current Social Sustainability Indexes of current land use (ACSSI) and Accumulated Predicted Social Sustainability Indexes (APSSI) of 4 scenarios were calculated and compared (Table 6.17). The comparison indicates Scenario II has the highest ASSI and Scenario I has the lowest ASSI. It also indicates all scenarios have the great improvement of APSSI compared to the ACSSI of current land use. Therefore, scenario II is the highest performance scenario for social development.



(a) (b) (c)

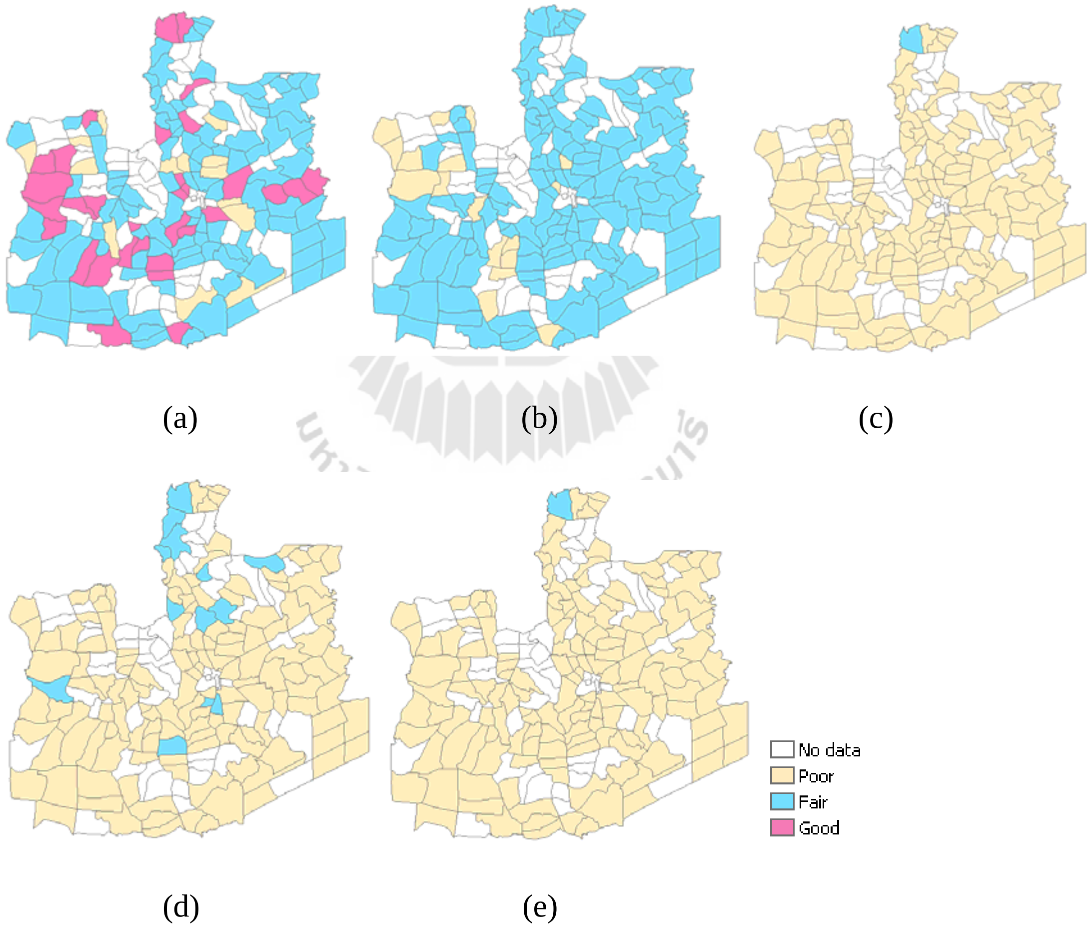
(d) (e)

Figure 6.23 Comparison of SSIs (a) current (b) scenario I (c) scenario II (d) scenario III a (e) scenario III b.

6.6.3 Comparison of PEnSI

According to the results of sustainability assessment and prediction, the spatial distribution of CEnSI and PEnSI were compared in Figure 6.24. The Accumulated Current Environment Sustainability Indexes of current land use

(ACEnSI) and Accumulated Predicted Environment Sustainability Indexes (APEnSI) of 4 scenarios were calculated and compared (Table 6.17). The comparison indicates Scenario I has the lowest AEnSI and Scenario II has the highest AEnSI. This indicates that scenario II has the greatest environment impacts. It also indicates all scenarios make the great pollution compared to the current land use. Therefore, scenario I is the best suitable scenario for environment conservation policy.



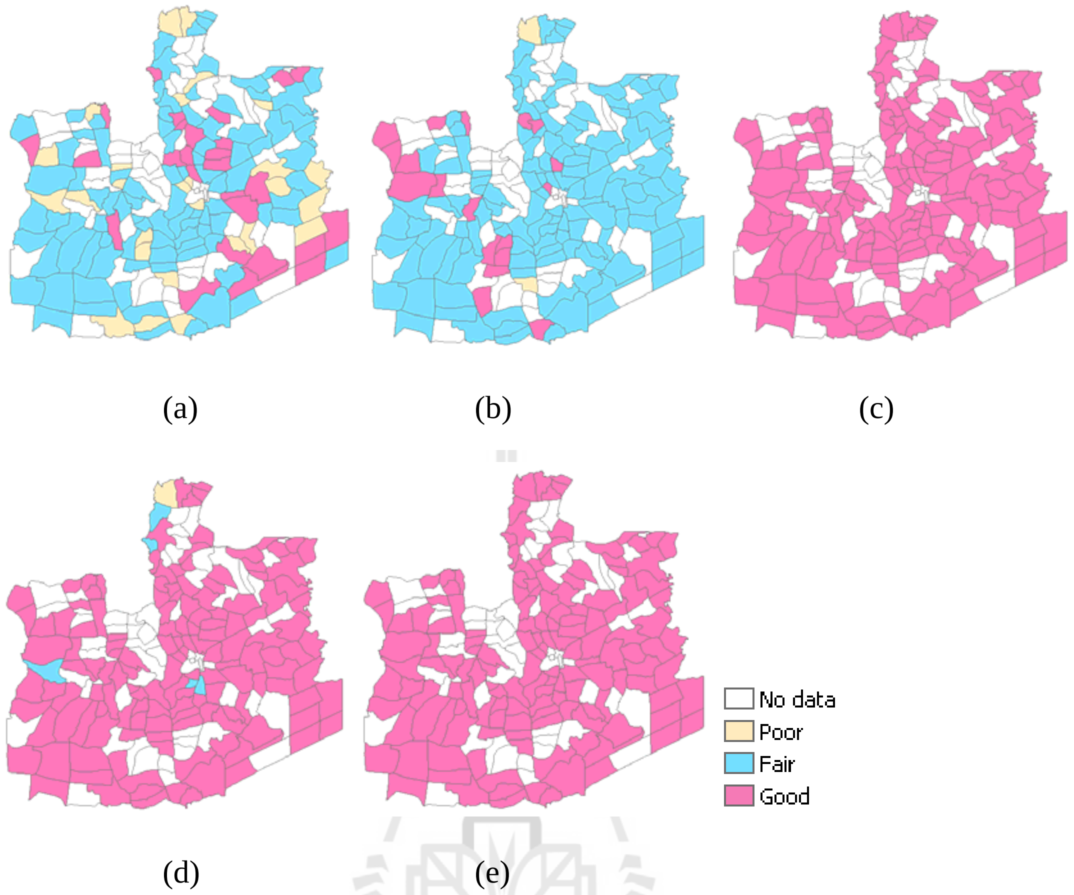
(a) (b) (c)

(d) (e)

Figure 6.24 Comparison of EnSIs (a) current (b) scenario I (c) scenario II (d) scenario III a (e) scenario III b.

6.6.4 Comparison of PTSI

According to the results of sustainability assessment and prediction, the spatial distribution of CTSI and PTSI were compared in Figure 6.25. The Accumulated Current Total Sustainability Indexes of current land use (ACTSI) and Accumulated Predicted Total Sustainability Indexes (APTSI) of 4 scenarios were calculated and compared (Table 6.17). The comparison indicates that Scenario I has the lowest ATSI and Scenario II has the highest ATSI. This indicates that scenario II has the greatest total sustainability value. It also indicates all scenarios make the great improvement total sustainability in comparing with the current land use. Therefore, scenario II is the best performance suitable scenario for total development policy.



(a) (b) (c)

(d) (e)

Figure 6.25 Comparison of TSIs (a) current (b) scenario I (c) scenario II (d) scenario III a (e) scenario III b.

6.7 Results and discussion

The spatial distributions of ESI, SSI, EnSI and TSI of all scenarios were compared in Figures 6.22, 6.23, 6.24, 6.25, respectively. AESI, ASSI, AEnSI, and ATSI were summarized in Tables 6.18, 6.19, 6.20, and 6.21, respectively.

Table 6.18 illustrates that scenario II have highest AESI value compared with the other scenarios. We can conclude that scenario II is the best performance land-use pattern for stimulating economic sustainability index. In scenario II, all sub-districts are classified as good in sustainability index.

Table 6.19 illustrates that scenario II have highest ASSI value compared with the other scenarios. We can conclude that scenario II is the best performance land-use pattern for stimulating social sustainability index. In scenario II, 122 sub-districts are classified as good in sustainability index classifications, only 6 and 21 sub-districts are classified as fair and poor, respectively.

Table 6.20 illustrates that scenario I have the best AEnSI value compared with the other scenarios. We can conclude that scenario I is the best performance land-use pattern for stimulating environment sustainability index. In scenario I, 132 sub-districts are classified as fair in sustainability index classifications, only 17 sub-districts are classified as poor.

Table 6.21 illustrates that scenario II have the best ATSI value compared with the other scenarios. We can conclude that scenario I is the best performance land-use pattern for stimulating total sustainability index. In scenario II, all sub-districts are classified as good in sustainability index classifications.

Table 6.18 Comparison of classified AESI of all scenarios of land use.

	AESI	**Number of sub-districts**			
		Good	**Fair**	**Poor**	**Total**
Current	0.7185	27	85	37	149
Scenario I	20.1338	26	117	6	149
Scenario II	2091.6752	149	0	0	149
Scenario IIIa	997.0987	146	0	3	149
Scenario IIIb	2058.1315	149	0	0	149

Table 6.19 Comparison of classified ASSI of all scenarios of land use.

	ASSI	Number of sub-districts			
		Good	Fair	Poor	Total
Current	-0.25640	36	95	18	149
Scenario I	1.10288	14	135	0	149
Scenario II	451.7296	122	6	21	149
Scenario IIIa	225.0306	105	28	16	149
Scenario IIIb	434.9126	120	8	21	149

Table 6.20 Comparison of classified AEnSI of all scenarios of land use.

	AEnSI	Number of sub-districts			
		Good	Fair	Poor	Total
Current	-1.9024	32	103	14	149
Scenario I	46.2236	0	132	17	149
Scenario II	2120.9163	2	35	112	149
Scenario IIIa	1013.6792	0	13	136	149
Scenario IIIb	2089.5132	0	1	148	149

Table 6.21 Comparison of classified ATSI of all scenarios of land use.

	ATSI	Number of sub-districts			
		Good	Fair	Poor	Total
Current	-0.4783	27	95	27	149
Scenario I	23..8476	18	129	2	149
Scenario II	1773.5457	149	0	0	149
Scenario IIIa	844.0480	143	5	1	149
Scenario IIIb	1726.2613	149	0	0	149

When consider the results as a whole, the results indicates that scenario II which maximize the industrial area was the best performance scenario and suitable for economic, social and total sustainability improvement in development policy. Scenario

II may be considered as economic, social and total motivated land-use plan and scenario I may consider as environmental conservation land-use plan.

6.8 Conclusion

This chapter attempts to develop the sustainability models applying Geographically Weighted Regression (GWR). These sustainability models were introduced as the new integrated models which can be used to predict and compare the SIs of all aspects in the different scenarios in the local level.

This chapter divided into three parts, first of all, the sustainability model is developed, secondly, the predictions of SI were calculated and finally the comparisons of SI were investigated. In sustainability modeling, GWR analysis as the local regression model was applied to analyze spatial variations of non-stationarity in the study area. Non stationarity of the relationship between sustainability index and the proportion of land-use types is examined via GWR technique. GWR models explained considerably more variance in the relationship, in comparison with corresponding OLS models, as evidenced by the decrease in AIC values and increase in the R^2 and R^2 adjusted. Moran's I indicates that spatial autocorrelation of residuals was significantly reduced in GWR for all models. The results of the sustainability modeling were used as the tools in the prediction of sustainability index of various scenarios of land use. The results of sustainability prediction were compared to investigate which land-use scenario should be suitable for specific development policies. The results indicates that scenario II which maximize the industrial area was the best performance scenario and suitable for economic, social and total sustainability improvement in development policy. However, scenario I should be applied when the environment are concerned.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

There were four main parts in this study including (1) land suitability assessments (2) land allocations for the different scenarios (3) sustainability index assessments (4) sustainability modeling and predictions. Their results were concluded and recommendations for land-use planning and further research were also carried out in the followings.

7.1 Conclusions

7.1.1 Land suitability assessment

Following the objective 1, land suitability assessments for agriculture and industry were conducted. The factors and criteria including their scores used for land suitability assessment of agriculture were adopted from FAO guideline and the LDD expert opinions while ones for the industry were obtained from previous studies, entrepreneurs, and expert opinions. The rank reciprocal method was applied for weighting criteria in agricultural land suitability assessment while the pairwise comparison was for the industrial. The SAW was used to generate both land suitability maps which were classified into highly suitable, moderately suitable, marginally suitable, and not suitable. These maps were further used for the land allocation process. The results of the assessments can be concluded as follows.

1) For agriculture, 4.21 and 75.27 percent of the total area were respectively classified as highly and moderately suitable. Only few percent of total area was classified as marginally and not suitable for rice cultivation. Most suitable areas (S1) for crops were located in the upper central and the northeast of the province due to high quality of soil and marginal flood hazard. Small areas in the northwest were classified as not suitable (N). The marginally suitable areas (S3) were located in the western part due to the presence of flood hazard and the long distance from water bodies.

2) For industry, 35.59 and 33.14 percent of the total area were respectively classified as highly and moderately suitable. Only few percent of the total area was classified as marginally and not suitable. Most suitable area was more likely to locate nearby the main road because of the influence of accessibility and the proximity of electric line. Obviously, not suitable and marginally suitable areas were located in the west and the north of the area due to the influence of flood hazard and agglomeration factors. Other marginally suitable areas appeared in the southeast of the area due to poor agglomeration and electricity factors.

7.1.2 Land allocation for the different scenarios

Land allocation for the different scenarios was the second objective of the study. Four possible land-use scenarios or policies were proposed, which were the promotion of agriculture, industry, and their combination with orientation of either one. The combining operations of different types of land suitability were performed using results of those land suitability assessments. This resulted in four Land Suitability Combination Matrixes (LSCM) developed to be the rules for allocating.

Using the cell-based local operation through the matrixes, the results were concluded as follows:

In the scenario I, 80.88 % of the study area was suitable for agriculture. Only 1.56% should be allocated to be the industrial land. In the scenario II, 69.53% of the area was allocated to be suitable for industry and only 12.90% should be for agriculture. In the scenario IIIa, almost half of the land (47.61%) was allocated for agriculture and 34.81% go for industry. In the scenario IIIb, the land was allocated to be suitable for industry more than agriculture. 68.31% of the study area was allocated to be industry and only 14.12% was for agriculture.

7.1.3 Sustainability assessment

Following the objective 3, sustainability assessment was conducted. This part aims at evaluating the sustainability indexes in four aspects. The sustainability indexes including CESI, CSSI, CEnSI, and CTSI were introduced in this part. For assessments of all indexes, factor analysis was used to examine the relationships of all indicators or variables and reduced a large number of variables into one or few key factors.

In CESI and CEnSI assessments, 12 and 5 variables were respectively selected and grouped into one key factor each. In CSSI assessment, 11 variables were reduced into three key factors including education and social status, insecurity status, and knowledge accessibility. In CTSI assessment, all of CSIs variables (CESI, CSSI and CEnSI) were concluded and grouped into one key factor.

The CESIs, CSSIs, CEnSIs, and CTSIs were classified as good, fair, and poor. Their spatial distributions were concluded with some explanations as follows:

(1) For CESIs, most areas with good CESIs appeared in 37 sub-districts which were concentrated in the central part and scattered to the southeast of the province. The fair ones appeared in 85 sub-districts which were dispersed in all parts of the study area. The poor ones covering 27 sub-districts concentrated in the northwest were rice paddy or agricultural areas and always flooded during the rainy season. There were four industrial estates located in the central and east of the study area due to the availability of transport networks connectable to the Eastern Seaboard. Furthermore, most of the manufactures located in the industrial estates were large companies with high rate of employment. The presence of manufactures and labors were intensive driving forces of the urban expansion and the economic growth.

(2) For CSSIs, most areas with good CSSIs appeared in 36 sub-districts which were concentrated in the central part and scattered in the southeast and the northeast of the province due to the influences of education, social status and knowledge accessibility factors which are the positive effects of the urban and industrial expansion. The fair ones appeared in 95 sub-districts which were found in all parts of the study area. The poor ones covering 18 sub-districts are most scattered in the periphery of the province due to the influences of insecurity factors which are the negative effects of the urban and industrial expansion.

(3) For CEnSIs, most areas with good CEnSIs appeared in 32 sub-districts which were concentrated in the northwest and scattered to southwest and the central of province. The fair ones appeared in 103 sub-districts which were found in all parts of the study area. The poor ones covering 14 sub-districts were scattered in the central and the south of the province.

(4) For CTSIs, most areas with good CTSIs appeared in 27 sub-districts which were concentrated in the north central and the southeast of province. The fair CTSIs covering 95 sub-districts were dispersed in all parts of the province. The poor CTSIs covering 27 sub-districts scattered in the periphery of the province were probably influenced by the poor CESIs, CSSIs and CEnSIs.

7.1.4 Sustainability modeling and prediction

7.1.4.1 Sustainability modeling

The objective of this part is to develop the sustainability models using Geographically Weighted Regression (GWR) to analyze the spatial relationships between land use and sustainability index. This results are the answers of the forth the fifth and the sixth objectives of the study.

In this study, the GWRSMs including EGWRSMs, SGWRSMs, EnGWRSMs, and TGWRSMs were introduced. From these GWRSMs, the relationships between land use and CESIs, CSSIs, CEnSIs, and CTSIs were illustrated. In order to find the best GWRSM, the bandwidth of neighbors was varied. The best performance GWRSM is selected by comparing the statistical value generated from ArcGIS version 9.3 such as AICc, condition number, R^2, R^2 adjusted, residual squares, Moran's I of residual. Each GWRSM were compared to EOLSM to demonstrate the improvement of the GWRSM performance. As a result, the EGWRSMs, SGWRSMs, EnGWRSMs, and the TGWRSMs with bandwidth 30 were selected. The results were concluded as follows:

(1) All GWRSMs have higher performance than the EOLSMs by comparing the significant statistical value such as the AICc, condition number, R^2, R^2 adjusted, residual squares, Moran's I of residual.

(2) Local R2 value of the most appropriate EGWRSM, SGWRSM, ENGWRSM, and TGWRSM are 0.8363, 0.5117, 0.5355, and 0.7655 respectively. All of these R2 were higher than the ones of OLSSMs.

(3) It is found that most of high R2 values of EGWRSM, SGWRSM, ENGWRSM, and TGWRSM were in the eastern of the study area or in the high proportion of industrial area.

7.1.4.2 Sustainability Prediction

The objective of this part is to predict the sustainability indexes of different land-use scenarios established by the allocation process. All GWRSMs were used as the models to predict SI of each scenario. In this part, inputs feature classes or prediction locations were scenario I, scenario II, scenario IIIa and scenario IIIb. The predicted sustainability indexes (PSIs) of each land-use scenario including PESIs, PSSIs, PEnSIs and PTSIs were calculated through GWRSMs. Then, each PSI was compared separately to other scenarios. The comparison of PSSIs will provide the information about which scenario can achieve the social development. The result of comparisons will help the decision makers in land-use planning to select the scenario of land use which suitable for their policies. The results were concluded that scenario II is the best performance scenario in economic, social, environment and total aspects while scenario I is the best performance scenario in environment aspect.

7.2 Recommendations

The recommendations were conducted according to the objectives in particular part of the analysis and concentrated for the land-use planners and further study as follows:

7.2.1 Recommendations for land-use planner

1) The land-use planner should adjust the proportion of land use and determine the land-use zoning by considering the primeval fundamental characteristics of land and the strategic plans of the province as well. Phra Nakhon Si Ayutthaya is known as food larder or the land of rice for long time and has been recognized as the ancient historical land. The Phra Nakhon Si Ayutthaya Historical Park has been a UNESCO World Heritage Site since December 1991. The primitive agricultural area which highly suitable for rice cultivation and the areas near the Historical Park should be seriously declared as the protected zones. The expansion of industries should be restricted in these areas. Bang Pahan and Nakhon Luang districts which are highly suitable for rice cultivation should be reserved, as well as Lad Bua Luang, Wang Noi, Bang Sai, Phra Nakhon Si Ayutthaya, Sena, Bang Pa-in, Bang Ban and Uthai districts which have been declared to be the agricultural land reform since 2001.

2) The sustainability indexes estimated by sustainability models in this study can be applied to other areas. They should be used as the benchmark of quality of life for all sub-districts in Thailand. However, these sustainability indexes should be arranged to the village level in the future if the village boundary map is available.

3) In the sustainability modeling and prediction, among these four scenarios, the scenario I is the most similar to the existing land use due to the

proportion area of agriculture and industry. For the land-use planner, the scenario II, the industrial maximizing, is the best performance scenario and suitable for economic, social and total sustainability improvement and motivation in development policy. However, the scenario I should be applied when the environment is concerned.

4) This study will be constructive as a guideline for national land-use planning, particularly zoning for agriculture and industry in the conflict areas.

7.2.2 Recommendations for further researches

1) In the land suitability assessment for agriculture, factors and criteria can be different for areas with different characteristics. In this study, flood hazard was important factor to be considered because of its impacts to the study area, but it can be omitted if it was not harm and affect the study area.

2) In the industrial land suitability assessment, factors and criteria used in this study were obtained from the view point of the experts and entrepreneur because the specific objective in this part was concentrated on administrative industrial location. In fact, for further research, particularly the one which is concentrated on only industrial aspect, the various opinions from other parties such as stake holders, economist, scientists, ecologist or conservationist should be involved to cover all dimensions of the industrial location assessment.

3) The scenarios of land allocation were concentrated on the agriculture and industry due to their conflicts in this study area. Therefore, other proposes of land allocation can be performed differently depending on the characteristics of conflicts in the areas studied.

4) In the sustainability assessment, the results of some sub-districts were missing due to the limitation of data availability from BMN and NRD data. In

the near future all data should be resurveyed for further study. More indicators other than existing ones in BMN and NRD data such as air pollution should also be considered to involve in the sustainability assessment.

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APPENDICES

APPENDIX A

QUESTIONNAIRE

แบบสอบถามผู้เชี่ยวชาญและผู้ประกอบการอุตสาหกรรม
การวิเคราะห์ศักยภาพของพื้นที่อุตสาหกรรม

1. กรุณาเรียงลำดับ ปัจจัยที่สำคัญในการเลือกที่ตั้งโรงงานอุตสาหกรรมจากสำคัญมากไปหาน้อย

ปัจจัย	ลำดับความสำคัญ	น้ำหนักคะแนน (ทุกข้อรวมกันน้ำหนัก 100 คะแนน)
ความสะดวกในการเข้าถึง		
สาธารณูปโภค		
ราคาที่ดิน		
แหล่งแรงงาน		
สิ่งอำนวยความสะดวก		
การรวมกลุ่มอุตสาหกรรม		
สภาพภูมิประเทศ		

2. การเปรียบเทียบปัจจัยของตารางกับปัจจัยด้านขวาของตารางทีละคู่ ว่าปัจจัยใดมีความสำคัญกว่ากันระดับใด

ในการเปรียบเทียบระหว่างปัจจัยต่างๆมีระดับการวัดความสำคัญกว่ากันอยู่ 9 ระดับ คือ

ระดับ	1	2	3	4	5	6	7	8	9
ความหมาย	สำคัญเท่ากัน	อยู่ระหว่างเท่ากันกับ สำคัญกว่าปานกลาง	สำคัญกว่าปานกลาง	อยู่ระหว่างสำคัญกว่าปานกลางกับสำคัญกว่าค่อนข้างมาก	สำคัญกว่าค่อนข้างมาก	อยู่ระหว่างสำคัญกว่าค่อนข้างมากกับสำคัญกว่ามาก	สำคัญกว่ามาก	อยู่ระหว่างสำคัญกว่ามากกับสำคัญกว่ามากที่สุด	สำคัญกว่ามากที่สุด

CURRICULUM VITAE

Name : Miss Suriporn Charungthanakij

Place of Birth : Nakhon Sawan

Education :

1987 Master of Business Administration, Faculty of Commerce and Accountancy, Chulalongkorn University, Bangkok, Thailand.

1982 Bachelor of Arts (Economics), Faculty of Economics, Thammasat University, Bangkok, Thailand.

Grants and Fellowships : The Royal Thai Government Scholarships from the Commission on Higher Education.

Position and Place of Work :

Lecturer in Geography Department, Faculty of Arts, Silpakorn University, Sanamchandra Palace Campus, Nakhon Pathom, Thailand. 73000. Tel.034-255840**.**

E-mail Address**:** scharung@hotmail.com, scharung@gmail.com, suriporn@su.ac.th

Publications :

Suriporn Charungthanakij and Sunya Sarapirome. 2010. Land suitability assessment for industrial location development using MCDA. In **Proceedings of the 31th Asian Conference on Remote Sensing 2010**, Nov 01 - 05. Hanoi, Vietnam.

Specialization : Land-use Planning, Industrial Location Analysis**,** Marketing Analysis in Industrial Geography, Financial Analysis in Industrial Geography, Logistic and Transportation Geography.

ตัวอย่าง

หากท่านคิดว่าปัจจัยความสะดวกในการเข้าถึงมีความสำคัญกว่าปัจจัยสภาพแวดล้อมในระดับสำคัญกว่ามากที่สุด **ให้ท่านวงกลมที่** เลข 9 ในช่องปัจจัยแรกสำคัญกว่าปัจจัยหลัง

คู่ที่	ปัจจัยแรก	ปัจจัยหลัง	ปัจจัยแรกสำคัญกว่าปัจจัยหลังในระดับ	เท่ากัน	ปัจจัยหลังสำคัญกว่าปัจจัยแรกในระดับ
7	**ความสะดวกในการเข้าถึง**	**สภาพแวดล้อม**	**[✓ 9] 8 7 6 5 4 3 2**	**1**	**2 3 4 5 6 7 8 9**

หากท่านคิดว่าปัจจัยราคาที่ดินสำคัญกว่าปัจจัยสภาพภูมิประเทศในระดับอยู่ระหว่าง สำคัญกว่าค่อนข้างมาก กับ สำคัญกว่ามาก **ให้ท่านวงกลมที่**เลข 6 ในช่องปัจจัยหลังสำคัญกว่าปัจจัยแรก

คู่ที่	ปัจจัยแรก	ปัจจัยหลัง	ปัจจัยแรกสำคัญกว่าปัจจัยหลังในระดับ	เท่ากัน	ปัจจัยหลังสำคัญกว่าปัจจัยแรกในระดับ
34	**สภาพภูมิประเทศ**	**ราคาที่ดิน**	**9 8 7 6 5 4 3 2**	**1**	**2 3 4 5 6 [✓ 7] 8 9**

กรุณาทำเครื่องหมายลงในตารางเพื่อเปรียบเทียบปัจจัยแต่ละคู่ต่อไปนี้

คู่ที่	ปัจจัยแรก	ปัจจัยหลัง	ปัจจัยแรกสำคัญกว่าปัจจัยหลังในระดับ	เท่ากัน	ปัจจัยหลังสำคัญกว่าปัจจัยแรกในระดับ
1	**ความสะดวกในการเข้าถึง**	**สาธารณูปโภค**	**9 8 7 6 5 4 3 2**	**1**	**2 3 4 5 6 7 8 9**
2	**ความสะดวกในการเข้าถึง**	**ราคาที่ดิน**	**9 8 7 6 5 4 3 2**	**1**	**2 3 4 5 6 7 8 9**
3	**ความสะดวกในการเข้าถึง**	**แหล่งแรงงาน**	**9 8 7 6 5 4 3 2**	**1**	**2 3 4 5 6 7 8 9**
4	**ความสะดวกในการเข้าถึง**	**สิ่งอำนวยความสะดวก**	**9 8 7 6 5 4 3 2**	**1**	**2 3 4 5 6 7 8 9**
5	**ความสะดวกในการเข้าถึง**	**การรวมกลุ่มอุตสาหกรรม**	**9 8 7 6 5 4 3 2**	**1**	**2 3 4 5 6 7 8 9**
6	**ความสะดวกในการเข้าถึง**	**สภาพภูมิประเทศ**	**9 8 7 6 5 4 3 2**	**1**	**2 3 4 5 6 7 8 9**
9	**สาธารณูปโภค**	**ราคาที่ดิน**	**9 8 7 6 5 4 3 2**	**1**	**2 3 4 5 6 7 8 9**
10	**สาธารณูปโภค**	**แหล่งแรงงาน**	**9 8 7 6 5 4 3 2**	**1**	**2 3 4 5 6 7 8 9**
11	**สาธารณูปโภค**	**สิ่งอำนวยความสะดวก**	**9 8 7 6 5 4 3 2**	**1**	**2 3 4 5 6 7 8 9**
12	**สาธารณูปโภค**	**การรวมกลุ่มอุตสาหกรรม**	**9 8 7 6 5 4 3 2**	**1**	**2 3 4 5 6 7 8 9**
13	**สาธารณูปโภค**	**สภาพภูมิประเทศ**	**9 8 7 6 5 4 3 2**	**1**	**2 3 4 5 6 7 8 9**

คู่ที่	ปัจจัยแรก	ปัจจัยหลัง	ปัจจัยแรกสำคัญกว่าปัจจัยหลังในระดับ	เท่ากัน	ปัจจัยหลังสำคัญกว่าปัจจัยแรกในระดับ
16	**ราคาที่ดิน**	**แหล่งแรงงาน**	**9 8 7 6 5 4 3 2**	**1**	**2 3 4 5 6 7 8 9**
17	**ราคาที่ดิน**	**สิ่งอำนวยความสะดวก**	**9 8 7 6 5 4 3 2**	**1**	**2 3 4 5 6 7 8 9**
18	**ราคาที่ดิน**	**การรวมกลุ่มอุตสาหกรรม**	**9 8 7 6 5 4 3 2**	**1**	**2 3 4 5 6 7 8 9**
19	**ราคาที่ดิน**	**สภาพภูมิประเทศ**	**9 8 7 6 5 4 3 2**	**1**	**2 3 4 5 6 7 8 9**
22	**แหล่งแรงงาน**	**สิ่งอำนวยความสะดวก**	**9 8 7 6 5 4 3 2**	**1**	**2 3 4 5 6 7 8 9**
23	**แหล่งแรงงาน**	**การรวมกลุ่มอุตสาหกรรม**	**9 8 7 6 5 4 3 2**	**1**	**2 3 4 5 6 7 8 9**
24	**แหล่งแรงงาน**	**สภาพภูมิประเทศ**	**9 8 7 6 5 4 3 2**	**1**	**2 3 4 5 6 7 8 9**
27	**สิ่งอำนวยความสะดวก**	**การรวมกลุ่มอุตสาหกรรม**	**9 8 7 6 5 4 3 2**	**1**	**2 3 4 5 6 7 8 9**
28	**สิ่งอำนวยความสะดวก**	**สภาพภูมิประเทศ**	**9 8 7 6 5 4 3 2**	**1**	**2 3 4 5 6 7 8 9**
31	**การรวมกลุ่มอุตสาหกรรม**	**สภาพภูมิประเทศ**	**9 8 7 6 5 4 3 2**	**1**	**2 3 4 5 6 7 8 9**

3. ปัจจัยความสะดวกในการเข้าถึง

3.1 ท่านคิดว่า ที่ตั้งของโรงงานไม่ควรห่างจากถนนสาธารณะสายหลัก เกินกว่าระยะทางเท่าไร

1. ไม่ควรห่างเกิน 1 กิโลเมตร
2. ไม่ควรห่างเกิน 3 กิโลเมตร
3. ไม่ควรห่างเกิน 5 กิโลเมตร
4. ไม่ ควรห่างเกิน 10 กิโลเมตร
5. อื่นๆ ระบุ________________________________

3.2 ท่านคิดว่า ที่ตั้งของโรงงานไม่ควรห่างจากถนนสาธารณะสายรอง เกินกว่าระยะทางเท่าไร

1. ไม่ควรห่างเกิน 100 เมตร
2. ไม่ควรห่างเกิน 500 เมตร
3. ไม่ควรห่างเกิน 1 กิโลเมตร
4. ไม่ควรห่างเกิน 3 กิโลเมตร
5. อื่นๆ ระบุ________________________________

4. ปัจจัยสาธารณูปโภค

4.1 ท่านคิดว่า ที่ตั้งของโรงงานไม่ควรห่างจากแหล่งน้ำที่ใช้ในการประกอบอุตสาหกรรม เช่น ท่อประปา คลอง แม่น้ำ เกินกว่าระยะทางเท่าไร

1. ไม่ควรห่างเกิน 100 เมตร
2. ไม่ควรห่างเกิน 300 เมตร
3. ไม่ควรห่างเกิน 500 กิโลเมตร

4 ไม่ควรห่างเกิน 1 กิโลเมตร

5. อื่นๆ ระบุ________________________________

4.2 ท่านคิดว่า ที่ตั้งของโรงงานไม่ควรห่างจากสายไฟฟ้าสายหลัก ไม่เกินระยะทางเท่าไร

1. ไม่ควรห่างเกิน 100 เมตร
2. ไม่.ควรห่างเกิน 300 เมตร
3. ไม่ควรห่างเกิน 500 กิโลเมตร
4. ไม่ควรห่างเกิน 1 กิโลเมตร
5. อื่นๆ ระบุ________________________________

5. ปัจจัยราคาที่ดิน

5.1 ท่านคิดว่าราคาที่ดินสูงสุด ที่โรงงานยอมรับได้ ควรมีราคาไม่เกินเท่าไร

1. ไม่ควรเกินไร่ละ 5 แสนบาท
2. ไม่ควรเกินไร่ละ 1 ล้านบาท
3. ไม่ควรเกินไร่ละ 5 ล้านบาท

4 ไม่ควรเกินไร่ละ 10 ล้านบาท

5. อื่นๆ ระบุ________________________________

6. ปัจจัยแหล่งแรงงาน

6.1 แหล่งแรงงานที่สำคัญของโรงงาน ควรได้มาจากแหล่งใดจึงจะดีที่สุด

1. ชุมชนเล็กๆรอบๆ โรงงาน
2. ชุมชนใหญ่หรือเมืองใหญ่ใกล้เคียง
3. แรงงานอพยพจากที่อื่นๆ

6.2 จากข้อ 6.1 โรงงาน ควรมีแหล่งแรงงานอยู่ใกล้ๆ ไม่ควรห่างเกินระยะทางเท่าไรจึงจะยอมรับได้

1. ไม่.ควรห่างเกิน 5 กิโลเมตร
2. ไม่ควรห่างเกิน 10 กิโลเมตร
3. ไม่.ควรห่างเกิน 15 กิโลเมตร
4. ไม่ควรห่างเกิน 20 กิโลเมตร
5. อื่นๆ ระบุ________________________________

7. ปัจจัยสิ่งอำนวยความสะดวก

7.1 ท่านคิดว่า ที่ตั้งโรงงาน ควรตั้งอยู่ใกล้เมือง เป็นระยะห่างมากที่สุดไม่เกินเท่าไร เพื่อจะได้รับสิ่งอำนวยความสะดวก เช่น ธนาคาร โรงพยาบาล สถานีตำรวจ หนวยงานราชการ สถานศึกษา ร้านค้า

1. ไม่.ควรห่างเกิน 5 กิโลเมตร
2. ไม่ควรห่างเกิน 10 กิโลเมตร
3. ไม่ควรห่างเกิน 15 กิโลเมตร
4. ไม่ควรห่างเกิน 20 กิโลเมตร
5. อื่นๆ ระบุ______________________________

8. ปัจจัยการรวมกลุ่มอุตสาหกรรม

8.1 ในมุมมองของผู้ประกอบการ โรงงาน ควรตั้งอยูในนิคมหรือใกล้กับนิคมอุตสาหกรรม หรือย่านอุตสาหกรรมหรือไม่ เพราะเหตุใด

1. ตั้งอยู่ในนิคมอุตสาหกรรมหรือในย่านอุตสาหกรรม
2. ตั้งห่างจากนิคมอุตสาหกรรมหรือย่านอุตสาหกรรมไม่เกิน 1- 5 กม
3. ตั้งห่างจากนิคมอุตสาหกรรมหรือย่านอุตสาหกรรมไม่เกิน 6-10 กม
4. ตั้งห่างจากนิคมอุตสาหกรรมหรือย่านอุตสาหกรรมไม่เกิน 11-15 กม
5. อื่นๆ ระบุ ______________________________

9. ปัจจัยสภาพภูมิประเทศ

9.1 ท่านคิดว่าในการตั้งโรงงานปัญหาสภาพภูมิประเทศที่สำคัญที่สุดคือเรื่องใด

1. ปัญหาน้ำท่วม
2. ปัญหาอื่นๆ ระบุ______________________________

10. หากคำนึงถึงปัญหาสิ่งแวดล้อม พื้นที่แบบใดที่ควรเป็นที่ตั้งของโรงงาน

10.1 กรุณาให้เรียงลำดับพื้นที่ที่เหมาะสมกับการตั้งโรงงานจากมากไปหาน้อย

ปัจจัย	**เรียงลำดับ (1 หมายถึงเหมาะสมมากที่สุด)**	**ควรมีระยะห่างไม่น้อยกว่ากี่เมตร (ระบุ)**
พื้นที่ว่างหรือหนาแน่นน้อย		
พื้นที่เกษตรหรือใกล้พื้นที่เกษตร		
พื้นที่อยู่อาศัยหรือใกล้ที่อยู่อาศัย		
พื้นที่อุตสาหกรรมหรือใกล้ย่านอุตสาหกรรม		
พื้นที่พาณิชยกรรมหรือใกล้ตลาด		
ใกล้พื้นที่ป่าหรือสวนป่า		

________**ขอบพระคุณที่กรุณาแสดงความคิดเห็น เพื่อประโยชน์ในทางการศึกษา**___________

APPENDIX B

CLASSIFIED CURRENT SUSTAINABILITY INDEXES (CSIs) OF SUB-DISTRICTS IN PHRA NAKHON SI AYUTTHAYA

Table B.1 The resulted CESI classification at sub-district level.

Sub-district ID	Sub-district name	District Name	FAC1_1	CESI	Normal_CES	CESI_class
140107	PAK KRAN	PHRA NAKHON SI AYUTTHAYA	0.1389	0.1040	0.2700	Fair
140108	PHU KHAO THONG	PHRA NAKHON SI AYUTTHAYA	0.0563	0.0422	0.2550	Fair
140109	SAMPHAO LOM	PHRA NAKHON SI AYUTTHAYA	-0.1341	-0.1004	0.2203	Fair
140110	SUAN PHRIK	PHRA NAKHON SI AYUTTHAYA	0.4843	0.3625	0.3329	Good
140111	KHLONG TAKHIAN	PHRA NAKHON SI AYUTTHAYA	-0.2924	-0.2188	0.1915	Fair
140112	WAT TUM	PHRA NAKHON SI AYUTTHAYA	0.4978	0.3726	0.3353	Good
140113	HAN TRA	PHRA NAKHON SI AYUTTHAYA	0.0158	0.0118	0.2476	Fair
140114	LUMPHLI	PHRA NAKHON SI AYUTTHAYA	-0.8433	-0.6312	0.0912	Poor
140115	BAN MAI	PHRA NAKHON SI AYUTTHAYA	0.9413	0.7045	0.4160	Good
140116	BAN KO	PHRA NAKHON SI AYUTTHAYA	1.0022	0.7501	0.4271	Good
140117	KHLONG SUAN PHLU	PHRA NAKHON SI AYUTTHAYA	-0.3024	-0.2263	0.1897	Fair
140119	KO RIAN	PHRA NAKHON SI AYUTTHAYA	0.5597	0.4189	0.3466	Good
140120	BAN POM	PHRA NAKHON SI AYUTTHAYA	-0.2153	-0.1612	0.2055	Fair
140121	BAN RUN	PHRA NAKHON SI AYUTTHAYA	-0.2940	-0.2201	0.1912	Fair
140202	CHAMPA	THA RUEA	0.5211	0.3900	0.3396	Good
140203	THA LUANG	THA RUEA	-0.1071	-0.0801	0.2252	Fair
140204	BAN ROM	THA RUEA	-0.1967	-0.1472	0.2089	Fair
140206	WANG DAENG	THA RUEA	-0.6512	-0.4874	0.1262	Fair
140207	PHO EN	THA RUEA	-0.0443	-0.0332	0.2366	Fair
140208	PAK THA	THA RUEA	-0.8481	-0.6348	0.0904	Poor
140209	NONG KHANAK	THA RUEA	-0.1579	-0.1182	0.2160	Fair

Table B.1 The resulted CESI classification at sub-district level (Continued).

Sub-district ID	Sub-district name	District Name	FAC1_1	CESI	Normal_CES	CESI_class
140210	THA CHAO SANUK	THA RUEA	1.5151	1.1340	0.5205	Good
140303	BO PHONG	NAKHON LUANG	2.5583	1.9148	0.7104	Good
140304	BAN CHUNG	NAKHON LUANG	0.2938	0.2199	0.2982	Fair
140305	PAK CHAN	NAKHON LUANG	2.4013	1.7973	0.6818	Good
140306	BANG RAKAM	NAKHON LUANG	0.3527	0.2640	0.3089	Good
140307	BANG PHRAKHRU	NAKHON LUANG	3.6032	2.6969	0.9005	Good
140308	MAE LA	NAKHON LUANG	0.6975	0.5221	0.3717	Good
140309	NONG PLING	NAKHON LUANG	-0.7086	-0.5303	0.1158	Fair
140310	KHLONG SAKAE	NAKHON LUANG	2.9787	2.2295	0.7869	Good
140309	NONG PLING	NAKHON LUANG	-0.7086	-0.5303	0.1158	Fair
140310	KHLONG SAKAE	NAKHON LUANG	2.9787	2.2295	0.7869	Good
140403	SANAM CHAI	BANG SAI	-0.3482	-0.2606	0.1813	Fair
140404	BAN PAENG	BANG SAI	-0.8164	-0.6111	0.0961	Poor
140405	NA MAI	BANG SAI	-0.3680	-0.2755	0.1777	Fair
140407	KHAE OK	BANG SAI	-0.2067	-0.1547	0.2071	Fair
140408	KHAE TOK	BANG SAI	-0.6793	-0.5085	0.1211	Fair
140409	CHANG LEK	BANG SAI	-0.1311	-0.0981	0.2209	Fair
140410	KRACHAENG	BANG SAI	-0.7821	-0.5854	0.1024	Fair
140411	BAN KLUENG	BANG SAI	-0.8831	-0.6610	0.0840	Poor
140412	CHANG NOI	BANG SAI	-0.5050	-0.3780	0.1528	Fair
140413	HO MOK	BANG SAI	-0.6142	-0.4597	0.1329	Fair
140415	KOK KAEO BURAPHA	BANG SAI	-0.3279	-0.2454	0.1850	Fair
140416	MAI TRA	BANG SAI	-0.3201	-0.2396	0.1865	Fair
140417	BAN MA	BANG SAI	-0.2563	-0.1918	0.1981	Fair
140418	BAN KO	BANG SAI	-0.7302	-0.5465	0.1118	Fair
140421	PHO TAENG	BANG SAI	-0.1309	-0.0980	0.2209	Fair
140422	CHIANG RAK NOI	BANG SAI	-0.2583	-0.1933	0.1977	Fair
140423	KHOK CHANG	BANG SAI	-0.1581	-0.1183	0.2159	Fair
140506	KOP CHAO	BANG BAN	-0.2834	-0.2121	0.1931	Fair
140507	BAN KHLANG	BANG BAN	-0.6245	-0.4674	0.1310	Fair
140310	KHLONG SAKAE	NAKHON LUANG	2.9787	2.2295	0.7869	Good
140309	NONG PLING	NAKHON LUANG	-0.7086	-0.5303	0.1158	Fair
140509	NAMTAO	BANG BAN	0.0409	0.0306	0.2522	Fair
140510	THANG CHANG	BANG BAN	-0.4097	-0.3066	0.1702	Fair
140511	WAT TAKU	BANG BAN	-0.7805	-0.5842	0.1027	Fair
140512	BANG LUANG	BANG BAN	-0.8650	-0.6474	0.0873	Poor

Table B.1 The resulted CESI classification at sub-district level (Continued).

Sub-district ID	Sub-district name	District Name	FAC1_1	CESI	Normal_CES	CESI_class
140602	CHIANG RAK NOI	BANG PA-IN	-0.6409	-0.4797	0.1281	Fair
140603	BAN PHO	BANG PA-IN	-0.0187	-0.0140	0.2413	Fair
140604	BAN KROT	BANG PA-IN	1.1521	0.8623	0.4544	Good
140605	BANG KRASAN	BANG PA-IN	3.4516	2.5834	0.8729	Good
140606	KHLONG CHIK	BANG PA-IN	-0.1354	-0.1013	0.2201	Fair
140607	BAN WA	BANG PA-IN	0.6341	0.4746	0.3601	Good
140608	WAT YOM	BANG PA-IN	0.5633	0.4216	0.3472	Good
140609	BANG PRADAENG	BANG PA-IN	0.0235	0.0176	0.2490	Fair
140610	SAM RUEAN	BANG PA-IN	-0.4977	-0.3725	0.1541	Fair
140615	TALING CHAN	BANG PA-IN	-1.2447	-0.9316	0.0182	Poor
140617	TALAT KRIAP	BANG PA-IN	-0.2368	-0.1772	0.2016	Fair
140618	KHANON LUANG	BANG PA-IN	-0.0777	-0.0582	0.2306	Fair
140701	BANG PAHAN	BANG PAHAN	1.5729	1.1773	0.5310	Good
140702	KHAYAI	BANG PAHAN	0.6275	0.4697	0.3589	Good
140703	BANG DUEA	BANG PAHAN	0.4964	0.3715	0.3351	Good
140704	SAO THONG	BANG PAHAN	-0.6021	-0.4507	0.1351	Fair
140705	THANG KLANG	BANG PAHAN	-0.3224	-0.2413	0.1860	Fair
140707	HAN SANG	BANG PAHAN	0.0963	0.0721	0.2622	Fair
140708	BANG NANG RA	BANG PAHAN	1.5273	1.1431	0.5227	Good
140709	TANIM	BANG PAHAN	0.3742	0.2801	0.3128	Good
140710	THAP NAM	BANG PAHAN	-0.1609	-0.1204	0.2154	Fair
140711	BAN MA	BANG PAHAN	-0.0924	-0.0692	0.2279	Fair
140713	BAN LI	BANG PAHAN	0.0169	0.0126	0.2478	Fair
140714	PHO SAM TON	BANG PAHAN	1.5750	1.1789	0.5314	Good
140715	PHUT LAO	BANG PAHAN	1.2871	0.9634	0.4790	Good
140716	TAN EN	BANG PAHAN	-0.7430	-0.5561	0.1095	Fair
140801	PHAK HAI	PHAK HAI	0.1802	0.1349	0.2775	Fair
140803	BAN KHAE	PHAK HAI	0.5341	0.3998	0.3419	Good
140804	LAT NAM KHEM	PHAK HAI	-0.8430	-0.6310	0.0913	Poor
140806	THA DIN DAENG	PHAK HAI	-0.9920	-0.7425	0.0642	Poor
140807	DON LAN	PHAK HAI	-0.2224	-0.1664	0.2042	Fair
140808	NA KHU	PHAK HAI	-0.1830	-0.1370	0.2114	Fair
140809	KUDI	PHAK HAI	-1.0549	-0.7895	0.0527	Poor
140810	LAM TAKHIAN	PHAK HAI	-0.8272	-0.6191	0.0942	Poor
140811	KHOK CHANG	PHAK HAI	-0.8554	-0.6402	0.0890	Poor
140814	LAT CHIT	PHAK HAI	-1.1108	-0.8314	0.0425	Poor
140815	NA KHOK	PHAK HAI	-0.0770	-0.0577	0.2307	Fair
140902	KHOK MUANG	PHACHI	-0.2798	-0.2094	0.1938	Fair
140903	RASOM	PHACHI	-0.9515	-0.7121	0.0715	Poor

Table B.1 The resulted CESI classification at sub-district level (Continued).

Sub-district ID	Sub-district name	District Name	FAC1_1	CESI	Normal_CES	CESI_class
140904	NONG NAM SAI	PHACHI	-0.1540	-0.1153	0.2167	Fair
140905	DON YA NANG	PHACHI	-0.5119	-0.3832	0.1515	Fair
140906	PHAI LOM	PHACHI	-0.1326	-0.0992	0.2206	Fair
140908	PHRA KAEO	PHACHI	-0.3483	-0.2607	0.1813	Fair
141001	LAT BUA LUANG	LAT BUA LUANG	-0.8993	-0.6731	0.0810	Poor
141002	LAK CHAI	LAT BUA LUANG	-0.1941	-0.1453	0.2094	Fair
141003	SAM MUEANG	LAT BUA LUANG	-0.5453	-0.4082	0.1455	Fair
141004	PHRAYA BANLUE	LAT BUA LUANG	-0.6917	-0.5177	0.1188	Fair
141005	SINGHANAT	LAT BUA LUANG	-0.6001	-0.4492	0.1355	Fair
141006	KHU SALOT	LAT BUA LUANG	-0.3954	-0.2959	0.1728	Fair
141102	BO TA LO	WANG NOI	1.3816	1.0341	0.4962	Good
141104	LAM SAI	WANG NOI	2.6500	1.9834	0.7270	Good
141105	SANAP THUEP	WANG NOI	1.1441	0.8563	0.4530	Good
141106	PHAYOM	WANG NOI	0.9740	0.7290	0.4220	Good
141107	HAN TAPHAO	WANG NOI	-1.0010	-0.7493	0.0625	Poor
141108	WANG CHULA	WANG NOI	1.9320	1.4460	0.5964	Good
141109	KHAO NGAM	WANG NOI	0.1422	0.1064	0.2706	Fair
141110	CHAMAEP	WANG NOI	0.8233	0.6162	0.3946	Good
141202	BAN PHAEN	SENA	0.0765	0.0573	0.2586	Fair
141204	SAM KO	SENA	-0.6377	-0.4773	0.1286	Fair
141205	BANG NOM KHO	SENA	2.4633	1.8437	0.6931	Good
141207	MAN WICHAI	SENA	-0.7536	-0.5640	0.1076	Fair
141208	BAN PHO	SENA	-0.1718	-0.1286	0.2135	Fair
141209	RANG CHORAKHE	SENA	-0.9183	-0.6873	0.0776	Poor
141211	BAN THAEO	SENA	0.1981	0.1483	0.2808	Fair
141212	CHAI NA	SENA	-0.3858	-0.2888	0.1745	Fair
141213	SAM TUM	SENA	-0.7701	-0.5764	0.1045	Fair
141214	LAT NGA	SENA	-0.8223	-0.6155	0.0950	Poor
141215	DON THONG	SENA	-0.5344	-0.4000	0.1474	Fair
141216	BAN LUANG	SENA	-0.7887	-0.5903	0.1012	Fair
141301	BANG SAI	BANG SAI	-0.1938	-0.1451	0.2094	Fair
141302	KAEO FA	BANG SAI	-0.8373	-0.6267	0.0923	Poor
141303	TAO LAO	BANG SAI	-0.8903	-0.6664	0.0827	Poor
141304	PLAI KLAT	BANG SAI	-0.9247	-0.6921	0.0764	Poor
141306	WANG PHATTHANA	BANG SAI	-0.7291	-0.5457	0.1120	Fair
141401	KHAN HAM	UTHAI	4.1496	3.1059	1.0000	Good
141402	BAN CHANG	UTHAI	0.1197	0.0896	0.2665	Fair
141403	SAM BANDIT	UTHAI	-0.2213	-0.1657	0.2044	Fair
141404	BAN HIP	UTHAI	-0.3700	-0.2770	0.1774	Fair

Table B.1 The resulted CESI classification at sub-district level (Continued).

Sub-district ID	Sub-district name	District Name	FAC1_1	CESI	Normal_CES	CESI_class
141405	NONG MAI SUNG	UTHAI	-0.1775	-0.1329	0.2124	Fair
141406	UTHAI	UTHAI	0.6686	0.5005	0.3664	Good
141407	SENA	UTHAI	-1.3445	-1.0063	0.0000	Poor
141408	NONG NAM SOM	UTHAI	-0.8480	-0.6347	0.0904	Poor
141409	PHO SAO HAN	UTHAI	-0.6429	-0.4812	0.1277	Fair
141410	THANU	UTHAI	2.0706	1.5498	0.6216	Good
141411	KHAO MAO	UTHAI	-0.6410	-0.4798	0.1281	Fair
141502	KATHUM	MAHARAT	-1.0960	-0.8203	0.0452	Poor
141505	BANG NA	MAHARAT	-0.5563	-0.4164	0.1435	Fair
141509	BAN NA	MAHARAT	-0.4531	-0.3391	0.1623	Fair
141510	BAN KHWANG	MAHARAT	-0.0665	-0.0498	0.2326	Fair
141511	THA TO	MAHARAT	1.6541	1.2381	0.5458	Good
141512	BAN MAI	MAHARAT	0.3289	0.2462	0.3046	Good
141601	BAN PHRAEK	BAN PHRAEK	-0.8957	-0.6704	0.0817	Poor
141602	BAN MAI	BAN PHRAEK	0.2093	0.1566	0.2828	Fair
141603	SAM PHANIANG	BAN PHRAEK	-1.0278	-0.7693	0.0576	Poor
141604	KHLONG NOI	BAN PHRAEK	-1.0925	-0.8177	0.0459	Poor
141605	SONG HONG	BAN PHRAEK	-1.0879	-0.8143	0.0467	Poor

Table B.2 The resulted CSSI classification at sub-district level.

Sub-district ID	Sub-district name	District Name	WFac 1_3	WFac 2_3	WFac 3_3	Total WF	CSSI	Nor_ CSSI	CSSI_ Class
140107	PHRA NAKHON SI AYUTTHAYA	PHRA NAKHON SI AYUTTHAYA	-22.2350	43.4920	9.6010	-56.1250	-0.5610	0.2500	Fair
140108	PHRA NAKHON SI AYUTTHAYA	PHRA NAKHON SI AYUTTHAYA	-2.7570	98.7870	-0.6260	-102.1710	-1.0210	0.0910	Poor
140109	PHRA NAKHON SI AYUTTHAYA	PHRA NAKHON SI AYUTTHAYA	-1.8660	136.4050	9.7290	-128.5420	-1.2850	0.0000	Poor
140110	PHRA NAKHON SI AYUTTHAYA	PHRA NAKHON SI AYUTTHAYA	46.7460	-6.7250	8.8050	62.2770	0.6220	0.6590	Good
140111	PHRA NAKHON SI AYUTTHAYA	PHRA NAKHON SI AYUTTHAYA	-0.5440	-10.7110	4.3040	14.4700	0.1440	0.4940	Fair
140112	PHRA NAKHON SI AYUTTHAYA	PHRA NAKHON SI AYUTTHAYA	4.4630	-4.4010	3.9760	12.8410	0.1280	0.4880	Fair
140113	PHRA NAKHON SI AYUTTHAYA	PHRA NAKHON SI AYUTTHAYA	16.2560	-44.1990	18.2740	78.7300	0.7870	0.7160	Good
140114	PHRA NAKHON SI AYUTTHAYA	PHRA NAKHON SI AYUTTHAYA	-30.4420	5.7590	4.9140	-31.2870	-0.3120	0.3360	Fair
140115	PHRA NAKHON SI AYUTTHAYA	PHRA NAKHON SI AYUTTHAYA	15.3320	29.6472	20.2760	5.9613	0.0590	0.4650	Fair
140116	PHRA NAKHON SI AYUTTHAYA	PHRA NAKHON SI AYUTTHAYA	6.5330	9.7004	8.7446	5.5777	0.0550	0.4630	Fair
140117	PHRA NAKHON SI AYUTTHAYA	PHRA NAKHON SI AYUTTHAYA	-31.7460	5.0590	6.9700	-29.8350	-0.2980	0.3410	Fair
140119	PHRA NAKHON SI AYUTTHAYA	PHRA NAKHON SI AYUTTHAYA	25.4807	27.3886	5.1241	3.2162	0.0322	0.4557	Fair
140120	PHRA NAKHON SI AYUTTHAYA	PHRA NAKHON SI AYUTTHAYA	-2.0302	31.2882	7.4854	-25.8331	-0.2583	0.3552	Fair
140121	PHRA NAKHON SI AYUTTHAYA	PHRA NAKHON SI AYUTTHAYA	-12.6015	-27.9154	3.9750	19.2889	0.1929	0.5113	Fair
140202	THA RUEA	THA RUEA	61.4643	-20.7757	8.1450	90.3851	0.9039	0.7571	Good
140203	THA RUEA	THA RUEA	-2.6172	52.6213	14.2633	-40.9752	-0.4098	0.3028	Fair
140204	THA RUEA	THA RUEA	8.2720	37.4428	5.4748	-23.6961	-0.2370	0.3626	Fair
140206	THA RUEA	THA RUEA	-21.9406	30.9698	9.0042	-43.9062	-0.4391	0.2927	Fair
140207	THA RUEA	THA RUEA	67.6708	-5.7991	-44.1674	29.3025	0.2930	0.5459	Fair
140208	THA RUEA	THA RUEA	-37.9363	25.8528	5.5563	-58.2327	-0.5823	0.2432	Poor
140209	THA RUEA	THA RUEA	-13.8020	-17.5012	6.5237	10.2228	0.1022	0.4799	Fair
140210	THA RUEA	THA RUEA	61.6054	-31.2258	7.6255	100.4567	1.0046	0.7920	Good
140303	NAKHON LUANG	NAKHON LUANG	94.0811	-1.5271	7.0014	102.6096	1.0261	0.7994	Good
140304	NAKHON LUANG	NAKHON LUANG	-27.5604	18.4801	9.8995	-36.1410	-0.3614	0.3196	Fair
140305	NAKHON LUANG	NAKHON LUANG	114.8665	-22.1760	0.9211	137.9635	1.3796	0.9217	Good
140306	NAKHON LUANG	NAKHON LUANG	9.1465	8.1279	15.7191	16.7378	0.1674	0.5024	Fair
140307	NAKHON LUANG	NAKHON LUANG	84.0558	-6.9530	5.9773	96.9861	0.9699	0.7800	Good
140308	NAKHON LUANG	NAKHON LUANG	46.8196	-2.0832	8.2321	57.1349	0.5713	0.6422	Good
140309	NAKHON LUANG	NAKHON LUANG	-21.6163	-6.7106	5.0054	-9.9003	-0.0990	0.4103	Fair

Table B.2 The resulted CSSI classification at sub-district level (Continued).

Sub-district ID	Sub-district name	District Name	WFac 1_3	WFac 2_3	WFac 3_3	Total WF	CSSI	Nor_ CSSI	CSSI_ Class
140310	NAKHON LUANG	NAKHON LUANG	130.7846	-27.5083	2.3142	160.6071	1.6061	1.0000	Good
140403	BANG SAI	BANG SAI	-20.4143	41.5962	-32.0390	-94.0495	-0.9405	0.1193	Poor
140404	BANG SAI	BANG SAI	3.9752	-41.1716	-32.6342	12.5126	0.1251	0.4878	Fair
140405	BANG SAI	BANG SAI	17.8532	-29.1005	-35.6590	11.2947	0.1129	0.4836	Fair
140407	BANG SAI	BANG SAI	6.4496	-30.1073	-33.7670	2.7899	0.0279	0.4542	Fair
140408	BANG SAI	BANG SAI	-3.2819	-9.9201	-33.4414	-26.8032	-0.2680	0.3519	Fair
140409	BANG SAI	BANG SAI	28.0829	-36.5894	-37.4594	27.2129	0.2721	0.5387	Fair
140410	BANG SAI	BANG SAI	-21.7313	-9.6989	2.3355	-9.6969	-0.0970	0.4110	Fair
140411	BANG SAI	BANG SAI	-11.4659	-52.7744	4.1037	45.4123	0.4541	0.6016	Good
140412	BANG SAI	BANG SAI	9.4011	-35.3786	-2.6218	42.1579	0.4216	0.5904	Good
140413	BANG SAI	BANG SAI	-17.7709	22.4425	-30.3751	-70.5885	-0.7059	0.2004	Poor
140415	BANG SAI	BANG SAI	-14.7201	7.9327	-30.6639	-53.3167	-0.5332	0.2602	Fair
140416	BANG SAI	BANG SAI	-15.7204	4.0353	-29.6885	-49.4442	-0.4944	0.2736	Fair
140417	BANG SAI	BANG SAI	1.9028	43.9814	-34.1073	-76.1859	-0.7619	0.1811	Poor
140418	BANG SAI	BANG SAI	-12.1522	-32.8887	-28.0596	-7.3232	-0.0732	0.4192	Fair
140421	BANG SAI	BANG SAI	-25.2559	28.1380	-29.6305	-83.0244	-0.8302	0.1574	Poor
140422	BANG SAI	BANG SAI	-10.2581	-29.7707	-21.8851	-2.3725	-0.0237	0.4363	Fair
140423	BANG SAI	BANG SAI	-26.6620	12.4172	8.4146	-30.6646	-0.3066	0.3385	Fair
140506	BANG BAN	BANG BAN	-10.0179	-39.4709	8.1526	37.6056	0.3761	0.5746	Good
140507	BANG BAN	BANG BAN	-22.1295	-42.1794	6.8577	26.9077	0.2691	0.5376	Fair
140509	BANG BAN	BANG BAN	11.6350	46.1477	14.5220	-19.9906	-0.1999	0.3754	Fair
140510	BANG BAN	BANG BAN	-18.1375	26.5370	-31.2337	-75.9082	-0.7591	0.1820	Poor
140511	BANG BAN	BANG BAN	-32.6748	-9.6119	5.0598	-18.0031	-0.1800	0.3823	Fair
140512	BANG BAN	BANG BAN	-19.7239	-3.5125	-29.1887	-45.4001	-0.4540	0.2875	Fair
140602	BANG PA-IN	BANG PA-IN	-37.0193	-5.3373	10.5437	-21.1382	-0.2114	0.3714	Fair
140603	BANG PA-IN	BANG PA-IN	-19.1755	35.2076	16.6242	-37.7590	-0.3776	0.3140	Fair
140604	BANG PA-IN	BANG PA-IN	28.8706	76.1981	8.9734	-38.3540	-0.3835	0.3119	Fair
140605	BANG PA-IN	BANG PA-IN	104.1293	25.6811	6.0710	84.5191	0.8452	0.7369	Good
140606	BANG PA-IN	BANG PA-IN	-0.9728	5.5308	10.0561	3.5525	0.0355	0.4568	Fair
140607	BANG PA-IN	BANG PA-IN	39.1397	16.3250	33.7806	56.5953	0.5660	0.6403	Good
140608	BANG PA-IN	BANG PA-IN	34.8946	16.3858	16.1862	34.6951	0.3470	0.5645	Good
140609	BANG PA-IN	BANG PA-IN	-33.8918	14.8703	7.0226	-41.7395	-0.4174	0.3002	Fair
140610	BANG PA-IN	BANG PA-IN	11.6210	38.2620	-35.4835	-62.1246	-0.6212	0.2297	Poor
140615	BANG PA-IN	BANG PA-IN	-20.5658	7.0209	-28.8265	-56.4132	-0.5641	0.2495	Poor
140617	BANG PA-IN	BANG PA-IN	-33.3479	30.4285	6.6255	-57.1509	-0.5715	0.2469	Poor
140618	BANG PA-IN	BANG PA-IN	-13.6238	-10.4980	-29.6938	-32.8196	-0.3282	0.3311	Fair
140701	BANG PAHAN	BANG PAHAN	50.0089	31.4089	7.3913	25.9913	0.2599	0.5344	Fair
140702	BANG PAHAN	BANG PAHAN	35.4429	14.8711	-36.8328	-16.2610	-0.1626	0.3883	Fair
140703	BANG PAHAN	BANG PAHAN	23.9474	2.0511	12.5553	34.4516	0.3445	0.5637	Good
140704	BANG PAHAN	BANG PAHAN	-18.9464	-12.6358	11.2356	4.9249	0.0492	0.4616	Fair
140705	BANG PAHAN	BANG PAHAN	5.1663	71.6980	-4.4535	-70.9852	-0.7099	0.1991	Poor
140707	BANG PAHAN	BANG PAHAN	19.0545	22.0840	17.2332	14.2038	0.1420	0.4937	Fair
140708	BANG PAHAN	BANG PAHAN	64.6963	-46.8382	14.3623	125.8968	1.2590	0.8800	Good
140709	BANG PAHAN	BANG PAHAN	44.3898	-50.2506	16.6096	111.2500	1.1125	0.8293	Good
140710	BANG PAHAN	BANG PAHAN	-18.2895	-65.6073	11.9362	59.2540	0.5925	0.6495	Good
140711	BANG PAHAN	BANG PAHAN	13.1307	-25.4587	12.8385	51.4279	0.5143	0.6224	Good
140713	BANG PAHAN	BANG PAHAN	14.1625	-38.0399	12.5195	64.7219	0.6472	0.6684	Good
140714	BANG PAHAN	BANG PAHAN	61.2228	-23.9708	10.8824	96.0760	0.9608	0.7768	Good
140715	BANG PAHAN	BANG PAHAN	53.7669	-14.8351	11.0603	79.6623	0.7966	0.7201	Good
140716	BANG PAHAN	BANG PAHAN	8.1940	-39.6284	-33.3851	14.4374	0.1444	0.4945	Fair

Table B.2 The resulted CSSI classification at sub-district level (Continued).

Sub-district ID	Sub-district name	District Name	WFac 1_3	WFac 2_3	WFac 3_3	Total WF	CSSI	Nor_ CSSI	CSSI_ Class
140801	PHAK HAI	PHAK HAI	3.2298	81.0319	4.5316	-73.2706	-0.7327	0.1912	Poor
140803	PHAK HAI	PHAK HAI	40.7115	13.5624	11.7390	38.8881	0.3889	0.5790	Good
140804	PHAK HAI	PHAK HAI	-20.7909	-0.5846	5.5674	-14.6390	-0.1464	0.3939	Fair
140806	PHAK HAI	PHAK HAI	-34.2972	42.5915	3.9998	-72.8889	-0.7289	0.1925	Poor
140807	PHAK HAI	PHAK HAI	-14.1720	-2.8603	11.4872	0.1755	0.0018	0.4452	Fair
140808	PHAK HAI	PHAK HAI	-18.5782	-7.4358	9.0215	-2.1209	-0.0212	0.4372	Fair
140809	PHAK HAI	PHAK HAI	-37.1407	-11.2260	7.5163	-18.3984	-0.1840	0.3809	Fair
140810	PHAK HAI	PHAK HAI	-41.7684	-3.9731	7.6405	-30.1548	-0.3015	0.3403	Fair
140811	PHAK HAI	PHAK HAI	-22.5159	-8.7656	-28.0311	-41.7814	-0.4178	0.3001	Fair
140814	PHAK HAI	PHAK HAI	-31.8598	-35.5453	9.0890	12.7746	0.1277	0.4887	Fair
140815	PHAK HAI	PHAK HAI	-26.5762	-34.3389	12.7487	20.5113	0.2051	0.5155	Fair
140902	PHACHI	PHACHI	-29.4532	-9.8483	10.3814	-9.2235	-0.0922	0.4127	Fair
140903	PHACHI	PHACHI	-24.3970	-6.0401	-28.3827	-46.7396	-0.4674	0.2829	Fair
140904	PHACHI	PHACHI	0.7873	4.3791	4.8505	1.2587	0.0126	0.4489	Fair
140905	PHACHI	PHACHI	-21.6725	-39.0335	8.6883	26.0494	0.2605	0.5346	Fair
140906	PHACHI	PHACHI	10.4090	-25.2729	3.9992	39.6810	0.3968	0.5818	Good
140908	PHACHI	PHACHI	-29.0980	-12.1615	10.8948	-6.0417	-0.0604	0.4237	Fair
141001	LAT BUA LUANG	LAT BUA LUANG	-26.0234	-6.4343	10.2461	-9.3429	-0.0934	0.4122	Fair
141002	LAT BUA LUANG	LAT BUA LUANG	-35.2083	-4.5668	8.3387	-22.3028	-0.2230	0.3674	Fair
141003	LAT BUA LUANG	LAT BUA LUANG	-6.2611	11.0105	5.2537	-12.0179	-0.1202	0.4030	Fair
141004	LAT BUA LUANG	LAT BUA LUANG	-31.1062	13.4020	10.8754	-33.6328	-0.3363	0.3282	Fair
141005	LAT BUA LUANG	LAT BUA LUANG	-38.4219	26.7440	7.4370	-57.7289	-0.5773	0.2449	Poor
141006	LAT BUA LUANG	LAT BUA LUANG	-36.5003	-8.9021	7.9881	-19.6101	-0.1961	0.3767	Fair
141102	WANG NOI	WANG NOI	44.8940	7.9275	3.4186	40.3851	0.4039	0.5842	Good
141104	WANG NOI	WANG NOI	42.0891	5.9996	8.5724	44.6619	0.4466	0.5990	Good
141105	WANG NOI	WANG NOI	25.4652	16.8081	10.6660	19.3231	0.1932	0.5114	Fair
141106	WANG NOI	WANG NOI	41.8550	-13.3769	8.1584	63.3902	0.6339	0.6638	Good
141107	WANG NOI	WANG NOI	-40.7000	-11.0705	8.7771	-20.8523	-0.2085	0.3724	Fair
141108	WANG NOI	WANG NOI	44.5792	-16.6669	9.0447	70.2909	0.7029	0.6876	Good
141109	WANG NOI	WANG NOI	41.0824	-9.9723	-36.8077	14.2470	0.1425	0.4938	Fair
141110	WANG NOI	WANG NOI	44.2088	-25.2952	-36.3054	33.1986	0.3320	0.5594	Good
141202	SENA	SENA	11.7706	-3.1227	3.0285	17.9218	0.1792	0.5065	Fair
141204	SENA	SENA	-16.4398	-50.1633	9.5385	43.2619	0.4326	0.5942	Good
141205	SENA	SENA	21.5460	67.0133	18.6021	-26.8652	-0.2687	0.3516	Fair
141207	SENA	SENA	-36.0144	-15.9420	10.5178	-9.5545	-0.0955	0.4115	Fair
141208	SENA	SENA	-8.1774	13.4176	-32.7805	-54.3756	-0.5438	0.2565	Fair
141209	SENA	SENA	-29.9592	25.4150	4.6959	-50.6783	-0.5068	0.2693	Fair
141211	SENA	SENA	1.8991	-31.0217	-29.9899	2.9310	0.0293	0.4547	Fair
141212	SENA	SENA	-38.2137	20.3103	8.6961	-49.8280	-0.4983	0.2722	Fair
141213	SENA	SENA	-36.9636	-34.2702	8.4660	5.7726	0.0577	0.4645	Fair
141214	SENA	SENA	-33.0438	-48.2893	8.3171	23.5627	0.2356	0.5260	Fair
141215	SENA	SENA	-25.0163	-3.3870	12.8845	-8.7447	-0.0874	0.4143	Fair
141216	SENA	SENA	-31.5340	-28.9264	10.8253	8.2177	0.0822	0.4730	Fair
141301	BANG SAI	BANG SAI	6.4235	16.8983	11.2125	0.7377	0.0074	0.4471	Fair
141302	BANG SAI	BANG SAI	-18.8366	-36.7173	8.7121	26.5928	0.2659	0.5365	Fair
141303	BANG SAI	BANG SAI	-7.9534	27.5006	-33.2411	-68.6951	-0.6870	0.2070	Poor
141304	BANG SAI	BANG SAI	-30.8597	-44.6899	14.0277	27.8578	0.2786	0.5409	Fair

Table B.2 The resulted CSSI classification at sub-district level (Continued).

Sub-district ID	Sub-district name	District Name	WFac 1_3	WFac 2_3	WFac 3_3	Total WF	CSSI	Nor_ CSSI	CSSI_ Class
141306	BANG SAI	BANG SAI	-21.9811	-37.0420	-26.1328	-11.0719	-0.1107	0.4063	Fair
141401	UTHAI	UTHAI	58.2852	53.5442	12.1638	16.9047	0.1690	0.5030	Fair
141402	UTHAI	UTHAI	-17.1377	24.5586	7.3658	-34.3306	-0.3433	0.3258	Fair
141403	UTHAI	UTHAI	-32.8154	5.7999	9.7709	-28.8444	-0.2884	0.3448	Fair
141404	UTHAI	UTHAI	-31.2548	29.9302	8.1125	-53.0726	-0.5307	0.2610	Fair
141405	UTHAI	UTHAI	-25.0025	-32.1854	10.7758	17.9588	0.1796	0.5067	Fair
141406	UTHAI	UTHAI	55.0160	10.3208	12.5544	57.2496	0.5725	0.6425	Good
141407	UTHAI	UTHAI	-39.7880	-1.0493	6.9070	-31.8317	-0.3183	0.3345	Fair
141408	UTHAI	UTHAI	-34.2355	-42.9843	10.1567	18.9055	0.1891	0.5099	Fair
141409	UTHAI	UTHAI	-35.7139	14.4397	8.3891	-41.7645	-0.4176	0.3001	Fair
141410	UTHAI	UTHAI	78.4490	10.0441	3.3062	71.7111	0.7171	0.6926	Good
141411	UTHAI	UTHAI	-22.2786	1.3643	5.4542	-18.1887	-0.1819	0.3816	Fair
141502	MAHARAT	MAHARAT	-30.5793	-5.1989	-27.0497	-52.4301	-0.5243	0.2632	Fair
141505	MAHARAT	MAHARAT	-15.0844	-34.5077	12.4290	31.8523	0.3185	0.5547	Good
141509	MAHARAT	MAHARAT	-31.7317	-10.3679	9.1980	-12.1658	-0.1217	0.4025	Fair
141510	MAHARAT	MAHARAT	-18.1783	-45.4458	11.8065	39.0739	0.3907	0.5797	Good
141511	MAHARAT	MAHARAT	12.6386	-9.0748	9.7905	31.5039	0.3150	0.5535	Good
141512	MAHARAT	MAHARAT	4.5836	-21.2553	-30.1435	-4.3047	-0.0430	0.4297	Fair
141601	BAN PHRAEK	BAN PHRAEK	-36.8533	-42.9082	9.0832	15.1381	0.1514	0.4969	Fair
141602	BAN PHRAEK	BAN PHRAEK	6.6136	36.4162	-34.5949	-64.3975	-0.6440	0.2218	Poor
141603	BAN PHRAEK	BAN PHRAEK	-32.8284	-2.6571	8.4925	-21.6788	-0.2168	0.3696	Fair
141604	BAN PHRAEK	BAN PHRAEK	-44.0980	7.0987	6.8324	-44.3643	-0.4436	0.2911	Fair
141605	BAN PHRAEK	BAN PHRAEK	-23.8046	61.1516	-32.8982	-117.8544	-1.1785	0.0370	Poor

Table B.3 The resulted CEnSI classification at sub-district level.

Sub-district ID	Sub-district name	District Name	FAC1_2	CEnSI	Nor_CEnSI	EnSI_Class
140107	PAK KRAN	PHRA NAKHON SI AYUTTHAYA	-0.6838	-0.5339	0.0000	Good
140108	PHU KHAO THONG	PHRA NAKHON SI AYUTTHAYA	-0.6838	-0.5339	0.0322	Good
140109	SAMPHAO LOM	PHRA NAKHON SI AYUTTHAYA	-0.1228	-0.0959	0.1263	Fair
140110	SUAN PHRIK	PHRA NAKHON SI AYUTTHAYA	0.2592	0.2024	0.1903	Fair
140111	KHLONG TAKHIAN	PHRA NAKHON SI AYUTTHAYA	-0.3937	-0.3074	0.0808	Fair
140112	WAT TUM	PHRA NAKHON SI AYUTTHAYA	-0.6838	-0.5339	0.0322	Good
140113	HAN TRA	PHRA NAKHON SI AYUTTHAYA	0.0375	0.0293	0.1532	Fair
140114	LUMPHLI	PHRA NAKHON SI AYUTTHAYA	-0.6838	-0.5339	0.0322	Good
140115	BAN MAI	PHRA NAKHON SI AYUTTHAYA	0.1765	0.1378	0.1765	Fair
140116	BAN KO	PHRA NAKHON SI AYUTTHAYA	-0.4691	-0.3663	0.0682	Fair
140117	KHLONG SUAN PHLU	PHRA NAKHON SI AYUTTHAYA	-0.6838	-0.5339	0.0322	Good
140119	KO RIAN	PHRA NAKHON SI AYUTTHAYA	0.0375	0.0293	0.1532	Fair
140120	BAN POM	PHRA NAKHON SI AYUTTHAYA	-0.4154	-0.3243	0.0772	Fair
140121	BAN RUN	PHRA NAKHON SI AYUTTHAYA	-0.6838	-0.5339	0.0322	Good
140202	CHAMPA	THA RUEA	-0.2805	-0.2190	0.0998	Fair
140203	THA LUANG	THA RUEA	0.4703	0.3673	0.2258	Fair
140204	BAN ROM	THA RUEA	-0.2475	-0.1932	0.1054	Fair
140206	WANG DAENG	THA RUEA	-0.1982	-0.1548	0.1136	Fair
140207	PHO EN	THA RUEA	0.0287	0.0224	0.1517	Fair
140208	PAK THA	THA RUEA	-0.4622	-0.3609	0.0694	Fair
140209	NONG KHANAK	THA RUEA	-0.2316	-0.1809	0.1080	Fair
140210	THA CHAO SANUK	THA RUEA	0.8451	0.6599	0.2886	Fair
140303	BO PHONG	NAKHON LUANG	1.2196	0.9523	0.3514	Poor
140304	BAN CHUNG	NAKHON LUANG	-0.4143	-0.3235	0.0774	Fair
140305	PAK CHAN	NAKHON LUANG	0.8211	0.6411	0.2846	Fair
140306	BANG RAKAM	NAKHON LUANG	-0.3694	-0.2884	0.0849	Fair
140307	BANG PHRAKHRU	NAKHON LUANG	2.8932	2.2591	0.6321	Poor
140308	MAE LA	NAKHON LUANG	-0.3694	-0.2884	0.0849	Fair
140309	NONG PLING	NAKHON LUANG	-0.2227	-0.1739	0.1095	Fair
140310	KHLONG SAKAE	NAKHON LUANG	2.6438	2.0644	0.5903	Poor
140403	SANAM CHAI	BANG SAI	-0.5603	-0.4375	0.0529	Fair
140404	BAN PAENG	BANG SAI	-0.6838	-0.5339	0.0322	Good
140405	NA MAI	BANG SAI	-0.6838	-0.5339	0.0322	Good
140407	KHAE OK	BANG SAI	-0.4593	-0.3586	0.0698	Fair

Table B.3 The resulted CEnSI classification at sub-district level (Continued).

Sub-district ID	Sub-district name	District Name	FAC1_2	CEnSI	Nor_CEnSI	EnSI_Class
140408	KHAE TOK	BANG SAI	-0.6838	-0.5339	0.0322	Good
140409	CHANG LEK	BANG SAI	-0.6838	-0.5339	0.0322	Good
140410	KRACHAENG	BANG SAI	-0.4202	-0.3281	0.0764	Fair
140411	BAN KLUENG	BANG SAI	-0.5450	-0.4255	0.0555	Fair
140412	CHANG NOI	BANG SAI	-0.5850	-0.4568	0.0488	Good
140413	HO MOK	BANG SAI	-0.4952	-0.3866	0.0638	Fair
140415	KOK KAEO BURAPHA	BANG SAI	-0.5191	-0.4053	0.0598	Fair
140416	MAI TRA	BANG SAI	-0.5610	-0.4380	0.0528	Fair
140417	BAN MA	BANG SAI	-0.5715	-0.4463	0.0510	Fair
140418	BAN KO	BANG SAI	-0.1965	-0.1534	0.1139	Fair
140421	PHO TAENG	BANG SAI	-0.6838	-0.5339	0.0322	Good
140422	CHIANG RAK NOI	BANG SAI	-0.5276	-0.4120	0.0584	Fair
140423	KHOK CHANG	BANG SAI	-0.4593	-0.3586	0.0698	Fair
140506	KOP CHAO	BANG BAN	-0.5610	-0.4380	0.0528	Fair
140507	BAN KHLANG	BANG BAN	-0.5555	-0.4337	0.0537	Fair
140509	NAMTAO	BANG BAN	0.3307	0.2582	0.2023	Fair
140510	THANG CHANG	BANG BAN	-0.0948	-0.0740	0.1310	Fair
140511	WAT TAKU	BANG BAN	-0.5715	-0.4463	0.0510	Fair
140512	BANG LUANG	BANG BAN	-0.4622	-0.3609	0.0694	Fair
140602	CHIANG RAK NOI	BANG PA-IN	-0.2475	-0.1932	0.1054	Fair
140603	BAN PHO	BANG PA-IN	-0.1383	-0.1080	0.1237	Fair
140604	BAN KROT	BANG PA-IN	0.6861	0.5357	0.2619	Fair
140605	BANG KRASAN	BANG PA-IN	2.4249	1.8935	0.5536	Poor
140606	KHLONG CHIK	BANG PA-IN	-0.5603	-0.4375	0.0529	Fair
140607	BAN WA	BANG PA-IN	0.4377	0.3418	0.2203	Fair
140608	WAT YOM	BANG PA-IN	0.3743	0.2922	0.2096	Fair
140609	BANG PRADAENG	BANG PA-IN	-0.5274	-0.4118	0.0584	Fair
140610	SAM RUEAN	BANG PA-IN	-0.5588	-0.4364	0.0531	Fair
140615	TALING CHAN	BANG PA-IN	-0.2953	-0.2306	0.0973	Fair
140617	TALAT KRIAP	BANG PA-IN	-0.4367	-0.3410	0.0736	Fair
140618	KHANON LUANG	BANG PA-IN	-0.5610	-0.4380	0.0528	Fair
140701	BANG PAHAN	BANG PAHAN	0.4492	0.3508	0.2222	Fair
140702	KHAYAI	BANG PAHAN	-0.0526	-0.0411	0.1380	Fair
140703	BANG DUEA	BANG PAHAN	-0.2805	-0.2190	0.0998	Fair
140704	SAO THONG	BANG PAHAN	-0.5940	-0.4638	0.0472	Good
140705	THANG KLANG	BANG PAHAN	-0.3724	-0.2908	0.0844	Fair
140707	HAN SANG	BANG PAHAN	0.0296	0.0231	0.1518	Fair
140708	BANG NANG RA	BANG PAHAN	0.6277	0.4901	0.2521	Fair
140709	TANIM	BANG PAHAN	-0.2805	-0.2190	0.0998	Fair
140710	THAP NAM	BANG PAHAN	-0.6838	-0.5339	0.0322	Good
140711	BAN MA	BANG PAHAN	0.6295	0.4916	0.2525	Fair
140713	BAN LI	BANG PAHAN	0.0178	0.0139	0.1498	Fair
140714	PHO SAM TON	BANG PAHAN	2.2015	1.7190	0.5161	Poor
140715	PHUT LAO	BANG PAHAN	2.3083	1.8024	0.5340	Poor
140716	TAN EN	BANG PAHAN	-0.3976	-0.3104	0.0802	Fair
140801	PHAK HAI	PHAK HAI	1.1390	0.8894	0.3379	Poor
140803	BAN KHAE	PHAK HAI	2.7050	2.1122	0.6005	Poor

Table B.3 The resulted CEnSI classification at sub-district level (Continued).

Sub-district ID	Sub-district name	District Name	FAC1_2	CEnSI	Nor_CEnSI	EnSI_Class
140804	LAT NAM KHEM	PHAK HAI	-0.0871	-0.0680	0.1323	Fair
140806	THA DIN DAENG	PHAK HAI	5.0867	3.9719	1.0000	Poor
140807	DON LAN	PHAK HAI	5.0867	3.9719	1.0000	Poor
140808	NA KHU	PHAK HAI	-0.4952	-0.3866	0.0638	Fair
140809	KUDI	PHAK HAI	-0.2708	-0.2115	0.1014	Fair
140810	LAM TAKHIAN	PHAK HAI	-0.6838	-0.5339	0.0322	Good
140811	KHOK CHANG	PHAK HAI	-0.6838	-0.5339	0.0322	Good
140814	LAT CHIT	PHAK HAI	-0.6838	-0.5339	0.0322	Good
140815	NA KHOK	PHAK HAI	-0.4237	-0.3308	0.0758	Fair
140902	KHOK MUANG	PHACHI	-0.1968	-0.1537	0.1139	Fair
140903	RASOM	PHACHI	-0.6838	-0.5339	0.0322	Good
140904	NONG NAM SAI	PHACHI	0.0375	0.0293	0.1532	Fair
140905	DON YA NANG	PHACHI	-0.2953	-0.2306	0.0973	Fair
140906	PHAI LOM	PHACHI	-0.1587	-0.1239	0.1203	Fair
140908	PHRA KAEO	PHACHI	-0.3044	-0.2377	0.0958	Fair
141001	LAT BUA LUANG	LAT BUA LUANG	0.3916	0.3058	0.2125	Fair
141002	LAK CHAI	LAT BUA LUANG	-0.3964	-0.3095	0.0804	Fair
141003	SAM MUEANG	LAT BUA LUANG	0.0375	0.0293	0.1532	Fair
141004	PHRAYA BANLUE	LAT BUA LUANG	0.3062	0.2391	0.1982	Fair
141005	SINGHANAT	LAT BUA LUANG	-0.6838	-0.5339	0.0322	Good
141006	KHU SALOT	LAT BUA LUANG	-0.4054	-0.3165	0.0789	Fair
141102	BO TA LO	WANG NOI	0.5474	0.4275	0.2387	Fair
141104	LAM SAI	WANG NOI	1.2529	0.9783	0.3570	Poor
141105	SANAP THUEP	WANG NOI	0.2749	0.2146	0.1930	Fair
141106	PHAYOM	WANG NOI	-0.5042	-0.3937	0.0623	Fair
141107	HAN TAPHAO	WANG NOI	-0.5042	-0.3937	0.0623	Fair
141108	WANG CHULA	WANG NOI	0.8022	0.6264	0.2814	Fair
141109	KHAO NGAM	WANG NOI	0.7159	0.5590	0.2669	Fair
141110	CHAMAEP	WANG NOI	0.7308	0.5706	0.2694	Fair
141202	BAN PHAEN	SENA	-0.0427	-0.0333	0.1397	Fair
141204	SAM KO	SENA	-0.3358	-0.2622	0.0906	Fair
141205	BANG NOM KHO	SENA	1.8231	1.4236	0.4526	Poor
141207	MAN WICHAI	SENA	-0.5940	-0.4638	0.0472	Good
141208	BAN PHO	SENA	-0.6838	-0.5339	0.0322	Good
141209	RANG CHORAKHE	SENA	-0.6838	-0.5339	0.0322	Good
141211	BAN THAEO	SENA	-0.5276	-0.4120	0.0584	Fair
141212	CHAI NA	SENA	-0.1514	-0.1182	0.1215	Fair
141213	SAM TUM	SENA	-0.6838	-0.5339	0.0322	Good
141214	LAT NGA	SENA	-0.3378	-0.2638	0.0902	Fair
141215	DON THONG	SENA	-0.4712	-0.3679	0.0678	Fair
141216	BAN LUANG	SENA	-0.1357	-0.1060	0.1241	Fair
141301	BANG SAI	BANG SAI	0.4792	0.3742	0.2272	Fair
141302	KAEO FA	BANG SAI	-0.6838	-0.5339	0.0322	Good
141303	TAO LAO	BANG SAI	-0.6838	-0.5339	0.0322	Good

Table B.3 The resulted CEnSI classification at sub-district level (Continued).

Sub-district ID	Sub-district name	District Name	FAC1_2	CEnSI	Nor_CEnSI	EnSI_Class
141304	PLAI KLAT	BANG SAI	-0.6015	-0.4696	0.0460	Good
141306	WANG PHATTHANA	BANG SAI	-0.3741	-0.2921	0.0841	Fair
141401	KHAN HAM	UTHAI	3.2081	2.5050	0.6849	Poor
141402	BAN CHANG	UTHAI	-0.4712	-0.3679	0.0678	Fair
141403	SAM BANDIT	UTHAI	-0.5610	-0.4380	0.0528	Fair
141404	BAN HIP	UTHAI	-0.6838	-0.5339	0.0322	Good
141405	NONG MAI SUNG	UTHAI	-0.6838	-0.5339	0.0322	Good
141406	UTHAI	UTHAI	0.4703	0.3673	0.2258	Fair
141407	SENA	UTHAI	-0.0665	-0.0519	0.1357	Fair
141408	NONG NAM SOM	UTHAI	-0.0821	-0.0641	0.1331	Fair
141409	PHO SAO HAN	UTHAI	-0.5610	-0.4380	0.0528	Fair
141410	THANU	UTHAI	1.0288	0.8033	0.3194	Poor
141411	KHAO MAO	UTHAI	-0.6838	-0.5339	0.0322	Good
141502	KATHUM	MAHARAT	-0.5940	-0.4638	0.0472	Good
141505	BANG NA	MAHARAT	-0.4691	-0.3663	0.0682	Fair
141509	BAN NA	MAHARAT	-0.2995	-0.2338	0.0966	Fair
141510	BAN KHWANG	MAHARAT	-0.4593	-0.3586	0.0698	Fair
141511	THA TO	MAHARAT	-0.2348	-0.1833	0.1075	Fair
141512	BAN MAI	MAHARAT	-0.4691	-0.3663	0.0682	Fair
141601	BAN PHRAEK	BAN PHRAEK	-0.2506	-0.1957	0.1048	Fair
141602	BAN MAI	BAN PHRAEK	0.0229	0.0179	0.1507	Fair
141603	SAM PHANIANG	BAN PHRAEK	-0.2953	-0.2306	0.0973	Fair
141604	KHLONG NOI	BAN PHRAEK	-0.6838	-0.5339	0.0322	Good
141605	SONG HONG	BAN PHRAEK	-0.6838	-0.5339	0.0322	Good

Table B.4 The resulted CTSI classification at sub-district level.

Sub-district ID	Sub-district name	District Name	FAC1_2	TSI	Normal_TSI	TSI_Class
140107	PAK KRAN	PHRA NAKHON SI AYUTTHAYA	-0.6347	-0.4211	0.1943	Fair
140108	PHU KHAO THONG	PHRA NAKHON SI AYUTTHAYA	-1.0237	-0.6792	0.1201	Poor
140109	SAMPHAO LOM	PHRA NAKHON SI AYUTTHAYA	-1.0910	-0.7238	0.1072	Poor
140110	SUAN PHRIK	PHRA NAKHON SI AYUTTHAYA	0.7932	0.5263	0.4668	Good
140111	KHLONG TAKHIAN	PHRA NAKHON SI AYUTTHAYA	-0.1732	-0.1149	0.2824	Fair
140112	WAT TUM	PHRA NAKHON SI AYUTTHAYA	0.0526	0.0349	0.3255	Fair
140113	HAN TRA	PHRA NAKHON SI AYUTTHAYA	0.6240	0.4140	0.4345	Fair
140114	LUMPHLI	PHRA NAKHON SI AYUTTHAYA	-0.8818	-0.5850	0.1471	Poor
140115	BAN MAI	PHRA NAKHON SI AYUTTHAYA	0.5334	0.3539	0.4172	Fair
140116	BAN KO	PHRA NAKHON SI AYUTTHAYA	0.3053	0.2026	0.3737	Fair
140117	KHLONG SUAN PHLU	PHRA NAKHON SI AYUTTHAYA	-0.6300	-0.4179	0.1952	Fair
140119	KO RIAN	PHRA NAKHON SI AYUTTHAYA	0.2883	0.1913	0.3705	Fair
140120	BAN POM	PHRA NAKHON SI AYUTTHAYA	-0.4558	-0.3024	0.2285	Fair
140121	BAN RUN	PHRA NAKHON SI AYUTTHAYA	-0.2505	-0.1662	0.2676	Fair
140202	CHAMPA	THA RUEA	0.8137	0.5399	0.4707	Good
140203	THA LUANG	THA RUEA	-0.1773	-0.1176	0.2816	Fair
140204	BAN ROM	THA RUEA	-0.3655	-0.2425	0.2457	Fair
140206	WANG DAENG	THA RUEA	-0.7031	-0.4665	0.1813	Fair
140207	PHO EN	THA RUEA	0.2157	0.1431	0.3566	Fair
140208	PAK THA	THA RUEA	-1.0035	-0.6657	0.1239	Poor
140209	NONG KHANAK	THA RUEA	-0.0826	-0.0548	0.2997	Fair
140210	THA CHAO SANUK	THA RUEA	1.7729	1.1762	0.6538	Good
140303	BO PHONG	NAKHON LUANG	2.4000	1.5922	0.7734	Good
140304	BAN CHUNG	NAKHON LUANG	-0.3076	-0.2041	0.2567	Fair
140305	PAK CHAN	NAKHON LUANG	2.4448	1.6220	0.7820	Good
140306	BANG RAKAM	NAKHON LUANG	0.1406	0.0933	0.3423	Fair
140307	BANG PHRAKHRU	NAKHON LUANG	3.4758	2.3060	0.9787	Good
140308	MAE LA	NAKHON LUANG	0.6031	0.4001	0.4305	Fair
140309	NONG PLING	NAKHON LUANG	-0.4781	-0.3172	0.2242	Fair
140310	KHLONG SAKAE	NAKHON LUANG	3.5872	2.3799	1.0000	Good
140403	SANAM CHAI	BANG SAI	-1.0933	-0.7254	0.1068	Poor
140404	BAN PAENG	BANG SAI	-0.5348	-0.3548	0.2134	Fair
140405	NA MAI	BANG SAI	-0.3446	-0.2286	0.2497	Fair
140407	KHAE OK	BANG SAI	-0.2501	-0.1659	0.2677	Fair

Table B.4 The resulted CTSI classification at sub-district level (Continued).

Sub-district ID	Sub-district name	District Name	FAC1_2	TSI	Normal_TSI	TSI_Class
140408	KHAE TOK	BANG SAI	-0.7745	-0.5139	0.1676	Poor
140409	CHANG LEK	BANG SAI	-0.1173	-0.0778	0.2930	Fair
140410	KRACHAENG	BANG SAI	-0.5864	-0.3891	0.2035	Fair
140411	BAN KLUENG	BANG SAI	-0.2585	-0.1715	0.2661	Fair
140412	CHANG NOI	BANG SAI	-0.1308	-0.0868	0.2905	Fair
140413	HO MOK	BANG SAI	-1.0068	-0.6680	0.1233	Poor
140415	KOK KAEO BURAPHA	BANG SAI	-0.7566	-0.5020	0.1710	Fair
140416	MAI TRA	BANG SAI	-0.7399	-0.4909	0.1742	Fair
140417	BAN MA	BANG SAI	-0.9202	-0.6105	0.1398	Poor
140418	BAN KO	BANG SAI	-0.4577	-0.3037	0.2281	Fair
140421	PHO TAENG	BANG SAI	-0.9606	-0.6373	0.1321	Poor
140422	CHIANG RAK NOI	BANG SAI	-0.3392	-0.2251	0.2507	Fair
140423	KHOK CHANG	BANG SAI	-0.4844	-0.3214	0.2230	Fair
140506	KOP CHAO	BANG BAN	-0.0576	-0.0382	0.3044	Fair
140507	BAN KHLANG	BANG BAN	-0.2891	-0.1918	0.2603	Fair
140509	NAMTAO	BANG BAN	-0.0055	-0.0037	0.3144	Fair
140510	THANG CHANG	BANG BAN	-0.8000	-0.5308	0.1628	Poor
140511	WAT TAKU	BANG BAN	-0.7084	-0.4700	0.1802	Fair
140512	BANG LUANG	BANG BAN	-0.9128	-0.6056	0.1412	Poor
140602	CHIANG RAK NOI	BANG PA-IN	-0.5436	-0.3606	0.2117	Fair
140603	BAN PHO	BANG PA-IN	-0.3512	-0.2330	0.2484	Fair
140604	BAN KROT	BANG PA-IN	0.4874	0.3233	0.4084	Fair
140605	BANG KRASAN	BANG PA-IN	3.1300	2.0766	0.9127	Good
140606	KHLONG CHIK	BANG PA-IN	-0.2520	-0.1672	0.2673	Fair
140607	BAN WA	BANG PA-IN	0.8862	0.5879	0.4845	Good
140608	WAT YOM	BANG PA-IN	0.6623	0.4394	0.4418	Fair
140609	BANG PRADAENG	BANG PA-IN	-0.5149	-0.3416	0.2172	Fair
140610	SAM RUEAN	BANG PA-IN	-0.9151	-0.6071	0.1408	Poor
140615	TALING CHAN	BANG PA-IN	-1.1008	-0.7303	0.1054	Poor
140617	TALAT KRIAP	BANG PA-IN	-0.7132	-0.4732	0.1793	Fair
140618	KHANON LUANG	BANG PA-IN	-0.5049	-0.3349	0.2191	Fair
140701	BANG PAHAN	BANG PAHAN	1.0743	0.7127	0.5204	Good
140702	KHAYAI	BANG PAHAN	0.1343	0.0891	0.3411	Fair
140703	BANG DUEA	BANG PAHAN	0.3749	0.2487	0.3870	Fair
140704	SAO THONG	BANG PAHAN	-0.4624	-0.3067	0.2272	Fair
140705	THANG KLANG	BANG PAHAN	-0.8320	-0.5520	0.1567	Poor
140707	HAN SANG	BANG PAHAN	0.1631	0.1082	0.3466	Fair
140708	BANG NANG RA	BANG PAHAN	1.8880	1.2526	0.6757	Good
140709	TANIM	BANG PAHAN	0.9080	0.6024	0.4887	Good
140710	THAP NAM	BANG PAHAN	0.1145	0.0760	0.3373	Fair
140711	BAN MA	BANG PAHAN	0.5983	0.3969	0.4296	Fair
140713	BAN LI	BANG PAHAN	0.5096	0.3381	0.4127	Fair
140714	PHO SAM TON	BANG PAHAN	2.2961	1.5233	0.7536	Good
140715	PHUT LAO	BANG PAHAN	2.0841	1.3827	0.7132	Good
140716	TAN EN	BANG PAHAN	-0.3755	-0.2491	0.2438	Fair
140801	PHAK HAI	PHAK HAI	-0.0353	-0.0234	0.3087	Fair

Table B.4 The resulted CTSI classification at sub-district level (Continued).

Sub-district ID	Sub-district name	District Name	FAC1_2	TSI	Normal_TSI	TSI_Class
140803	BAN KHAE	PHAK HAI	1.5922	1.0563	0.6193	Good
140804	LAT NAM KHEM	PHAK HAI	-0.5211	-0.3458	0.2160	Fair
140806	THA DIN DAENG	PHAK HAI	0.9886	0.6559	0.5041	Good
140807	DON LAN	PHAK HAI	1.8900	1.2539	0.6761	Good
140808	NA KHU	PHAK HAI	-0.2911	-0.1932	0.2599	Fair
140809	KUDI	PHAK HAI	-0.7160	-0.4750	0.1788	Fair
140810	LAM TAKHIAN	PHAK HAI	-0.8660	-0.5745	0.1502	Poor
140811	KHOK CHANG	PHAK HAI	-0.9674	-0.6418	0.1308	Poor
140814	LAT CHIT	PHAK HAI	-0.6638	-0.4404	0.1888	Fair
140815	NA KHOK	PHAK HAI	-0.0429	-0.0285	0.3072	Fair
140902	KHOK MUANG	PHACHI	-0.2720	-0.1804	0.2635	Fair
140903	RASOM	PHACHI	-1.0481	-0.6954	0.1154	Poor
140904	NONG NAM SAI	PHACHI	-0.0442	-0.0294	0.3070	Fair
140905	DON YA NANG	PHACHI	-0.1439	-0.0955	0.2880	Fair
140906	PHAI LOM	PHACHI	0.1826	0.1211	0.3503	Fair
140908	PHRA KAEO	PHACHI	-0.3201	-0.2124	0.2543	Fair
141001	LAT BUA LUANG	LAT BUA LUANG	-0.3186	-0.2114	0.2546	Fair
141002	LAK CHAI	LAT BUA LUANG	-0.4119	-0.2733	0.2368	Fair
141003	SAM MUEANG	LAT BUA LUANG	-0.3199	-0.2123	0.2544	Fair
141004	PHRAYA BANLUE	LAT BUA LUANG	-0.4454	-0.2955	0.2304	Fair
141005	SINGHANAT	LAT BUA LUANG	-0.9759	-0.6474	0.1292	Poor
141006	KHU SALOT	LAT BUA LUANG	-0.4844	-0.3213	0.2230	Fair
141102	BO TA LO	WANG NOI	1.1377	0.7548	0.5325	Good
141104	LAM SAI	WANG NOI	2.0105	1.3338	0.6991	Good
141105	SANAP THUEP	WANG NOI	0.7643	0.5071	0.4613	Good
141106	PHAYOM	WANG NOI	0.7214	0.4786	0.4531	Fair
141107	HAN TAPHAO	WANG NOI	-0.8020	-0.5321	0.1624	Poor
141108	WANG CHULA	WANG NOI	1.7109	1.1351	0.6419	Good
141109	KHAO NGAM	WANG NOI	0.4520	0.2999	0.4017	Fair
141110	CHAMAEP	WANG NOI	0.9059	0.6010	0.4883	Good
141202	BAN PHAEN	SENA	0.1545	0.1025	0.3449	Fair
141204	SAM KO	SENA	-0.0840	-0.0558	0.2994	Fair
141205	BANG NOM KHO	SENA	1.6030	1.0635	0.6213	Good
141207	MAN WICHAI	SENA	-0.6405	-0.4250	0.1932	Fair
141208	BAN PHO	SENA	-0.7596	-0.5039	0.1705	Fair
141209	RANG CHORAKHE	SENA	-1.0635	-0.7056	0.1125	Poor
141211	BAN THAEO	SENA	-0.0956	-0.0634	0.2972	Fair
141212	CHAI NA	SENA	-0.6120	-0.4061	0.1986	Fair
141213	SAM TUM	SENA	-0.5657	-0.3753	0.2075	Fair
141214	LAT NGA	SENA	-0.3177	-0.2108	0.2548	Fair
141215	DON THONG	SENA	-0.4888	-0.3243	0.2221	Fair
141216	BAN LUANG	SENA	-0.3411	-0.2263	0.2503	Fair
141301	BANG SAI	BANG SAI	0.1066	0.0708	0.3358	Fair

Table B.4 The resulted CTSI classification at sub-district level (Continued).

Sub-district ID	Sub-district name	District Name	FAC1_2	TSI	Normal_TSI	TSI_Class
141302	KAEO FA	BANG SAI	-0.4364	-0.2895	0.2322	Fair
141303	TAO LAO	BANG SAI	-1.1889	-0.7887	0.0886	Poor
141304	PLAI KLAT	BANG SAI	-0.4334	-0.2875	0.2327	Fair
141306	WANG PHATTHANA	BANG SAI	-0.5553	-0.3684	0.2095	Fair
141401	KHAN HAM	UTHAI	3.2294	2.1425	0.9317	Good
141402	BAN CHANG	UTHAI	-0.3935	-0.2610	0.2403	Fair
141403	SAM BANDIT	UTHAI	-0.5384	-0.3572	0.2127	Fair
141404	BAN HIP	UTHAI	-0.8379	-0.5559	0.1555	Poor
141405	NONG MAI SUNG	UTHAI	-0.2088	-0.1385	0.2756	Fair
141406	UTHAI	UTHAI	0.9193	0.6099	0.4909	Good
141407	SENA	UTHAI	-0.8678	-0.5757	0.1498	Poor
141408	NONG NAM SOM	UTHAI	-0.2648	-0.1757	0.2649	Fair
141409	PHO SAO HAN	UTHAI	-0.8248	-0.5472	0.1580	Poor
141410	THANU	UTHAI	1.8720	1.2419	0.6727	Good
141411	KHAO MAO	UTHAI	-0.6916	-0.4588	0.1835	Fair
141502	KATHUM	MAHARAT	-1.1209	-0.7436	0.1015	Poor
141505	BANG NA	MAHARAT	-0.1872	-0.1242	0.2797	Fair
141509	BAN NA	MAHARAT	-0.4117	-0.2731	0.2369	Fair
141510	BAN KHWANG	MAHARAT	0.0899	0.0596	0.3326	Fair
141511	THA TO	MAHARAT	0.8853	0.5874	0.4844	Good
141512	BAN MAI	MAHARAT	-0.0699	-0.0463	0.3021	Fair
141601	BAN PHRAEK	BAN PHRAEK	-0.3807	-0.2526	0.2428	Fair
141602	BAN MAI	BAN PHRAEK	-0.3906	-0.2591	0.2409	Fair
141603	SAM PHANIANG	BAN PHRAEK	-0.7386	-0.4900	0.1745	Fair
141604	KHLONG NOI	BAN PHRAEK	-1.0927	-0.7250	0.1069	Poor
141605	SONG HONG	BAN PHRAEK	-1.6529	-1.0966	0.0000	Poor

APPENDIX C

GEOGRAPHICALLY WEIGHTED REGRESSION THEORY

Geographically Weighted Regression (GWR)

A recently statistical technique, Geographically Weighted Regression (GWR), developed by Fotheringham, Brunderson and Charlton in 1996 is an extension of the traditional standard regression framework. GWR is a local spatial statistical technique used to analyze spatial non-stationarity, defined as when the measurement of relationships among variables differs from location to location (Fotheringham et al., 2002). GWR is promoted as a means of removing spatial non-stationarity through local analysis. In standard applications of regression known as Ordinary Least Square (OLS), a dependent variable is linked to a set of independent variables with one of the main outputs of regression being the estimation of parameter that links each independent variable to the dependent variable. In GWR, instead of calibrating a single regression equation, GWR generates a separate regression equation for each observation. Each equation is calibrated using a different weighting of the observations contained in the data set. Each GWR equation may be expressed as

$$\hat{Y}_i = \beta_o(u_i, v_i) + \sum_k \beta_k(u_i, v_i)\, x_{ik} + \varepsilon_i$$

Where (u_i ,v_i) captures the coordinate location of i in space and $\beta_k (u_i ,v_i)$ is a realization of continuous function $\beta_k (u,v)$ at point i (Fotheringham et al., 2002).

In the case of spatial data, the distance between observations is calculated as the distance between polygon centroids. The distance decay function, which may take a variety of forms, is modified by a bandwidth setting at which distance the weight rapidly approaches zero. The bandwidth may be manually chosen by the analyst or optimized using an algorithm that seeks to minimize a cross-validation score (CV), given as

$$\mathrm{CV} \quad = \quad \sum_i (\mathrm{Y}_i - \hat{\mathrm{Y}}_{i \neq i})^2$$

Where i s the number of observations, and observation i is omitted from calculation so that in areas of sparse observations the model is not calibrated solely on i. Alternatively, the bandwidth may be chosen by minimizing the Akaike Information Criteria (AIC) score, given as

$$\mathrm{AIC} \;=\; 2\mathrm{n}\, \log_{c} (\sigma') + \mathrm{n}\, \log_{c} (2\text{л}) + \mathrm{n}\, \{(\mathrm{n}+tr(\mathrm{s}))/(\mathrm{n}-2-tr(\mathrm{s}))\} \qquad (6.6)$$

Where tr(s) is the trace of the hat matrix. The AIC method has advantage of taking into account the fact that the degree of freedom may vary among models centered on different observations. Comparisons of the AICc values from multiple models with the same independent variable provide a relatively simple way to decide the best model. A lower AICc value indicates a closer approximation of the model to reality (Wang et al., 2005).

Interpreting GWR results

A common approach to regression analysis is to identify the very best OLS model possible, before moving to GWR regression (Mitchell, 2005).

Examine the statistical report

1. Bandwidth or Neighbours this is the bandwidth or number of neighbors used for each local estimation and is perhaps the most important parameter for Geographically Weighted Regression. It controls the degree of smoothing in the model.

2. Residual Squares: this is the sum of the squared residuals in the model. The smaller this measure, the closer the fit of the GWR model to the observed data. This value is used in a number of other diagnostic measures.

3. Effective Number: this value reflects a tradeoff between the variance of the fitted values and the bias in the coefficient estimates, and is related to the choice of bandwidth. The effective number is used to compute a number of diagnostic measures.

4. Sigma: this value is the square root of the normalized residual sum of squares where the residual sum of squares is divided by the effective degrees of freedom of the residual. This is the estimated standard deviation for the residuals. Smaller values of this statistic are preferable.

5. AICc: this is a measure of model performance and is helpful for comparing different regression models. Taking into account model complexity, the model with the lower AICc value provides a better fit to the observed data. If the AICc values for two models differ by more than 3, the model with the lower AICc is held to be better.

6. R^2: R-Squared is a measure of goodness of fit. Its value varies from 0.0 to 1.0, with higher values being preferable. It may be interpreted as the proportion of dependent variable variance accounted for by the regression model.

7. R^2 Adjusted: Because of the problem described above for the R2 value, calculations for the adjusted R-squared value normalize the numerator and denominator by their degrees of freedom. This has the effect of compensating for the number of variables in a model, and consequently the Adjusted R2 value is almost always smaller than the R2 value.

Examine the output feature class residuals.

1. Condition Number: this diagnostic evaluates local collinearity. In the presence of strong local collinearity, results become unstable. Results associated with condition numbers larger than 30, may be unreliable.

2. Local R2: these values range between 0.0 and 1.0 and indicate how well the local regression model fits observed y values. Very low values indicate the local model is performing poorly.

3. Predicted: these are the estimated (or fitted) y values computed by GWR.

4. Residuals: to obtain the residual values, the fitted y values are subtracted from the observed y values. Standardized residuals have a mean of zero and a standard deviation of 1.

5. Coefficient Standard Error: these values measure the reliability of each coefficient estimate. Confidence in those estimates are higher when standard errors are small in relation to the actual coefficient values. Large standard errors may indicate problems with local collinearity.

CURRICULUM VITAE

Name : Miss Suriporn Charungthanakij

Place of Birth : Nakhon Sawan

Education :

1987 Master of Business Administration, Faculty of Commerce and Accountancy, Chulalongkorn University, Bangkok, Thailand.

1982 Bachelor of Arts (Economics), Faculty of Economics, Thammasat University, Bangkok, Thailand.

Grants and Fellowships : The Royal Thai Government Scholarships from the Commission on Higher Education.

Position and Place of Work :

Lecturer in Geography Department, Faculty of Arts, Silpakorn University, Sanamchandra Palace Campus, Nakhon Pathom, Thailand. 73000. Tel.034-255840.

E-mail Address**:** scharung@hotmail.com, scharung@gmail.com, suriporn@su.ac.th

Publications :

Suriporn Charungthanakij and Sunya Sarapirome. 2010. Land suitability assessment for industrial location development using MCDA. In **Proceedings of the 31th Asian Conference on Remote Sensing 2010**, Nov 01 - 05. Hanoi, Vietnam.

Specialization : Land-use Planning, Industrial Location Analysis**,** Marketing Analysis in Industrial Geography, Financial Analysis in Industrial Geography, Logistic and Transportation Geography.